DEVELOPMENT OF COMPLEX SOCIETIES IN THE YILUO REGION: A GIS BASED POPULATION AND AGRICULTURAL AREA ANALYSIS

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Keywords: Yiluo Project, GIS, settlement patterns, Chinese Neolithic, Shang Dynasty

ABSTRACT

The Yiluo basin is the heartland of the origin of early states in China. Based on archaeological data from the ongoing Yiluo project, I construct a GIS based study detailing the carrying capacity, catchment productivity, population fluctuation and development of social complexity in the surveyed region from the Peiligang to the Erlitou period. The study demonstrates that, although increase of population coincided with the initiation of social complexity, it probably did not lead to it in any direct causal way. Instead, the growing population might have provided more opportunities for elites to manipulate different strategies to maintain power and establish a more complex social structure. The study employs two models to explain the initiation of social complexity: 1) the "tribute" model, 2) the "special resources" model. Although there are some limitations in this study and some of the specific interpretations may change as more data and finer chronological controls become available, the analytical methods I employ here have shown great potential for application in future studies.

INTRODUCTION

The Yiluo River valley is a vast fertile alluvial basin bounded by the Mangling Hills to the north, the Xiao and Xiong'er Mountains to the west, the Funiu Mountains to the south and the Songshan Mountains to the southeast. The research area is situated in the eastern part of the Yiluo valley, from where the highlands of the Songshan Mountains descend to the Yiluo plains (Figure 1). (Gongxian County Chronicle Editorial Board 1991:43, 69-70; Liu *et al.* 2002-2004).

According to ancient texts, the Yiluo basin witnessed the birth of the Xia dynasty – the first dynasty in China. Thus, this significant region has long been the focus of Chinese archaeologists who regard the pursuit of the origins of the early state or civilization in China as their mission (Chen 1997). Surveys and excavations at the famous Erlitou site over the past 40 years have yielded much information suggesting that this settlement, covering an area of 300 ha, was the largest settlement of the Erlitou period, not only in the Yiluo basin but anywhere in China. Furthermore, the palace/temple complex, residential areas, burials, and craft workshops producing bronze, ceramic and bone objects demonstrate that this site was a political, economic and ritual centre (Erlitou Working Team 1984a, b, 1985, 2001; Institute of Archaeology 1999; Liu 2006). However, it is only in recent years that several archaeological projects have been launched to systematically study the social-developmental trajectory of this significant region. Among them is the Yiluo Project, an international collaborative and interdisciplinary archaeological program involving archaeologists from Australia, China, America and England (Liu *et al.* 2002-2004; Liu and Chen 2001).

During the first six field seasons from January 1997 to June 2002, full-coverage surveys were conducted over the alluvial plains and loess tableland along five small river valleys in the Yiluo region: the Wuluo, the Caohe, the Gan'gou, the Majian and the Liujian (Fig. 1). A total area of about 219 sq. km was surveyed, and 194 sites dating from the late Peiligang to the Zhou period were recorded.

The 6000 years of time span covered by these sites includes six archaeological periods, which are further partitioned into phases:

1. Late Peiligang (ca. 6000-5000 BC);
2. Yangshao, subdivided into Early (ca. 5000-4000 BC), Middle (ca. 4000-3500 BC), and Late (ca. 3500-3000 BC) phases;
3. Longshan, subdivided into Early (ca. 3000-2500 BC), and Late (ca. 2500-2000 BC) phases;
4. Erlitou (ca. 1900-1500 BC), subdivided into four phases, I-IV, approximately 100 years for each phase;
5. Shang, subdivided into Early Shang or Erligang (ca. 1600-1300 BC), and Late Shang or Yinxu (ca. 1300-1046 BC) phases;
6. Zhou, subdivided into Western Zhou (1046-771 BC) and Eastern Zhou (771-206 BC) phases.

All sites can be allocated to period based on the diagnostic sherds collected during the survey.

Based on data from the project, I have constructed a GIS- based study detailing population fluctuations and the development of social complexity in the Yiluo area. The basic framework of my study consists of three parts: estimation of population size; reconstruction of carrying capacity and catchment productivity; and interpretation of the relationships between population fluctuations and the development of complex society.

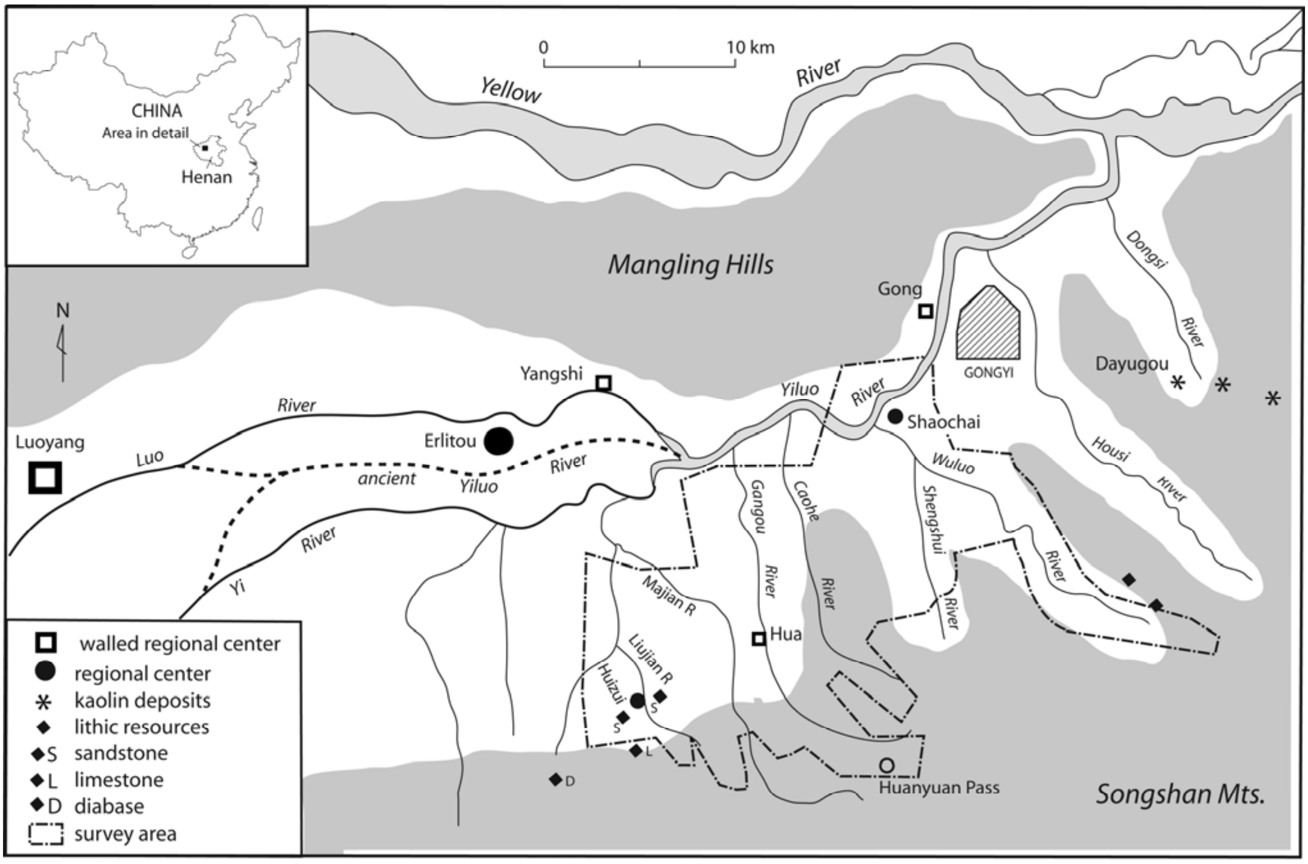

Figure 1. Important sites and resources in the Yiluo River valley.

ESTIMATION OF POPULATION SIZE

Population size and density in prehistoric China are difficult to estimate, as most sites have only been partially excavated and little systematic research has been undertaken in regards to population size based on archaeological evidence. To estimate the population of the Yiluo region I refer to Chinese research on the population sizes of other Neolithic sites: Yuchisi (Institute of Archaeology 2001) and Jiangzhai (Banpo Museum 1989). Both settlements have been almost completely excavated and exemplify good preservation of houses and artefacts of everyday use. Rich and reliable data can be derived from the two sites to estimate the relationship between population size and floor area, as well as settlement size. The calculated average density of the two sites, that is 57 people/ha (Banpo Museum 1989:68-69, 352-357; Institute of Archaeology 2001:325-328; Zhao 1998; Zhu 1994), is used as the population density for my study.

HOW MANY AGRICULTURAL HECTARES DID A PERSON NEED?

According to records for Gongyi County, the average annual yield of millet in 1933 was 375 kg/ha (Gongxian County Chronicle Editorial Board 1991:260). Observing experienced peasants (van Wersch 1972), about 15% of the harvest would have been kept back for seed, leaving a total consumable millet production of 315 kg/ha. For each person, Gongyi County records indicate an average annual consumption of about 245 kg of processed grain (Gongxian County Chronicle Editorial Board 1991:479), and 192 kg for children up to 14 years. These data give an average of 219 kg/person. Milling efficiency must also be considered. Using traditional milling techniques and assuming consumer acceptance of the resulting product, efficiency can be placed between 80 and 90%. Assuming an average efficiency of 85%, 258 kg (219/0.85) of grain would be needed to support an average person for one year.

The area of agricultural land that could support one person can be calculated by dividing the annual consumption average of 258 kg by the consumable yield of grain (315 kg) per hectare. The Gongyi County records thus suggest that each person needed about 0.8 ha for support. However, fallow land was also an important factor. According to several ancient texts, fallow land was very common in the Spring and Autumn period (770-221 BC) (Chen 1991:126). In this study, I use a conservative figure, allowing one year of fallow for every year of cropping. Thus, the actual land needed per person increases to 1.6 ha, and this value is used in calculations of carrying capacity and catchment productivity.

GIS-BASED ANALYSIS OF CARRYING CAPACITY AND CATCHMENT PRODUCTIVITY

Carrying capacity represents an upper limit for population growth within an area. First developed by zoologists in

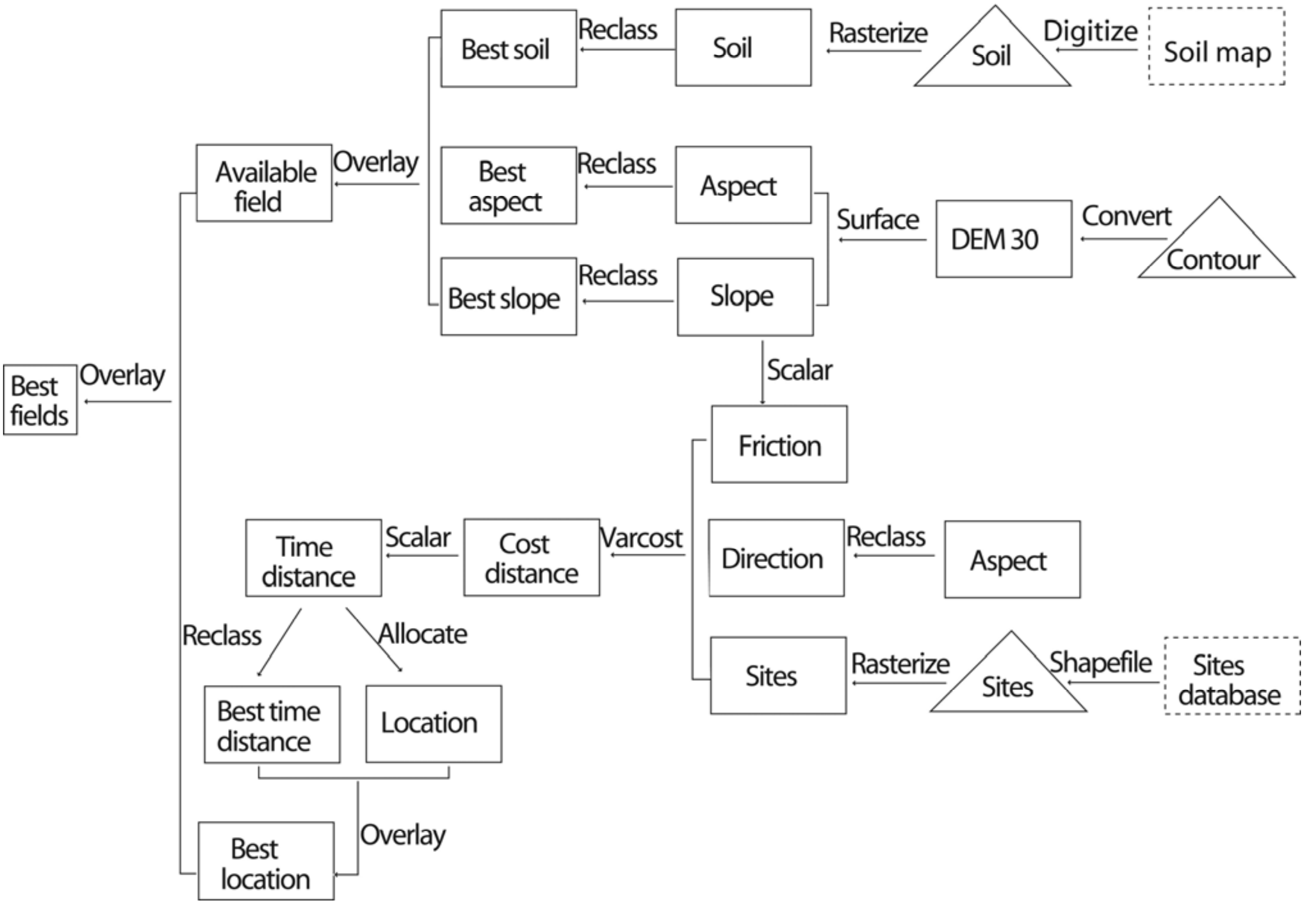

Figure 2. Cartographic model of the Gongyi GIS Analysis.

the 1930s, this concept has been widely applied and debated by anthropologists and archaeologists since the 1950s (Hassan 1981:164). Hassan points out that human populations tend to subsist at levels below their maximum carrying capacity, maintaining their numbers at a level that is 20-60% of the maximum population size possible. This optimum carrying capacity level is a successful response to periodic, unpredictable fluctuations in the available yields of utilizable resources.

Two GIS programs – IDRISI and CARTARLINX - provided effective methods for me to conduct my study in the survey region. As millet was the only food resource considered in my research, the carrying capacity can be defined as the total population supportable by the available millet fields in the surveyed area. Similarly, the catchment productivity per site is calculated using the area of millet fields within the catchment of that site.

After obtaining the digitalized contour map of the Yiluo basin made by Mr Jianguo Liu of the Institute of Archaeology, Chinese Academy of Social Sciences, a referenced database was established for each cultural period identified in the Yiluo project. The site distribution, soil and river maps of the Yiluo region were then digitized. (Figure 2) illustrates the variables considered in my GIS analysis. Several factors needed to be taken into consideration for any estimation of carrying capacity, including slope, aspect, elevation and soil type, all of which can affect the land use pattern.

The digital contour map was prepared from four 1:50,000 topographic maps and configured to Universal Transverse Mercature (UTM) projection. Once digitised, the contour layer was transformed into an analytical surface featuring a Digital Elevation Model (DEM). This process was completed using IDRIS 32. A common method of creating a DEM is by digitising contour lines from a topographic map on a vector platform and then converting that vector to raster format. Considering the aims of the analysis and the scale of the digital map, a resolution of 30 m, which means each pixel in the DEM map represents 30 by 30 m, was chosen. In the image of DEM30, several layers can be added to express other information, such as layers within sites, rivers, and survey area boundaries (Figure 3).

Two other raster images for slope and aspect were produced from the DEM30 with the Surface Module, which can calculate slope gradient, aspect and analytical hill shade images from a surface model. It was assumed that slopes between zero and 20 degrees were best for millet fields, since steep slopes are usually covered with rocks, exposed to erosion and difficult to cultivate. By Reclassing the values in the slope image, a Boolean image for “Best Slope” was generated. This image has only two values: 0, representing those areas with slopes greater than 20 degrees; and 1, representing those areas with

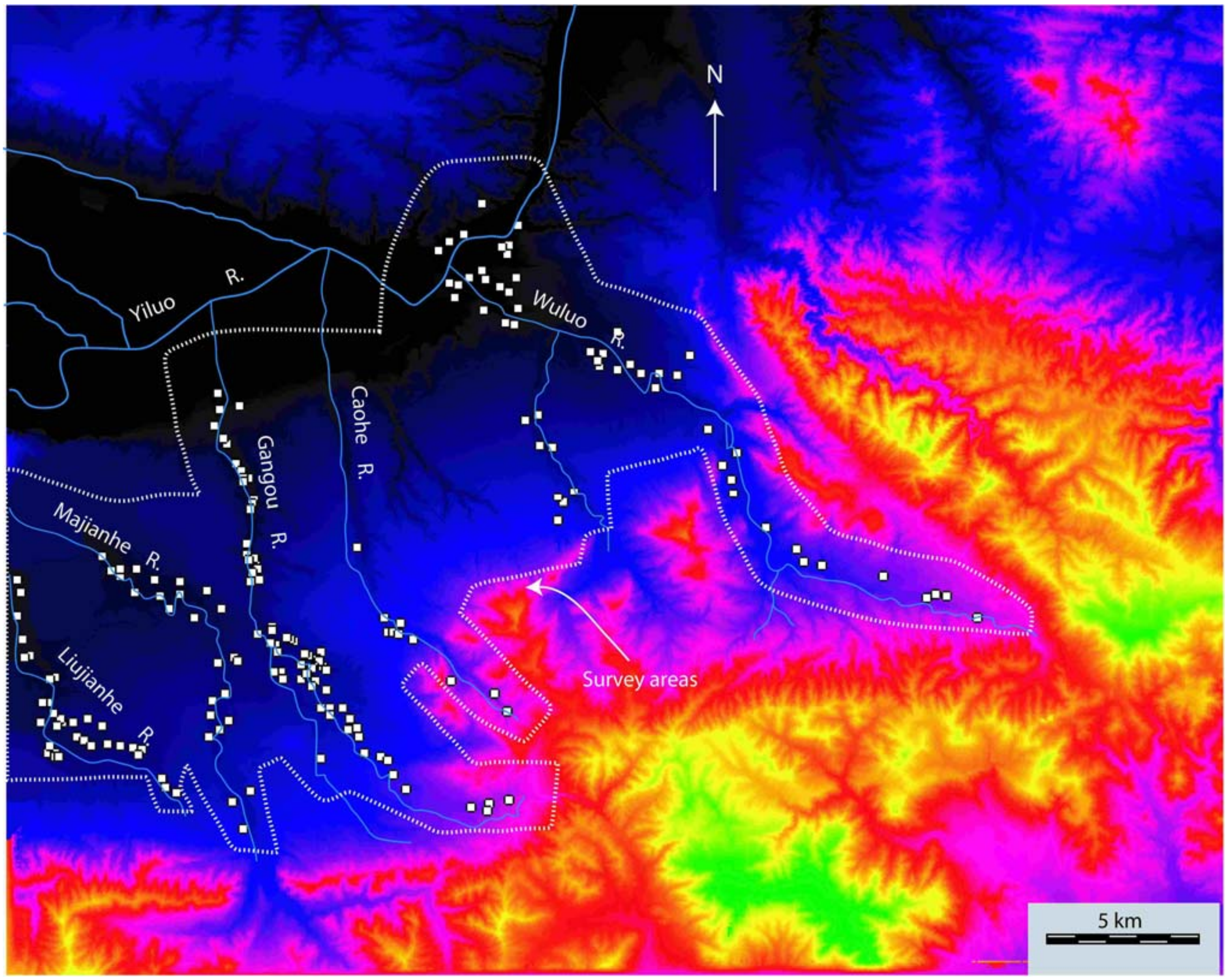

Figure 3. The site distribution and the survey areas in the Yiluo Project.

slopes less than 20 degrees. It is assumed that the best compass aspect when considering available sunlight lies between 45 and 225 degrees, so another Boolean image for "Best Aspect" was produced by Reclassing the values in the aspect image. In the "Best Aspect" image, value 0 represents the area with aspects <45 or >225 degrees, and the value 1 represents the areas with aspects between 45 and 225 degrees. Also considered was the elevation suitable for cultivation.

I digitized the soil maps of the surveyed region using the CARTALINX software and converted it into a Raster image. For the Gongyi and Yanshi regions, available information on soil distribution, soil depth, natural plant productivity and agricultural productivity can be determined for each of the total of 24 soil types in the study area. Most of the soils are varieties of dark brown soil that are fertile and suitable for agriculture (Gongxian County Chronicle Editorial Board 1991: 99-104). However, there are several types that are unsuitable, such as some kinds of sandy brown loam and dark brown marl.

The Reclass module was applied again to give a new value 0 to all the soils unsuitable for agriculture, and a value of 1 to all the soils suitable for agriculture. Another Boolean image for "Best Soil" was produced. Finally, the OVERLAY module was applied to multiply together the three Boolean images – (Best Slope)(Best Aspect)(Best Soil) - and this operation produced a new Boolean image for "Available field". In this image, those areas that have a value of 1 in all three images (areas suitable for agriculture) keep their value (1X1 = 1). Those areas that have a value of 0 in any of the three images (areas not suitable for agriculture due to problems with slope, aspect or soil type) will get a value 0 in the new image.

Applying the Area module in IDRISI to the data, the surveyed region would have an available area of 29,681.64 ha for millet, as calculated from the image of Available Field within the surveyed region. At 1.6 ha/person, this area could have supported 18,551 persons. It needs to be pointed out, however, that millet was not the only staple in this region during prehistoric and historic times. An archaeobotanic study from the survey area reveals that millet was the dominant crop, while rice, soybean and wheat were gradually added over time (Lee *et al.* 2007). However, since it is difficult to estimate the proportions of these crops in subsistence, we simply use the millet data to calculate total agricultural production.

The first thing required before estimation of the catchment productivity of each site is to decide where the boundaries were located. Two methods have been employed in previous studies of catchment size. One was based on the assumption that the majority of the people will tend to spend their nights in their settlement, so the radius of a catchment was decided by the time needed to make for a return trip within a day (cf. Brumfiel 1976; Vita-Finzi and Higgs 1970). The other method simply takes the ethnographic record as reference, and assumes a radius for a catchment (Chisolm 1968:131). It was assumed that agriculturalists would walk only a certain maximum distance to reach their fields, and that this maximum distance was the same for all sites during a given period. While one hour's walking distance is assumed to be the radius of the catchment area of each site in this study, travel across a terrain with varying slopes and at different walking speeds has been allowed for.

To estimate the effect of friction on walking across different slopes, a walking experiment was conducted with the assistance of my colleagues. From this, a "Time Distance" image was produced, in which the value of each pixel is the number of hours it takes for travel from the nearest site. Giving the values over 1 hour a new value 0, and values less than 1 hour a new value 1, a Boolean image of "Best Time" was obtained.

In order to determine the catchment of each site, I applied another module of IDRISI – Allocate – to get a new image "Location". Allocate assigns each cell to the nearest of a set of designated features. It is used as a follow-on to the DISTANCE, COST or VARCOST modules. In the output of all these three modules, the distance of each cell to the nearest feature is indicated, but not the name of the feature itself. The Allocate function designates names for these features. Each cell will therefore end up with one of the identifiers of the original feature from which the distance was calculated. In the "Location" images, each site will have its own Thiessen polygon around the site, which indicates the catchment.

The Overlay module was applied to multiply the "Location" images of different periods with the Boolean image "Best Time". The "Best Location" images are then obtained, in which the Thiessen polygon of each site is constrained within the radius of one hour.

The last step was to multiply the Best location images with the Available Field image (derived above) by applying the Overlay module. This produces the "Best Field" images, in which polygons of different colours represent the areas suitable for agriculture within the catchments of the different sites (Figs. 4 to 13). The area of each Thiessen polygon can be computed automatically. Tables 1-10 (after the text) show site sizes, estimated populations, catchment productivities (CP), necessary fields (NF) and land-use ratios (NF/CP) for the sites in each period.

DISCUSSION AND CONCLUSIONS

Population size and the development of social complexity

As Figure 14 shows, the population size of the study area fluctuated dramatically from the Peiligang to the Erlitou period. The first noticeable increase took place in the middle Yangshao phase, reaching a peak in the late Yangshao. However, a sharp decline occurred in the early Longshan phase, when the population fell below that of the middle Yangshao phase. A dramatic population increase followed this decline and the population reached a higher point than the Late Yangshao in the late Longshan phase, this being the first time that the optimum carrying capacity was exceeded, at 67.4% of the maximum carrying capacity. Another large-scale increase in population size occurred in the Erlitou period, when the population reached its maximum, well above the optimum carrying capacity, at 78% of the maximum carrying capacity.

Significantly, the increase of population size coincided with the initiation of social complexity. The middle Yangshao phase witnessed both the first noticeable population increase and the emergence of a two-tiered settlement hierarchy system, indicating a more complex social structure. After that, social complexity spurred the population to a high level in the late Yangshao phase, and kept it at a relatively high level in the late Longshan phase, although the most marked population decline happened in the early Longshan phase.

The results, however, do not support any assumption that "population pressure" was the prime mover for the initiation of social complexity. As Hassan has argued, one of the major weaknesses of the population pressure concept lies in confusing population increase with population pressure. An increase in population size does not necessarily imply that the resources are being depleted and that famine is around the corner (Hassan 1978). Though the population kept increasing from the middle Yangshao to the late Yangshao phases, it still only reached 33 % of the maximun carrying capacity and was not likely to introduce survival pressures. Population increase might just have provided more opportunity for elites to manipulate different strategies intentionally, in order to maintain power and establish a more complex social structure. This initial population increase apparently did not cause significant pressure on resources. The archaeological data show that two-tiered hierarchy systems developed long before any significant level of population pressure.

Population size rose significantly in the Erlitou period and might have caused environmental pressure, resulting in a slight decline from Erlitou II to Erlitou IV. This seems to support Hassan's argument that, when an area is facing population pressure, instead of developing a more complex social structure there will occur a more intensive exploration for local resources under existing technology (Hassan 1978).

From the Peiligang to the early Yangshao period, all sites had enough catchment productivity (or enough agricultural land within their catchments) to support their residents (Tables 1-2; Figs 4-5). However, a dramatic change started in the late Yangshao period. Twelve of the 48 sites became short of agricultural land within their catchment territories, even though the overall land-use ratio for the region was only 49% (Table 4; Fig. 7). This imbalance between sites continued into the later periods,

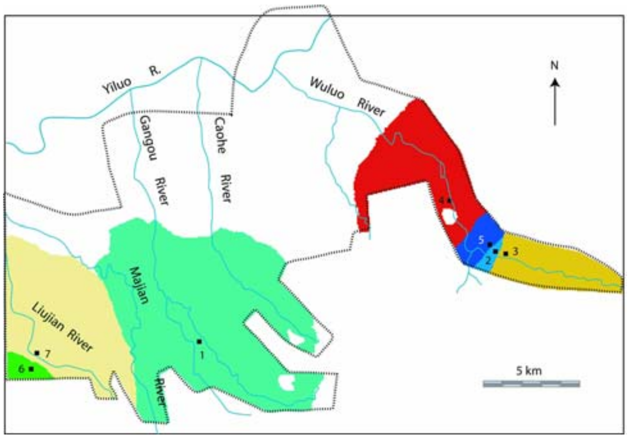

Figure 4. Site distributions and catchments in the Late Peiligang Period.

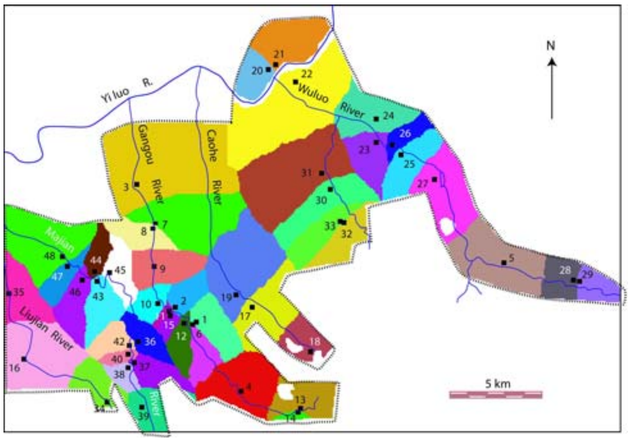

Figure 7. Late Yangshao Period.

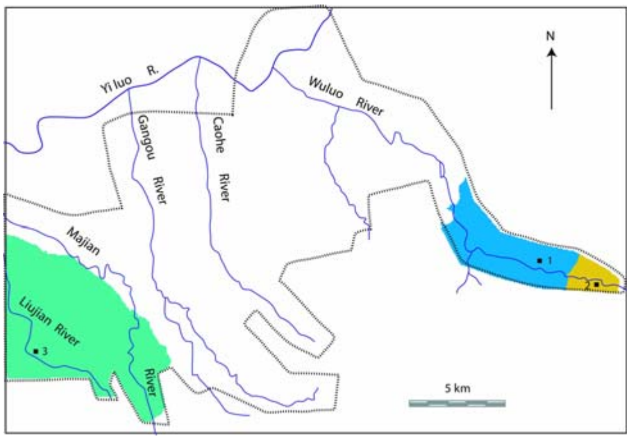

Figure 5. Early Yangshao Period.

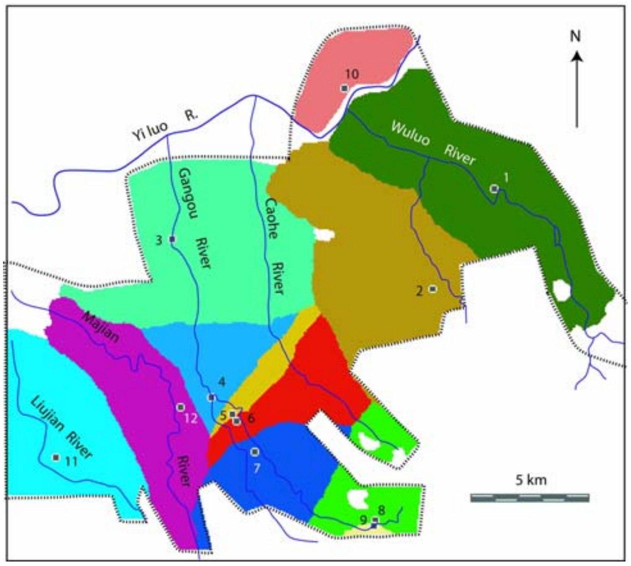

Figure 8 . Early Longshan Period.

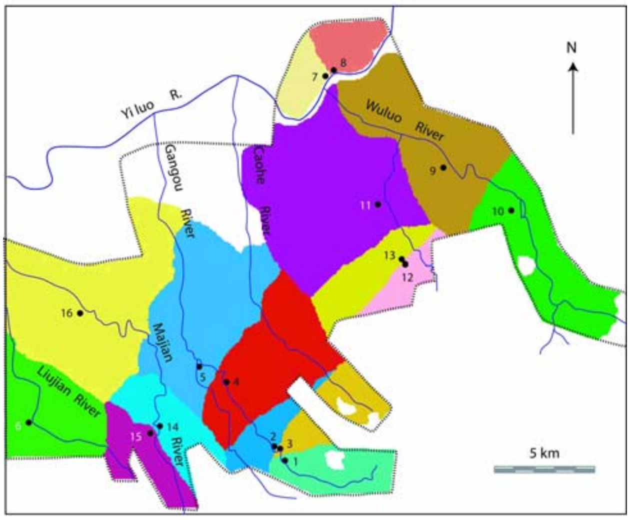

Figure 6. Middle Yangshao Period.

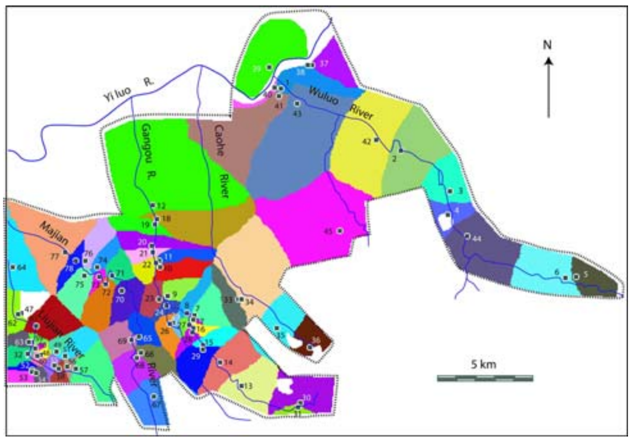

Figure 9. Late Longshan Period.

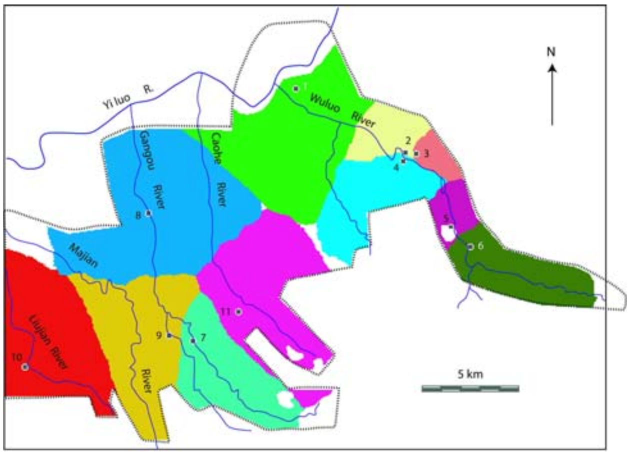

Figure 10. Erlitou I.

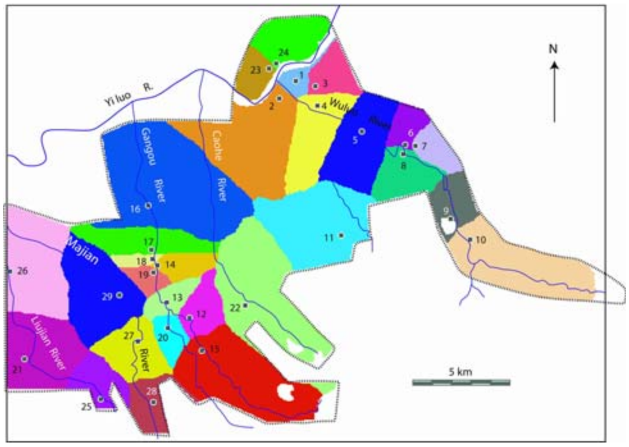

Figure 11. Erlitou II.

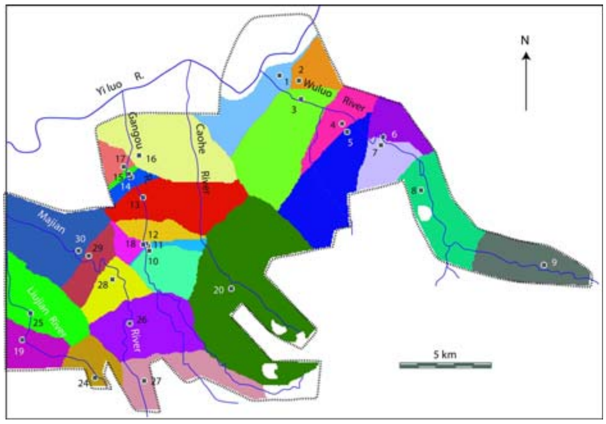

Figure 12. Erlitou III.

and can be regarded as a new land-use pattern which had a close relationship with the development of social complexity.

I employ two models to explain the shortage of agricultural land for some sites. The "tribute" model proposes that the food shortfall of the central sites in a settlement hierarchy system was met by tribute from the other sites. A two-tiered settlement hierarchy emerged in the middle

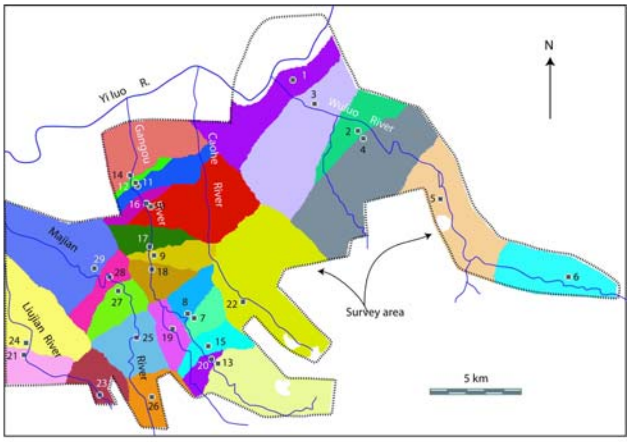

Figure 13. Erlitou IV.

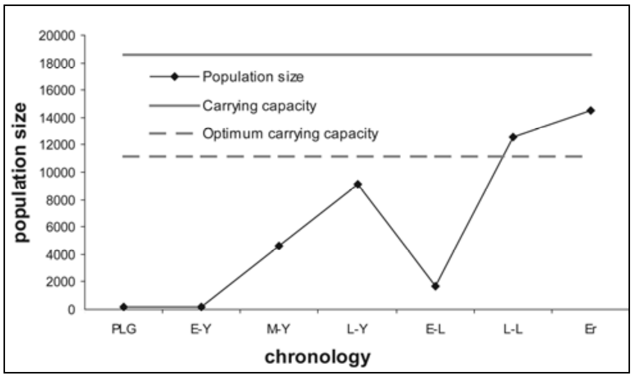

Figure 14. Fluctuations of population size through time.

Yangshao period and developed into a three-tiered settlement hierarchy in the Erlitou period. After the middle Yangshao, most of the central sites no longer had enough agricultural land within their catchments to support their populations. Gathering tribute from the surrounding lower level sites became an important strategy for survival.

The "special resources" model proposes that sites short of agricultural land might have had special resources which could be exchanged for food. Such special resources included both natural resources, such as stone for tools and clay for pottery, and technical resources such as some special method of craft production. This model can be employed to explain the shortfall in agricultural land at some relatively small low-level sites, as well as at some high-level sites such as Xikouzi Northwest, dating to Erlitou Phases II-IV, which shows a severe land shortage (Tables 8-10; Figs 11-13).

The two models would not always have operated separately. On the contrary, they often cooperated in economic systems that developed political central control but lacked diversified market economies. Liu and Chen's (2003) sophisticated interpretation of the complex economic system of early states on the Central Plains provides one way of understanding the economic system in this study area, especially during the Erlitou period. According to their study, the central sites were usually the centers of craft specialization, located near natural resources. For example, the Huizui site, a local center in the Liujian valley, was also a center for stone tool manufacture (Henan Cultural Bureau 1961; Ford 2001; Liu and Chen 2003; Liu *et al.* this volume).

Although some river valleys suffered from a shortage of agricultural land in some phases, the surveyed area as a whole had enough cultivable land in all ten chronological phases. In other words, shortages at some sites could always be covered from the resources of other sites within the region. Noticeably, from Erlitou phase II, the population size in the surveyed area fluctuated around optimum carrying capacity. This indicates that this region might have produced little crop surplus to support the capital settlement of the Erlitou polity. This implies that the redistribution of food in the form of tribute might have primarily occurred at the local level, and that food itself was not the main tribute item which the regional centers in the study area submitted to the capital.

A noticeable fact demonstrated by the archaeological data is that the shortage of catchment productivity did not coincide with the emergence of settlement hierarchy. In the middle Yangshao period, when the two-tiered settlement hierarchy first formed in the study area, the Zhaocheng site (20 ha), as a local center, suffered a shortage of agricultural land, while the other two local centers (Huizui and Beizhai Spoutheast) had enough agricultural land to support themselves (Table 3; Figure 6). In the late Yangshao, the Huizui site still had enough agricultural land to be self-sufficient, though its land-use ratio increased from 56% to 75% (Table 4; Figure 7). It was in the late Longshan period, when several small sites of less than 1 ha (sites 48, 52, 59 and 60) emerged nearby, that the Huizui site began to suffer a catchment productivity shortfall (Table 6; Figure 9), and was likely to have been supported by those small sites. Thus, it appears that the tribute model might have been established after the site hierarchy had been developed.

In spite of some limitations, GIS-based research can offer a better understanding of the relationships between population size, catchment productivity and the development of social complexity in an area that was part of the heartland of early states in China. Although some specific interpretations may change as more data and finer chronological controls become available, the analytical methods employed have shown great potential for application in future studies.

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Table 1: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Late Peiligang phase.

Id	*Site name*	*Site no*	*Phase*	*SS (ha)*	*Population*	*CP (ha)*	*NF (ha)*	*Land-use ratio*
	Gangou River			0.5	28.5	8073.6	45.6	1%
1	Fudian E	00-124	P	0.5	28.5	8073.6	45.6	1%
	Wuluo River			1.8	102.6	4308.6	164.16	4%
2	Tieshenggou	98-029	P	0.2	11.4	114.3	18.24	16%
3	Dongshanyuan	98-041	P	0.7	39.9	1329.6	63.84	5%
4	Wuluoxipo	98-042	P	0.5	28.5	2480	45.6	2%
5	Beiying	98-044	P	0.4	22.8	384.7	36.48	9%
	Liujian River			1.5	85.5	3893.3	136.8	4%
6	Suangquan SW	02-171	P	0.5	28.5	223.8	45.6	20%
7	Liujuanhe Shuike E	02-187	P	1	57	3669.5	91.2	2%
Total				3.8	216.6	16275.5	346.56	2%

Table 2: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Early Yangshao phase.

ID	*Site name*	*Site no*	*Phase*	*SS (ha)*	*Population*	*CP (ha)*	*NF (ha)*	*Land-use ratio*
	Wuluo River			1.7	96.9	2160.5	155.04	7%
1	Shecun E	98-035	E-Y	0.2	11.4	1787.4	18.24	1%
2	Danangou	98-038	E-Y	1.5	85.5	373.1	136.8	37%
	Liujian River			1	57	4917.8	91.2	2%
3	Liujuanhe Shuike E	02-187	E-Y	1	57	4917.8	91.2	2%
Total				2.7	153.9	7078.3	246.24	3%

Table 3: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Middle Yangshao phase. (Continued on next page)

ID	*Site name*	*Site no*	*Phase*	*SS (ha)*	*Population*	*CP (ha)*	*NF (ha)*	*Land-use ratio*
	Gangou River			29	1653	7607.3	2644.8	35%
1	Zhaocheng	00-077	M-Y	20	1140	942.8	1824	193%
2	Zhaocheng W	00-078	M-Y	2.5	142.5	574.1	228	40%
3	Zhaocheng SW	00-079	M-Y	1	57	749	91.2	12%
4	Fengzhai NW	00-090	M-Y	2.5	142.5	2346.3	228	10%
5	Sanguanmiao	00-105	M-Y	3	171	2995.1	273.6	9%
	Liujian River			10	570	1632.7	912	56%
6	Huizui	00-127	M-Y	10	570	1632.7	912	56%
	Majian River			21	1197	5757.9	1915.2	33%
14	Laotunzhai	02-199	M-Y	6	342	998.1	547.2	55%
15	Laozhouzhai	02-200	M-Y	6	342	855.1	547.2	64%
16	Beizhai SE	02-218	M-Y	9	513	3904.7	820.8	21%
	Wuluo River			21	1197	11295.9	1915.2	15%
7	Sigou SE	01-152	M-Y	3	171	517.3	273.6	53%
8	Shijiazhuang SW	01-153	M-Y	1	57	617.3	91.2	15%
9	Weizhuang	98-018	M-Y	5.5	313.5	2780.8	501.6	18%
10	Wuluoshuiku W	98-025	M-Y	2	114	2092	182.4	9%

11	Yulinzhuang S	98-050	M-Y	1.5	85.5	3820.6	136.8	4%
12	Didong	98-052	M-Y	4	228	481.3	364.8	76%
13	Longgudui	98-053	M-Y	4	228	986.6	364.8	37%
Total				81	4617	26293.8	7387.2	28%

Table 4: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Late Yangshao phase. (Continued on next page)

ID	*Site name*	*Site no*	*Phase*	*SS (ha)*	*Population*	*CP (ha)*	*NF (ha)*	*Land-use ratio*
	Gangou River			44.56	2539.92	8324.9	4063.87	49%
1	Nancunzhai SE	00-061	L-Y	1	57	533.1	91.2	17%
2	Sangou S	00-066	L-Y	4	228	315	364.8	116%
3	Liulezhai S	00-075	L-Y	1	57	2508	91.2	4%
4	Zhaocheng	00-077	L-Y	20	1140	972.3	1824	188%
6	Fengzhai NW	00-090	L-Y	2.5	142.5	342.5	228	67%
7	Gujiadun E	00-096	L-Y	0.06	3.42	1253.6	5.472	0%
8	Gujiatun S	00-098	L-Y	0.8	45.6	397	72.96	18%
9	Matun Xicun	00-102	L-Y	0.2	11.4	655.1	18.24	3%
10	Sanguanmiao N	00-104	L-Y	0.75	42.75	291.6	68.4	23%
11	Sanguanmiao	00-105	;L-Y	3	171	61.5	273.6	445%
12	Huachenghe N	00-108	L-Y	3	171	301.2	273.6	91%
13	Xingcun E	00-121	L-Y	2	114	521.6	182.4	35%
14	Bangezhai	00-123	L-Y	5.75	327.75	72.4	524.4	724%
15	Sanggouwudui N	00-126	L-Y	0.5	28.5	100	45.6	46%
	Caohe River			7.25	413.25	2482.9	661.2	27%
17	Caohe shuiku W	00-133	L-Y	1	57	715.1	91.2	13%
18	Caomai	01-135	L-Y	2.5	142.5	368.9	228	62%
19	Beihougou NW	01-139	L-Y	3.75	213.75	1398.9	342	24%
	Wuluo River			29.7	1692.9	11942.3	2708.64	23%
5	Dongshanyuan	98-041	L-Y	0.7	39.9	1216.3	63.84	5%
20	Sigou S	01-151	L-Y	0.5	28.5	375.3	45.6	12%
21	Sigou SE	01-152	L-Y	3	171	750.8	273.6	36%
22	Shaochai	97-1001	L-Y	5	285	2221.8	456	21%
23	Weizhuang	98-018	L-Y	5.5	313.5	539.8	501.6	93%
24	Weizhuang W	98-019	L-Y	0.2	11.4	769	18.24	2%
25	Luokou NE	98-022	L-Y	0.4	22.8	589.6	36.48	6%
26	Weizhuang NE	98-023	L-Y	0.3	17.1	261.2	27.36	10%
27	Wuluoshuiku W1	98-025	L-Y	2	114	922.7	182.4	20%
28	Shangzhuang	98-037	L-Y	1	57	405.5	91.2	22%
29	Shangzhuang SE	98-039	L-Y	0.4	22.8	327.2	36.48	11%
30	Tianpocun	98-049	L-Y	1.2	68.4	757.6	109.44	14%
31	Yulinzhuang S	98-050	L-Y	1.5	85.5	1832	136.8	7%
32	Didong	98-052	L-Y	4	228	461.7	364.8	79%
33	Longgudui	98-053	L-Y	4	228	511.8	364.8	71%
	Liujian River			11	627	1608.5	1003.2	53%
16	Huizui	00-127	L-Y	10	570	1219.3	912	75%
34	Jiulongshuiku	02-183	L-Y	1	57	389.2	91.2	23%
35	Zhengcun W	02-194	L-Y	1.5	85.5	562.8	136.8	24%
	Majian River			65.5	3733.5	4748.1	5973.6	79%
36	Xinzhai N	02-197	L-Y	5	285	357.1	456	128%
37	Laotunzhai	02-199	L-Y	6	342	351.3	547.2	156%
38	Laozhouzhai	02-200	L-Y	6	342	188.1	547.2	291%
39	Dongguanmao E	02-202	L-Y	5	285	388.2	456	117%
40	Bucun SE	02-204	L-Y	4	228	117.5	364.8	310%
42	Bucun E	02-206	L-Y	1	57	305.3	91.2	30%
43	Nan Wujiawan SE	02-213	L-Y	4.5	256.5	469.8	410.4	87%
44	Bei Wujiawan	02-214	L-Y	6	342	252.9	547.2	216%

45	Jintun E	02-215	L-Y	1	57	419.9	91.2	22%
46	Diaoqiaozhai SE	02-216	L-Y	8	456	477.6	729.6	153%
47	Beizhai SE	02-218	L-Y	9	513	310.9	820.8	264%
48	Beizhai N	02-219	L-Y	10	570	1109.5	912	82%
Total				159.5	9092.07	29669.5	14547.3	49%

Table 5: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Early Longshan phase.

ID	*Site name*	*Site no*	*Phase*	*SS (ha)*	*Population*	*CP (ha)*	*NF (ha)*	*Land-use ratio*
	Wuluo River			4.3	245.1	9430.7	392.16	4%
1	Weizhuang NE	98-023	E-L	0.3	17.1	4860.3	27.36	1%
2	Didong	98-052	E-L	4	228	4570.4	364.8	8%
	Gangou River			17.5	997.5	11005.6	1596	15%
3	Liulezhai S	00-075	E-L	1	57	4781.6	91.2	2%
4	Sanguanmiao	00-105	E-L	1	57	1375.7	91.2	7%
5	Huachenghe N	00-108	E-L	3	171	533	273.6	51%
6	Huachenghe E	00-112	E-L	0.75	42.75	1488.8	68.4	5%
7	Yanliangzhai W	00-114	E-L	4	228	1597.2	364.8	23%
8	Xingcun E	00-121	E-L	2	114	1156.9	182.4	16%
9	Bangezhai	00-123	E-L	5.75	327.75	72.4	524.4	724%
10	Sigou SE	01-152	E-L	4	228	1134.6	364.8	32%
	Liujian River			2	114	2876.6	182.4	6%
11	Gaozumiao	02-167	E-L	2	114	2876.6	182.4	6%
	Majian River			1	57	2962.7	91.2	3%
12	Mahe N	02-207	E-L	1	57	2962.7	91.2	3%
Total				28.8	1641.6	27410.2	2626.56	10%

Table 6: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Late Longshan phase. (Continued on next page)

ID	*Site nameITE NAME*	*SITE N0*	*Phase*	*SS (ha)*	*Population*	*CP (ha)*	*NF (ha)*	*Land-use ratio*
	Wuluo River			44.2	2519.4	12177.8	4031.04	33%
1	Nanshi	97-1003	L-L	0.2	11.4	80.1	18.24	23%
2	Luokou NE	98-022	L-L	20	1140	1013.5	1824	180%
3	Wulu nandian	98-032	L-L	3	171	465.5	273.6	59%
4	Siyuangou	98-034	L-L	1.5	85.5	221.7	136.8	62%
5	Shangzhuang SE	98-039	L-L	0.4	22.8	342.3	36.48	11%
6	Shecun SE	98-040	L-L	0.4	22.8	703.6	36.48	5%
37	Yemaogou	01-144	L-L	7	399	321	638.4	199%
38	Donggou N	01-146	L-L	6	342	320.7	547.2	171%
39	Sigou S	01-151	L-L	4	228	1133.5	364.8	32%
40	Xiaocidian N	97-1004	L	0.2	11.4	19.3	18.24	95%
41	Xiaocidian S	97-1005	L	0.5	28.5	1095.4	45.6	4%
42	Weizhuang	98-018	L	0.2	11.4	1470.1	18.24	1%
43	Nanshi lunan	98-046	L	0.2	11.4	2105	18.24	1%
44	Shuanghe	98-047	L	0.1	5.7	946.6	9.12	1%
45	Jinzhongsi	98-054	M-L	0.5	28.5	1939.5	45.6	2%
	Gangou River			62.76	3577.32	8271.3	5723.71	69%
7	Naicunzhai S	00-060	L-L	0.5	28.5	281.6	45.6	16%
8	Nancunzhai S	00-063	L-L	1	57	188.5	91.2	48%
9	Sangou NW	00-067	L-L	1.5	85.5	172.8	136.8	79%
10	Matun	00-069	L-L	6	342	258.7	547.2	212%
11	Matun N	00-070	L-L	2.5	142.5	184.6	228	124%
12	Nianzizhuang NW	00-073	L-L	1	57	2686.1	91.2	3%
13	zhaocheng	00-077	L-L	0.1	5.7	565.2	9.12	2%
14	Xiaoxiang SW	00-080	L-L	4.5	256.5	520.6	410.4	79%

15	YLZ shuiku W	00-087	L-L	2	114	157.4	182.4	116%
16	Fengzhai SW	00-089	L-L	2.2	125.4	61.2	200.64	328%
17	Fengzhai NW	00-090	L-L	2.5	142.5	15.2	228	1500%
18	Gujiadun E	00-096	L-L	0.06	3.42	820	5.472	1%
19	Gujiatun S	00-098	L-L	0.8	45.6	223.7	72.96	33%
20	Lijiagou E	00-099	L-L	7.5	427.5	305.6	684	224%
21	Sunjiamen S	00-100	L-L	0.15	8.55	116.1	13.68	12%
22	Matun Xicun	00-102	L-L	0.2	11.4	135.3	18.24	13%
23	Sanguanmiao N	00-104	L-L	0.75	42.75	180.3	68.4	38%
24	Sanguanmiao	00-106	L-L	0.5	28.5	97.9	45.6	47%
25	Huachenghe W	00-109	L-L	3	171	47.1	273.6	581%
26	Fuxicun N	00-110	L-L	13	741	179.2	1185.6	662%
27	Huachenghe E	00-112	L-L	0.75	42.75	42.9	68.4	159%
28	Fubeicun N	00-113	L-L	0.5	28.5	92.2	45.6	49%
29	Yanliangzhai W	00-114	L-L	4	228	345.1	364.8	106%
30	Xingcun E	00-121	L-L	2	114	521.6	182.4	35%
31	Bangezhai	00-123	L-L	5.75	327.75	72.4	524.4	724%
	Caohe River			6	342	2270.3	547.2	24%
33	Xinhougou	00-130	L-L	1	57	283	91.2	32%
34	Xinhougou E	00-131	L-L	1.5	85.5	1330.5	136.8	10%
35	Nangou	00-134	L-L	1	57	406	91.2	22%
36	Caomai	01-135	L-L	2.5	142.5	250.8	228	91%
	Liujian River			46	2622	2625.4	4195.2	160%
32	Huizui	00-127	L-L	10	570	112.5	912	811%
47	Zhengyao	01-140	L-L	0.5	28.5	150.2	45.6	30%
48	Xiqijiayao SE	02-164	L-L	0.5	28.5	32.3	45.6	141%
49	Lucun	02-168	L-L	1	57	87.7	91.2	104%
50	Xiqijiayao NW	02-166	L-L	5	285	20.9	456	2182%
51	Lucun NE	02-169	L-L	1.5	85.5	210.2	136.8	65%
52	Quanzhai W	02-170	L-L	0.5	28.5	41.9	45.6	109%
53	Suangquan SW	02-171	L-L	0.5	28.5	75	45.6	61%
54	Suangquan N	02-172	L-L	1	57	59.4	91.2	154%
55	Lucun	02-177	L-L	0.5	28.5	67.8	45.6	67%
56	Rencai SW	02-178	L-L	0.5	28.5	50.3	45.6	91%
57	Rencai SE	02-179	L-L	3	171	468.1	273.6	58%
58	Lucun S	02-186	L-L	1	57	74.5	91.2	122%
59	Xiqijiaya NW	02-188	L-L	1	57	41.1	91.2	222%
60	Liujuanhe Shuike E	02-187	L-L	1	57	40.9	91.2	223%
61	Zhengyao S	02-189	L-L	3	171	426	273.6	64%
62	Liuguogucheng	02-190	L	0.5	28.5	162.8	45.6	28%
63	Huizui N	02-192	L	3	171	68.7	273.6	398%
64	Jianxicun NW	02-196	L-L	12	684	435.1	1094.4	252%
	Majian River			60.5	3448.5	4182.7	5517.6	132%
65	Xinzhai N	02-197	L-L	5	285	211.6	456	216%
66	Tunzhai NW	02-198	L-L	2	114	228.5	182.4	80%
67	Xikouzi NW	02-201	L-L	2	114	396.7	182.4	46%
68	Laotunzhai	02-199	L-L	6	342	338.9	547.2	161%
69	Bucun E	02-206	L-L	1	57	270.4	91.2	34%
70	Zhangwan N	02-210	L-L	20	1140	316.4	1824	576%
71	Linxiaozhai	02-211	L-L	2	114	188.5	182.4	97%
72	Linxiaozhai SW	02-212	L-L	1	57	343.5	91.2	27%
73	Nan Wujiawan SE	02-213	L-L	4.5	256.5	56.7	410.4	724%
74	Bei Wujiawan	02-214	L-L	8	456	145.2	729.6	502%
75	Diaoqiaozhai SE	02-216	L-L	4	228	312.1	364.8	117%
76	Qiuhe W	02-221	L-L	2	114	256.6	182.4	71%
77	Beizhai N	02-219	L-L	2	114	964.4	182.4	19%
78	Fenghuangtai S	02-220	L-L	1	57	153.2	91.2	60%
Total				219.5	12509.2	29527.5	20014.8	68%

Table 7: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Erlitou phase I.

ID	*Site no*	*Site no*	*Phase*	*SS (ha)*	*Population*	*NF (ha)*	*CP (ha)*	*Land-use ratio*
	Wuluo River			86	4902	7843.2	9821.8	80%
1	Shaochai	97-1001	EI	60	3420	5472	4239.6	129%
2	Weizhuang SE	98-020	EI	6	342	547.2	896	61%
3	Weizhuang	98-021	EI	0.4	22.8	36.48	383.4	10%
4	Luokou NE	98-022	EI	18	1026	1641.6	1967.8	83%
5	Siyuangou	98-034	EI	1.5	85.5	136.8	531.3	26%
6	Shuanghe	98-047	EI	0.1	5.7	9.12	1803.7	1%
	Gangou River			8.25	470.25	752.4	11058.9	7%
7	Fengzhai SW	00-089	EI	2	114	182.4	2331.2	8%
8	Shijiagou NE	00-093	EI	4	228	364.8	5480.5	7%
9	Fuxicun N	00-110	EI	2.25	128.25	205.2	3247.2	6%
	Liujian River			25	1425	2280	3244.2	70%
10	Huizui	00-127	EI	25	1425	2280	3244.2	70%
	Caohe River			0.5	28.5	45.6	3360.9	1%
11	Xinhougou	00-130	EI	0.5	28.5	45.6	3360.9	1%
Total				119.8	6825.75	10921.2	27485.5	40%

Table 8: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Erlitou phase II. (Continued on next page)

ID	*Site name*	*Site no*	*Phase*	*SS (ha)*	*Population*	*NF (ha)*	*CP (ha)*	*Land-used ratio*
	Wuluo River			95.5	5443.5	8709.6	10997.8	79%
1	Shaochai	97-1001	EII	60	3420	5472	215.6	2538%
2	Xiaocidian S	97-1005	EII	2	114	182.4	2068.7	9%
3	Dianchang b	98-005	EII	3.5	199.5	319.2	498.2	64%
4	Dianchang SE	98-008	EII	1.5	85.5	136.8	1119.4	12%
5	Feiyao SE	98-011	EII	2	114	182.4	1329.2	14%
6	Weizhuang SE	98-020	EII	6	342	547.2	355.6	154%
7	Weizhuang	98-021	EII	0.4	22.8	36.48	383.4	10%
8	Luokou NE	98-022	EII	18	1026	1641.6	720.4	228%
9	Siyuangou	98-034	EII	1.5	85.5	136.8	531.3	26%
10	Shuanghe	98-047	EII	0.1	5.7	9.12	1803.7	1%
11	Jinzhongsi	98-054	EII	0.5	28.5	45.6	1972.3	2%
	Gangou River			25.25	1439.25	2302.8	8394.1	27%
12	Nancunzhai SW	00-062	EII	2	114	182.4	542.5	34%
13	Sangou W	00-068	EII	6	342	547.2	366.2	149%
14	Matun N	00-070	EII	2.5	142.5	228	374.7	61%
15	YLZ shuiku W	00-087	EII	2	114	182.4	2129.7	9%
16	Shijiagou NE	00-093	EII	4	228	364.8	3377.5	11%
17	Lijiagou E	00-099	EII	5	285	456	872.6	52%
18	Jiatun	00-101	EII	0.5	28.5	45.6	145.1	31%
19	Matun Xitun S	00-103	EII	1	57	91.2	249.9	36%
20	Fuxicun N	00-110	EII	2.25	128.25	205.2	335.9	61%
	Caohe River			2.25	128.25	205.2	2327.9	9%
22	Xinhougou YchE	00-132	EII	2.25	128.25	205.2	2327.9	9%
23	Sigou S	01-151	EII	0.5	28.5	45.6	329.5	14%
24	Sigou SE	01-152	EII	2	114	182.4	745.9	24%
	Liujian River			41	2337	3739.2	3550.9	105%
21	Huizui	00-127	EII	25	1425	2280	1394.2	164%
25	Xiahousi	02-182	EII	4	228	364.8	533.6	68%
26	Jianxicun NW	02-196	EII	12	684	1094.4	1623.1	67%
	Majian River			38	2166	3465.6	2959.1	117%
27	Xinzhai N	02-197	EII	10	570	912	864	106%

28	Xikouzi NW	02-201	EII	18	1026	1641.6	504.7	325%
29	Zhangwan N	02-210	EII	10	570	912	1590.4	57%
Total				204.5	11656.5	18650.4	29305.2	64%

Table 9: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Erlitou phase III.

ID	*Site name*	*SITE N0*	*Phase*	*SS (ha)*	*Population*	*CP (ha)*	*NF (ha)*	*Land-use ratio*
	Wuluo River			92.7	5283.9	10086.5	8454.24	84%
1	Shaochai	97-1001	EIII	60	3420	1003.6	5472	545%
2	Dianchang beiluE	98-005	EIII	3.5	199.5	498.2	319.2	64%
3	Dianchang SE	98-008	EIII	1.5	85.5	2133.9	136.8	6%
4	Feiyao SE	98-011	EIII	2	114	720.1	182.4	25%
5	Feiyao S2	98-013	EIII	0.5	28.5	1836.9	45.6	2%
6	Weizhuang SE	98-020	EIII	6	342	597.1	547.2	92%
7	Luokou NE	98-022	EIII	18	1026	653.4	1641.6	251%
8	Wuluoxipo 1	98-033	EIII	0.2	11.4	1398.8	18.24	1%
9	Shangzhuang	98-037	EIII	1	57	1244.5	91.2	7%
	Gangou River			18.5	1054.5	5689.1	1687.2	30%
10	Matun N	00-070	EIII	2.5	142.5	804.9	228	28%
11	Wangman	00-071	EIII	3	171	156.1	273.6	175%
12	Luoyanzhuang SW	00-072	EIII	1	57	415.9	91.2	22%
13	Nianzizhuang NW	00-073	EIII	1	57	1544.9	91.2	6%
14	Gangou zhuchang	00-074	EIII	6	342	194.3	547.2	282%
15	Liulezhai S	00-075	EIII	1	57	64.1	91.2	142%
16	Gangounan	00-076	EIII	0.5	28.5	2020.5	45.6	2%
17	Huilongwan xincun E	00-083	EIII	3	171	259.8	273.6	105%
18	Jiatun	00-101	EIII	0.5	28.5	228.6	45.6	20%
	Caohe River			2.25	128.25	4157.7	205.2	5%
20	Xinhougou YchE	00-132	EIII	2.25	128.25	4157.7	205.2	5%
	Liujian River			32	1824	2524.5	2918.4	116%
19	Huizui	00-127	EIII	25	1425	678.6	2280	336%
24	Xiahousi	02-182	EIII	4	228	514	364.8	71%
25	Zhengyao S	02-189	EIII	3	171	1331.9	273.6	21%
	Majian River			43	2451	5808.4	3921.6	68%
26	Xinzhai N	02-197	EIII	10	570	1661.4	912	55%
27	Xikouzi NW	02-201	EIII	18	1026	1110.6	1641.6	148%
28	Zhangwan N	02-210	EIII	10	570	694.2	912	131%
29	Bei Wujiawan	02-214	EIII	3	171	583	273.6	47%
30	Qiuhe W	02-221	EIII	2	114	1759.2	182.4	10%
Total				188.45	10741.65	28266.2	17186.6	61%

Table 10: Data for site size (SS), estimated population, catchment productivity (CP), necessary field area (NF) and land-use ratio in the Erlitou phase IV. (Continued on next page)

ID	*Site name*	*Site no*	*Phase*	*SS (ha)*	*Population*	*CP (ha)*	*NF (ha)*	*Land-use ratio*
	Wuluo River			65.2	3716.4	10281.4	5946.24	58%
1	Shaochai	97-1001	EIV	60	3420	1412.5	5472	387%
2	Dianchang SE	98-008	EIV	1.5	85.5	2416.2	136.8	6%
3	Feiyao SE	98-011	EIV	2	114	767.5	182.4	24%
4	Feiyao S2	98-013	EIV	0.5	28.5	2749.5	45.6	2%
5	Wuluoxipo 1	98-033	EIV	0.2	11.4	1691.2	18.24	1%
6	Shangzhuang	98-037	EIV	1	57	1244.5	91.2	7%
	Gangou River			36.4	2074.8	8655.8	3319.68	38%

7	Nancunzhai SE	00-061	EIV	1	57	342.5	91.2	27%
8	Nancunzhai SW	00-062	EIV	2	114	388.8	182.4	47%
9	Luoyanzhuang SW	00-072	EIV	1	57	463.5	91.2	20%
10	Nianzizhuang NW	00-073	EIV	1	57	1680.4	91.2	5%
11	Gangou zhuchang	00-074	EIV	6	342	535.9	547.2	102%
12	Liulezhai S	00-075	EIV	1	57	119.2	91.2	77%
13	Xiaoxiang SW	00-080	EIV	4.5	256.5	1529.5	410.4	27%
14	Huilongwan xincun E	00-083	EIV	3	171	1254.1	273.6	22%
15	Yanliangzhai SW	00-086	EIV	3	171	454.8	273.6	60%
16	Shijiagou NE	00-093	EIV	4	228	223.9	364.8	163%
17	Lijiagou E	00-099	EIV	5	285	477.1	456	96%
18	Matun Xitun S	00-103	EIV	1	57	482.6	91.2	19%
19	Fuxicun NE	00-111	EIV	1.9	108.3	471.8	173.28	37%
20	Xiaoxiang W	00-115	EIV	2	114	231.7	182.4	79%
	Caohe River			2.25	128.25	2731.5	205.2	8%
22	Xinhougou YchE	00-132	EIV	2.25	128.25	2731.5	205.2	8%
	Liujian River			32	1824	2430.7	2918.4	120%
21	Huizui	00-127	EIV	25	1425	551.8	2280	413%
23	Xiahousi	02-182	EIV	4	228	523.5	364.8	70%
24	Huizui N	02-192	EIV	3	171	1355.4	273.6	20%
	Majian River			43	2451	4447.7	3921.6	88%
25	Xinzhai N	02-197	EIV	10	570	881.2	912	103%
26	Xikouzi NW	02-201	EIV	18	1026	511.8	1641.6	321%
27	Zhangwan N	02-210	EIV	10	570	539.8	912	169%
28	Linxiaozhai	02-211	EIV	2	114	459.2	182.4	40%
29	Bei Wujiawan	02-214	EIV	3	171	2055.7	273.6	13%
Total				178.8	10194.5	28547.1	16311.1	57%