GIS-based visibility studies of the Nasca geoglyphs at Palpa, Peru

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**ABSTRACT:** The Nasca lines or geoglyphs in southern Peru are known as one of archaeology’s greatest mysteries. Since the 1980s, however, new approaches have helped to better understand their function and meaning. The recent photogrammetric recording of 1,500 geoglyphs in the vicinity of Palpa enabled for the first time a GIS-based analysis. Geoglyph visibility is one of their most discussed traits. While modern observers tend to view the geoglyphs from the air, their creators viewed and perceived them from the ground. The Palpa dataset allowed us to quantify geoglyph visibility and intervisibility by applying viewshed analysis and the Kolmogorov-Smirnov goodness-of-fit test. This investigation has shed new light on the cultural role of the geoglyphs in ancient Nasca society. In this paper we present some recent results of the GIS-based analysis of the Palpa geoglyphs, which is still underway. Furthermore, we discuss some general methodological issues of GIS applications in archaeology.

1 INTRODUCTION

The world famous Nasca lines or geoglyphs carved into the desert surface on the south coast of Peru in prehispanic times (400 BC – 800 AD) have proven to be notoriously hard to record, date, and interpret. Numerous, often rather speculative hypotheses have been put forward to explain the geoglyphs ever since their scientific rediscovery in the 1920s (Aveni 1990). Since the 1980s, a new interpretation has emerged from fieldwork in Nasca and elsewhere, explaining the Nasca geoglyphs in the framework of well documented Andean concepts of social organization and religious traditions (see overview in Lambers 2004). Plausible as this new approach may be, a major obstacle for geoglyph research has always been the lack of suitable field data, such that the proposed hypotheses could not be tested with archaeological means. A GIS-based analysis of the Nasca geoglyphs has been a desideratum for some time (Silverman & Proulx 2002:179). GIS is expected to reveal patterning and order in the apparent mess of lines, trapezoids, and figures. It is also hoped to help understand how the ancient inhabitants of the Nasca region created and perceived their cultural landscape.

A dataset suitable for a GIS-based analysis was produced for the first time when more than 1,500 geoglyphs in the vicinity of Palpa, in the northern part of the Nasca basin (Fig. 1), were recorded, modeled and visualized with photogrammetric means in the framework of the Nasca-Palpa project (Reindel & Grün 2005). In this interdisciplinary endeavor, initiated in 1997 by the Swiss-Liechtenstein Foundation for Archaeological Research Abroad (SLSA, Zurich), proven methods of aerial photogrammetry were combined with extensive archaeological fieldwork in order to obtain detailed information on the geometry as well as the archaeological attributes of all preserved geoglyphs in an area of 89 km² around Palpa (Reindel, Lambers & Grün 2003; Lambers, Sauerbier & Grün 2005). The archaeological analysis of the Palpa geoglyphs, partially performed in a GIS environment, has allowed us to gain significant new insights into the way the geoglyphs were built, used, and perceived by the society that created them (Lambers 2004).
The GIS-based analysis of the Palpa geoglyphs is still ongoing. New results of recent visibility studies are presented in this paper. To put them into a proper context, certain methodological issues encountered during our project are here discussed beforehand.

2 TECHNICAL AND METHODOLOGICAL ISSUES

From the point of view of GIS technology and methodology, working with the Palpa geoglyphs is a challenging task. This is due on the one hand to the nature of archaeological data in general, and on the other hand, to technical limitations concerning archaeological GIS applications.

2.1 The nature of archaeological data

In common GIS applications, like e.g. cadastral GIS for administrative purposes or enterprise GIS for business purposes, spatial datasets usually meet certain requirements concerning data quality, integrity, and suitability for the purpose at hand. Datasets may be supposed by the user to be up-to-date, compatible, and complete, or else there are procedures available to routinely acquire or update datasets or to obtain information about the nature and quality of their content.

In archaeological GIS applications the situation is much more complicated. What archaeologists seek to investigate are past societies and cultures. What they would need for such a purpose are datasets from ancient times, comparable in completeness and reliability to the above mentioned ones. Such a level of data quality is obviously impossible to achieve. “Although we would wish it, the past – manifest in artifacts – does not come to us unchanged” (Schiffer 1996:5). What archaeologists have to deal with are scarce remains, or fragments, of the material culture of the society under study. Ancient settlements, buildings, and artifacts tend to be partially destroyed, built over, or even washed away from their original location. Thus, neither the geometry nor the attributes of ancient objects can usually be recorded completely. The degree of preservation may furthermore vary considerably, such that one object may be recorded in a much more detailed way than a less well preserved one. To complicate matters further, the ratio of loss will never be reliably known.

In the case of the Palpa geoglyphs, though many of them are quite well preserved, virtually all of them have suffered some degree of destruction. Most geoglyphs are grouped in complexes that grew over time as new geoglyphs were added, existing ones modified, and older ones obliterated (Lambers 2004). After their abandonment, the resulting geoglyph fields were affected by
erosion, and many geoglyphs close to inhabited zones have been partially destroyed by modern land use in recent decades. Thus, it is hardly possible to record any geoglyph as it was during its time of use, i.e. the time of interest to archaeological research. Furthermore, it is impossible to know how many geoglyphs are lost forever.

Archaeological datasets are thus necessarily incomplete and inconsistent. To bridge the gap between available and needed data, it is often attempted in a first analytical step to draw informed conclusions on, or to reconstruct, the missing parts. This step requires additional knowledge from other sources, but even so necessarily introduces certain biases to the dataset.

In the case of the Palpa geoglyphs, during photogrammetric image analysis only actually preserved parts were recorded and stored in vector format in the database. In a reconstructive step, these preserved sections were then combined into polygons representing the most plausible original shape of each geoglyph (Sauerbier & Lambers 2004). In order to ensure data transparency, reconstructed polygons were kept easily distinguishable from original vectors. Though plausible, the resulting polygon dataset has to be treated with caution just like any reconstruction, as it represents but one among many possible images of the past.

Yet another source of error is introduced when archaeological data – e.g. settlement locations from a certain time period – are analyzed in relation to datasets from different time periods, e.g. DEMs describing the modern topography of the study area. Alterations caused by natural as well as anthropogenic processes, which are often hard to quantify, are that way systematically neglected. Fortunately, in Palpa the desert turned out to be very stable since the time the geoglyphs were made (Eitel et al. 2005), but in other regions these natural and anthropogenic changes may have altered the landscape considerably.

The examples given here show that datasets used in archaeological GIS applications tend to be far below common standards of data reliability, integrity, and completeness in other GIS applications. This has to be kept in mind when assessing conclusions based on their analysis. Further problems arise from the limited availability and applicability of additional data, data models, and algorithms for archaeological applications.

### 2.2 Availability of data, tools, and methods

A practical problem familiar to any researcher working in remote locations is the limited availability of digital spatial datasets. In Peru, digital topographic and geological maps became available only recently, after our project had started. Their scale is still not good enough for spatial analysis on the level of a single, or several neighboring, sites. Accordingly, for our intended study we had to document not only the geoglyphs, but also the topography of the area of investigation. Data acquisition and processing thus consumed a great deal of the time available for the whole study.

The need for self-developed solutions extended to data modeling as well. While there are standard models available for common GIS applications, archaeological GIS is still a relatively small subfield of GIS studies, and very few ready-made solutions, like suitable data models, are available. Due to the inherent variety in archaeological data and acquisition methods, standardized data models can anyway not cover all potential cases. This is especially evident for objects like the geoglyphs, as in Palpa they are investigated on a large scale for the first time. Thus, the archaeological typology and subsequently the data model for the Palpa data had to be developed from scratch (Lambers & Sauerbier 2003) to provide a data structure suitable for a common analysis of spatial as well as archaeological data.

Current GIS software packages offer a wide variety of integrated analysis tools for vector and raster data that are easily applicable and user-friendly. However, a meaningful quality assessment of the obtained results is not implemented and, therefore, has to be accomplished by the user. Different applications of specific algorithms require different ways of such an assessment. In archaeological GIS applications, the interpretation of results often requires archaeological expertise, but is even so difficult due to lacking benchmarks, which in this case would be knowledge of past circumstances.

Analyses based on a priori assumptions have to be dealt with as probabilistic methods, especially when dealing with incomplete or flawed datasets like those necessarily common in archaeology. Their outcome is just the most likely result. A case in point are analyses based on digital elevation models (DEMs), e.g. least cost path calculation, site catchment analysis,
viewshed analysis and other topographic analyses (aspect, slope). For use in such calculations, a DEM is usually processed as a regular grid derived from the original measured points. DEM accuracy is one of the factors strongly influencing the quality of a viewshed calculation (Fisher 1991). Moreover, the absolute accuracy of a DEM is unknown in most cases, simply because no reference data of significantly higher accuracy is available.

These examples show that technical as well as methodological constraints have to be taken into account when applying GIS technology to archaeological research, a field with special requirements and prerequisites that GIS is still not sufficiently tailored to meet. Some of these issues apply to the visibility studies of the Palpa geoglyphs as well, while others could be mitigated by choosing appropriate datasets and methods, as described in the following chapter.

3 VISIBILITY AND INTERVISIBILITY OF THE PALPA GEOGLYPHS

"At first glance, there is nothing in the pampa’s bleak landscape to arouse interest. ... From an aircraft, on the other hand, this same surface presents an extraordinary spectacle. Like a gigantic abandoned sketch pad, the pampa is crowded with a profusion of man-made designs. ... [W]hy did the Nazca artists, some two thousand years ago, apparently ignore the earthbound perspective of an ordinary viewer?" (Hadingham 1987:3f).

The notion that geoglyphs can only be seen and understood adequately when viewed from above has become firmly embedded in the popular literature. For modern travelers to the Nasca region, their first encounter with the geoglyphs usually occurs when flying over them in a small aircraft starting from the Nasca airstrip. The striking contrast between the impressive maze of geoglyphs as seen from above and the little that can be recognized on the pampa from the ground has strongly contributed to the modern myth of the “mysterious” Nasca lines and has triggered many rather unscientific attempts to explain them.

The aerial perspective, however, is neither the only possible nor the most appropriate one. The first researchers who reported on the desert markings near Nasca in the 1920s had indeed spotted them from the ground. It should come as no surprise that over the following decades, primarily those researchers who knew the geoglyphs from own fieldwork on the pampa proposed reasonable interpretations that were not purely speculative, like some better known ones, but rather firmly grounded on what we know today of ancient Andean cultures (see overviews in Aveni 1990; Silverman & Proulx 2002; Lambers 2004). This is obviously due to the fact that the ground perspective was shared by the people who built the geoglyphs as well. Geoglyphs were seen and perceived from the ground in ancient times. The question then is, Was geoglyph location and placement determined, among other factors, by visibility and intervisibility considerations, and if so, how?

In the archaeological record as documented on Palpa geoglyph sites, there is evidence indicating that geoglyph complexes were associated with certain social groups (Lambers 2004). Members of those groups gathered on occasions on geoglyph sites in order to create new, or to enlarge existing geoglyphs, or to perform certain ceremonies upon them. These ceremonies encompassed ritual activities in a religious framework (water and fertility cult) as well as in a social context (group identity and status). GIS-based analysis of spatial distribution of geoglyph complexes through time shows that these sites remained in use far longer than common settlements, thus indicating the importance of geoglyphs as cultural benchmark that transcended sociopolitical change. This cultural importance is also stressed by the fact that geoglyph related activity apparently involved not just specialists, but large parts of the ancient population. It may reasonably be argued that this crucial cultural role played by geoglyphs in ancient Nasca society required a high degree of general geoglyph visibility and, since groups of people may have been present on different geoglyph sites at the same time, also intervisibility between geoglyph sites.

A first step towards investigating this question was to choose four viewpoints on and off geoglyph fields that were marked by crossing lines, wooden posts, or other significant features and to determine what could be seen from those points. The resulting viewsheds (explained in the following subchapter) coincide neatly with the location of other geoglyph complexes across the terrain and thus seem to corroborate the notion that geoglyph visibility and intervisibility were important. In order to put this preliminary result to a more rigorous test, and generally to learn more about geoglyph visibility in the Palpa area, our recent investigations pursued a more
systematic approach, incorporating statistical procedures to assess visibility data. 639 geoglyphs situated on Cresta de Sacramento and Cerro Carapo, low ranges of hills to the north and east of Palpa, respectively, were investigated (Figs. 1, 2; see also Reindel, Lambers & Grün 2003: map supplement).

3.1 Base data

Generally, visibility studies are on the one hand based on terrain data (e.g. a DEM) and on the other hand on a sample of target points (e.g. archaeological sites) for which visibility values are calculated. To obtain statistically relevant data, visibility calculations should be performed at a regional scale. Visibility can be described in terms of lines of sight (LoS). The LoS method, based on two given points and a terrain model, is designed to calculate intervisibility between those two points (Wheatley & Gillings 2002). This basic methodology is also used to calculate viewsheds, which are the cumulative result of LoS calculations between a given target point and surrounding points.

If more than one target point is involved, two viewshed varieties can be distinguished: multiple and cumulative viewsheds. A multiple viewshed is the binary result of the union of various viewsheds which are related to a single theme (Ruggles et al. 1993), whereas a cumulative viewshed is generated by summing various single-theme viewsheds (Wheatley 1995; Lake, Woodman & Mithen 1998). The accuracy of viewshed calculations depends on various parameters that either have to be introduced to the algorithm or considered during the interpretation of the results. These parameters depend on the DEM (Kvamme 1990a; Van Leusen 2002), the earth’s shape, refraction, and further parameters described in detail elsewhere (Van Leusen 2004; Zamora 2005, and references cited therein).

The DEM used for the visibility study of the Palpa geoglyphs was a composite of the photogrammetrically measured DTM of the core study area of 89 km² around Palpa (Fig. 1) derived from aerial imagery at a scale of 1/7000 (Sauerbier & Lambers 2003), and a larger DEM of the same region derived from ASTER imagery. A grid with a mesh size of 30 m was generated automatically in PCI Geomatica 8.2 from one ASTER scene, oriented beforehand using the provided control points. Outliers were detected and eliminated semi-automatically using Raindrop Geomagic Studio 4.0. Both terrain datasets were then intersected using the ArcGIS mosaic function that applies a weighted average method to achieve a smooth surface in the overlapping region. That way, height values were obtained from the more accurate DTM for the main study area, and from the ASTER DEM for the surrounding area. The resulting DEM was then interpolated to a grid with a mesh size of 100 m, as a smaller cell size would have been too time consuming to calculate. The total area covered by the grid is of 803 km², out of which 164 km² comprise the main area of interest around Palpa, corresponding to the original 89 km² of DTM data rounded off to obtain a rectangular area. The area was chosen such as to include all points from which the main part of the geoglyph concentrations on Cresta de Sacramento and Cerro Carapo are potentially visible. This was determined by calculating a viewshed with an unlimited radius for a location on Cresta de Sacramento known to be highly visible from all directions.

In order to obtain quantitative data on the general visibility of the study area, a background cumulative viewshed index (CVI; Van Leusen 2002) was calculated in ArcGIS 9.0. Target points were distributed regularly over the terrain instead of randomly, with a distance of 100 m to each other. This distribution corresponds to each cell of the DEM, such that a total viewshed was calculated. The larger DEM, extending beyond the core area 6 to 10 km in all directions, ensured that edge effects (Van Leusen 2002) were avoided. The parameters earth curvature, refraction, and observer’s height of 1.5 m were accounted for in the calculation. Earth curvature and refraction were corrected in ArcGIS in a common approach. Based on a given projection, in our case UTM Zone 18S with WGS 84 as horizontal and vertical datum, the following formula was applied to the DEM (Kraus 1993):

\[ Z_{\text{actual}} = Z_{\text{surface}} - 0.87 \times F(D^2/2R_{\text{earth}}) \]  \( (1) \)

Here, \( Z_{\text{surface}} \) is the original height value of the DEM, whereas the second term is a function of \( D^2 \), the distance from the observation point, and the earth’s radius.
Figure 2: Cumulative viewshed map of Cresta de Sacramento, overlaid with geoglyph layer.

The resulting background CVI map, a subsection of which is shown in Figure 2, indicates for each cell the number of cells from which it is visible. Here, cells in red have a high visibility index, whereas blue indicates that the cell is visible from relatively few other cells. The visibility values are highest on the hillsides along Río Palpa and Río Viscas and on the flanks of the
higher hills surrounding the floodplain (cp. Fig. 1). The flat plateaus on both Cresta de Sacra-
mento and Cerro Carapo show high values, too. On the other hand, the whole Río Grande val-
ley, but also many small sidevalleys branching off from the larger ones have quite low visibility
values. The geoglyphs on Cresta de Sacramento and Cerro Carapo are also shown on the map
(Fig. 2). A visual inspection of the geoglyphs shows that many of them are located on cells with
a high visibility index, namely on hillsides and plateaus. Others, however, are placed in rather
hidden locations. To assess this distribution pattern in a more substantiated way, it is quantified
in the following with statistical means.

3.2 Analysis of geoglyph visibility

In order to assess the CVI of points of archaeological interest (in this case, the geoglyphs) it has
to be compared to the CVI of arbitrary terrain points as described above (background data). Sta-
tistical comparison allows to determine if the distribution of frequencies of visibility of both
samples is identical within a given level of significance $\alpha$. A widely used hypothesis test for
visibility studies is the Kolmogorov-Smirnov (KS) goodness-of-fit test (Kvamme 1990b), appli-
cable either as a one or a two sample version. The test checks for the acceptance of two hy-
potheses:

- The null hypothesis (H0), stating that the cumulative frequency distribution of sample 1 is
equal to the cumulative frequency distribution of sample 2.
- The hypothesis H1, stating that both cumulative frequency distributions are not equal.

When performing the two-tailed KS test, the sample datasets are divided into class intervals,
for each of which the difference of the cumulative frequency probabilities is calculated and
compared to the critical value $D_{\text{crit}}$, which is determined for large sample data as follows:

$$D_{\text{crit}} = c(\alpha) \sqrt{\frac{n_1 + n_2}{n_1 n_2}}$$

For the coefficient $c(\alpha)$, a value of 1.36 is tabulated for large samples and $\alpha = 0.05$ for a con-
fidence interval of 95 % (Miller 1956). The number of target points in the two datasets is repre-
sented by $n_1$ and $n_2$, respectively. The null hypothesis is rejected if $D_{\text{max}}$, the maximum value of
the cumulative frequency probability differences, exceeds $D_{\text{crit}}$. In visibility studies, it can then
be assumed that a significant deviation of both distributions exists and therefore, that a relation
between the location of tested points and the spatial variable visibility is likely. Dependency of
the investigated points on other spatial variables, e.g. slope, cannot be detected within the same
test and therefore has to be tested separately.

The first dataset to be used as background in the two-tailed KS test was the cumulative view-
shed map for the regular raster of terrain points described above. The second dataset consisted
of target points representing the geoglyphs only. For its calculation, a polygon layer containing
the geoglyphs of Cresta de Sacramento and Cerro Carapo was rasterized, resulting in a raster of
regularly distributed points with 10 m distance in both X and Y direction representing the geo-
glyphs, stored in shapefile format to enable correction of earth curvature and refraction and to
consider the observer’s height. Since the KS test investigates the distribution of two sample da-
tsets, the different mesh sizes of 10 m for the geoglyph points and 100 m for the general raster
points has no relevant effect. Though it would have been possible to use the polygon layer di-
rectly to define target points, the algorithm implemented in ArcGIS would then consider points
on the geoglyph outlines only. Cumulative viewsheds were calculated for the geoglyph target
points in the same way as for the regular raster.

The cumulative frequencies of visibility values of both datasets, displayed in Figure 3, were
then compared applying the two-tailed KS test. Since $D_{\text{crit}} = 0.015$, and $D_{\text{max}}$ was calculated as
0.222, the null hypothesis was rejected. Therefore, the alternative hypothesis H1, stating that
both cumulative probability distributions differ significantly, was accepted.
In Figure 3, the thin curve represents the cumulative probabilities of the 100 m raster target points, or the general terrain background. It shows a steep gradient in classes 1 to 35, containing the cumulative probabilities of cells with low visibility values, and a very flat gradient in classes 36 to 100, where visibility increases. The second curve, representing the cumulative probabilities for the geoglyphs, shows that classes of lower visibility contain relatively more geoglyph points than raster points. On the other hand, the geoglyph curve shows a steep gradient in the classes of higher visibility.

About 41.2% of the area, where geoglyphs are located, is not related to high visibility (class 1). A second group, classes 2 to 33 (low visibility) corresponding to 28.9% of the area covered by geoglyphs, clearly shows a lower increase of the number of member cells for the geoglyphs than for the background sample in the same interval. These geoglyphs may have been constructed without considering visibility, which is most likely for the lower classes of this interval, or they may be related to locally deviating visibility values. Finally, a third significant group covers the classes from 34, the inflection point of the thick curve, to 100, where steepness increases, exceeding the gradient of the background curve. In this interval, another 30.0% of geoglyph points are classified, meaning that they have a higher relation to visibility as compared to the background.

In archaeological terms, the first result is thus that geoglyph visibility differs from general terrain visibility. Figure 4 offers a different view on the data discussed above, corroborating this finding. While the curve in Figure 3 shows accumulated probabilities, these are displayed in absolute values in Figure 4, shown at a logarithmic scale.
Figure 4 visualizes the absolute probability of membership of DEM cells in classes of visibility, here numbered from 0 (low) to 100 (high visibility). The curve representing the visibility of the background contains most members in low visibility classes, whereas the curve representing the geoglyphs shows higher numbers in the classes of high visibility.

In short, these figures show that roughly one third of the Palpa geoglyphs are placed in locations with low visibility values and another third in locations with high visibility values, as compared to the background visibility index. Whether this association was aimed at when the geoglyphs were created cannot be decided yet. As mentioned above, dependency of geoglyph location on other spatial variables, e.g. slope or aspect, has to be tested before drawing definite conclusions. The visibility index of the remaining third part of the geoglyphs corresponds more or less to the background visibility index. Either these locations bear no relation to visibility, or else to local minima or maxima. This aspect will have to be tested separately in a later study. A further step will be to study the composition of each geoglyph group in more detail in order to find out if they show other common traits, e.g. if certain geoglyph types, or geoglyphs of certain chronological phases, were preferably placed in hidden or rather in prominently visible places.

3.3 Analysis of geoglyph intervisibility

Another approach to ground-based visual perception of the Palpa geoglyphs is to study their intervisibility. As described above, social groups associated with certain geoglyph complexes may have been present on their respective sites simultaneously. Activity on geoglyph sites may have assumed an interactive and maybe competitive character, raising group awareness and determining group status (Lambers 2004). If this assumption was true, then geoglyph intervisibility is likely to have played an important role.

In order to investigate intervisibility between geoglyphs, the 100 m raster sample of target points served again as background data to evaluate general intervisibility over the whole area.
To generate the geoglyph target point layer, the existing geoglyph polygon layer was rasterized with 10 m mesh size to achieve representative points regularly covering the geoglyphs. The viewshed calculation was then performed using the raster points revectorized in shapefile format to enable correction of earth curvature and refraction, as well as taking into account the observer’s height. From the resulting cumulative viewshed map, only cells containing target points on geoglyphs were extracted. The two-tailed KS hypothesis test was applied to both samples with the result that the null hypothesis of identical distribution of both cumulative probabilities was notably rejected: $D_{\text{crit}} = 0.023 < D_{\text{max}} = 0.444$. In archaeological terms, this means that intervisibility values between geoglyphs were clearly different from intervisibility values between points distributed regularly over the terrain.

In Figure 5, the curve of the cumulative probabilities of membership in visibility classes for the geoglyphs shows a markedly different progression than the curve representing the background raster points. Only few geoglyph points belong to classes of low intervisibility. A steep gradient of the geoglyph curve can be observed between classes 36 and 56, containing 50.5 % of the geoglyph points, an interval where only 13.0 % of the background points are classified. In this interval of medium visibility concerning the area from where a cell is visible, a relation between geoglyph placement and high intervisibility is most likely. Another remarkably steep gradient of the geoglyph curve occurs between classes 90 and 100, classes of very high intervisibility, which contain another 9.7 % of the geoglyph points. This interval presumably contains points on geoglyphs situated in areas of high concentration of geoglyphs, consequentially resulting in high intervisibility.

The probabilities of membership in intervisibility classes ($1 = $ low intervisibility, $100 = $ maximum intervisibility) underline the result. In Figure 6, displaying again absolute instead of accumulated values, the geoglyph curve shows a high rate of members of visibility classes 36 to 50, compared to the curve displaying the visibility of background raster points. Furthermore, the classes 90 to 100 contain a high number of geoglyph cells in comparison to the curve displaying raster point intervisibility.

Figure 5. Cumulative intervisibility probabilities for geoglyphs and 100 m raster points.
Figure 6. Comparison of absolute probabilities of intervisibility between geoglyphs and between a 100 m raster of target points (logarithmic scale, for technical reasons values of 0.0001 represent 0 values).

This result clearly shows that a predominant part (roughly two thirds) of the Sacramento and Carapo geoglyphs were placed in locations showing a high degree of intervisibility to other geoglyphs. In other words, intervisibility between geoglyph sites was generally higher than between arbitrary points over the terrain. It may thus be concluded that intervisibility between geoglyph complexes was a determining factor when the creators of the geoglyphs decided where to place new ones.

4 RESULTS AND CONCLUSIONS

Visibility of the Palpa geoglyphs was studied here taking into account parameters such as earth curvature, refraction, observer’s height and terrain edge effects. Further parameters could not be modeled due to lack of information as to their nature, meaning that the methodological issues mentioned in chapter 2 could be addressed only partially. Among the parameters not accounted for are potential correlations between visibility and other spatial variables such as slope or aspect. The Kolmogorov-Smirnov goodness-of-fit test does not allow to distinguish the influence and correlations of more than one spatial variable simultaneously, so that each variable has to be tested separately. In future studies, it should therefore be investigated in a similar approach if locations of geoglyphs follow a pattern depending e.g. on slope or aspect. The results of such tests then have to be compared in order to draw conclusions based on archaeological knowledge.

The results of the two tests described in this paper so far show a) that the visibility distribution of the geoglyphs differs significantly from the visibility distribution of arbitrary terrain points, and b) that the intervisibility distribution of the geoglyphs also differs from the general intervisibility properties of the terrain, with a clear tendency toward higher intervisibility of the geoglyphs. From the point of view of Nasca geoglyph research, this strengthens the notion that visibility may have been an ordering principle behind geoglyph distribution, although further studies are needed to draw definite conclusions. Thus far we know that about two thirds of the
Palpa geoglyphs are located in places with either higher or lower visibility values than average. Concerning intervisibility, the tendency is much clearer. Roughly two thirds of the Palpa geoglyphs were placed such that they were well visible from other geoglyphs. While this is partially inevitable due to the common grouping of geoglyphs into complexes, most of these geoglyphs are visible from other complexes as well. This supports the idea of group activity on geoglyph complexes intended to be seen by other groups, thus allowing glimpses on social dynamics in ancient Nasca society. This study further shows which aspects have to be studied in more detail to better assess geoglyph visibility: dependency on slope and aspect, local visibility, and possibly dependency on geoglyph attributes like type or chronology.

In a more general sense, this study further stresses the need to adopt a ground-based perspective when studying the geoglyphs. Against common perception, geoglyph visibility, and especially intervisibility, on the ground is higher than often stated in the literature. It may even have influenced in some way or another geoglyph distribution. Thus, GIS clearly opens up new avenues in Nasca geoglyph research as it is able to support archaeological reasoning.

REFERENCES


