Archaeobotanical and GIS-based Approaches to Prehistoric Agriculture in the Upper Ying Valley, Henan, China

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Abstract

Archaeobotanical survey has sampled a series of late Neolithic to early Bronze Age settlements in the upper Ying valley (part of the central plain of China) and provided useful data for understanding prehistoric arable ecology and farming during a period of increasing local social complexity. A combination of the modelling functions offered by Geographic Information Systems (GIS) and the data reduction possibilities offered by Principal Component Analysis (PCA) allow us to explore the relationships between local arable ecology, crop-processing strategies and the natural environment. The results suggest that differences in the natural environment around each site are a good explanation for varying patterns of wild food collection, but in contrast, social and cultural factors seem to be much better at explaining variation in farming practice and crop-processing at different sites.

Keywords

archaeobotany, crop processing, millet, rice, Principle Component Analysis, Mantel Matrices

1. Introduction

Over the last few years, archaeobotany has provided an increasingly important perspective on the rise of early complex societies in China (e.g. Zhao 2005, 2006). This methodological emphasis both reflects and has encouraged the development of a wider body of theory about the development of prehistoric agriculture in the central plain of China (e.g. Jin and Luan 2006; Lee and Bestel 2007). While most of this work has been focused at the intra-site scale, nevertheless, wider regional patterns of crop use and population change have also attracted attention, primarily through the collection of archaeological survey datasets (Qiao 2007; Lee et al. 2007; Fuller and Zhang 2007). What has mostly been missing up to present however, has been a systematic, quantitative attempt to integrate site-based archaeobotany with a broader landscape-scale analysis.

This paper seeks to fill this gap: it draws its data from an archaeobotanical survey project along the upper Ying valley, in China's central plain, that was designed to explore the relationship between changing agricultural strategies and the emergence of more complex society over the crucial period from the late Neolithic to early Bronze Age (ca.4000-1500 BC). Despite the project only being able to collect samples

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from a relatively small number of sites, the results have revealed interesting and recurrent trends in crop processing and subsistence strategies in the region (Fuller and Zhang 2007). Moreover, this preliminary analysis has suggested that some of the variability in observed archaeobotanical patterns might be explained by their spatial correlation with particular environmental variables, or their temporal correlation with particular cultural changes (Zhang 2007: 770-773). This paper therefore considers these correlations more formally, taking advantage of the exploratory and confirmatory potential offered both by modern Geographic Information Systems (GIS) and multivariate statistics.

The upper Ying valley is an alluvial basin in Henan province, bordered by the Luoyang basin to the northwest, within China's central plain (figure 1a). It is in this region that China's earliest state-level society developed in the early 19th century BC (Lee 2002; Liu and Chen 2003). Bounded by the Songshan mountains to the north and the Jishan mountains to the south, the Ying river flows west to east, gradually gathering new branch streams from the adjacent mountains. Most prehistoric sites are found at the locations where these branches converge (figure 1b) and, from the 1950s onwards, this was one of the first areas where Chinese archaeologists looked for the origins of Chinese civilization (Xu 1959). Since then, no less than five archaeological survey projects have been carried out in this region and nearly 40 sites dating from late Neolithic to early Bronze Age have been discovered (LAT 1961; HPICR and CCRYC 1991; An 1997; HPICRA et al. 1998; Zhang 2007).

The local chronology in this region is based on both ceramic typology and radiocarbon dating and, in combination, these suggest three broad archaeological divisions (Zhang 2007: 760-763): a late Neolithic 'Yangshao' phase (ca.4000-2500 BC), a transitional 'Longshan' phase (ca.2500-1800 BC) and an early Bronze Age 'Erlitou' phase (ca.1800-1600 BC). Although more precise sub-periods can sometimes be distinguished, the relatively small number of individual sites in the area does not usually facilitate archaeological interpretation at the level of these more detailed time spans. Previous work has also distinguished two different groups of settlements in this region, each with distinct cultural traditions and different levels of social complexity (Zhang 2007: 672-684). For our purposes here however, we focus on just one group of settlements, in the upper Ying valley, comprising 18 individual locations, with evidence from one or more of the three main archaeological periods.

2. Research Context

Previous research has identified the basic subsistence crops used in this region during the late Neolithic to early Bronze Age (Fuller and Zhang 2007). Millet (*Setaria italica* and *Panicum miliaceum*) was the dominant crop throughout, with *Setaria italica* the dominant species. Rice (*Oryza sativa*) was present at almost all sites and in most periods, but it is only a minority component of the total, archaeologically-recovered, cereal assemblage and seems to have been relatively rare. The soybean (*Glycine max/soja*) probably was collected as a wild species although a domestication process by Longshan times is possible. Wheat (*Triticum sp.*) first appeared in the area during the early Bronze Age and must have been introduced to China from the West (Zohary and Hopf 2000: 57-58), but there is no clear evidence that this introduction significantly changed the profile of local food consumption at this stage. Overall therefore, the data offers a relatively consistent picture of crop *use* over time and between the settlements of the valley, but a picture that becomes more varied when, instead, we consider potential diversity in crop *harvesting and processing* between individual sites.

The sequence of operations involved in these tasks allows for substantial variation in practice, as well as opportunities for both innovation and information-sharing between people or communities. Harvesting is addressed again below, but it is worth noting here that an important recent agenda in archaeobotany has been the need to improve our understanding of the different strategies involved in crop-processing (e.g. Van der Veen and Jones 2006; Fuller ans Stevens 2009). Increasing attention has also been paid by Chinese archaeologists to this issue over the last few years, both in the discussion of carbonized plant remains (Fuller and Zhang 2007) and phytolith assemblages (Jin et al. 2007). In theory, all of the different stages that crops go through, from the field to the cooking pot, are of potential interest to archaeobotanists, including harvesting, drying, threshing, winnowing, storage, pounding and sieving. At each stage, there may be corresponding waste left at an archaeological site suggesting, at first glance, a huge number of different, contingent and context-specific explanations for a given set of plant remains. However, ethnoarchaeological research suggests that what is, in fact, most regularly observed in the archaeological record of settlement sites is typically the waste from the routine, everyday work involved in transforming the crop from its state-in-storage to something ready for cooking (Stevens 2003). Accidentally or deliberately burnt for some reason, the charred remains from this kind of routine crop-processing find their way into everyday rubbish and the fills of other kinds of archaeological feature.

A key contribution that this proposed model of *routine crop-processing* makes is to suggest that the nature of the archaeological features themselves will often have limited bearing on the patterns of routine crop-processing remains that are present, as long as the deposits in these features show signs of including everyday rubbish. More practically, it also implies that we can hope to address questions of local farming practice by considering the overall content of archaeological plant assemblages, rather than only concentrating on the minutiae of their separate archaeological contexts (e.g. Harvey and Fuller 2005: 741; Fuller and Stevens 2009). This model therefore offers a crucial underpinning for archaeobotanical survey, indicating that we might reasonably investigate regional-scale variation in agricultural activities via archaeobotancial samples that have been collected from different sites and different contexts. Such a methodological assumption is particularly relevant in the central plain of China, where most sites have been in continuous occupation for hundreds of years and the plant remains within each site had been redeposited, moved and mixed repeatedly.

This methodological emphasis on investigating routine crop-processing patterns can also provide insight into the varying ways in which labour might be mobilised for farming activities. For example, if reasonably abundant sources of human and animal labour are available for crop-processing in the stages prior to crop storage, then this reduces the need for such processing later on, making the subsequent, everyday use of these stored crops far more convenient, because they now include comparatively less chaff, spikelet bases, straw and weeds (Fuller and Stevens 2009). The degree of pre-storage labour input will often therefore have an on-site archaeological signature that we explore further below. In any case, the preliminary study of the archaeobotanical survey results (Fuller and Zhang 2007) revealed some recurrent crop-processing patterns in the upper Ying valley, but further analysis is still needed. Many different factors, both social and natural, might exert an influence on farming practices, how communities stored their food, and/or the time and labour spent on different stages of crop-processing. In the discussion below, we therefore deploy a range of multivariate statistics and GIS-led methods to explore these potential causal factors further. More precisely, we will consider the possible role of geographical proximity and social connectedness among prehistoric sites in this area, possible changes in practice over time, and also variation in the natural environment around each site. The following section describes the creation and integration of these various analytical variables in greater detail.

3. Dataset Preparation

3.1 Archaeobotanical Data

The collection of archaeobotanical samples suitable for studying the complexity of arable ecology and agricultural activities was a core objective of recent regional survey of the upper Ying valley, but despite this targeted effort, the overall number of available samples is limited. Of the 20 late Neolithic to early Bronze Age sites recorded by previous surveys in this region, only 18 remain sufficiently well-preserved to allow re-exploration, and, of these, only 9 have exposed archaeological deposits from which sufficiently large soil samples for flotation could be obtained from clean contexts. Table 1 lists these sites and offers a summary of the samples taken from them (see figure 1b for their locations). In general, multiple samples were taken from each site and, with one possible exception (the Erlitou period site of Shidao), these exhibit reassuring uniformity in their archaeobotanical results, prompting us, for our purposes here, to work with a single generalized archaeobotanical pattern for each site. Below we draw upon the raw analysis of these samples (details in Fuller, et al. n.d.) to generate a range of indices relevant to two broad aspects of the agricultural economy in this region, that we can loosely term arable ecology and crop processing.

3.1.1 Arable Ecology

This is a broad term that is used here to refer to the general biological environment in which agricultural activities take place, particularly with respect to the overall balance of weed, wild fruit and crop types. For each site, six variables have been calculated from the original archaeobotanical data: the ratios of (i) *rice* to *millet* and (ii) *Setaria* to *Panicum*, and the percentages of (iii) *wetland weed species,* (iv) *dryland weed species*, (v) *soybeans* and (vi) *wild fruits* (table 2).

The first two of these measures can potentially be used as indicators of crop choice. Since the cultivation of rice requires more sophisticated drainage systems than millet, and since rice also seems to have been less common overall than millet in the local economy (Lee et al. 2007: 1092; Lee and Bestel 2007: 57), local variations in the ratio of rice to millet may reflect local community decisions about crop priorities and variations in the sophistication of local agricultural techniques. Turning to the cultivation of millet in particular, the ratio of *Setaria* to *Panicum* may provide a useful indicator of the varying scale of local agricultural production. For example, later Chinese historical records (e.g. *Qimin Yaoshu* Vol.2 *Shuji*) indicate that *Panicum* was often used as a pioneer species to settle new millet planting areas and a large percentage of *Panicum* within the millet assemblage might therefore reflect the expansion of agricultural production into new fields. The second two measures can perhaps be used for subtler characterisation of the local environment for agriculture. For example, most of the weed species discovered in the survey are those that infest fields-in-crop and some of them reflect distinctive adaptations to wetter or drier land environments. The last two percentages offer a possible window onto the importance of wild food collection in the local ecology. While soybeans are present in considerable quantities in most of the archaeobotanical assemblages considered here, morphological analysis suggests that most of them are wild species and should therefore be viewed as one of the most important collected foods.

In order both to explore the interdependence of these six variables and to simplify subsequent comparison, we used Principle Component Analysis (PCA) to reduce them to three main factors (table 3, hereafter referred to as Arable Ecology Factors 1-3: or AEF1-AEF3), with a good level of extraction and accounting for 85% of the overall variance. The rotated components[4] show that the two original wild food collection indices (for soybeans and wild fruits) are strongly correlated and best explained by AEF1. Similarly, the original wetland and dryland weed variables are best simplified by AEF2, and the original ratios of rice to millet and *Setaria* to *Panicum* as AEF3.

3.1.2 Crop Processing

Crop-processing here refers to harvesting methods and post-harvest crop-processing activities. Harvesting is the first stage of crop-processing and the main source of variation here relates to the height at which the crop is harvested, for which we can make a rough distinction between (i) uprooting, (ii) reaping low on straw and (iii)

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[4] There is debate amongst archaeologists and others about whether it is appropriate to use a rotation of the main PCA factor axes or not (e.g. Shennan 1997: 301-303). However, for our purposes here, the rotation produces more balanced explanatory percentages between the three extracted factors so we have proceeded with it.

reaping high on straw. Ethnoarchaeological research indicates a range of factors that might encourage the harvesting of crops at a particular height, including the nature of the crop, its broader ecology, the conditions of its planting, local or adopted cultural tradition etc., (Hillman 1984: 117-120). These different influences may sometimes be discerned from the analysis of weed species vs. plant height: more precisely, if we assume that the weeds are harvested together with the crops, then uprooting and reaping low on straw might be represented in a weed pattern with more low-height stalks or prostrate species (see Li 1998 for Chinese weed heights). In contrast, reaping high on straw is likely to pick up more tall-standing weed species. Here, we calculate two measures for each species and then take the average: the *mean of maximum weed height* and the *mean of minimum weed height* (table 4).

For understanding variation in routine crop processing, two ratios may be suggested for millet archaeobotany as useful indicators (Fuller and Zhang 2007; cf. Harvey and Fuller 2005): the ratio of *grains to weeds* and the ratio of *hulled & immature to unhulled & mature* grains (table 4). At different stages of crop processing, these two ratios can change dramatically. For example, higher proportions of hulled and immature grains are expected in threshing products than in dehusking, winnowing and sieving processes. The latter should also reduce the proportions of weed seeds. While the actual processes responsible for variation in these ratios are known to be very complex, i.e. immature proportions may be affected by quality of grain-filling or harvest timing, while charring condition may affect levels of husk preservation. The grain to weed ratio may also be influenced by time spent on eliminating the weed from crops regardless of field management or other crop harvesting practices. Nevertheless, we expect these patterns to generally reflect patterns created by crop-processing.

3.2 Geospatial Data

In order to make sense of these site-specific archaeobotanical variables, we need to be able to see how strongly they correlate (or not) with neighbouring sites and/or with a model of the varying local environment around each site. Fortunately, modern remote sensing and Geographic Information Systems (GIS) allow us to exploit near-exhaustive environmental coverages (albeit at particular spatial resolutions) and to examine spatial relationships with ever increasing efficiency in terms of time and cost. Below, we outline the methods we have deployed for this purpose.

3.2.1 Primary Coverages

Our primary topographic coverage is a 30m digital elevation model (DEM) of the upper Ying valley that was extracted from the band 3 pair of an ASTER satellite image (e.g. Abrams 2002) and slightly adjusted, in both the horizontal and vertical plane, on the basis of known ground control points (figure 2a). Various secondary datasets were produced from the DEM, but three additional primary coverages consist of a geology map, an annual precipitation map and soil map (figures 2b-d). The geological data was initially digitised from a 1:500,000 scale paper map (HPBGM

1989), but was then adjusted for greater accuracy by checking the major unit borders on a composite of the ASTER short-wave infared bands (the latter dataset being commonly used for geological prospection). In particular, the accurate mapping of the first and second-stage, Pleistocene river terraces is crucial as this is where most of the archaeological sites are located. The precipitation and soil maps were digitised from coarser 1:1,000,000 scale maps (CHRRMWR and NIGLCAS 1999).

3.2.2 Cost Surfaces and Agricultural Catchments

One of the purported strengths of GIS for archaeologists has been its ability to model the cost of travel across a landscape, and thereby to explore both possible routes of past movement and to model possible economic or political territories. In fact, there have been a host of methodological failings associated with the way such cost surface models (as they are known) have been constructed. These have led in the past to some very unreliable results (for a recent discussion and further references, see Bevan in press), but more recent software implementations, such as the *r.walk* module in GRASS GIS (Fontenari et al. 2005) are much better-designed in this respect and are able to model the combined effects of anisotropic influences on travel time such as steepness of slope, as well as isotropic costs such as variable land cover. Here, we calculated individual cost surfaces from each site, based on the impact of variable terrain and added an extra 20-30 minutes for river crossings (depending on stream width). An example of such a cost surface is shown in figure 3a.

These cost surfaces also allow us to propose which parts of the surrounding landscape should be allocated to which contemporary site, based on shortest travel time. There are of course many other factors affecting the organization of agricultural holdings (at this village scale), but travel time is often an important factor and several studies have emphasised that a one-hour round-trip to the fields and back represents a key, cross-culturally relevant threshold (e.g. Chisholm 1968: 45-49; Zahavi 1979: 61-103; Bevan et al. 2003: 230). We therefore defined possible catchments for the upper Ying sites (separately for each phase) by first allocating each part of the landscape (i.e. each cell in our raster datasets) to the nearest site in terms of travel time, and then cropping these allocations to a maximum travel time of one hour (e.g. figure 3b).

3.2.3 Geographical Proximity

Here we consider two simple, geographical measures of the spatial relatedness of individual prehistoric sites: distance and adjacency. The first of these refers to Euclidean ‘as the crow flies’ distances between sites, while the second is coded as a topological relationship between site catchments: either partially overlapping (0; primarily relevant for non-contemporary site catchments), adjacent (1) or not adjacent (2). In all cases, we have decided to calculate these measurements between all pairs of sites regardless of their chronological phase, because, in contrast to the more socially-focused network indices considered below, here we wanted to consider geographical proximity as a plausible causal factor behind both the spatial diffusion of farming techniques over time and the cultural inheritance of such techniques from adjacent ancestral sites. This is also the reason why we prefer simple Euclidean distances, assuming that more topographically-sensitive walking distance would make less sense for non-contemporary sites.

3.2.4 Social Networks

Beyond these generic, chronology-free measures of proximity however, we are also interested in the complementary or contrasting impact of more highly social relationships between contemporary sites in the region. Two variables based on network analysis have therefore been included here: connectivity and accessibility. For both indices, we first create a topographically-sensitive network of linkages between contemporary sites, combining both terrestrial and riverine travel times. In the absence of any detailed knowledge of actual trackways in this period, the former are calculated via the cost surfaces produced for the site catchments above, and represent the shortest (anisotropic) walking time from one site to another overland. The latter assumes travel by canoe along the local waterways[5] and, for simplicity, averages out the directional and seasonal complexity that this would have involved, assuming instead, an even isotropic speed of ca.10 km per hour along the river system (e.g. Heyen 1972:72; Finney 1977). These terrestrial and riverine linkages builds a network among contemporary sites that allows as to consider the place of any individual site in its wider probable social context (figure 4a-c). Here we use two common network indices: a connectivity index evaluates the degree to which a site is well- or poorly-connected relative to others, while an accessibility index suggests how easily a site can be reached from any point in the network (for further details, see Conolly and Lake 2006: 234-252).

3.2.5 Sites and Their Local Environment

In order to investigate whether differences in the environment around each community might explain some of the variation in their farming practices, we also summarised a range of variables for each site's proposed catchment: (i) slope, (ii) exposure to prevailing winds, (iii) surface water flow, (iv) amount of river terrace, (v) precipitation and (vi) amount of different soil types.

The mean of logged slope was used for each catchment to avoid any problems of statistical summary that might arise from taking the mean of raw slope values, particularly in light of the fact that the latter are often lognormally-distributed (e.g. Speight 1971). The dominant winds in the region are from the northwest in the winter and from the east in the spring and summer (Editors for Dengfeng City Annuals 2008: 85), and exposure to these was measured for each grid cell based on the degree to which its aspect deviated from these prevailing directions. Surface water flow was measured as mean logged flow accumulation, again to avoid problems associated with

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[5] All of the sites in this study are located next to rivers and later historical documents also emphasize the importance of river systems for transport and political control in the central plain of China. The most famous record in this regard is the *Yugong* (regarded as one of the earliest Chinese historical documents) which suggests that the Great Yu, believed as the first king of the central kingdom of China, was the first to use the river systems to unify all nine states of China and also draw upon them for supplies (*Yugong Jiuzhou*).

a typically skewed distribution. The total area of river terrace in a catchment was used here as a very rough proxy measure for prime arable land, in light of the fact that the location of prehistoric sites is significantly-correlated with river terrace zones (K-S one-sample test, p=0.005) and these areas are known by modern farmers to offer many advantages in terms of fresh water supply, field management and soil quality. Precipitation was calculated as the mean value per catchment. The local soils of the region can be lumped into four broad categories (cinnamon, chao, purplish and skeletal soils), based on the mineral components, pH value, granulometry and physical structure (CHRRMWR and NIGLCAS 1999). The total amount of each soil type was calculated and included as separate values in the principal component analysis described below.

The summary values for each site catchment were then subject to PCA in order both to explore patterns of interaction between the variables and to reduce their complexity down to something more manageable. The results in table 5 suggest that the first four PCA factors (hereafter referred to as Natural Environment Factors 1-4: or NEF1-NEF4) account for nearly 90% of the variance and all but one of the original variables attains more than 80% extraction. NEF1 broadly reflects the association between increased water flow, amounts of river terrace, amounts of chao soil and lessening exposure to the dominant spring/summer wind from the east. NEF2 can be used to characterise the association between steepening slope, increasing amounts of cinnamon soil and decreasing amounts of chao soil. NEF3 broadly reflects the link between more annual rainfall, increasing amounts of purplish soil and decreasing amounts of skeletal soil. Finally, NEF4 mainly explains patterns associated with increasing exposure to the dominant winter wind from the northwest.

4. Data Analysis

We now turn to ways in which we can make use of the above datasets to understand the complex relationships that potentially exist between a particular prehistoric community's farming practices and its wider social and natural environment. Such a research objective is fraught with difficulties: some of these difficulties relate, of course, to the small number of sampled sites, as well as to problems of archaeobotanical taphonomy, GIS algorithms and multivariate data generalization. Further difficulties also relate to the problems associated with unpicking multivariate relationships in situations where pronounced patterns of spatial and temporal dependence and/or heterogeneity exist (as recent reviews in both ecology and archaeology have re-emphasised: Miller et al. 2007; Bevan and Conolly 2009). As the above should indicate however, we see many of these difficulties as surmountable, and with regard to the latter problems of spatio-temporal dependence, we have here taken care to: (i) reduce the spatial heterogeneity in our dataset by restricting the study to similar types of site in the upper Ying valley only (see above), (ii) incorporate explicit spatial and temporal factors in our analysis, and (iii) make use of Mantel matrices that work well with measures of spatio-temporal distance. Below our analysis proceeds in two steps, considering first a global regression of the above datasets, and then results from Mantel matrix tests.

4.1 Linear Regression

In this section, we use a linear regression to discuss possible relationships between the archaeobotanical data and GIS-based environmental data. One of the advantages of the PCA approach adopted above is that our new variables are now uncorrelated with one other, making it possible to proceed with a sequence of pair-wise regressions with greater confidence. To control for possible chronological variation, we have also divided the sites into two groups: Yangshao Period (ca.4000–2500BC) and Longshan to Erlitou Period (ca.2500–1600BC).

The results are presented in the table 6. Those high correlation coefficients with low p-values suggest that AEF1 is correlated with NEF1 and, to a less significant extent, also with NEF3. This implies a linkage between variation in differences in wild food collection strategy and differences in the local environment around each site, including greater exposure to the spring/summer wind, greater local water flow, the presence of more river terrace land, greater rainfall and certain preferred soil types. However these correlations (between AEF1 and NEF1) lessen for the later Longshan-Erlitou sites, possibly due to an overall decrease in wild food collection in the late period or to the small number of analytical samples. AEF2 on the other hand is strongly correlated with NEF4 (but only at marginal levels of statistical significance for each phase with the present sample). This implies that the original variables recording percentages of wet and dryland weeds are possibly linked to patterns of exposure to the prevailing winter wind.

Two further bits of negative evidence are of possible interest. First, NEF2, which primarily reflects the variability of terrain slope and cinnamon soil has no clear correlation with any of the archaebotanical data, whether the latter relates to farming or collecting practice. Second, AEF3, which relates to variation in the ratios of different crops also does not however exhibit any clear correlations with diversity in a site's natural environment. In general therefore, these linear regression results demonstrate that diversity of natural environment around each site can often explain the diversity in collecting behaviors but does not really explain diversity in farming behaviours. Indeed, the possible association of weed species (that we assume to be infesting farmed plots) with areas more exposed to the dominant winter wind also implies a natural cause for this variation rather than a cultural one.

4.2 Mantel Matrix Tests

A Mantel matrix test can provide statistical confirmation of linear correlations within matrices that measure similarity or dissimilarity between pairs of observed phenomena (Mantel 1967). Here, our pairs of observations are archaeological sites of the same phase and we convert our factors measuring geographical distance, social connections, chronology, environmental diversity and farming practice into dissimilarity matrices. The chronological difference between each pair of sites was expressed as a binary relationship indicating whether the sites were contemporary (1) and or not (0). This binary relationship was preferred over a linear scale of temporal similarity, in light of preliminary work which had suggested non-linear, oscillating variation in the intensity of crop processing over time (Fuller and Zhang 2007: 928-931, 954-958).

However, prior to considering how (i) our archaeobotanical data might be explained by (ii) our spatial, temporal and environmental variables, we first address possible interdependent relationships within the second of these datasets (which now include both the uncorrelated NEF factors and the other variables for chronology, distance, social connectivity, etc.) via a partial mantel matrix test in which two matrices are considered with a third one controlled. The results are shown in table 7 and suggest significant positive correlations between NEF3, accessibility and adjacency. A Further partial mantel tests indicate that the correlation between adjacency and accessibility disappears when the NEF3 is controlled (r= 0.198) and the same is true for the NEF3 and adjacency variables with accessibility controlled (r=0.179). However the relationship between NEF3 and accessibility remains strong with (r=0.731) or without (r=0.794) control. We suggest that this relationship is partly driven by the fact that sites located near the centres of networks also have catchments with higher annual rainfalls, greater amounts of purplish soils and lesser skeletal soils. Of course geographical distance and adjacency are also strongly correlated but it remains useful to treat them separately in the following analysis.

Table 8 then shows results from mantel matrix or partial mantel matrix tests (the choice of which is informed by the presence or absence of correlations in table 7) considering the relationship between those archaeobotanical indices relevant to farming practice and the various possible explanatory variables. Reassuringly, these tests come to the same conclusion as the linear regression with respect to the complete lack of correlation between the environmental variables and farming strategies. On the other hand, they also indicate that variation in weed harvesting height is correlated with simple geographic distance, but even more strongly with catchment adjacency. Furthermore, for the crop processing variables, we can note that the ratio of hulled/immature to unhulled/mature grains is significantly correlated with chronological phase, and the ratio of grains to weeds with a site's degree of accessibility within the social network (but interestingly not its number of connections). In general, therefore the Mantel matrix test results confirm those from our previous linear regression and also indicate that variation in harvesting and crop processing strategies are probably better explained by social and cultural factors, rather than environmental ones.

5. Discussion

Both recent theoretical models and preliminary analysis of the upper Ying data broadly supports the assumption that we can compare site-specific archaeobotanical samples to try to understanding patterns of regional variation in agricultural practice.

A series of commonly-used measures have therefore been produced that can plausibly be used as proxies for understand variation in harvesting practice, wild food collection and routine crop processing. In addition, we have made use of GIS to calculate various measures of inter-site proximity, to suggest possible site catchments and then to quantify aspects of the natural environment within each catchment. Thereafter, PCA allowed us to compress the complex results from the archaeobotanical study and the GIS-derived environmental variables into more analytically meaningful and intuitively manageable groups. Linear regression and Mantel matrices were then used as both exploratory and confirmatory methods for investigating how these different groups of variables co-vary and, ultimately, to suggest possible causal relationships.

On the one hand, the results suggest that differences in the natural environment around each site only really have a significant impact on patterns of soya and wild fruit collection, and have little to do with differences in farming practice between sites. On the other hand, social and cultural factors seem to be much better at explaining variation in farming practice at different sites. More precisely, similar habits with regard to harvesting height are typically shared by neighbours but not clearly related at any larger regional level. This conclusion deserves to be set back within its wider archaeological context. For example, study of the stone and shell remains from the Wangchenggang site suggest that there are two types of harvesting tool: a stone knife (that could be perforated or unperforated) and a sickle made of either stone or mussel shell. Li Yangsong has reconstructed the way these two tools were most likely used, on the basis of ethnographic comparison (School of Archaeology and Museology in Peking University 2002: 34), suggesting that the knives were held in hand to cut down cereal spikes from the tops of stems. In contrast, the stone or shell sickles had serrated edges and a bent shape that allowed them to be tied on the end of wooden sticks and used to cut crops from the bases of their stems (figure 5). So generally-speaking, the knife and sickle can be seen as two kinds of tools which were used to harvest crops at different heights. These suggestions have obvious relevance to our statistical findings here and, in future, might be taken further through greater attention to the tool repertoires at different sites in the upper Ying valley.

For patterns of routine crop-processing (as represented by proxy indicators such as the ratios or grain to weed or hulled/immature to unhulled/mature grains), it is intriguing that one of the social network variables provided the best explanation More interesting still, it is not the overall network structure or the number of connections that a site enjoyed that seems to have been important, but its accessibility within the local network. However, the details of the correlation here are important: the lower the accessibility index, the more easily a site could be reached from all others in the network, while the larger the grain to weed ratio and the smaller the hulled/immature to unhulled/mature ratio, the more labour and time was arguably devoted by the community to crop processing before storage. Hence, we actually have a negative correlation whereby the more accessible an individual site was within its immediate social network, the less time and effort it typically seems to have spent organising the extra labour necessary to process crops prior to storing them. This may suggest that agriculture was organized on a smaller scale in more focused units of production. More peripheral sites seem to have devoted more effort than more accessible ones, which may be a product of agricultural labour units, of larger households, extended social networks across the community. Overall this, and the previous results with respect to harvesting, might suggest the absence of much regional level organization to agriculture during this period. Habits were mainly consistent among immediate neighbours and the more accessible sites may have used their position for other cultural or political purposes but, if anything, these other purposes may have distracted, rather than encouraged, them from more intensive crop processing. What comes through the entire analysis is therefore the continuing local-scale of much farming activity, via the local household or semi-communal larger units. This household approach can be documented as having been the dominant mode of food production for many millennia of later Chinese history. Rice is, by contrast, one crop that some commentators have suggested was for elite consumption and might have been produced by more regional scales of labour organization (Lee et al. 2007: 57), but if so, we still need to find evidence for this in the upper Ying valley data.

Finally the importance of chronology remains a little difficult to decipher, not least because this study covers periods during which there is a notable increase in population. Expansion of population through founding new settlements, initially small, might have opened networks of communities in which an *ad hoc* family-focused approach was at first necessary and then later traditional. Declining soil fertility, including through expansion to more marginal lands, would probably also increase the number of immature seeds and add to the difficulty of husk-threshing.

In any case, such questions point clearly to the need for further research, and this paper has sought not only to promote such additional questioning but also to highlight the promise of archaeobotanical survey at the regional scale and emphasise the potential of interrogating the results via a combination GIS and multivariate statistics.

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Tables

Site Name	*Full Name*	*Period*	*No. of Samples*	*No. of Species*	*No. of Seeds*
1	Wangchenggang	Longshan	72	12	2601
2	Chengyao	Longshan	2	14	2110
3	Xifandian	Erlitou	3	26	287
4	Youfangtou	Longshan	1	17	681
5	Yuancun	Yangshao/Longshan	1	18	181
6	Yangcun	Yangshao/Longshan	2	21	232
7	Shidao	Erlitou	3	22	756
8	Shiyangguan	Yangshao/Longshan	1	22	329
10	Yuanqiao	Yangshao/Erlitou	2	33	3323

Table 1. Archaeobotanical data for the upper Ying valley survey by site. Note that the Wangchenggang values are summaries from the published excavation data (SAMPU & HPICRA 2007).

Site Name	***Rice/Millet***	***Setaria/Panicum***	***% Wetland Weed***	***% Dryland Weed***	***% Soybeans***	***% Wild fruits***
Wangchenggang	0.0074	1.6575	0.0012	0.0104	0.0927	0
Chengyao	0.7338	29	0.0055	0.2680	0	0
Xifandian	0.0515	16.5	0.0592	0.4007	0.0035	0
Youfangtou	0.036	6.1081	0.0059	0.3642	0.0191	0.0029
Yuancun	0.0526	14.5556	0	0.2983	0.0055	0
Yangcun	0	3.4737	0.0086	0.1293	0	0.0086
Shidao	0.0416	18.1395	0.0066	0.0146	0.0067	0.004
Shiyangguan	0.0748	37.5	0.003	0.0821	0	0.0152
Yuanqiao	0.0018	28.3	0.0045	0.1177	0.2832	0.0849

Table 2. Six measures of arable ecology based on archaeobotanical data from the sampled upper Ying valley sites.

	Initial Eigenvalues			*Extraction Sums of Squared Loadings*			*Rotation Sums of Squared Loadings*		
Component	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*
1	2.359	39.313	39.313	2.359	39.313	39.313	2.100	34.992	34.992
2	1.451	24.178	63.490	1.451	24.178	63.490	1.538	25.632	60.624
3	1.269	21.154	84.645	1.269	21.154	84.645	1.441	24.021	84.645
4	.563	9.386	94.031						
5	.318	5.301	99.331						
6	4.011E-02	.669	100.000						

Variables	*Communalities*		*Rotated Component*		
	Initial	*Extraction*	*AEF1*	*AEF2*	*AEF3*
Dryland weed	1.000	.765	-.220	.834	.144
Wetland weed	1.000	.819	-2.036E-02	.898	-.113
Rice/Millet	1.000	.831	-.311	2.347E-02	.857
Setaria/Panicum	1.000	.799	.372	-5.503E-03	.813
Soybean	1.000	.894	.929	-.155	-7.859E-02
Fruits	1.000	.970	.975	-.108	8.544E-02

Table 3. Results from Principal Component Analysis of six arable ecology variables.

Site Name	***Mean of Maximum Weed Height***	***Mean of Minimum Weed Height***	***Grains/Weeds***	***Hulled & Immature/ Unhulled & Mature***
Chengyao	89.5833	47.05	2.190909	0.66207
Xifandian	97.1831	41.6197	1.554348	0.31818
Youfangtou	107.9699	49.5489	1.608392	0.47345
Yuancun	81.7391	46.3044	2.545454	0.19084
Yangcun	95.7143	46.1539	7.478261	0.22727
Shidao	75.7143	28.3333	9.102273	0.30114
Shiyangguan	59.6667	18.6	4.893617	0.20444
Yuanqiao	104.9495	46.404	5.026471	0.23911

Table 4. Four measures of crop processing strategy based on archaeobotanical data from the sampled upper Ying valley sites.

Component	*Initial Eigenvalues*			*Extraction Sums of Squared Loadings*			*Rotation Sums of Squared Loadin*		
	Total	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumul %*
1	4.086	40.858	40.858	4.086	40.858	40.858	3.131	31.307	31.3
2	2.345	23.452	64.309	2.345	23.452	64.309	2.347	23.473	54.7
3	1.410	14.102	78.412	1.410	14.102	78.412	2.064	20.635	75.4
4	1.125	11.252	89.663	1.125	11.252	89.663	1.425	14.247	89.6
5	0.677	6.772	96.435						
6	0.239	2.387	98.822						
7	0.114	1.144	99.966						
8	3.410E-03	3.410E-02	100.000						
9	2.123E-16	2.123E-15	100.000						
10	-6.018E-16	-6.018E-15	100.000						

variables	*Communalities*		*Rotated Component*			
	Initial	*Extraction*	*NEF1*	*NEF2*	*NEF3*	*NEF4*
slope	1.000	0.983	-0.419	0.787	-0.144	-0.409
exposure to easterly wind	1.000	0.598	-0.742	-0.138	-0.165	2.786E-02
exposure to northwesterly wind	1.000	0.977	-8.248E-02	3.352E-02	0.130	0.976
flow accumulation	1.000	0.904	0.785	-0.530	-7.495E-02	2.689E-02
annual rainfall	1.000	0.839	0.426	0.107	0.762	0.258
river terrace	1.000	0.796	0.875	-0.132	0.112	2.547E-02
cinnamon soil	1.000	0.962	0.196	0.934	9.329E-02	0.206
chao soil	1.000	0.992	0.691	-0.716	-2.907E-02	3.712E-03
purplish soil	1.000	0.957	-0.428	4.312E-02	0.844	-0.242
skeletal soil	1.000	0.957	-0.365	0.103	-0.824	-0.368

Table 5. Results from Principal Component Analysis of the natural environment variables.

Yangshao Period	*r^2 with significance*	*Natural Environmental Diversity Factor*			
		NEF1	NEF2	NEF3	NEF4
Arable Ecology Factor	AEF1	$\boldsymbol{0.967_{0.017}}$	$0.562_{0.246}$	$\boldsymbol{0.849_{0.079}}$	$0.239_{0.511}$
	AEF2	$0.000_{0.981}$	$0.516_{0.282}$	$0.032_{0.821}$	$\boldsymbol{0.754_{0.132}}$
	AEF3	$0.146_{0.618}$	0.050_{0776}	$0.337_{0.420}$	$0.269_{0.481}$
Longshan-Erlitou Period	*r^2 with significance*	*Natural Environmental Diversity Factor*			
		NEF1	NEF2	NEF3	NEF4
Arable Ecology Factor	AEF1	$0.023_{0.807}$	$0.017_{0.836}$	$0.021_{0.818}$	$0.030_{0.782}$
	AEF2	$0.110_{0.586}$	$0.051_{0.714}$	$0.056_{0.701}$	$\boldsymbol{0.586_{0.132}}$
	AEF3	$0.011_{0.868}$	$0.190_{0.464}$	$0.002_{0.948}$	$0.356_{0.288}$

Table 6. Results from global linear regressions that consider the relationship between arable ecology and natural environmental diversity for a) the Yangshao period and b) the Longshan to Erlitou period (boldface and italicised numbers are those with greater statistical significance and discussed in the text).

	Connec-tivity	*Access-ibility*	*Distance*	*Adjacen-cy*	*Chrono-Logy*	*NEF1*	*NEF2*	*NEF3*	*NEF4*
Connectivity	1	0.334	0.432	0.437	0.119	-0.145	-0.405	-0.248	0.202
Accessibility		1	0.418	***0.489***	0.091	0.027	-0.320	***0.794***	0.299
Distance			1	***0.729***	-0.064	-0.275	0.069	0.466	0.365
Adjacency				1	0.139	-0.263	-0.252	***0.483***	0.370
Chronology					1	-0.129	-0.110	0.189	-0.033
NEF1						1	0.327	-0.057	0.055
NEF2							1	-0.377	-0.113
NEF3								1	0.290
NEF4									1

Table 7. Results from a Mantel matrix test that considers interdependence amongst chronological and environmental factors (boldface and italicised numbers are significant at $p<0.05$ or better).

	Connectivity	*Accessibility*	*Distance*	*Adjacency*	*Chronology*	*NEF1*	*NEF2*	*NEF3*	*NEF4*
Grain to weed	0.171	***0.629*** ***0.412***	0.341	0.269	0.134	-0.206	-0.148	***0.524*** 0.051	0.128
Hulled&immature grain	0.063	0.117 0.247	-0.267	0.095	***0.566***	-0.137	-0.112	-0.041 -0.222	-0.277
Max weed height	0.144	-0.082 0.015	0.428	***0.412***	-0.233	-0.129	0.209	-0.115 -0.082	0.179
Mix weed height	0.194	0.177 0.087	***0.675***	***0.644***	-0.050	-0.239	-0.076	0.157 0.027	0.390

Table 8. Results from a Mantel matrix test that considers the environmental factors correlated with particular farming activities (boldface and italicised numbers are significant at $p<0.05$).

Figure Captions

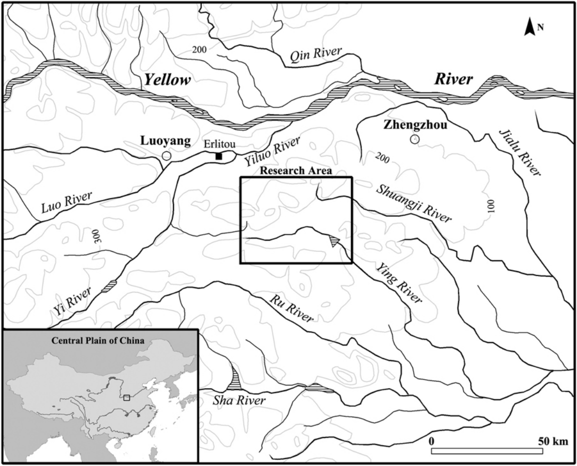
Figure 1. Location maps of: a) the Ying river valley in the central plain of China and b) archaeological sites in the upper Ying valley.

Figure 2. Primary environmental datasets: a) a 30m digital elevation model derived from ASTER imagery (with extracted stream network shown), b) geology enhanced via comparison with ASTER SWIR (the latter not shown), c) total annual precipitation, d) soil types.

Figure 3. Anisotropic cost surfaces used to suggest site catchments: a) an example of an r.walk cost surface from the Longshan site of Wangchenggang with the one hour isoline shown in black; b) an example for the Longshan phase of suggested sites catchments as mapped through a combination of the limit of 1-hour travel and allocation to the nearest site.

Figure 4. Suggested social networks in the upper Ying valley for sites from: a) the Yangshao phase, b) the Longshan phase and c) the Erlitou phase.

Figure 5. Prehistoric stone tools for harvesting from the Ying valley (drawings by Li Yangsong (SAMPU 2002:34)).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Zhengzhou
Luoyang
Erlitou
Yiluo River
Jialu River
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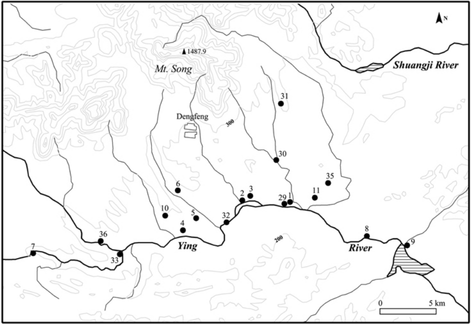
100
Luo River
300
Ying River
Yi River
Ru River
Central Plain of China
Sha River
0
50 km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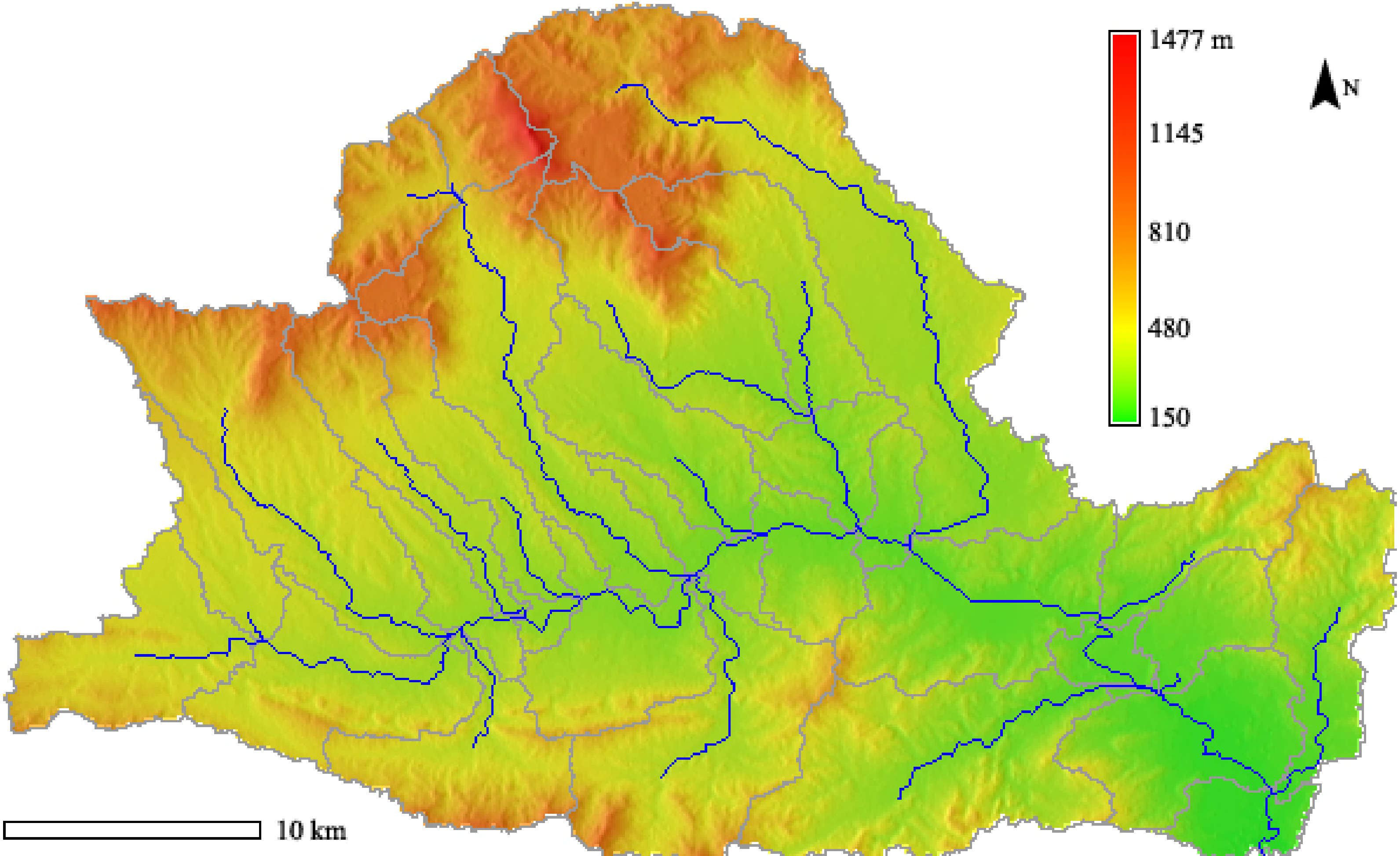
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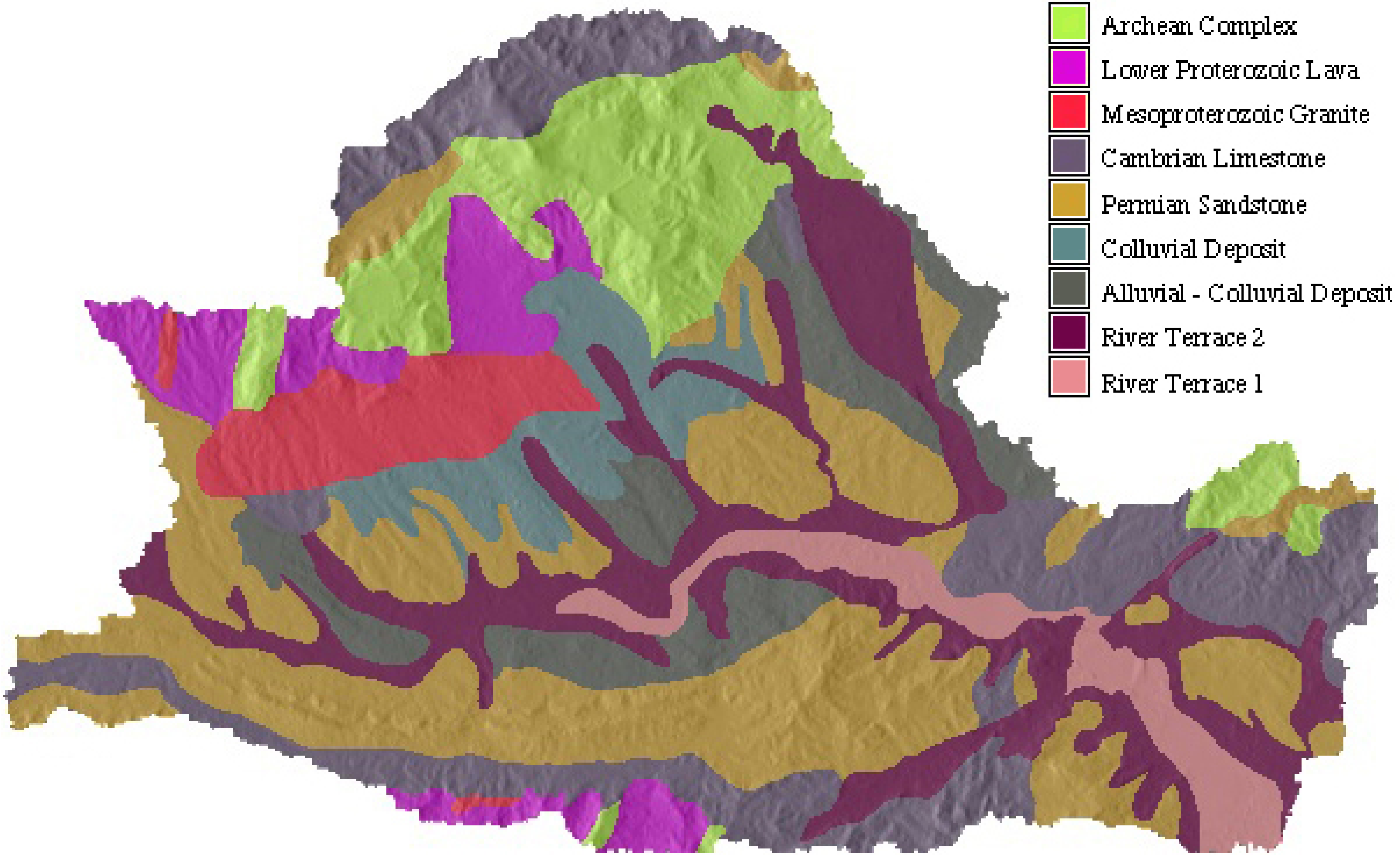
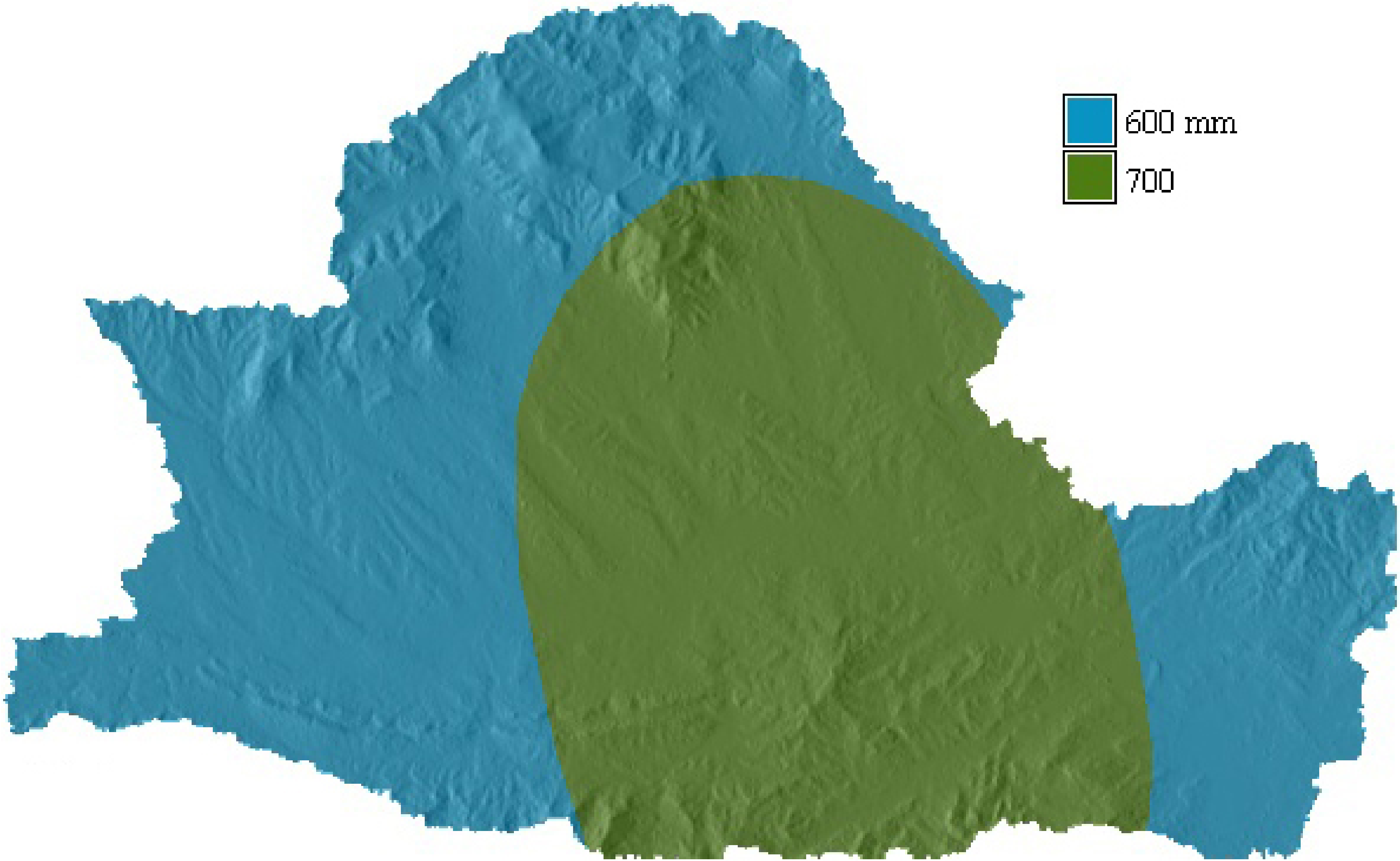

Archean Complex
Lower Proterozoic Lava
Mesoproterozoic Granite
Cambrian Limestone
Permian Sandstone
Colluvial Deposit
Alluvial - Colluvial Deposit
River Terrace 2
River Terrace 1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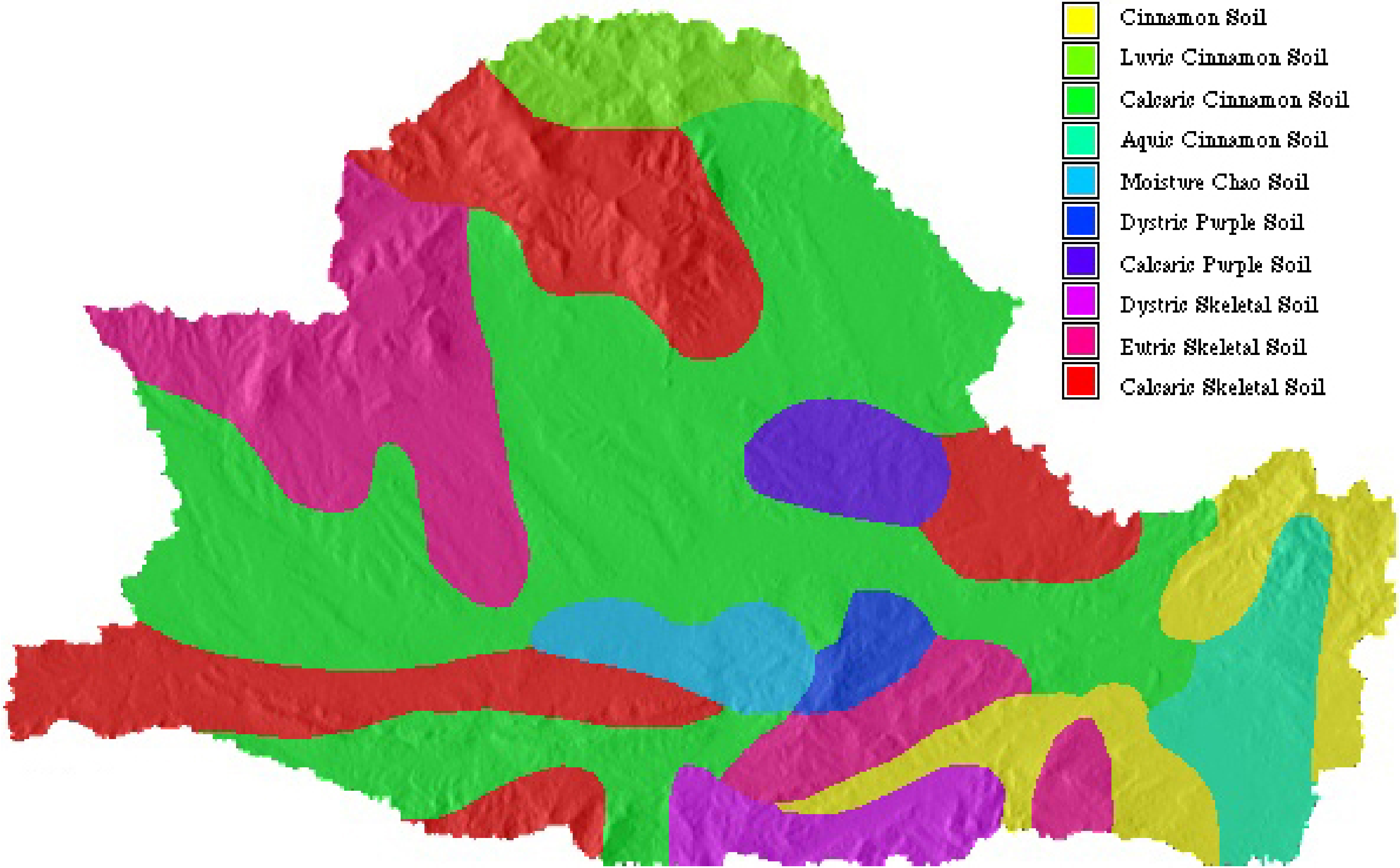
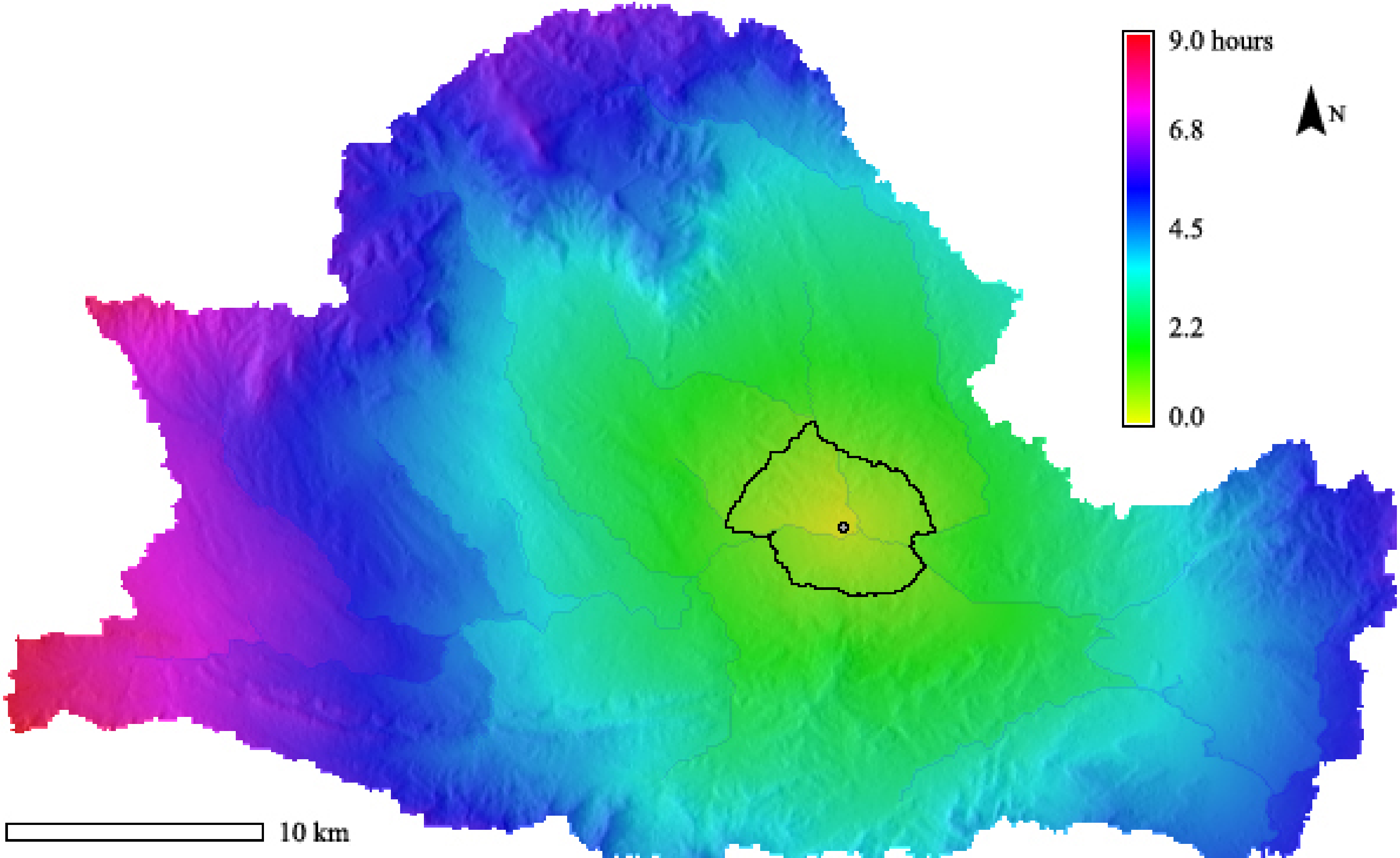
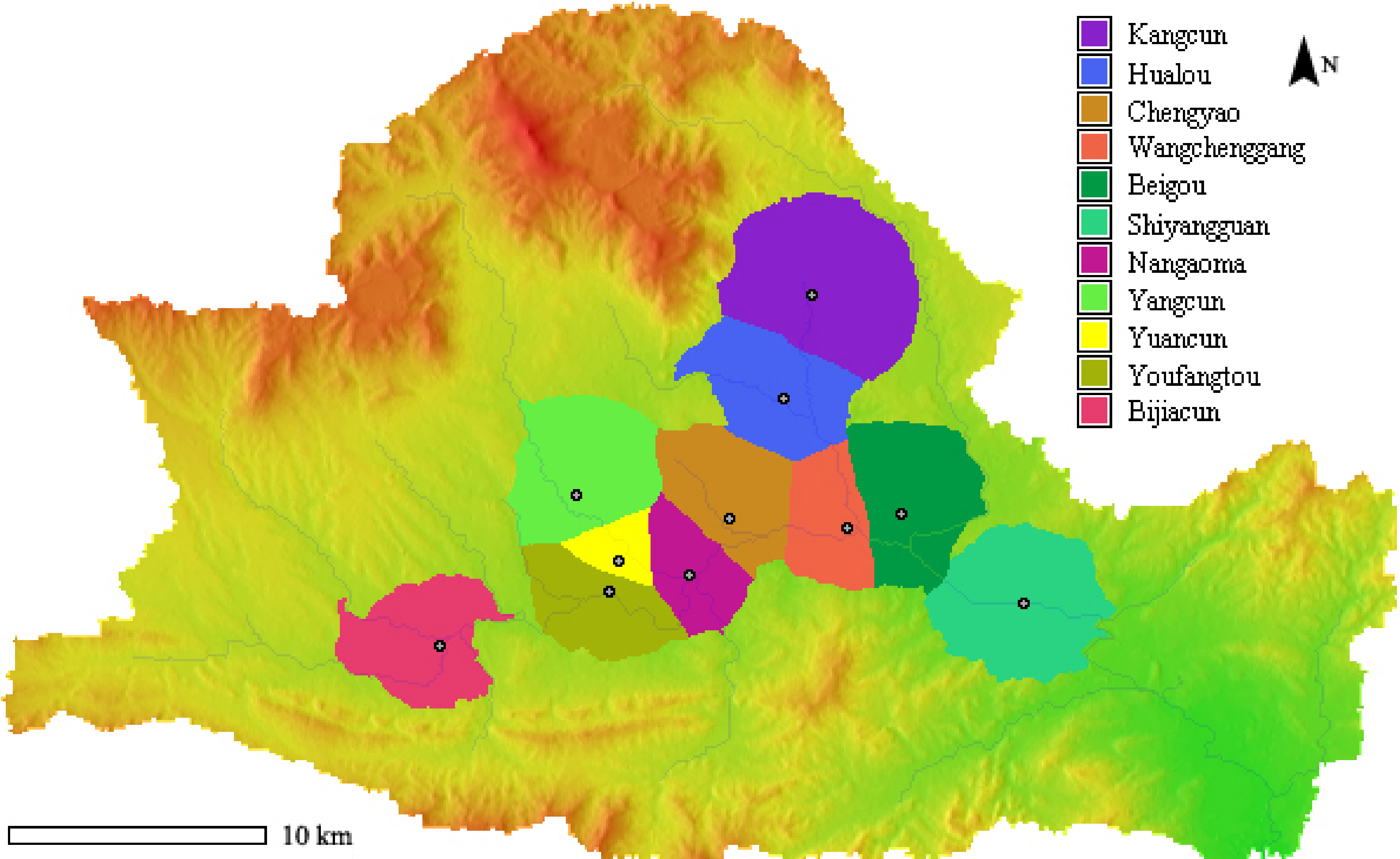
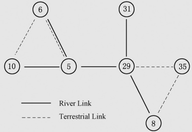
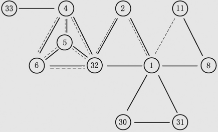
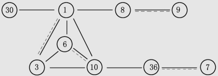

Cinnamon Soil
Luvic Cinnamon Soil
Calcaric Cinnamon Soil
Aquic Cinnamon Soil
Moisture Chao Soil
Dystric Purple Soil
Calcaric Purple Soil
Dystric Skeletal Soil
Eutric Skeletal Soil
Calcaric Skeletal Soil


9.0 hours
6.8
4.5
2.2
0.0
N
10 km


Kangcun
Hualou
Chengyao
Wangchenggang
Beigou
Shiyangguan
Nangaoma
Yangcun
Yuancun
Youfangtou
Bijiacun
N
10 km


6
31
10
5
29
35
8
River Link
Terrestrial Link


33
4
2
11
5
6
32
1
8
30
31


30
1
8
9
6
3
10
36
7