A Fresh View on the Nasca Lines: Investigating Geoglyph Visibility in Palpa (Ica, Peru)

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Abstract

The Nasca geoglyphs in southern Peru are today usually viewed from the air. This has led to the false impression that they are only visible from above. In contrast, archaeological evidence shows that a continuous and manifold chain of activities took place on geoglyph sites during the Nasca period (200 BC – AD 650), involving large parts of the ancient population. These activities likely required good visibility from the valley and from other geoglyph sites. The Palpa data set, comprising photogrammetrically recorded geoglyphs and a digital terrain model (DTM), allowed for the first time a geographic information system (GIS)-based study of geoglyph visibility, which is described in this paper. Lack of vegetation and stability of the landscape over time facilitated reliable viewshed calculation. A possible impact of visibility on geoglyph distribution was statistically tested by comparing the visibility index of points on geoglyphs vs. random terrain points. Similar tests were performed for the spatial variables elevation and slope degree. The results indicate that good visibility was an important criterion for the choice of place for new geoglyphs.

1 Introduction

The famed Nasca lines in the desert on the south coast of Peru, archaeologically known as geoglyphs, are well known but poorly understood (Aveni 1990; Lambers 2006). A great divide exists between the public perception of the geoglyphs and the archaeological knowledge about them. The basic question is, what was the function and meaning of the geoglyphs at the time when they were constructed and used?

Figure 1. Aerial view of trapezoids, lines, and spirals on Cresta de Sacramento, to the north of Palpa (photo: J. Isla).

There is a wide range of popular literature available that often offers flawed perspectives on the geoglyphs. The focus is usually on the geoglyphs on the *pampas* of Nasca, a vast plateau to the north of the city of Nasca, and especially on the biomorphic figures in this area. This limitation tends to obscure the fact that the dominant features on the *pampas* are lines and other geometric geoglyphs. Furthermore, many little-known geoglyphs exist in neighboring valleys as well, often in different archaeological and topographical contexts. Another bias is introduced by aerial photographs that are the principle means of illustration in the literature on the geoglyphs (Figure 1). They give the false impression that geoglyphs are only visibly from above, a notion supported by the flights over the *pampas* that today are the principal opportunity for tourists to see the Nasca lines. And finally, many highly-speculative ideas about geoglyph function and meaning have been propagated by non-specialists that do not consider the social, cultural, and historical context of the geoglyphs.

The reason why well-founded archaeological perspectives are rather underrepresented in the literature is that serious archaeological fieldwork on the *pampas* of Nasca has been surprisingly limited up to now. Research since the 1980s has emphasized the need to adopt a ground-based perspective (Figure 2) to understand the geoglyphs (Aveni 1990). Andean traditions of cultural concepts, social organization, and religious practice have been cogently (re-) adopted to explain the function and meaning of the geoglyphs in an Andean framework. Based on historical and archaeological analogy, geoglyphs are today interpreted as places for religious and social ceremonies, as manifestations of cultural and sacred space in the desert, as spatial expressions of social organization, and in some cases as pathways through the desert (Aveni 1990; Silverman and Proulx 2002). However, there is still a lack of well documented archaeological evidence to back these plausible hypotheses.

Figure 2. Ground view of a trapezoid on Pampa de San Ignacio, to the south of Palpa (photo: A. Gruen).

Figure 4. Re-enactment of people walking along a spiral geoglyph (conjectural scenario) (photo: M. Reindel).

In the framework of the Nasca-Palpa Archaeological Project conducted since 1997 in Palpa, in the northern part of the Nasca region (Figure 3), more than 1,500 geoglyphs have been thoroughly recorded by combining methods from field archaeology and aerial photogrammetry (Reindel and Gruen 2006; Lambers 2006). A high-resolution digital terrain model (DTM) of the study area was produced through a stereoscopic analysis of large-scale aerial images (Sauerbier and Lambers 2003). The resulting three-dimensional (3D) geoglyph map, archaeological attribute data, and the DTM offered for the first time the chance to investigate the spatial relationships between the geoglyphs and their natural and cultural environment in a geographic information system (GIS).

The detailed recording of archaeological evidence from geoglyph sites revealed consistent patterns of construction procedures, traces of use, and distribution of artifacts on the geoglyphs (Lambers 2006:chapter 6). The construction and remodeling of geoglyphs appears to have been a near-constant process that went on over many centuries, involved many people, and had an important social meaning in its own right. The use of geoglyphs took place parallel to, and intertwined with, construction activity, included walking along lines (Figure 4), gatherings around stone platforms, and the placement of offerings along geoglyph borders and on stone platforms. Goods placed on platforms, the most prominent of them being *Spondylus* shells, bear a strong relation to well-known Andean concepts of water and fertility. Geoglyphs were grouped in complexes that often grew considerably over the centuries and remained in use much longer than typical Nasca settlements. Thus, while these complexes cannot be directly related to specific settlements, they may have been associated with social groups that claimed places in the desert for ceremonies related to group identity and status.

The well-documented evidence of a highly dynamic and vibrant complex of activities that took place on geoglyph sites in the desert is hardly in concordance with the common notion that geoglyphs can only be seen from above. Rather, the dimension of these activities and their persistence over time hints at an important social role. It is unlikely that all this activity went on in hidden or hardly visible places. Thus, an investigation of geoglyph visibility seemed promising.

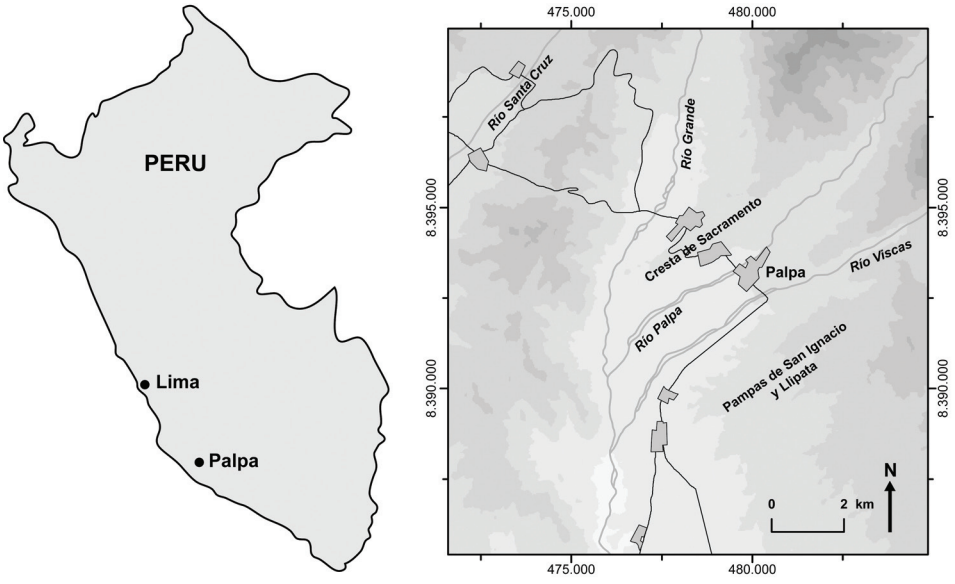

Figure 3. Palpa in the northern Nasca region on the south coast of Peru (coordinates: UTM 18S, WGS 84).

GIS-based visibility studies have become an important tool for the investigation of cultural landscapes in the last decade. A wide variety of recent literature on this topic exists that discusses in detail the procedures, possibilities, and problems of this methodology (Wheatley and Gillings 2000; Gillings and Wheatley 2001; Van Leusen 2002:chapter 6; Wheatley and Gillings 2002:chapter 10; Lake and Woodman

2003; Van Leusen 2004; Conolly and Lake 2006:225-233). In fact, the study of visibility is a field where archaeologists have actively contributed to the advancement of GIS methodology.

In the case of the Palpa geoglyphs, our first attempt to study geoglyph visibility was a calculation of single viewsheds of rather arbitrarily chosen points on geoglyphs that seemed interesting considering their archaeological context. The results indicated a high degree of inter-visibility between geoglyph complexes (Lambers 2006:112-116). This led us to attempt a comparison of geoglyph visibility to general terrain visibility in a more systematic fashion (Lambers and Sauerbier 2006). In the present paper, we discuss our recent efforts in geoglyph visibility studies that go beyond those described in previous publications, as they start from a better database, adopt a more rigorous methodological approach, and take into account the possible impact of additional spatial variables, like elevation and slope degree. The basic question to be answered was, does geoglyph visibility differ significantly from general terrain visibility? Considering the ample evidence of activity on geoglyph sites, our hypothesis stated that this was indeed the case. In order to test this hypothesis, we calculated a cumulative viewshed index for points on geoglyphs, on the one hand, and arbitrary terrain points, on the other hand, and compared the distribution of the values of both using a suitable statistical test. To assess the results, we then tested the variables elevation and slope degree in the same way.

2 Base Data

The study of the visibility of the Palpa geoglyphs was based on a digital elevation model (DEM) derived from aerial and satellite imagery, and two sets of target points: one on the geoglyphs, the other one randomly distributed over the study area.

For the study area around Palpa we had at our disposal a digital terrain model (DTM) with 2 m mesh size that we had generated through a stereoscopic analysis of large-scale aerial images taken in 1998 especially for the documentation of the Nasca geoglyphs in the vicinity of Palpa (Sauerbier and Lambers 2003). These analog, 23 cm x 23 cm black-and-white images had a scale of 1:7,000 that allowed us to discern of even the narrowest lineal geoglyphs. The terrain surface was measured prior to the actual geoglyph mapping because no adequate digital terrain data were available from other sources. To achieve a highly accurate DTM, we measured not only grid points with a varying point density adapted to the shape of the terrain, but also breaklines. This ensured a high geomorphological accuracy, which can be estimated using the empirical formula (Karel et al. 2006):

$$\sigma z = \pm\left(0.5\ \%\ h + \frac{0.5}{c} h \tan\alpha\right) \qquad (1)$$

with h being the flight altitude (in our case ca. 1,070 m above ground), c[mm] the camera constant (152.994 mm), and α the terrain slope. For the terrain in our study area in Palpa with a slope degree from 0 up to 45 %, the estimated DTM height accuracy ranges from σz= 0.16 m for flat areas to σz = 1.20 m for the steepest areas. Additionally, an interpolation error depending on the distance of grid cells to measured points has to be taken into account. The resulting DTM covered an area of 89 km² roughly oriented from southwest to northeast.

To avoid edge effects when calculating viewsheds, the

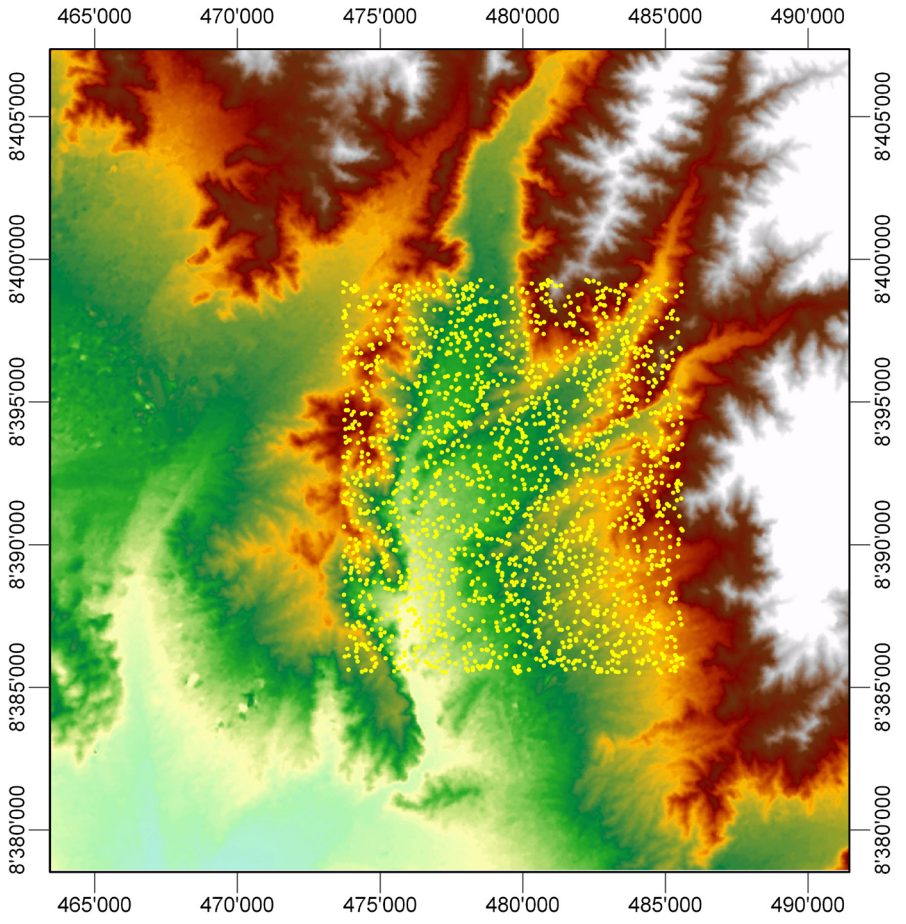

Figure 5. Combined DEM of 807 km² of the Palpa region with random points (white dots, yellow dots in CD-ROM color version) marking the core study area of 164 km² (coordinates: UTM 18S, WGS 84).

DTM had to be enlarged well beyond the area covered by the aerial images. Lacking suitable alternatives, we decided to purchase ASTER stereo scenes covering the surrounding landscape that allowed a digital surface model (DSM) to be generated at a resolution of 30 m. In order to roughly determine the required extension of the ASTER DSM, we calculated a viewshed with unlimited radius from a prominent point on Cresta de Sacramento close to the center of our study area that was known from our fieldwork to provide an excellent view of the surrounding landscape. For this calculation we used a coarser DSM that we had used in a previous study (Lambers and Sauerbier 2006). According to the extent of this viewshed, we generated a rectangular, north-south oriented DSM of 807 km² from the ASTER images.

To make use of the higher level of detail of our DTM of the core study area, we inserted it into the ASTER DSM, thus obtaining a combined DEM (Figure 5). For this purpose it was necessary to downsample the DTM of the core area from 2 m to 30 m for the sake of keeping the computation time in a reasonable limit, as it grows by squares of the mesh size. The DTM was inserted into the DSM by means of least squares 3D surface matching, a new method developed at the Institute of Geodesy and Photogrammetry of ETH Zurich (Gruen and Akca 2005). The surface matching yielded a global accuracy of σ_0 = 18.7 m for the ASTER DSM with respect to the DTM derived from the aerial images. Considering the footprint of 15 m of the ASTER images, this error value, which corresponded to 1.25 pixels, met the expectations, though DSMs derived from ASTER imagery usually have a higher accuracy in flat terrain and lower accuracy in mountainous areas (Kääb et al. 2003). As a result, we obtained a combined DEM with a highly accurate core area and a surrounding area at lower accuracy. For the purpose of the visibility study, we defined a rectangular area of 164 km² in the center of the combined DEM as our core study area, corresponding to the original DTM of 89 km² completed to form a north-south oriented, rectangular area (Figure 5). The area surrounding this core area served to avoid edge effects when calculating a cumulative viewshed index of points located within the core area.

We thus had at our disposal a DEM as a regular grid with a cell size of 30 m based on ASTER and aerial images. Though not optimal, this was the best terrain data that we could obtain with reasonable effort and cost. The cell size of 30 m was much smaller than that used in a preliminary study (Lambers and Sauerbier 2006).

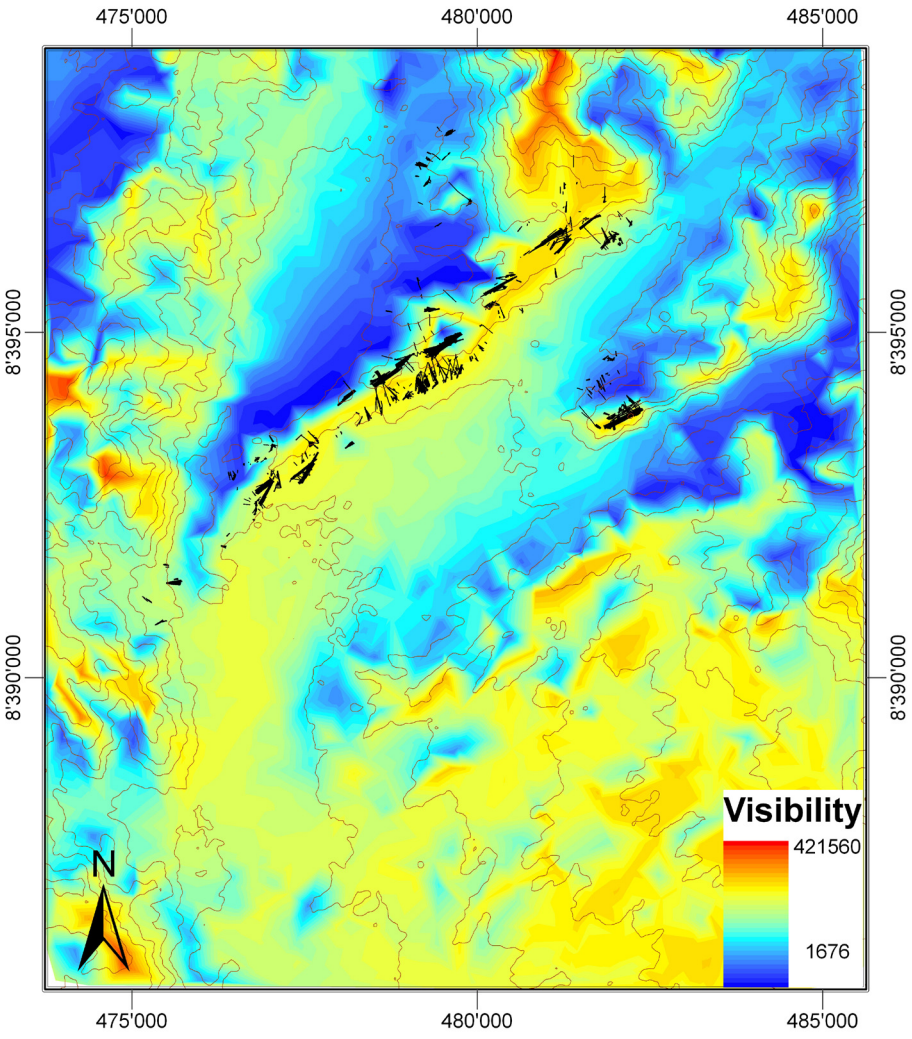

Figure 6. Interpolated visibility index of random points (blue: low visibility, red: high visibility). Geoglyphs considered in the present study are marked in black (coordinates: UTM 18S, WGS 84) (see CD-ROM for color image).

Of the more than 1,500 geoglyphs photogrammetrically mapped in the core study area, only 639 to the north and east of Palpa had been described in the field and modeled in 3D (Sauerbier and Lambers 2004). The visibility study described here was thus restricted to this subset of geoglyphs. These geoglyphs were built during different phases of the Nasca culture but mostly continued in use during various centuries as indicated by associated ceramics and can thus be considered partially contemporaneous (Lambers 2006: 76-94). Therefore, we decided to investigate all 639 geoglyphs in conjunction for the purpose of this study.

In order to define target points on the geoglyphs, we mapped the polygons representing the geoglyphs onto the DEM surface (Figure 6). We then defined the center point of each 30 m cell intersected by a geoglyph as a geoglyph point. This resulted in a regular raster of geoglyph points on big trapezoids and on densely concentrated geoglyph

sites while still allowing single narrow lines to be adequately represented in the data set. A total of 2,067 geoglyph points was that way defined in our core study area.

In order to obtain a reference data set for comparison, we calculated 2,067 points randomly distributed over our core study area. These arbitrary terrain points were determined using Matlab's random generator. In contrast to the geoglyph points, the random points may just by chance correspond to cell centers. For the purpose of visibility calculations the height values of the random points were interpolated from the DEM by means of bilinear interpolation. While some random points were coincidently located on geoglyphs, most of them were not. Rather, we chose to have them randomly distributed over the entire core study area of 164 km² (Figure 5).

The choice of this study area may seem questionable for two reasons. First, as mentioned above there are more geoglyphs in our core study area than the ones considered here, mainly to the south of Palpa (see Lambers 2006:supplement). Thus, the geoglyph target points cover only a subsample of existing geoglyphs. To avoid this problem we could have limited our study area to zones with mapped geoglyphs and some surrounding terrain. This, however, would have excluded much of the terrain to which we wanted to compare the geoglyph sites. Therefore, we decided against this option.

Second, the study area includes terrain not suitable for the construction of geoglyphs, like the irrigated valley floor as well as steep and rocky slopes of hills. It would have been an option to exclude these areas. However, then again we would have let the study area be determined by parameters outside the scope of our investigation.

In sum, both options would have meant restricting the study area to zones covered by geoglyphs, whereas one of our original aims was to compare such zones to terrain not covered by geoglyphs. In order not to introduce biases by allowing other parameters than the ones to be tested to determine our core study area, we opted for the arbitrary delimitation of our study area as described above.

The method of obtaining a representative data set of background points was another important issue. In a previous study (Lambers and Sauerbier 2006) we had chosen a regular raster of terrain points as background data set, with the point raster width corresponding to the DEM cell size. This seems the best approach as long as it is feasible in terms of reasonable computation times for total viewshed calculation. However, the DEM used in that study was rather coarse with a cell size of 100 m, such that it did not represent the terrain surface very well. The cell size of 30 m of the DEM used in the present study, while ensuring a better representation of the actual terrain surface, impeded the calculation of a total viewshed. Therefore, we decided to use a limited number of randomly distributed points as background data set. An important requirement for the statistical analysis that we aimed to undertake was that the background sample provided a significant data basis that was representative of the original data. The random point method allows for an efficient point thinning while still providing a statistically significant representation of the terrain. For statistical hypothesis testing it is important to achieve a good representation not in terms of spatial, but of statistical distribution. This means that the random points should represent the frequency of elevation values occurring across the whole terrain of the study area. For this purpose, random points are better suited than a resampled regular grid with a larger raster width.

3 Methodology

To the end of testing the hypothesis that visibility considerations may have influenced the choice of location of new geoglyphs, we needed to determine if the distribution of visibility values of geoglyphs points differed significantly from the distribution of visibility values of arbitrary terrain points.

In order to determine the required visibility indices, we calculated lines of sights between each cell of the extended DEM (comprising 935 x 959 = 896,665 cells) and each of the 2,067 geoglyph and terrain points in our core study area, respectively. While we mostly work with ESRI´s ArcGIS, we did not use the line of sight calculation implemented in this software for two reasons. First, the considerable amount of required computations caused a memory overflow. Second, the information as to whether the target points were visible from the DSM cells would have been stored in the starting points on the DSM cells, while we needed this information to be summed up in the target points. Therefore, we wrote a piece of software in C++ to undertake the calculation according to our requirements. This program can easily be enhanced for future applications to work with multi-resolution DEMs, which cannot be handled in the current release 9.1 of ArcGIS due to restrictions of the ESRI grid data structure.

The lines of sight between DEM cells and target points were calculated taking into account the parameters of observer´s height of 1.5 m at the starting point on the DEM cell, earth curvature, and refraction. The influences of earth curvature and refraction were corrected according to a formula that is also implemented in the ArcGIS visibility function:

$$\mathrm{Re}_{c\,/\,ref} = (1-k)\frac{D^2}{2R_{Earth}} \quad . \tag{2}$$

where Rec/ref is the influence of earth curvature and refraction, k= 0.13 is the refraction coefficient, D is the distance from the observer's position, and R_{Earth}= 6371 km is the radius of the earth.

We decided not to limit the radius of the lines of sight because we knew from our fieldwork in Palpa that certain terrain points, e.g., those close to mountain tops, are visible from a considerable distance. Besides, while the actual geoglyphs may not be discernable beyond a distance of a few kilometers, groups of people gathering on geoglyph sites or walking along lines would still have been clearly silhouetted against the desert background, as we observed on several occasions during our fieldwork.

Two further parameters often cited as questioning the results of viewshed calculations were of no concern for

our study in Palpa: paleovegetation and geomorphological change. Recent investigations into the paleoclimate and the landscape history of the Palpa region have shown that during the Nasca period (200 BC to AD 650), the *pampas* and hillsides on which the geoglyphs were built and used were in much the same shape as today, i.e., without any vegetation cover and only minimal geomorphological change occurred since (Eitel et al. 2005; Mächtle et al. 2006). Both paleovegetation and geomorphological change basically mattered on the valley floors where no geoglyphs were located. This facilitated reliable viewshed calculation.

In order to determine whether a target point was visible from a given DSM cell, a straight line between both points had to be tested for intersection with the surface. As the DEM was available as a discrete raster and not as a mathematically-described surface, discrete positions along the line of sight had to be tested as to whether their elevation was greater than, equal to, or below the DSM elevation at the corresponding position. Along a line of sight we used an increment of 0.5 m between points to be tested, which seemed reasonably small compared to the mesh size of the DEM. For values being greater or equal along one line of sight, we assumed that visibility existed and accordingly increased the count stored at the target point by 1. To achieve high accuracy it was necessary to interpolate elevation for positions that did not exactly match DEM cell centers, as each cell value was strictly speaking only valid for the cell center. Therefore, bilinear interpolation between four neighboring grid cells was applied in this case. After all DEM cells had been tested this way for one target point, the count was stored in an ASCII file together with the point coordinates, and the program restarted the loop for the next target point. For further analysis in ArcGIS, the ASCII file was then converted into a shape file.

The computation of a cumulative viewshed index for two times 2,067 target points took several days. As a result, for each point of the two data sets we obtained the number of cells of the extended DEM from which the point was probably visible, taking into account the quality of the available DEM and the parameters mentioned above. These cumulative visibility indices could then serve as a starting point for statistical tests.

Prior to this, we explored the results visually in order to get a first idea of the potential outcome of our investigation. We generated a visibility map of our core study area by interpolating visibility values of the 2,067 random terrain points (Figure 6). While this map is not suitable for any serious analysis due to the high potential error of the interpolated visibility index caused by the low point density, it did help us to visually identify areas of higher and lower visibility. Interestingly, most geoglyphs were concentrated in areas with a rather high visibility index. There were, however, clear exceptions to this apparent rule: some geoglyphs clearly seemed to be placed in areas with low visibility, while certain areas with high visibility did not have geoglyphs. In order to investigate this in a more systematic way, we turned to a statistical comparison of the distribution of visibility values between the two data sets.

4 Visibility

The calculation of cumulative visibility indices for the geoglyph points and randomly distributed background points resulted in two data sets, stored as shapefiles, that displayed the locations of the target points, each of which contained as an attribute the number of DEM cells from which it was visible. For a first comparison, these values were plotted in a histogram (Figure 7). The histogram clearly shows different distributions of visibility values. While the curve of the background data set shows a moderate gradient that slightly increases up to visibility values of approximately 300,000 cells, the curve of the geoglyph points is balanced

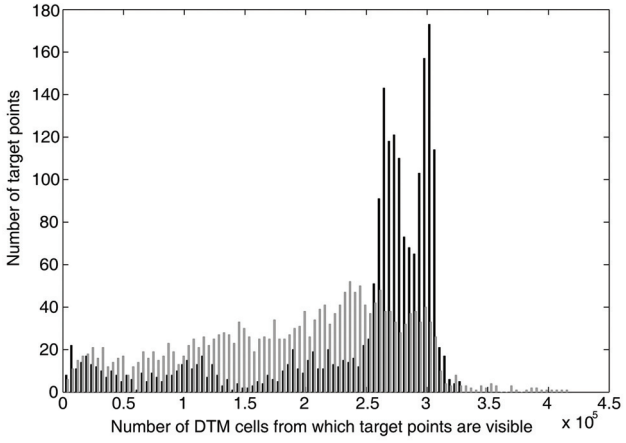

Figure 7. Visibility index of points on geoglyphs (black) vs. random points (gray).

at an almost constant value of up to 20 points in each visibility class until it increases sharply at a visibility value of 250,000 cells. This leads over to a broad maximum of target points with visibility values between ca. 250,000 and 310,000 cells. In this case, a visual inspection of the histograms already reveals a significant difference between both distributions.

In order to evaluate the data sets further with statistical methods, a two-tailed Kolmogorov-Smirnov goodness-of-fit test (KS-test) (Chakravarti et al. 1967) was applied to test the distributions of visibility values for both the geoglyph and the background points for significant differences. Compared to other goodness-of-fit tests, the KS test is a non-parametric hypothesis test that is independent of *a priori* knowledge or assumptions concerning the distribution of the two data sets to be compared (see Conolly and Lake 2006:122-135). It is therefore well-suited for a comparison of empirical data with a possible influence of spatial variables on the distribution.

First, the sample data has to be divided into a sufficient number of discrete classes, in our case 100. The test then compares the cumulative probabilities (CP) of membership in these classes. The maximum difference of the cumulative probability between both samples, D_{max}, is compared to the critical value D_{crit}, which is determined using the following formula:

$$D_{crit} = c(\alpha)\sqrt{\frac{n_1 + n_2}{n_1 n_2}} \quad . \tag{3}$$

where $c(\alpha) = 1.36$ for a significance level of $\alpha = 0.05$ (Miller 1956) and n_1, n_2 are the numbers of points in the two samples. The hypotheses to be tested are the null hypothesis H_0, which assumes that both samples feature equal distributions ($CP_1 = CP_2$), and the hypothesis H_1 stating that the distributions are not equal ($CP_1 \neq CP_2$).

Applied to our visibility data, the hypotheses were formulated as follows:

- H_0: Both distributions are equal; an impact of the spatial variable visibility on the location of geoglyphs is not likely.
- H_1: Both distributions are not equal; an impact is likely.

With 2,067 points in each sample, the calculation gave $D_{crit} = 0.0423$ for the data divided into 100 classes. The null hypothesis H_0 for geoglyph and background points was clearly rejected with $D_{max} = 0.4458 > D_{crit}$.

The cumulative probabilities (Figure 8) clearly show two significantly different distributions, again with a steep gradient of geoglyph visibility at about 250,000 cells. D_{max} is shown in the graph. Additionally, the plot shows that generally the visibility of geoglyph points is higher than that of random points.

As an intermediate result, we hence found that the distribution of visibility values for points on geoglyphs differed significantly from the distribution of visibility values for random points in that the visibility of geoglyphs was generally better. In archaeological terms, this seems to indicate that when a place was chosen to construct a new geoglyph, good visibility apparently was an important criterion. A relation between visibility and the location of geoglyphs is suggested both by archaeological plausibility and statistical evidence.

However, a possible impact of other terrain parameters on the choice of location of geoglyphs cannot be ruled out. The result of a KS test can be interpreted correctly only for variables that are independent from others. Other potential variables that may have determined geoglyph location are elevation and slope degree, as discussed in the following section. Therefore, separate KS tests were conducted for both variables, and tests concerning a possible correlation between all three spatial variables were undertaken.

5 Elevation and Slope Degree

Observations during fieldwork hinted at elevation and slope degree as further parameters that might have determined the choice of location for new geoglyphs. Both spatial variables clearly structure the landscape and thus influence human movement and perception.

Certain elevation ranges of the study area seem to have been preferred for geoglyph construction. The lowest terrain within the study area (close to the rivers) as well as the highest terrain (mountain tops and surrounding slopes) were clearly avoided. Geoglyphs are mainly located in an intermediate range of elevation. As for slope degree, the steepest parts of the study area were avoided as well. Geoglyphs are rather found on flat or gently sloped terrain. Both spatial variables may have had an impact on the choice of place for new geoglyphs and were therefore tested in the same way as visibility.

A histogram that plots the frequency of elevation values of the same geoglyph points and randomly distributed background points shows that geoglyphs mainly occur in a range between 330 and 620 m above sea level (a.s.l.), whereas the entire core study area covers elevations from 290 up to 1000 m a.s.l. (Figure 9). This confirms observations made in the field that the areas close to the rivers, as well as mountainous areas and steep slopes were not used for geoglyph construction.

To put this observation to a statistical test, a KS test was conducted in a similar way as for the variable visibility. For

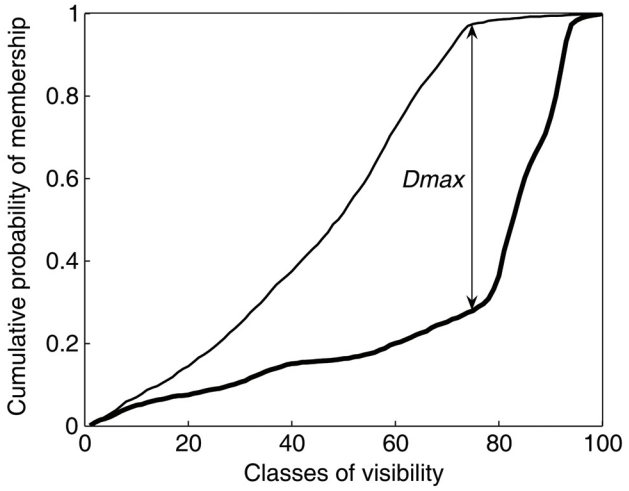

Figure 8. Cumulative probability of membership in visibility classes of points on geoglyphs (wide line) vs. random points (narrow line).

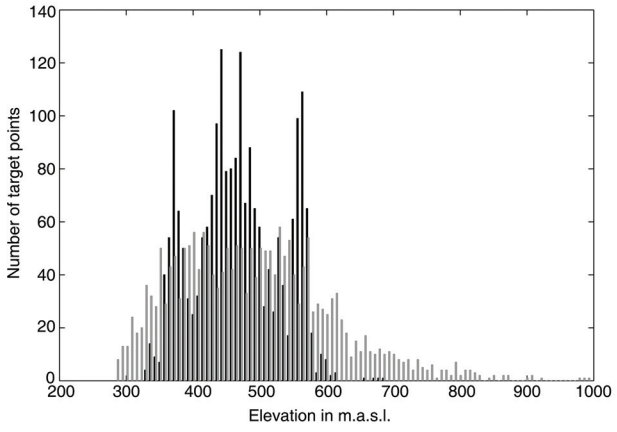

Figure 9. Elevation index of points on geoglyphs (black) vs. random points (gray).

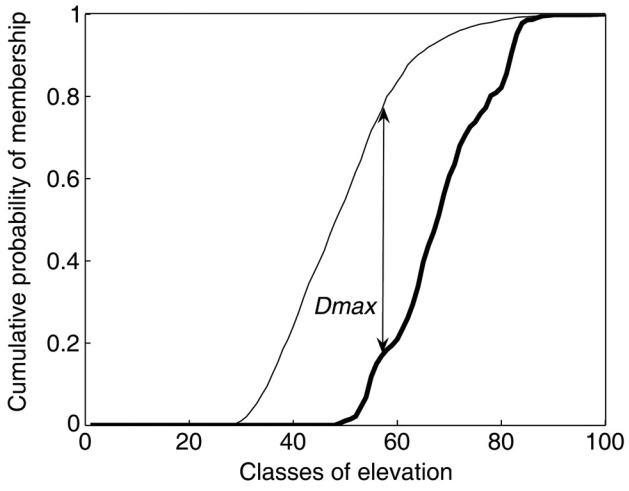

Figure 10. Cumulative probability of membership in elevation classes of points on geoglyphs (wide line) vs. random points (narrow line).

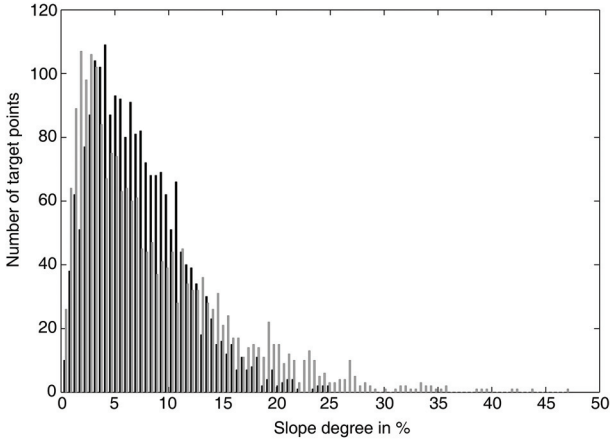

Figure 11. Slope degree index of points on geoglyphs (black) vs. random points (gray).

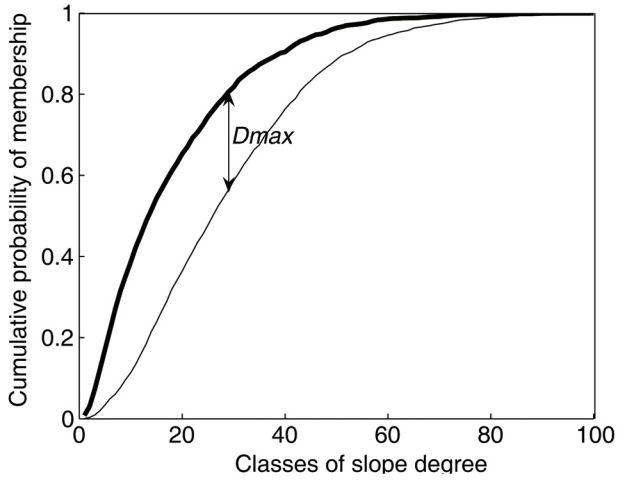

Figure 12. Cumulative probability of membership in slope degree classes of points on geoglyphs (wide line) vs. random points (narrow line).

this test, elevation values were assigned to both sample point data sets from the DSM using bilinear interpolation between the four neighboring cell centers. With D_{max} = 0.1854 vs. D_{crit} = 0.0423, the null hypothesis was rejected, though less clearly than with visibility. The cumulative probability plot (Figure 10) clearly shows the steepest gradient in the classes 60 to 80, corresponding to elevations from 330 to 620 m, where the background curve increases smoother than the geoglyph curve.

In a third KS test, slope degree distribution was investigated for both geoglyph and random points. For this purpose, slope degree values were assigned to the points of both data sets from a slope data set with 30 m mesh size derived from the DEM grid using the slope function in ArcGIS. This slope function calculates the maximum slope degree over a cell, considering its eight neighboring cells.

The histograms of both point samples show at first glance relatively similar, if slightly shifted, distributions of slope degree values (Figure 11). Nonetheless, the null hypothesis of equal distributions was again rejected, with D_{max} = 0.1220 exceeding D_{crit} = 0.0423 (Figure 12).

All in all, when compared to the results of the KS test for visibility, for slope degree and elevation the null hypothesis was less clearly rejected, but both distributions still differed significantly. Hence, in archaeological terms, based on statistical evidence alone, elevation and slope degree may just as well have been criteria when choosing locations to construct new geoglyphs.

6 Interdependency of Spatial Variables

Before discussing this finding, it seemed important to test possible interdependencies of all three tested variables. Both elevation and slope degree may be directly related to visibility and to each other. It has been suggested that high elevation automatically increases visibility over large distances (Van Leusen 2004). In our case such a direct relation seemed doubtful, since high visibility values were not restricted to the highest mountains (Figure 6), but a relationship remained to be tested. In the case of slope degree, according to our field experience geoglyphs on hillsides were better visible than those in flat terrain. On the other hand, geoglyphs in flat terrain were much better suited for group activity on geoglyph sites as described above. Thus, a possible relation was less clear and remained to be tested. Furthermore, it was unclear whether elevation and slope degree were independent variables, as at least in mountainous regions slope degree tends to increase close to mountain tops.

In order to assess whether the three tested variables were interrelated, we calculated pairwise Spearman's rank correlation coefficients for the random point sample between visibility and elevation, visibility and slope degree, and elevation and slope degree in order to detect possible linear and nonlinear correlations.

Spearman's rank correlation coefficient (Spearman 1904) considers linear and nonlinear correlation for unknown distributions of the sample data. Other statistical tests for nonlinear correlations usually require *a priori* knowledge

on the distribution of the samples, which in this case was not available, or would have been conjectural at best. The Spearman rank correlation coefficient requires ranked data and is calculated using the following formula:

$$\rho = 1 - \frac{6\sum d^2}{n^3 - n} \quad . \tag{4}$$

where ρ is the correlation coefficient with a domain of [-1,1], d is the difference of rank values of both samples, and n is the sample size. The Spearman rank correlation coefficients turned out to be 0.10 between visibility and elevation, -0.09 between visibility and slope degree, and 0.48 between elevation and slope. Thus, while the results indicate that visibility is correlated with neither elevation nor slope degree, there is a moderate correlation between elevation and slope degree.

To assess the statistical significance of the Spearman rank correlation coefficients, a test against Student's distribution was conducted (Zar 1972). First, the randomness t of the incidence of a certain value of ρ was computed:

$$t = \rho \sqrt{\frac{(n-2)}{(1-\rho^2)}} \, . \tag{5}$$

where ρ is the Spearman rank correlation coefficient computed using formula (4) and $n = 100$ is the sample size. Due to the relatively large sample size, the computed t for each pair of the aforementioned spatial variables could then be tested versus the standard normal distribution z calculated using the following formula:

$$z = |\rho| \sqrt{n-1} \quad . \tag{6}$$

where $|\rho| = 0.197$ is the tabulated critical value of the Spearman rank correlation coefficient at a 5% significance level (Zar 1972). The resulting values of t and z are compared in Table 1. A significant correlation between two variables can be assumed if $t > z$, which is the case for elevation and slope degree in the investigated data.

Table 1. Significance of the computed Spearman's rank correlation coefficients.

Spatial Variables	t vs. z	Significant correlation
elevation vs. slope degree	5.4165 > 1.9601	yes
visibility vs. slope degree	0.8946 < 1.9601	no
visibility vs. elevation	0.9949 < 1.9601	no

Based on the obtained results for the correlation and its significance, we concluded that no significant correlation between visibility and slope degree or elevation existed in our data. In other words, in our study region the variable visibility is independent of the variables elevation and slope degree. A statistically significant moderate positive correlation was revealed between elevation and slope degree, hinting at a possible dependency between these two variables. The statistical results presented here have to be considered as valid only for the examined data, as they depend on the individual topography of the area of investigation.

7 Results

The results of the Kolmogorov-Smirnov test are generally congruent for the three spatial variables visibility, elevation, and slope degree: independently of each other, all of them may have had an impact on the spatial distribution of geoglyphs. The calculation of the correlation coefficients and their significance shows no correlation between visibility and elevation, nor between visibility and slope degree, while there is a moderate positive correlation between elevation and slope degree. These statistical results have to be discussed in terms of archaeological plausibility in order to assess if association can indeed be interpreted as causal relation.

Considering the interdependency of the variables elevation and slope degree, the topography of the study area is characterized by two different levels of rather flat terrain: the valley floors and the *pampas* (Figures 3 and 5). Both are separated by sloped terrain forming the valley margins. Above the level of the *pampas*, the mountains rise to the highest elevation ranges in our study area. Thus, while slope degree indeed increases with elevation in the mountainous upper regions of our study area, there are also steep slopes on a lower level of elevation, namely between the valley floors and the *pampas*. Therefore, the positive correlation between both spatial variables is only moderate, and they are here discussed independently of each other.

Concerning elevation, the geoglyphs in the study area are largely restricted to an elevation range between 330 and 620 m a.s.l. While the terrain below this range corresponds to the valley floor, the terrain above this range is formed by steep, rocky terrain. Both kinds of terrain are not suitable for geoglyph construction due to their construction technique that requires a stony desert pavement. In the study area, this kind of terrain prevails in the indicated elevation range. Thus, there is a causal relation between the presence of geoglyphs and elevation caused by technical requirements. This preference for specific elevation values, however, is valid only in our study area. Further up or downriver, suitable terrain for geoglyph construction would be situated at higher or lower elevation, respectively. Thus, while there is a causal relation between elevation range and geoglyph placement, this relation covers the entire terrain suitable for geoglyph construction and does not tell us anything about possible preferences for specific locations within this range.

Technical necessity can also explain the range of slope degree covered by geoglyphs. The steepest parts of the terrain (> 25°) were largely inaccessible and coincided to a large degree with rocky hillsides where no geoglyph could be constructed. The lower ranges of slope degree largely coincided with the rocky or sandy ridges and plateaus that

were suitable for geoglyph construction. This also explains why there are relatively few geoglyphs located in very flat terrain, since this corresponds mostly to the valley floor where no geoglyph could be constructed. Of more interest are preferences for certain sections within the range of slope degree covered by geoglyphs. While even relatively steep terrain was apparently still regarded as suitable for the construction of some geoglyphs, most geoglyphs are located in gently sloped terrain (2° to 11°). This range corresponds once again to the flat plateaus, or *pampas*, which in our study area are always slightly sloping towards the southwest, and the lower sections of the hillsides that frame the valleys. This preference may be explained by flat terrain being more accessible, and thus being better suited for group activity that left so many traces in the archaeological record of the Palpa geoglyphs. This functional necessity would confirm the importance of these social acts. Thus, a causal relation between slope degree and geoglyph placement seems plausible to a certain degree, even though it has to be kept in mind that a considerable number of geoglyphs was apparently placed in locations that were not easily accessible.

A similar, but much clearer relation can be inferred between geoglyph location and visibility. There is a clear peak of high visibility values for points on geoglyphs. The deviation between both data sets is much stronger than with the other variables tested. Apparently, geoglyphs were preferentially constructed in well visible locations, without totally avoiding badly visible places. This preference can best be explained with functional rather than technical requirements and was likely due to the social importance of the group activity described above. While these acts were certainly important for the individuals who participated in them, they were at the same time designed to be seen by people on other geoglyph sites or in the settlements and fields down in the valleys. Visibility considerations seem to have been a principal component of the conceptual framework of the geoglyphs. This hypothesis, developed on the basis of archaeological evidence from geoglyph sites, is confirmed by statistical evidence.

8 Conclusions

The foremost result of the investigation described here is that geoglyph visibility from the ground is much better than generally assumed. While our fieldwork had already confirmed that each and every geoglyph is indeed visible and discernable on the ground, our GIS-based study of geoglyph visibility on a regional level indicates that most geoglyphs were deliberately located such that they were especially well visible. Technically speaking, geoglyphs themselves may not have been visible beyond a certain range, but groups of people gathering on them were certainly visible from far away against the background of the monotonous desert surface.

Our investigations lend support to the impression gained from the considerable evidence of group activity documented during fieldwork, that the main function of most geoglyphs was to serve as a stage were gatherings and ceremonies were held. The importance of these activities, the specific nature of which will probably always remain elusive, for the entire Nasca society is stressed by the fact that they were well visible from other geoglyph complexes, from neighboring hills, and from the valleys. Group activity on geoglyph sites thus transcended the realm of the people actively engaged in it by visually involving other people in remote locations.

The purpose of activity on geoglyph sites may have been to raise awareness of group identity among group members as well as non-members through visible acts that were significant in a common conceptual framework shared by all members of Nasca society. The social groups associated with geoglyph complexes may thus have been a constitutive part of ancient Nasca society. While the social structure and political organization of Nasca society is still a matter of considerable debate (Silverman and Proulx 2002; Isla and Reindel 2006), the geoglyphs certainly played an important role in this regard. How these dynamic social processes changed through time, and what caused their end at some point in the 7th to 8th century AD, remains to be investigated.

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