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GIS in Palaeolithic Archaeology. A Case Study from the Southern Netherlands.

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but when there's too much of nothing,
nobody should look
(Bob Dylan, 1967)

Abstract

This paper examines locational features of Palaeolithic and Mesolithic findspots in the loess region of the southern Netherlands, using a Geographic Information System (GIS). GIS applications in hunter-gatherer archaeology have so far been rather rare, although (as is true for later periods) GIS could be a useful tool for the locational analysis of hunter-gatherer stone artefact distributions. This paper deals with the methodological problems encountered when trying to extract environmental variables from a GIS and using them for analysis. The accuracy of digital maps, the statistical tests to investigate the relationship between artefact distribution and environmental variables and the use of predictive modelling are discussed using the south of Dutch Limburg as the study area. It will be concluded that, in our study, GIS has proven to be a valuable tool as a first step of research, dealing with the representativeness and interpretation of Palaeolithic and Mesolithic lithic scatters documented from a geologically dynamic loess landscape. However, due to a number of methodological flaws, GIS is as yet not the analytical tool we can use to answer our research questions.

1 Introduction

The study of regional settlement systems, dealing with aspects such as spatial organisation, mobility, subsistence and lithic resource strategies of prehistoric hunter-gatherers, has become an important topic in modern Palaeolithic research (see for instance Audouze 1992; Féblot-Augustins 1993; Geneste 1988; Soffer 1987; Straus 1986; Weniger 1989). This type of research testifies to a welcome shift from the site-oriented perspective, long dominating Palaeolithic archaeology, to a clear regional and even a landscape perspective (Thacker 1996). Though not necessarily mutually exclusive, there are some clear differences between these two perspectives. In the site-oriented approach emphasis is placed on the site as the basic unit of analysis: the material content and other characteristics of one or a few well-excavated, more or less contemporaneous sites are often used to make inferences about Palaeolithic land use. In the landscape approach, it is not (a selection of) sites that are the main interest, but the archaeological record 'as one of continuous character within a dynamic geomorphic context' (Zvelebil *et al* 1992, 194-195). In the landscape approach all archaeological data, including for instance off-site cultural residues, and (palaeo)environmental information are collected, combined and used in the analysis. One important aspect of the landscape approach concerns the relationship between archaeological find locations and characteristics of the natural landscape embracing these archaeological locations. There are at least two options to investigate this relationship: an analysis based on field observations and an analysis with the use of a GIS. In the first case the analysis will be based mainly on data collected in the field, with the GIS approach the main source of information will be digitized existing maps.

The research presented in this article starts from a landscape perspective and uses a GIS as the first step in an analysis that eventually will lead to inferences about hunter-gatherer land use during the Palaeolithic and Mesolithic in the loess region of the southern Netherlands. A second goal stems from cultural resource management (CRM) and examines the preservation and the (chance of) discovery of archaeological material by way of predictive modelling.

The assemblages under study consist of Palaeolithic and/or Mesolithic artefacts, most of which are surface scatters discovered by amateur archaeologists during intensive field surveys. Generally speaking, these scatters are not chosen for excavation for reasons such as absence of organic materials or disturbances by modern land use. Consequently, this large body of surface material has largely remained ignored in traditional regional studies. In our opinion, however, these scatters should be integrated in any study dealing with Palaeolithic and Mesolithic settlement systems to enlarge the archaeological dataset and to increase its geographical representativeness. Only through their inclusion will it be possible to reach the point where inferences can be made about prehistoric hunter-gatherer organisation (Blezer *et al* 1996).

During the process of establishing whether GIS is a suitable tool for our region and for our research questions a number of methodological problems were encountered which will not easily be overcome. This paper will discuss these problems and will suggest some possible solutions. Many of the problems described below are the result of differences in goals between CRM-oriented research and academic research and have been discussed before (Van Leusen 1996). The main difference between what Van Leusen calls the CRM approach and the academic approach is the emphasis on prediction for the CRM approach and on interpretation and explanation in the academic approach. Generalising, one can say that CRM-oriented research looks for spatial patterns in archaeological material in the landscape in order to predict the location of more material, whereas an academic, research-oriented study looks for the same spatial patterns in archaeological material in the landscape in order to understand and explain human behaviour in the past. This study is the first to attempt to combine both approaches in one research project.

In the next two sections the research area is described and the research questions are formulated. The fourth section of the paper is devoted to three methodological topics: the accuracy of the datasets, methods to investigate the relationship between distribution of archaeological material and environmental variables and methods of predictive modelling.

2 The research area

The research area is situated in the southern part of the Dutch province of Limburg between the cities of Maastricht and Aachen and measures about 30km x 20km (see Fig. 1). It forms part of a loess zone about 180km long and 60km wide, embracing the central and north-eastern part of Belgium, Dutch Limburg and neighbouring parts of the German Lower Rhine region. The area is hilly and varies in height between 40m above sea level in the north and more than 300m above sea level in the south-east. In the west it is bounded by the river Maas. Tributaries of the Maas in the area include the rivers Geul, Gulp and Geleenbeek.

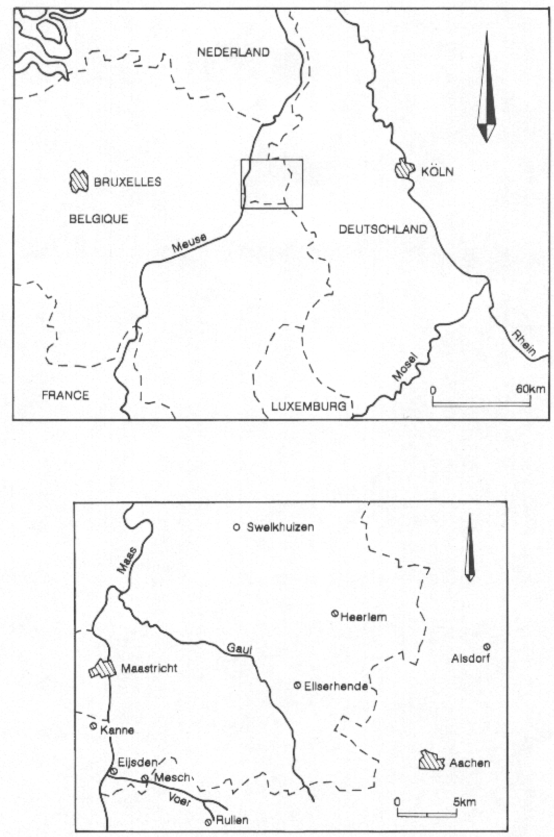

Figure 1: Map of the study area.

In the area the geological subsoil consists mainly of chalk of Upper Cretaceous age (Felder 1975; Kuyl 1980). These deposits are for the main part covered with gravels deposited in the course of the Pleistocene from east to west by the river Maas. On top of these gravels lie loess sediments, which for the greater part are of Upper Weichselian (Pleniglacial) age. Almost the whole research area is covered with a mantle loess, with the exception of stream- and dry valleys which are filled in with Holocene fluvial and colluvial sediments. In the south-eastern part, older geological formations also outcrop. Distinctive elements in the landscape are relatively high, loess covered plateaux and numerous, partly deeply incised stream- and dry valleys.

The area chosen for study in fact can be considered as being highly representative for the much larger hilly loess area of north-western Europe south of the flat, north European plain. As a consequence, we consider the results of the GIS research presented here also of importance for the study of the Palaeolithic and

Mesolithic record in other parts of this extensive loess area.

3 Research questions

The southern part of Limburg has often been used for archaeological regional analysis, with or without the use of GIS. Wansleeben and Verhart (Wansleeben 1988; Wansleeben and Verhart 1995a, 1995b) investigated the Mesolithic-Neolithic transition on the basis of differences in site distribution patterns with the help of GIS, Van Leusen (1993) used a GIS to test a model for the Neolithic Linear Band Keramik culture and Peterson (1996) tested a model for Roman land division.

The research described below is the first step in an investigation that tries to analyse and interpret Palaeolithic and Mesolithic findspots from the Dutch loess area from a landscape perspective. One important topic deals with the effect of the geological processes on the preservation and surface visibility of Palaeolithic and Mesolithic material in the area. We consider this topic as an important and valuable component of a regional, landscape-oriented approach. In the loess region of Limburg geological processes have been contributing to the differential survival of sediments relevant to the preservation of Palaeolithic and Mesolithic (and of course later) material and - by implication - the ‘ingredients’ of these particular records are available for archaeological research (Rensink In press a and b). Knowledge of the effects of geological processes is, therefore, necessary before one can proceed with the interpretation of the archaeological dataset in terms of prehistoric use of the landscape. With this perspective in mind, we have formulated a number of research questions:

- how do we recognize Middle and Late Pleistocene land surfaces and where do we have evidence for preservation and erosion of these former land surfaces?

- what are the chances of recovering Palaeolithic and Mesolithic material *in situ*?

- what are the present day characteristics of the documented find spots?

- to what degree have geological processes affected the original distribution of Palaeolithic and Mesolithic material?

- can we detect diachronic differences in the patterning of the archaeological material and how do we explain these observed differences?

With regard to these last two questions, one of the problems is how to evaluate correctly areas without find spots. Does this point to a selective use of specific zones by hunter-gatherers, or are these ‘empty’ areas a result of erosion or recovery processes? In more general terms: to what degree is the observed distribution of stone artefacts across the area representative for the use of the landscape by prehistoric hunter-gatherers?

4 Methodological topics

4.1 GIS: the data

The first step in the analysis was to establish the locational characteristics for every find spot of Palaeolithic and Mesolithic material in the region. In order to do this the following maps in a digital format were used: the geomorphological map, the soil map, both scale 1 : 50.000, and a loess map derived from the geological map.

4.1.1 The spatial database

A topic often neglected by archaeologists in a GIS analysis is the accuracy of maps. Taking environmental information on find spots from digitised existing maps instead of collecting this data in the field introduces a great source of error. In order to establish the magnitude of this error we used data from the Agro Pontino Survey to compare the different sources of information.

During the eighties a team of Dutch, American and Italian scholars and students studied the archaeology and the past environment of the Agro Pontino (Lazio, Italy) (Voorrips *et al* 1991). The Agro Pontino is a coastal plain along the Tyrrhenian Sea c. 80 kilometres south-east of Rome. Data was collected by way of a regional survey based on principles of random sampling (Loving *et al* 1991). From every field surveyed a vast amount of information was collected. Comparing the soil type from the soil map of the Agro Pontino (Sevink *et al* 1991) with the data on soil type collected by the field survey for 1154 observations, the information does not match in 441 cases, i.e. 38 %. According to soil scientists, in about 30% of the cases the information on a map does not correspond with the information collected on the actual spot. This is caused by the pooling of small soil units into so-called associations and the existence of complexes, units that in the field could not be mapped in detail and of course simply by errors. Add to this the errors made by digitizing these maps and the reliability of these maps is very low.

In contrast to the Agro Pontino, similar information for South Limburg is not yet available. However if we look at for instance the Middle Palaeolithic find distribution on the loess map we notice that there are 20 find spots in unit 7, the coherent loess cover. We know that the loess found at the surface in the area was deposited in the Pleniglacial of the last ice age, that means *after* the Middle Palaeolithic. Middle Palaeolithic artefacts in situ *on top of* the loess are therefore impossible. Of course this is a problem of scale. This observation alone already seems to indicate that the maps used for our analyses are not suitable for answering our detailed research questions. Burrough (1986, 103-135) gives an overview of the sources of errors in a GIS analysis.

To establish if the number of find spots in some land units are higher or lower than expected on the basis of chance alone, some researchers use statistical tests like the chi-square test. Since most maps with environmental data have many categories, in most cases the number of land units has to be reduced in order to decrease the number of units without any find spots. This is done in order to satisfy the rule for the minimum size of expected frequency in each cell. In our case this meant that the soil map, the geomorphological map and the loess map had to be simplified. So to increase the statistical reliability, we further decreased the accuracy of our maps by generalisation.

The statistician Hays (1981, 552) warns against this practice of pooling categories to attain large expected frequencies on other grounds. 'The whole rationale for the chi-square approximation rests on the randomness of the sample, and that the categories into which observations may fall are chosen in advance. When we start pooling categories after the data are seen, we are doing something to the randomness of the sample, with unknown consequences for our inferences. ..... This practice is to be avoided if at all possible'.

4.1.2 The archaeological database

At the moment the archaeological database consists of 76 registrations of Middle Palaeolithic finds, 16 registrations of Upper Palaeolithic finds and 44 registrations of Mesolithic material. Information collected about the find spots include co-ordinates, period, number of artefacts, type of artefacts and size of the find area. Most of the material has been dated by typological and technological means, whereas for the Middle Palaeolithic we could use additional information by looking at the sort of patina. The result is that the archaeological dataset has a coarse temporal resolution. Mixing of flint artefacts belonging to various periods and collected from one and the same spot forms a serious problem, as is the case with recovery processes. The sample of find spots used for our Limburg analysis is not a random sample of find spots in the area. Most of the archaeological material comes from surveys by amateur archaeologists and only a small portion from research excavations. This means that the information is difficult to compare. We do not know the sample size since we do not know what proportion of the area has been looked at. Higher than expected site densities can easily be the result of selective covering of the research area. It is well known, for instance, that plateau areas used as arable land and having a high archaeological visibility are favourite survey areas for amateur archaeologists. In short, we are dealing with a geographically biased dataset telling us perhaps more about the location of survey areas than about the real distribution of Palaeolithic and Mesolithic finds across this particular stretch of land.

4.2 GIS: the analysis

4.2.1 Testing spatial relationships

First the number of find spots in every map unit was established with a simple crosstab. The next step was to investigate if there are units with a more, and units with a less than expected frequency. For the expected frequency, normally a random distribution of archaeological material over the landscape is assumed. There is still not an accepted way of assessing the frequencies.

Often the chi-square test is used to investigate the relationship between site distribution and environmental variables. Sometimes it is used in a way that is not permitted. Before using the chi-square test one has to satisfy a number of assumptions. Most of what follows has been discussed elsewhere (Van Leusen 1995), but it cannot be stressed often enough.

The most violated assumption for the chi-square test has to do with the expected frequencies. Siegel (1956, 110) formulates the conditions as follows:

‘When k is larger than 2 (and thus *df* > 1), the chi-square test may be used if fewer than 20% of the cells have an expected frequency of less than 5 and if no cell has an expected frequency of less than 1‘.

Hays (1981, 541), in his much used textbook called simply *Statistics* is even more strict:

‘Many rules of thumb exist, but as a conservative rule one is usually safe in using this chi-square test for goodness of fit if each *expected* frequency is 10 or more when the number of degrees of freedom is 1, or if the expected frequencies are each 5 or more where the number of degrees of freedom is greater than 1‘.

Still, however, some archaeologists use chi-square to test the relationship between site distribution and an environmental variable when for some categories the expected site frequency is less than five (Odé and Verhagen 1992; Soonius and Ankum 1991).

Yates’ correction is often named as the solution in cases like this. Statisticians, however, do not agree when we are allowed to use this correction. Thomas (1976, 281) says that where there is one sample and more than two categories (as in our case) one is allowed to use Yates’ correction if more than two of the expected frequencies fall below 5. More recently Hays (1981: 542) warned to apply Yates’ correction only when there is one degree of freedom, which means not in the case of investigating the relationship between site distribution and environmental variables.

In our Limburg example an expected frequency of 5 or more is an exception. Palaeolithic and Mesolithic find spots are, for our type of analysis, relatively rare. For all three periods (Middle Palaeolithic, Upper Palaeolithic and Mesolithic) and for the three modified maps we used (soil map, geomorphological map and loess map) in only one case (see Fig. 2, the 78 Middle Palaeolithic find spots on the modified loess map) this rule is met. In all other cases we are not allowed to use chi-square.

unit	legenda	area	perc	O fs	E fs	(O-E)²/E
1	loess cover	346.47	050.03	35	39.03	00.4153
2	loam on slopes	163.47	023.61	37	18.41	18.7612
3	stream sediments	003.20	007.68	00	05.99	05.9920
4	no loess	129.33	018.68	06	14.57	05.0392
		692.48	**100.00**	**78**	**78.00**	**30.2077**

Figure 2. Chi-square test for the Middle Palaeolithic find spots on the modified loess map. df=3, I=0.05, critical value χ^2=7.8147.

Then of course there is the problem of spatial autocorrelation. One of the conditions for the chi-square test is that each and every observation categorized should be independent of every other observation. This however is not the case with for instance a soil map (Van Leusen 1996, 193). Soil type is the product of environmental variables and has a spatial component. Soil types tend to lie in groups of more or less related types and often change into each other gradually. This means soil type is not randomly spaced over the landscape.

But there is another problem with using the chi-square test in certain GIS applications. What are we testing with this chi-square test? We know that there is a strong relationship between environmental variables and the choice of location of settlements and specific activity areas in prehistory. We do not have to prove that again and again.

Ken Kvamme (1990, 271) for instance says about studies investigating the prehistoric human-land relationship:

‘The basic assumption is that the natural environment influenced in a large way the locations selected for site or activity placement by prehistoric peoples. Numerous empirical archaeological, ethnographic, and even theoretical studies support this notion’.

What we are interested in is the strength of this relationship and the direction. Chi-square does not tell us that.

Because of this prior knowledge of the strong correlation between natural environment and site or activity location use of the chi-square test is not very useful. There are, however, in archaeology many examples of the application of chi-square in the above mentioned manner, even in text books (cf. Hodder and Orton 1976, 225; Shennan 1988, 65-67).

The conclusion is that apparently in most if not in all cases we are not allowed to use the chi-square test to investigate the relationship between site distribution and environmental variables, and when we are allowed to use it, it is not very useful. The solution is of course to use alternative methods to test the relationship between a point pattern distribution and environmental variables. One of these methods is the Attwell-Fletcher test (Attwell and Fletcher 1985; 1987). This test was applied during the Agro Pontino Survey project (Kamermans 1993) and by Wansleeben and Verhart for their Limburg research (Wansleeben and Verhart 1995b). Recently Milco Wansleeben suggested some modifications for the test (Wansleeben and Verhart 1995b).

The Attwell-Fletcher test is designed to test the existence of a significant association between a point pattern distribution and categories of an environmental variable. It compares an observed pattern with a simulated random pattern. Two sets of hypotheses are tested. The null hypothesis for the first set is no association, the alternative hypothesis is that at least one category is favoured. In the other case the null hypothesis is of course the same but the alternative hypothesis is that at least one category is avoided. The main advantages of this test are that it can be applied to small samples, that it indicates the strength of the association and that it is directional (i.e. is a category favoured or avoided). The chi-square test can do nothing more than demonstrate the existence of a relationship. A weakness of the Attwell-Fletcher test is that also here the simulation does not take into account the inherent relationship between natural environment and site location. For both the Attwell-Fletcher test and the chi-square test one should be aware that the existence of an association does not necessarily imply a causal relationship. See for a more extensive discussion the original papers by Attwell and Fletcher (1985, 1987), Kamermans (1993) and Wansleeben and Verhart (1995b).

The viability of the results based on research that does not consider the weaknesses mentioned above should be questioned. These weaknesses are well known but most researchers continue to act as if they are not there. In the best case researches give a warning that their results should be viewed 'conservatively' (Kvamme and Jochim 1989, 17) but then continue as if that remark does not have any consequences.

In order to establish more weaknesses in the current practice we do exactly the same, we ignore most of what has been mentioned above and we continue with the regional analysis of South Limburg using the original, not modified, Attwell-Fletcher test.

4.2.2 Results of the Attwell-Fletcher test

The Attwell-Fletcher test is very conservative and shows only in a limited number of cases a correlation between find spot density and land units (in this test called categories). In the tables a correlation is indicated by an arrow. If the category weight is higher than that of the 95% percentile the category is favoured, if the category weight is below that of the 5% percentile the category is avoided. If we look at the modified soil map, we can say that for the Middle Palaeolithic we find a higher than expected density of find spots on the Tertiary and Middle Pleistocene plateaux (see Fig. 3, category 8). The modified geomorphological map confirms this by pointing to a higher than expected density on the plateaux (see Fig 4, category 4).

In order to reduce the influence of differences in the way archaeological material was collected a distinction was made between surface finds and other (cf. from excavations or sections) finds. The surface finds were divided into 'large' surface find spots (i.e. more than five artefacts) and 'small' surface findspots (five or fewer artefacts).

For both the Upper Palaeolithic and the Mesolithic (see Fig. 5) the modified geomorphological map shows in general a more than expected density on the plateaux (category 5) as is the case for the Middle Palaeolithic. Large surface find spots dating from the Upper Palaeolithic appear more than expected on the Chalk.

In other words, assuming a high accuracy of the digital maps and using the Attwell-Fletcher test we can see a rather comparable distribution of Middle Palaeolithic, Upper Palaeolithic and Mesolithic find spots across the loess landscape of Dutch Limburg.

The following explanations may be relevant:

The Attwell-Fletcher analysis of the modified loess map points for all three time periods and almost all site types (all find spots, surface find spots, small surface find spots and large surface find spots) to a more than expected site density on the loess (see Fig 6, category 2). The general picture is that all our distinguished types of hunter-gatherer find spots from the Middle Palaeolithic up to the Mesolithic tend to lie on terraces covered with loess.

During all these periods prehistoric people used the land in a similar way that resulted in a similar site location pattern. From what we know about these time periods this does not seem very likely.

A second explanation would be that originally there were different patterns but, due to geological processes, these patterns for the greater part are lost. This explanation is very much favoured by modern geoarchaeologists (see for a recent example Waters and Kuehn 1996) and at least for some part seems to be valid for our study area as well.

However, as a third explanation we have to keep in mind, that the maps are not accurate and that we do not know how many of the documented finds were still close to their original location of deposition. The fact that according to the map Middle Palaeolithic finds are situated on top of the loess proves this point. We simply have dots with little additional information on an inaccurate map.

Our conclusion, mainly based on the last explanation, is that we have to look for another route. This can be done either by abandoning the GIS application altogether or by improving the dataset. In the last case this would mean, for instance, making more accurate digital maps and/or integrating field observations in the analysis.

Category	Legenda	Number of fs	Expected Proportions	Observed proportions	Category Weight
1	Disturbed	5	0.34	0.07	0.01
2	valley floor soils	1	0.05	0.01	0.02
3	sandy loess soils	1	0.03	0.01	0.03
4	loess soils on plateaus	10	0.16	0.13	0.05
5	loess soils on slopes	26	0.19	0.34	0.10
6	loess soils on colluvial valley floors	8	0.09	0.11	0.06
7	loess soils on alluvial fans	1	0.02	0.01	0.03
8 <--	soils on Tertiary and Middle Pleistocene plateaus	7	0.01	0.09	0.51
9	soils on Tertiary and Middle Pleistocene slopes	1	0.01	0.01	0.05
10	Middle Pleistocene valley floors	0	0.00	0.00	0.00
11	soils on chalk	16	0.08	0.21	0.14

Figure 3. Attwell-Fletcher test for the Middle Palaeolithic find spots and the modified soil map. Number of find spots = 76, number of categories = 11, number of simulations = 200. 95th percentile = 0.35 +- 0.190, 5th percentile = 0.00 +- 0.000.

Category	Legenda	number of fs	expected proportions	observed proportions	category weight
1	steep slopes	38	0.39	0.53	0.12
2	isolated hills	1	0.02	0.01	0.05
3	high hills with plateaus	0	0.00	0.00	0.00
4 <--	Plateaus	3	0.01	0.04	0.36
5	Terraces	20	0.23	0.28	0.10
6	plateau like features	0	0.00	0.00	0.00
7	fan formed slopes	0	0.03	0.00	0.00
8	not fan formed slopes	4	0.06	0.06	0.08
9	isolated low hills	0	0.02	0.00	0.00
10	low hills with plateaus	0	0.03	0.00	0.00
11	Plains	0	0.02	0.00	0.00
12	not valley formed depressions	3	0.02	0.04	0.22
13	shallow valleys (<5m)	2	0.07	0.03	0.04
14	valleys 5-30 m	1	0.04	0.01	0.03
15	deep valleys	0	0.07	0.00	0.00

Figure 4. Attwell-Fletcher test for the Middle Palaeolithic find spots and the modified geomorphological map. Number of find spots = 72, number of categories = 15, number of simulations = 200. 95th percentile =0.33 +- 0.037, 5th percentile = 0.00 +- 0.000.

Category	legenda	Number of fs	Expected Proportions	Observed Proportions	Category Weight
1	steep slopes	21	0.39	0.47	0.32
2	isolated hills	0	0.02	0.00	0.00
3	high hills with plateaus	0	0.00	0.00	0.00
4	plateaus	0	0.01	0.00	0.00
5 <--	terraces	23	0.23	0.51	0.60
6	plateau like features	0	0.00	0.00	0.00
7	fan formed slopes	0	0.03	0.00	0.00
8	not fan formed slopes	0	0.06	0.00	0.00
9	isolated low hills	0	0.02	0.00	0.00
10	low hills with plateaus	0	0.03	0.00	0.00
11	plains	0	0.02	0.00	0.00
12	not valley formed depressions	0	0.02	0.00	0.00
13	shallow valleys (<5m)	0	0.07	0.00	0.00
14	valleys 5-30 m	0	0.04	0.00	0.00
15	deep valleys	1	0.07	0.02	0.08

Figure 5. Attwell-Fletcher test for the Mesolithic find spots and the modified geomorphological map. Number of find spots = 45, number of categories = 15, number of simulations = 200. 95th percentile = 0.44 +- 0.024, 5th percentile = 0.00 +- 0.000.

Category	**legenda**	**number of fs**	**expected proportions**	**observed proportions**	**category weight**
1	loess cover	25	0.50	0.40	0.24
2 <--	loam on slopes	33	0.24	0.53	0.66
3 <--	stream sediments	0	0.08	0.00	0.00
4	no loess	4	0.19	0.06	0.10

Figure 6. Attwell-Fletcher test for the Middle Palaeolithic surface find spots and the modified loess map. Number of find spots = 62, number of categories = 4, number of simulations = 300. 95th percentile = 0.40 +- 0.007, 5th percentile = 0.07 +- 0.020.

4.2.3 Predictive modelling

Our second goal was to investigate the preservation and the (chance of) discovery of Palaeolithic and Mesolithic finds in the study area by way of predictive modelling.

Many archaeologists use quantitative site location studies for predictive modelling: to predict site locations. Various authors have warned against this practice. Savage (1990, 26) for instance regards such studies as 'empirical observations which inductively project site location', or, in other words, as 'simply correlational models'.

In the Netherlands it is common practice to combine the information derived from different environmental maps. This means that some kind of average is computed from the maps which have 'enough predictive value' (Verhagen 1995, 179). In this view, by combining different maps the predictive value does increase.

Van Leusen (1995, 36) recently criticised the practice in the Netherlands to perform chi-square tests for site distribution on different environmental factors since these environmental factors are strongly correlated:

'If a group of sites has a non-random distribution with respect to one of the variables (e.g. soil type), it will automatically have a similar non-random distribution to correlated variables (e.g. geomorphology)' (Van Leusen 1995, 41).

and

'The three environmental factors examined are strongly related, which means there is little sense in performing a separate chi-square test on all three' (Van Leusen 1995, 41).

We agree with Van Leusen that if find spots have a non-random distribution for one environmental variable they will probably have a non-random distribution for all other related environmental variables, but that does not mean that the resulting patterns one sees on the map will be the same.

In order to compare the outcome of such 'predictions' on the basis of different environmental variables we made three 'prediction' maps on the basis of the modified soil map, the modified geomorphological map and the loess map. Comparing the results of the modified soil map and the modified geomorphological map for the three different time periods we find that the 'predictions' contradict each other very often (see Fig 7). For example, the area with 'more find spots than expected' on the basis of the soil map overlaps only for a very small area with the 'favoured spots' on the basis of the geomorphological map. The same applies to the loess map.

However, on theoretical grounds this seems improbable. What is done, while comparing the location of find spots with environmental variables such as for instance soil type, is comparing human behaviour in choosing activity locations with the result of soil forming processes. The soil forming factors are parent material, climate, time, relief and living organisms. Many of these factors do not influence human behaviour in an important way. Parent material? For agriculture, yes, but for hunter-gatherers? And although the factors and processes responsible for the geomorphology of the landscape are more or less the same as for soils they act in a different way and on a different scale.

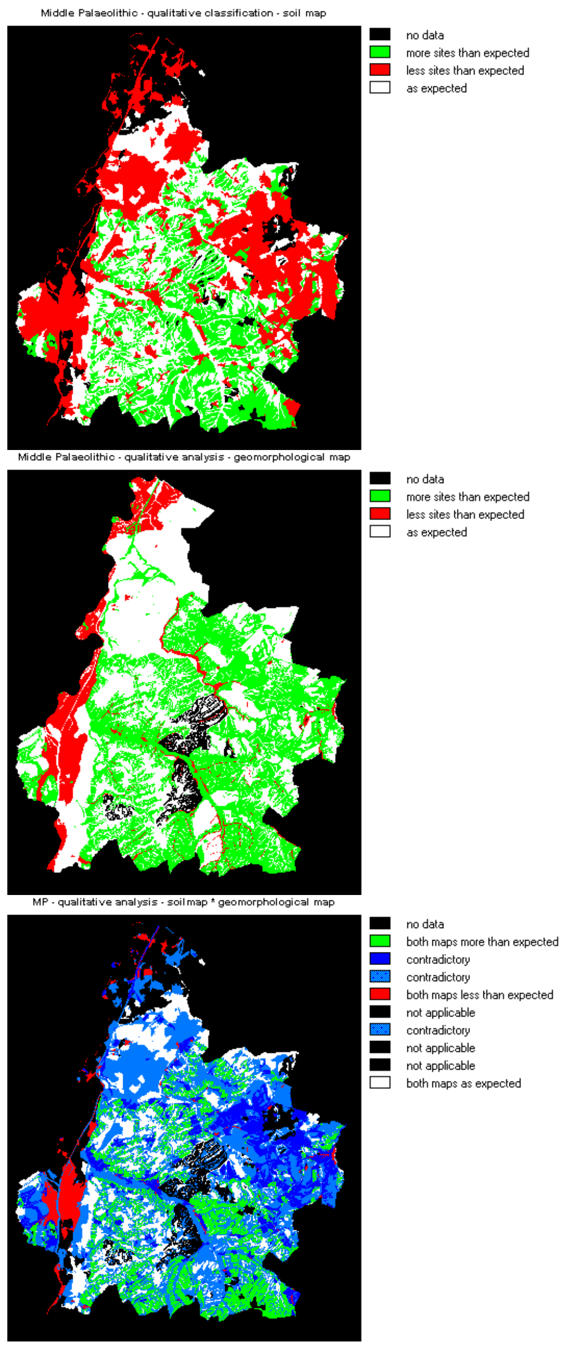

Figure 7. Predictive modelling on the basis of the soil map, the geomorphological map and a map of the combination of the results. For the soil and the geomorphological map green indicates more find spots than expected, red fewers find spots than expected, white as expected. For the combination map green indicates that both maps have these areas as more find spots than expected, red both maps fewer than expected, white both maps as expected and the blue colours indicate that the maps contradict each other.

Also not all the geomorphology forming factors influenced the choice of activity locations in the past. One of the geomorphic processes for instance is the extraterrestrial process of the impact of meteorites. It is not likely that for humans in the past the impact of meteorites was an important factor in their spatial behaviour. What we are trying to say is that it is at least not very elegant to predict the location of archaeological material from the comparison of the spatial pattern of material culture and environmental variables which are the result of a number of factors some of which do not influence human behaviour at all. Combining these maps in order to increase the predictive value makes the control one has over the variables that really influence site location even less.

'The three environmental factors examined are strongly related, which means there is little sense in performing a separate chi-square test on all three' (Van Leusen 1995, 41).

We agree with Van Leusen that if find spots have a non-random distribution for one environmental variable they will probably have a non-random distribution for all other related environmental variables, but that does not mean that the resulting patterns one sees on the map will be the same.

In order to compare the outcome of such 'predictions' on the basis of different environmental variables we made three 'prediction' maps on the basis of the modified soil map, the modified geomorphological map and the loess map. Comparing the results of the modified soil map and the modified geomorphological map for the three different time periods we find that the 'predictions' contradict each other very often (see Fig 7). For example, the area with 'more find spots than expected' on the basis of the soil map overlaps only for a very small area with the 'favoured spots' on the basis of the geomorphological map. The same applies to the loess map.

However, on theoretical grounds this seems improbable. What is done, while comparing the location of find spots with environmental variables such as for instance soil type, is comparing human behaviour in choosing activity locations with the result of soil forming processes. The soil forming factors are parent material, climate, time, relief and living organisms. Many of these factors do not influence human behaviour in an important way. Parent material? For agriculture, yes, but for hunter-gatherers? And although the factors and processes responsible for the geomorphology of the landscape are more or less the same as for soils they act in a different way and on a different scale. Also not all the geomorphology forming factors influenced the choice of activity locations in the past. One of the geomorphic processes for instance is the extraterrestrial process of the impact of meteorites. It is not likely that for humans in the past the impact of meteorites was an important factor in their spatial behaviour. What we are trying to say is that it is at least not very elegant to predict the location of archaeological material from the comparison of the spatial pattern of material culture and environmental variables which are the result of a number of factors some of which do not influence human behaviour at all. Combining these maps in order to increase the predictive value makes the control one has over the variables that really influence site location even less.

To check the approach of combining maps results in a better prediction, we used the difference between the proportion of the find spots incorporated in the model (p_s, i.e. the find spots in the area with a 'more than expected site density') and the proportion of the area incorporated in the model (p_a). This difference (p_s-p_a) is a measure for the 'performance' of the model. A great number of find spots in a small favourable area (a high value of p_s-p_a) points to a good predictive performance. The subtraction is part of the site location parameter K_j, recently introduced by Wansleeben and Verhart (1995b, 103). K_j is defined as

$$\sqrt{[p_s*((p_s-p_a)/p_w)]}$$

where:

p_s = the proportion of the sites incorporated in the model

p_a = the proportion of the area incorporated in the model

p_w = the proportion of the area without archaeological sites

The average site density must be less than 1 per unit cell.

Wansleeben and Verhart are using the parameter to monitor the predictive gain of their model when they adapt the area incorporated in the model. We are not sure if it is possible to use this parameter when comparing the predictive performance of different types of maps of the same area, so we opted for the use of the difference between p_s and p_a as an indicator.

If we compare the difference between p_s and p_a (see Fig. 8) of the predictive models on the basis of the modified soil map, the modified geomorphological map, the modified loess map and the combination maps of soil with geomorphology and soil with loess, we see that for all periods the soil map has the highest value. In almost all cases the combination maps have the lowest values. Concluding one could say that the soil map has the highest predictive power for the location of archaeological find spots.

	area	**p_a**	**O fs**	**p_s**	**p_s-p_a**
soil-mp	173.79	28.51	49	64.47	35.96
morph-mp	273.63	41.23	44	61.11	19.88
loess-mp	218.23	31.51	52	66.67	35.15
so/mo-mp	104.52	17.92	30	42.25	24.34
so/lo-mp	105.44	17.44	35	46.05	28.61
soil-up	51.48	8.44	7	30.43	21.99
morph-up	157.34	23.71	10	43.48	19.77
loess-up	163.47	23.61	10	41.67	18.06
so/mo-up	5.32	0.91	2	9.09	8.18
so-lo-up	29.06	4.81	4	17.39	12.58
soil-me	182.71	29.97	36	81.82	51.84
morph-me	150.75	22.72	23	51.11	28.39
loess-me	163.47	23.61	24	53.33	29.73
so/mo-me	27.22	4.67	17	38.64	33.97
so/lo-me	83.38	13.79	19	43.18	29.39

Figure 8. p_s and p_a values for the modified soil map, the modified geomorphological map, the modified loess map, the combined soil and geomorphological map and the combined soil and loess map for all three time periods Middle Palaeolithic, Upper Palaeolithic and Mesolithic.

This is not surprising. Although soil type is in theory not always a good indication for past human site location, it is a good indication for erosion. Almost all the soil forming factors play a role in the preservation of archaeological find spots. So if one is interested in the preservation of archaeological find spots, instead of prehistoric land use, soil type is a good indicator and the soil map, if accurate, may be an excellent choice for a GIS analysis.

For the relationship between past human site location and environmental variables it is necessary to use maps that indicate only the possible factors responsible for the choice of activity areas.

5 Conclusion

We consider our study area, the loess region of Limburg in the extreme south of the Netherlands, as an excellent working area to test and evaluate the workability of GIS in hunter-gatherer archaeology. It must be said, in fairness, that at this stage of research we are rather sceptical about the contribution of GIS to reach our main objective: the reconstruction of aspects of hunter-gatherer land use during the Palaeolithic and Mesolithic in the area. This is due both to lack of accuracy of the digital maps that we used in our GIS-analysis, recovery processes that have led to a (geographically) biased sample of find spots, and some methodological problems. Though the GIS-analysis has given us some insight into the locational features and distribution patterns of the Palaeolithic and Mesolithic find spots in the area, we still do not have appropriate answers to our research questions formulated earlier in this paper. It is clear that in order to proceed we have to improve both our spatial and archaeological database. This is something that can be done by digitizing more detailed maps and by going into the field in order to collect specific field information. We consider these activities as our main task for the near future. Subsequently, with these new data in hand, we should examine if we are still facing the same methodological problems and, if so, whether there are possibilities to overcome at least some of them.

For the CRM-application it is clear that predictive modelling should be done in a deductive way: one should start with a model (cf. Kamermans 1993; Van Leusen 1993) and create maps with variables important in this model instead of inductively deriving the variables and the model from known find spots and existing maps. The example from Limburg shows that it is very complicated, if not impossible, to extract the variables responsible for site location from various existing maps of the natural environment. Kamermans called the deductive approach land evaluation (Kamermans *et al* 1985; Kamermans 1993). This approach gives the opportunity to test models and predictions with the available data; the inductive approach needs a separate dataset to do this. This means new and expensive data collection, and because of these expenses an undesirable development for CRM-oriented research.

Recently Spikins (1995, 95) summarised the post-depositional processes that influence the interpretation of artefact scatters. Her conclusion is that it ‘brings us to the daunting realisation that the evidence (which the) artefact distributions across the landscape represent in the *present* is in fact a hierarchy of uncertainties’. Add to this the inaccuracies introduced by the use of GIS and one will end with something that might have nothing to do with the original prehistoric pattern.

Nonetheless, many decisions in the field of land management and planning are based on research that suffers from the above described uncertainties. Of course we can continue to fool ourselves and each other but at least we should add a warning to people who are making political decisions on the basis of our research that our results are at best estimates with a large uncertainty and at worst have nothing to do with reality whatsoever.

The problem with having a more conservative attitude towards the results of GIS analysis for planning purposes is that, most probably, fewer areas will be considered as of ‘high archaeological value’. This means that more areas will be destroyed by the construction of roads, railways and other building activities, which is the opposite effect to that desired by most archaeologists. Despite the obvious shortcomings discussed in this chapter, we should be very cautious of abandoning GIS in CRM-applications completely, mainly due to the absence of a good alternative.

If all the above mentioned severe problems remain and no solution appears within reach, our conclusion may be that, in particular for CRM-applications, GIS as yet is not the analytical tool some archaeologists would have us believe. At this moment the main strength of GIS lies in the visualisation of research conducted with traditional means in an accurate way.

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