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LIDAR DATA APPLICATION AT KOH KER

Lidar data acquisition

Lidar data acquisition for Koh Ker and other archaeological sites in Cambodia has been a focus of attention since 2009. Finally, under the guidance of the Khmer Archaeology Lidar Consortium (KALC) project, a comprehensive lidar survey of greater Angkor was undertaken in 2012. Koh Ker was also included in this survey of the central 67 km^2 area.

This report covers the methods applied to the lidar dataset and also the first level interpretation of the findings, which should followed by an intensive field survey later on.

Applied data products

The lidar dataset contains several data products: terrain (surface) model, colour aerial photography and raw lidar measure data. We exclusively used the terrain model data in our work. For any type of remote sensing application that targets archaeology, the biggest challenge is the removal of the canopy effect. Lidar actually provides a surface vegetation removal method, it ‘sees through’ canopy, so to speak, thus its terrain model is almost completely free of the effects of vegetation. It is generally accepted that underground features cause smaller or larger changes in the surface topography, changing the ground-water dynamics, erosion patterns or conciseness and other physical parameters of the soil or its

substrata. With these things in mind, our first level approach was to use the terrain model exclusively, leaving the option of utilising aerial photography for interpretation later where necessary.

Processing considerations and methods

The lidar terrain model arrived as a large set of discrete 3D points. After examining the density of the dataset, the decision was made to use a grid density of 0.2 metres. In technical terms this represents a major oversampling of the area, the reasons for which are discussed below.

Inverse distance squared weighting (IDW) was applied to the sparse set of points. When interpolating at such high resolution, the set is sparse in mathematical terms despite the millions of points provided by the lidar survey.

The resulting raster image for the area has a resolution of 50000x30425 pixels, that is, offers a ~1.5 Gpixel image. For easier presentation on printed sheets the area was divided into eight regions.

By thinking of an Angkorian landscape in which a network of roads, buildings, hydrologic features and irrigated agricultural areas built up the mesh of a low-density habitation pattern, we realised that our tests should target water flow. Thus instead of using traditional coloured or shaded terrain model visualisations we saw water flow as the key phenomenon. Water flow directions are highly sensitive even to the smallest changes in surface curvature. Our goal was to create a new type of visualisation using this fact to produce a more strongly contrasted image.

The results of flow-direction analysis are not intended for visual interpretation in general. Assisting professionals working on the interpretation, we worked out a method that converted the result of water flow analysis into a pseudo shading image. Furthermore, we removed the visual effect of absolute height differences from the target area. This change enabled us to visualise the area as a whole without losing the detail of local topographical differences in the resulting image.

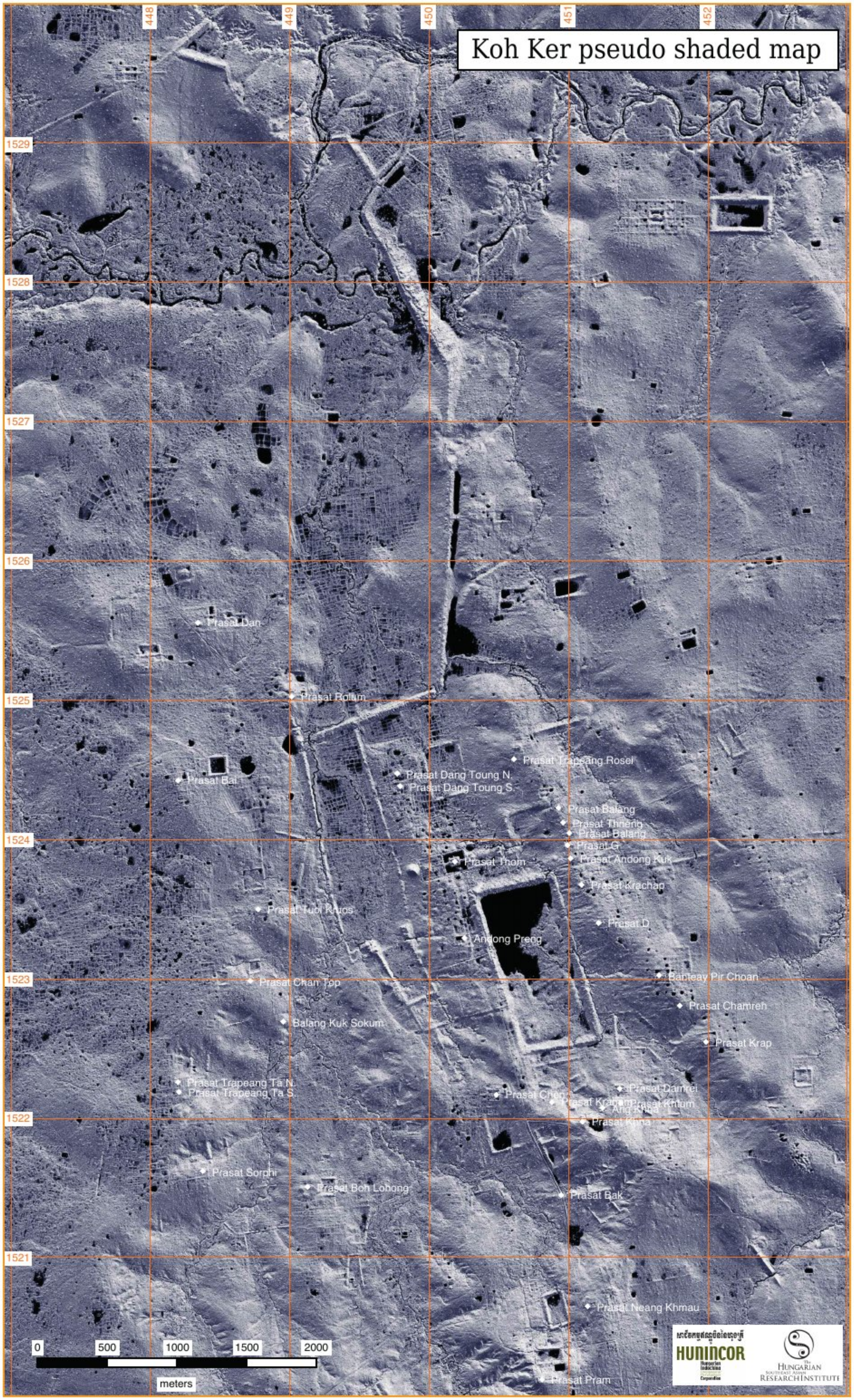


Figure 1: Pseudo shaded map of Koh Ker.

General notes on pseudo shading

Interpreting this type of pseudo shaded image requires the application of several rules.

- During the calculations a big loss of resolution occurs in both (N/S & E/W) geographical directions. Setting out from the originally sampled 0.2 metre grid the resulting image has a resolution of about around 1 metre in either direction. This is the reason for the original oversampling.
- Zooming out from the picture (depending on the displaying software) the user should switch to some pre-calculated, even lower resolution images if the displayed image seems to be coarse. This effect is caused by GIS software re-sampling mechanisms for zooming out being sub-optimal for these new pseudo shaded images.
- Surface water presence or basins without runoff, whether they have water inside or not, appear as black patches on the image. This last effect is the greatest advantage of this kind of visualisation in the case of Koh Ker.

Appearance and pattern of ponds

The presence of water surfaces and *no-runoff* patches are clearly evident on the pseudo shaded images. Around Banteay pir Choan and Prasat Krap these small black patches clearly draw out the pattern of the original land use network. The same is true on many areas of the map, albeit less clearly, especially along the north-northwest to south-southeast line of Prasat Thom (markers #18 and #17 on the region 5 map).

When compared to the same kind of patterns of habitation mounds and other structures, it is evident that the pseudo shaded map is a good source of quick first-sight analysis for Angkorian landscapes.

Digitising and classification of features

Identification and representation of key features

When used exclusively, remote sensing data sources limit the depth and accuracy of analysis in terms of dating. Field verification is essential in identifying the building techniques, materials and purposes of some features.

Being independent of, but also taking into consideration the issues above, we set up the following identification categories to enable habitation pattern investigations and excavation site identification in the future.

- Earthwork and hydrology—dams, raised pathways, embankments around reservoirs, moats and others in linear or closed forms. The question of applied materials such as possible stone reinforcement was only a second order aspect and thus not used during the identification process.
- Ponds—mostly linked to habitation mounds—are marked as points for enhanced display because of their importance in the habitation pattern.
- By examining the patterns on the surface regular networks of lines could also be identified. These are usually parallel with the pond patterns; however, their intended purposes were not examined individually. As footways or small embankments made of whatever material or technique, they are all the same in our investigations because we have concentrated exclusively on the structure.
- Even with an elementary knowledge of Khmer architecture from the Koh Ker era, it is possible to identify the built structures of the prasats, including their walls, separating them from the above mentioned linear and hydrologic features, which are marked as a different class.

Some data from earlier maps of the Koh Ker Project were added for easier orientation. These are primarily the named sites.

During the digitising process, the following guidelines were followed:

- Considering that digitisation is always generalisation, the main rule is that features are not reconstructed on the drawings to their ancient condition. For example:
- Broken lines (dams, embankments) have been left as they appear now and not connected where they have been separated or cut by current streams.
- Features deviating from the straight track are not realigned to their most plausible original path.
- Exceptions are those features classified as constructed. Where no points could be seen of the digitised feature and the missing point should have been a right-angled corner, the theoretical shape has been reconstructed (of the temple).
- Features with a reasonable width have also been represented with just a single line connecting the highest points or theoretical axis points or what could be the centre between the baselines.

- Points representing ponds are placed at the centre of the pond when the centre could be estimated from the regular network of other ponds and linear objects around such features.

In response to the opportunity to compare and contrast the traditionally prepared shaded terrain map with the pseudo shaded map, another map sheet was prepared that also contained the digitised and identified features of Koh Ker using the traditional shading as background (see Figure 2).

REGION 1

The main objects in region 1 are the prasat in the northwest and the road coming from the northeast that passes nearby (markers #1 and #2 on map). Erosion and the meandering stream have broken the linear features. Modern rice fields and flood basins now occupy the area. The remains, however, clearly show the importance of the area as the junction of the road/embankment coming from the south and the centre of Koh Ker (marker #3). There are also traces of complex hydrologic engineering here in the forms of possible flood gates or even canal locks if we think freely, however their dating and exact role is unsure yet (around and NW from marker #3). Original shapes and configurations are hard to judge or estimate not only because of erosion, but also because of possible past slow or sudden landslides and the filling of topographic valleys. The thick layers of fluvial sediment may require several test drills and bores at some point to get a picture of the earlier stages of the area around the stream.

REGION 2

Region 2 in the centre shows the clearest example of a local network with ponds and also a reservoir to the east. Being such a clean structure and spared from erosion on the local high ground, it is ideal for systematic archaeological excavations (marker #4).

This area is also the terminal point of a ‘highway’ coming from the south (marker #5) and contains many other features like small ponds. It leads along beside a watershed. On its western side there are more signs of smaller local networks or grids, but these are also good examples of features that need to be dated before they can be more precisely

Figure 2: Traditional shaded relief overview of Koh Ker (exaggeration factor: 5).

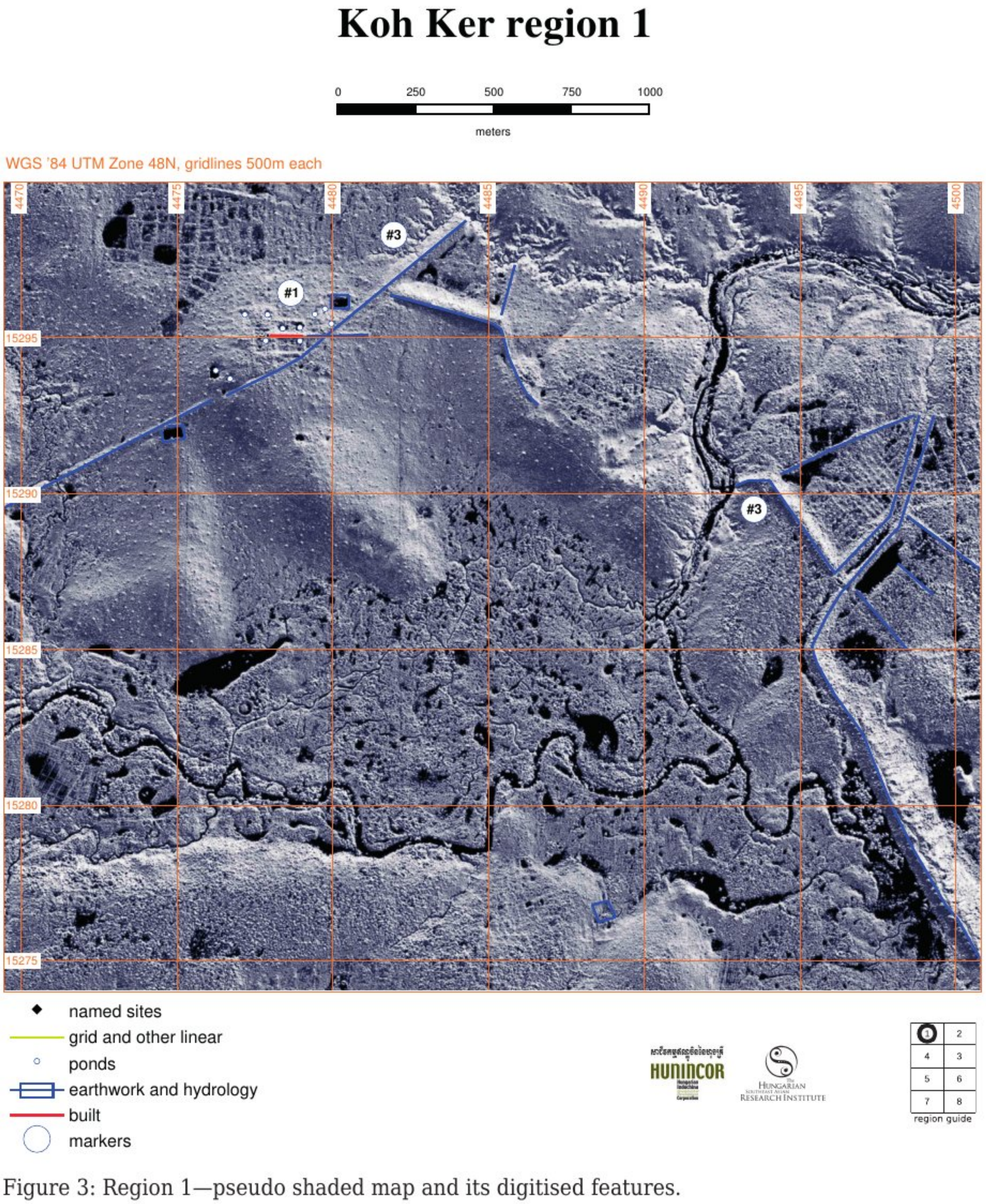
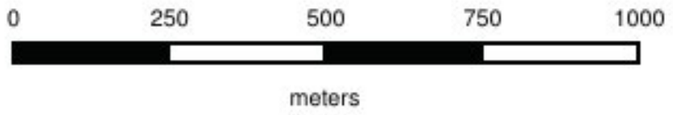


Figure 3: Region 1—pseudo shaded map and its digitised features.

classified. Present cultivation also limits the range and scope of the remote sensing evaluation. Other smaller reservoirs are also present in the area (marker #6).

Koh Ker region 2



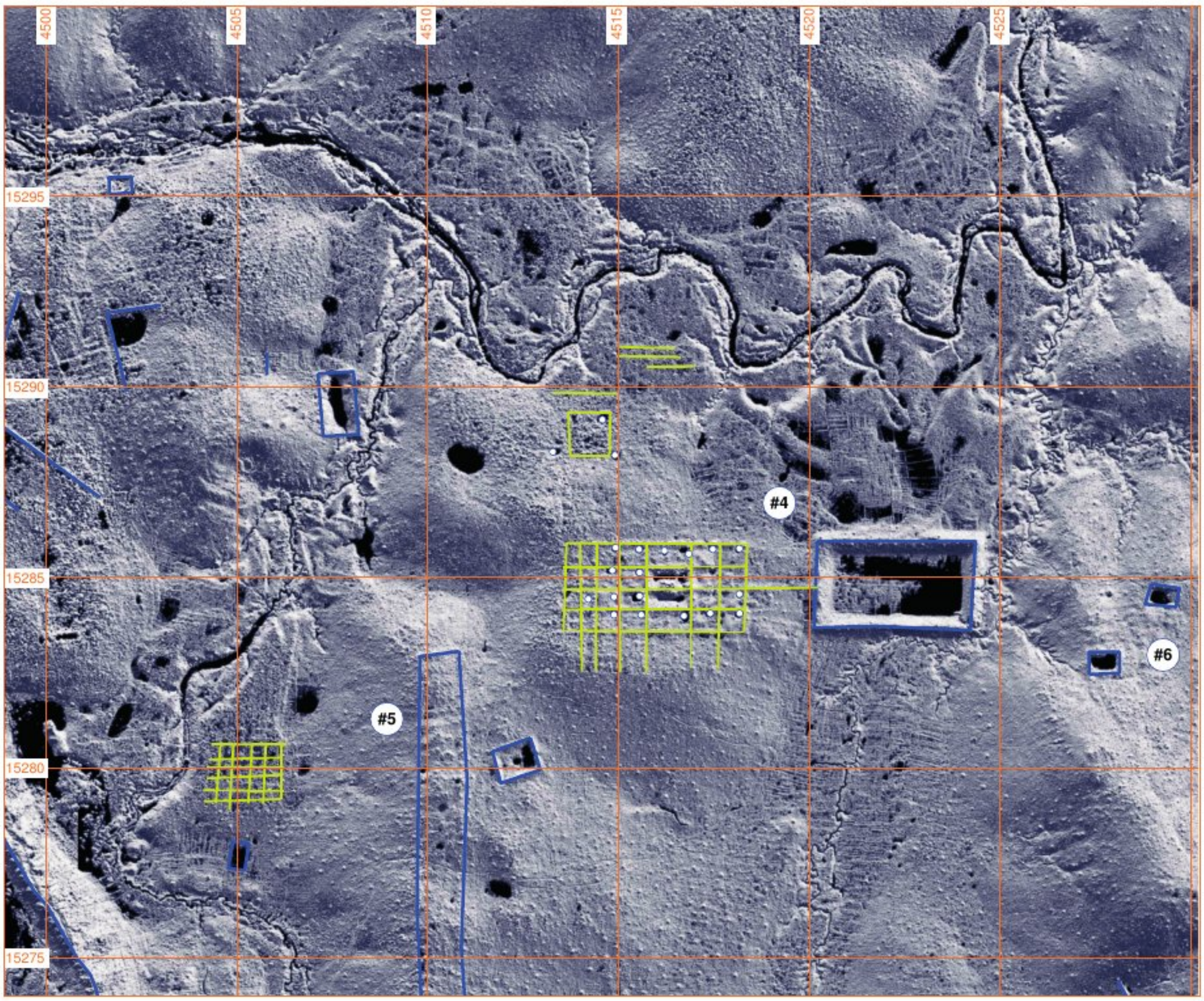


Figure 4: Region 2—pseudo shaded map and its digitised features.

REGION 3

Region 3, which is the northwest side of Koh Ker, generally shows many traces of earlier anthropogenic landscape changes. These changes do not exhibit a coherent structure such as that, for example, on the eastern

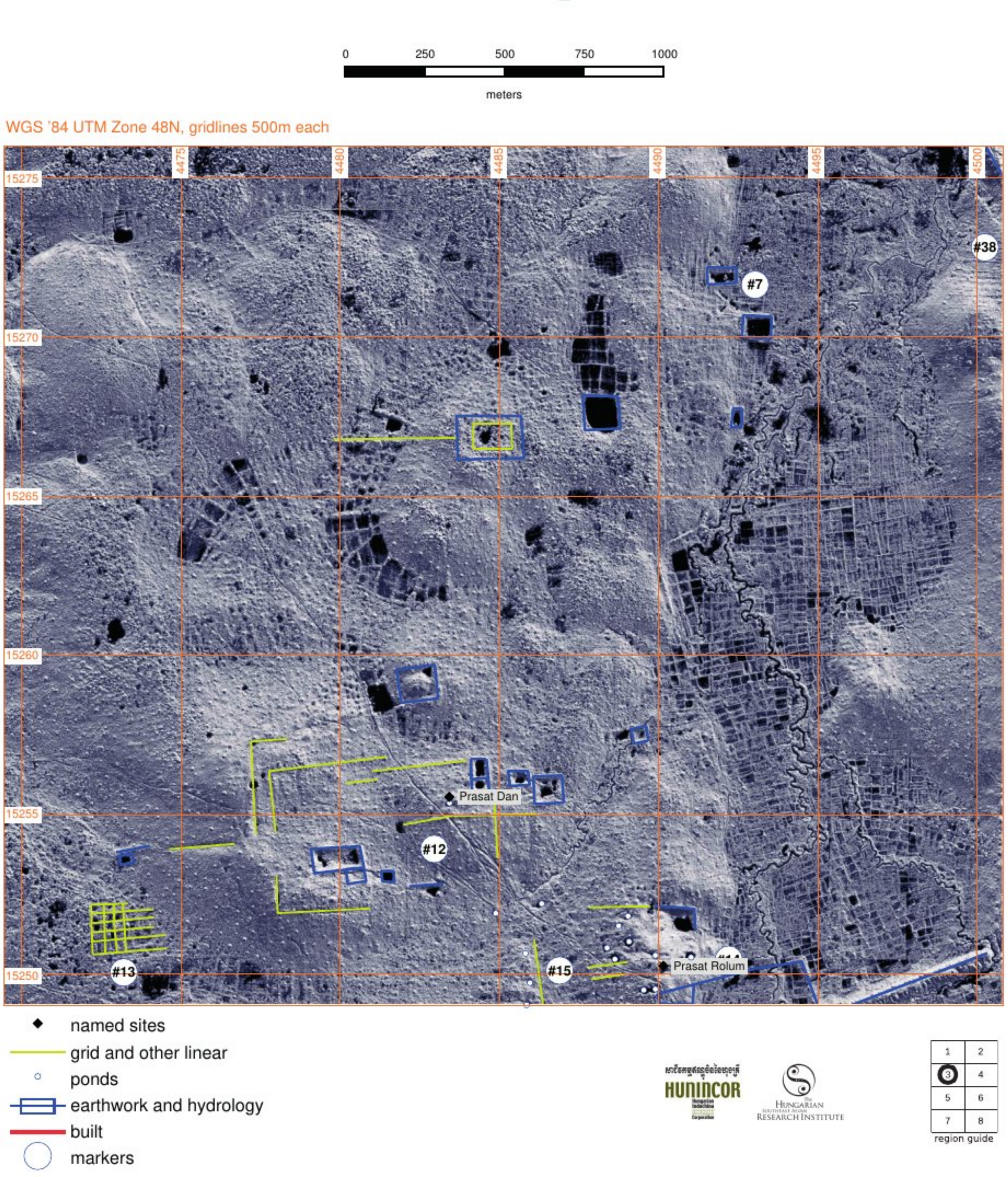


Figure 5: Region 3—pseudo shaded map and its digitised features.

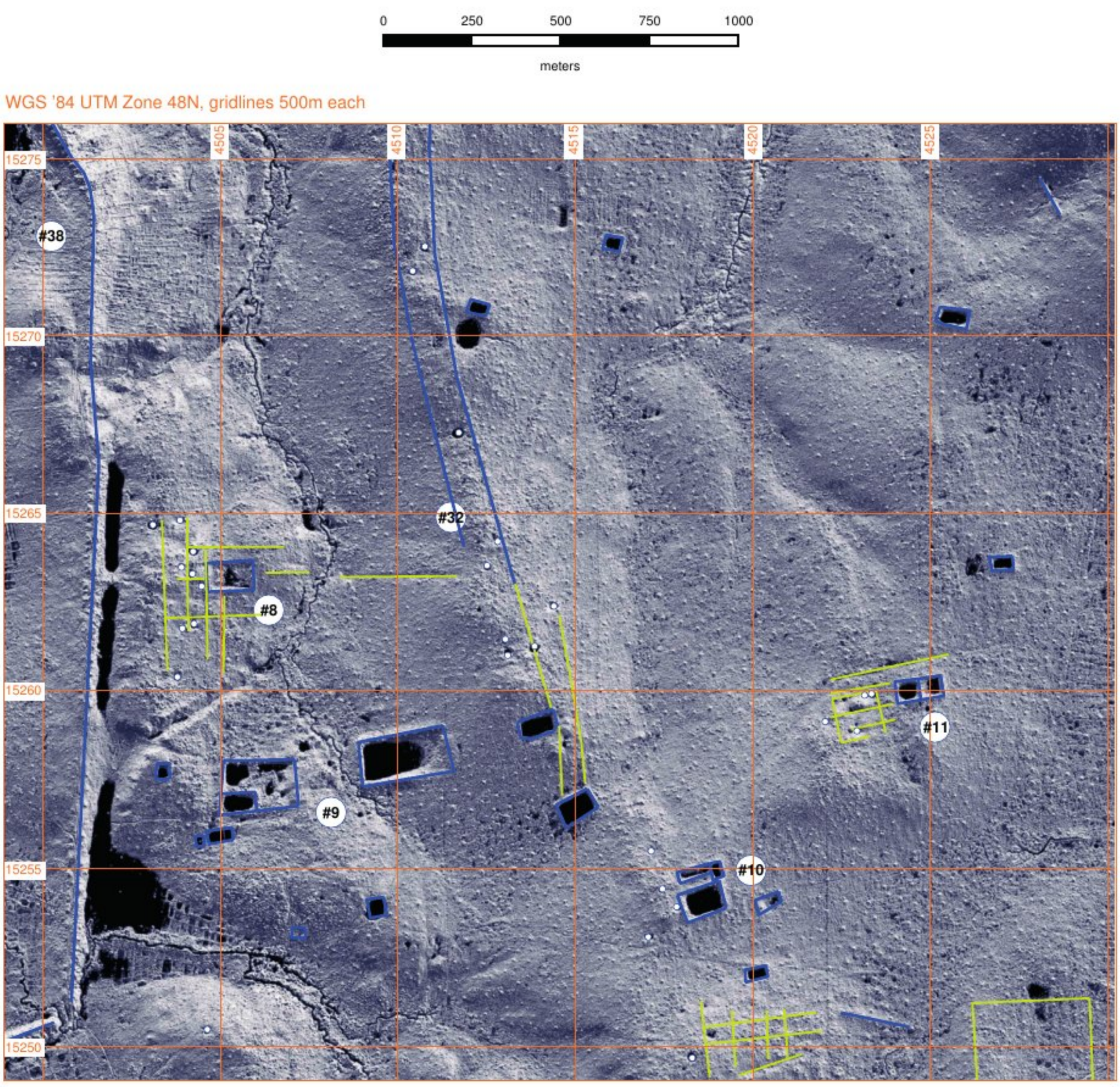


Figure 6: Region 4—pseudo shaded map and its digitised features

side of the Rahal. It is obvious that almost all local heights were occupied by different built structures (see marker #12 as an example). A pond network is also visible (marker #15) and reservoirs are omnipresent (marker #7). Reservoirs without a clearly visible embankment are sometimes a part of currently cultivated plots. Their size shows that

they could be examples of modern reuse of ancient features (southwest ~500m away from marker #7).

Prasat Dan and Rolum (marker #12 and #14) on the lidar seem to be set on local heights, while behind them traces of complex, but largely abandoned structures are visible. The system they present seems to be irregular when compared to others to the east. This irregular pattern of linear features could be a result of several rebuild phases or abandon/reoccupy cycles over the ages. What can be seen now was not an original contemporaneous feature. Excavation trenches crossing many of these lines could clarify the dating.

REGION 4

On this map sheet we are getting closer to the central areas. Individual reservoirs, pond/linear grids and the southern part of the 'highway' are all present (markers #9 and #10, #8 and #11, #32, respectively). The large embankment (marker #38) leading to the north clearly divides Koh Ker east to west, where in the west topographic features make the land better suited for cultivation.

The embankment itself now lies far from its ancient and most likely straight path. This status could be the result of a slow slide under the pressure of surface waters from the east and further facilitated by groundwater flow and the thin soils of the area. Such an artificial watershed is a major technical challenge as keeping back the surface waters from the eastern part—whatever the original purpose may have been—requires the knowledge of how to build a long dam without side support (on the western side). This is why a slow slide is the most likely scenario.

REGION 5

South of region 3 the same observations could also be made. A system of abandoned water management structures (markers #36 and #37) is located on the west side, which is a distorted reflection of what Rahal and its eastern zone represents. This example refers to water management and water facilities in the valley, and buildings and grid patterns above

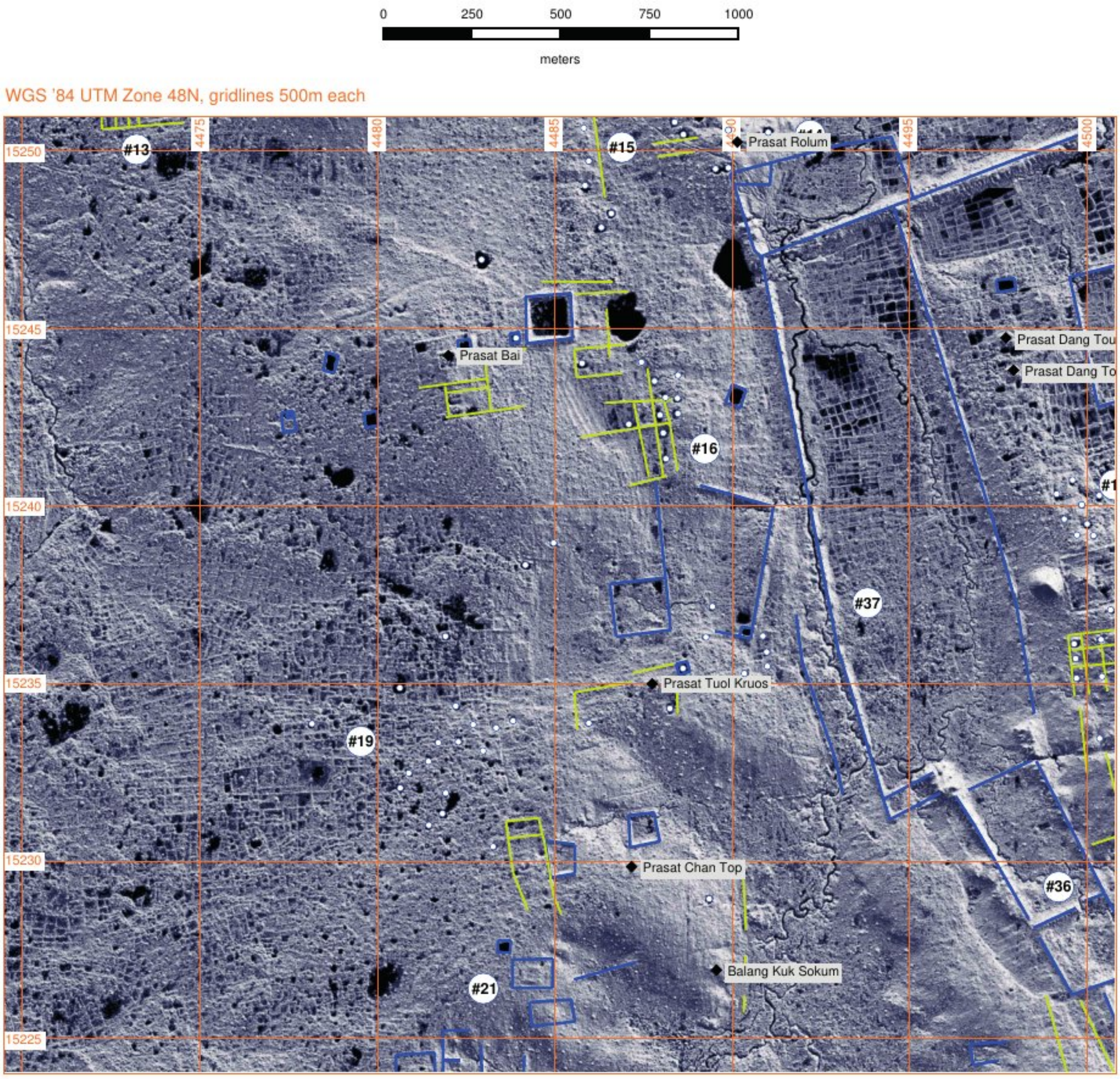


Figure 7: Region 5—pseudo shaded map and its digitised features.

on the watersheds and local heights. Currently, the former baray (marker #37) has been reused as a rice paddy and streams have broken through its northern embankment.

The habitation zone on this map sheet leads from Kuk Sokum. It contains some features on its west (marker #21), other temples to the

north, grids and ponds (marker #16), Prasat Bai itself and continues northwards (marker #15).

An extensive field survey is recommended to the west of this zone to clarify the origin, status and present day use of the rice fields and the network of pond-like features (between marker #19 and #21).

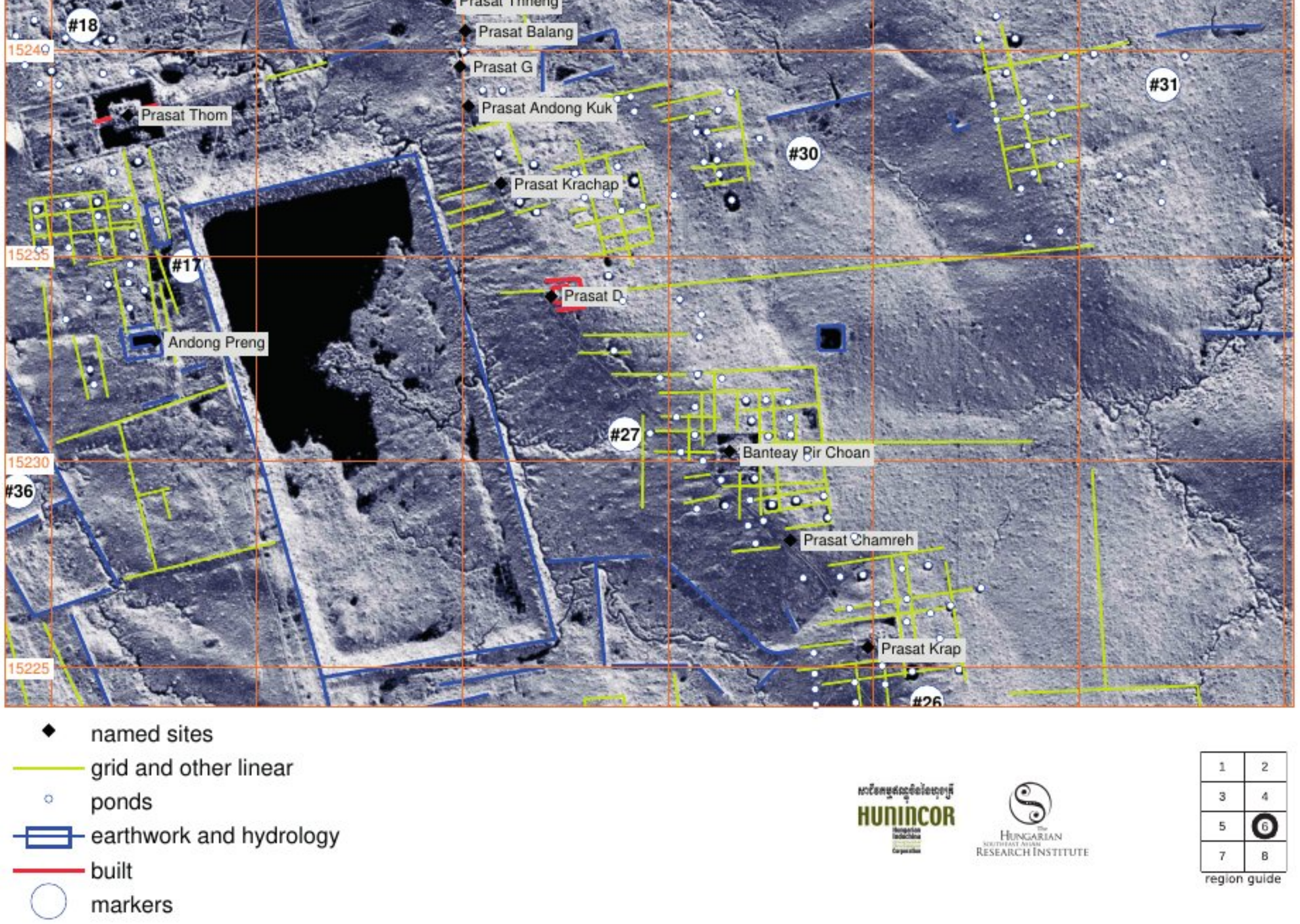


Figure 8: Region 6—pseudo shaded map and its digitised features.

REGION 6

Region 6 contains the central part of Koh Ker. Most features can be found on the watershed line to the east of the Rahal reservoir. To the west of the local high ground that forms the watershed, the effects of strong erosion can be observed. In particular, the grid of Banteay Pir Choan and its western part has been damaged and has partly disappeared (marker #27).

West of the northern prasats of the watershed (Balang, Thneng, etc.) there are the remains of a former reservoir with a strong embankment on its western side. There are also signs showing that its southern embankment is practically missing (or was removed or occupied when the Rahal was built). The visible parts of the structure are a logical continuation of the Prasat Thom features.

Prasat Thom, the Prang, and the buildings of this complex are all in a place where they would be endangered by flash floods without the presence of the Rahal. On the northwest – southeast line of Prasat Thom (between markers #18 and #17) one could observe the most disturbed area of the landscape. All typical elements could be found here, especially ponds and linear grids. Some grid lines running into the Rahal imply that many of these structures may be dated earlier than the building of Rahal itself.

The situation of Prasat Krachap is more inspiring. The remains of a grid to its east (marker #30) and another further on at the next watershed (marker #31) could be a good example of where we can check how different zones on different watersheds are connected to each other. Their transition may be worth an intensive local archaeological study. In the other direction, further linear features also connect Krachap to Rahal as well.

The omnipresent reservoirs and some more grids could also be observed in the northern area of the map sheet (marker #33) proving that Koh Ker also had the low density city landscape as it had been earlier and was later at Angkor, with essentially no city limits but rather a continuous change in density and land use texture.

REGION 7

Region 7 largely continues the pattern of region 5 in terms of the presence of lower density local centres. This area has many local watersheds in contrast to the big one that dominates the east side of the

Rahal and it results in a more widely distributed built environment. East of Rahal the average distance between the temples is as low as 50-200 metres with an average of close to 150 metres. Here in region 7, the local centres are 500 metres from each other. Another difference is that the eastern watershed is a long and continuous ridge, while in region 7 the watersheds are short and fragmented parts of the landscape. Local

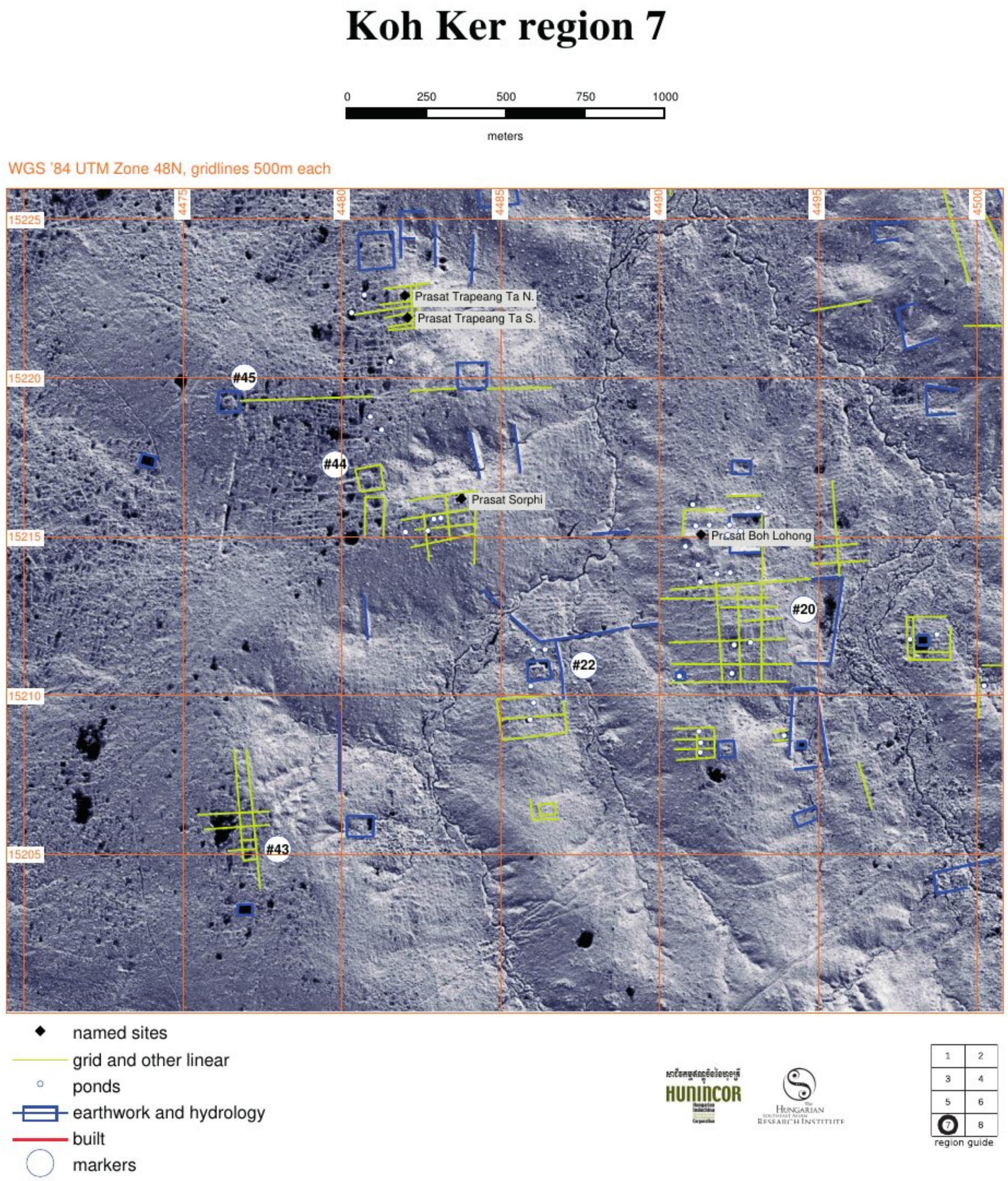


Figure 9: Region 7—pseudo shaded map and its digitised features.

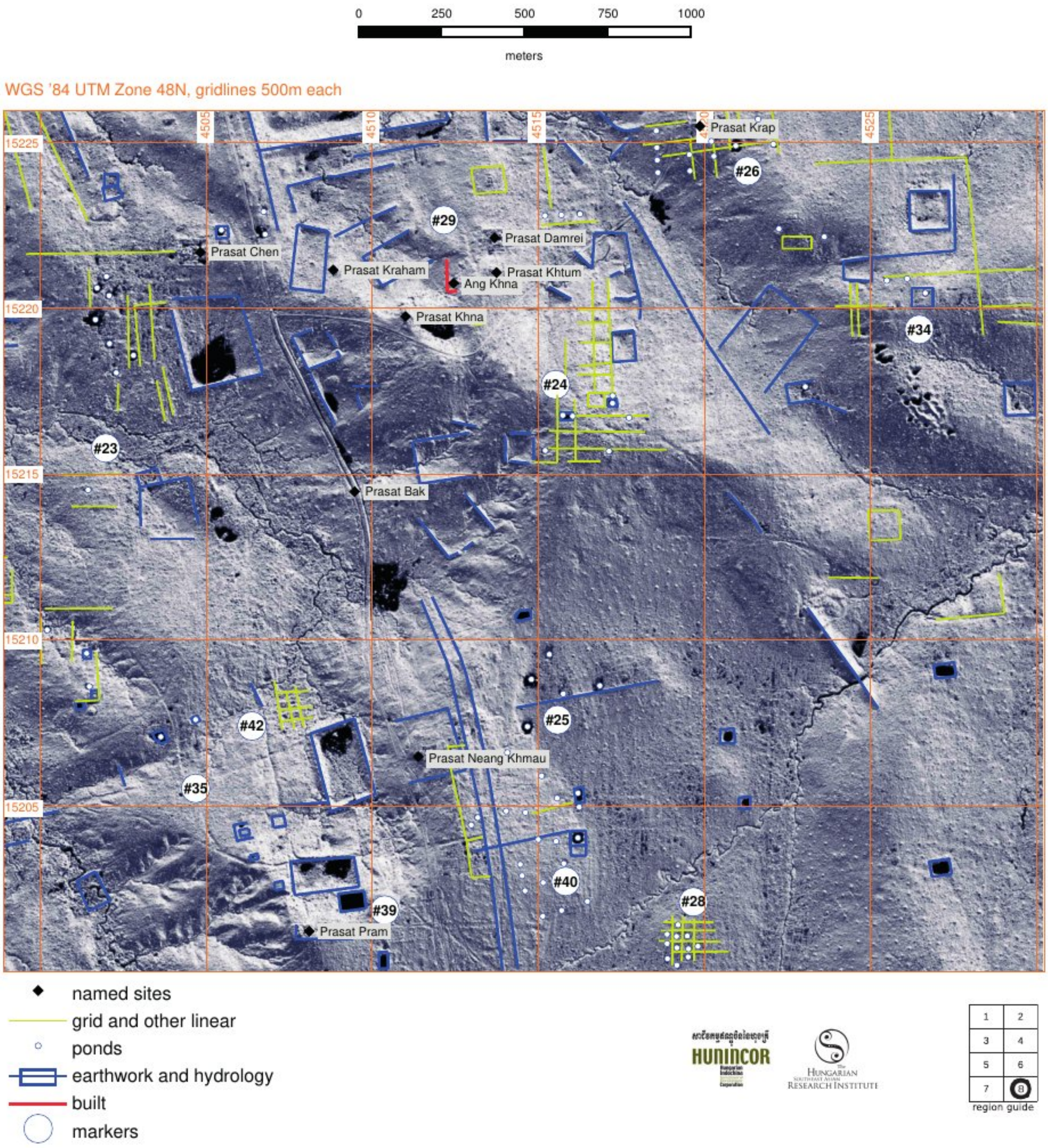


Figure 10: Region 8—pseudo shaded map and its digitised features.

grids (markers #22, #20 and Prasat Sorphi) are also present but not as well defined as those in region 6.

This is the region where, at the beginning of the small topographic valleys, a series of dams could be observed. See, for example, north of Prasat Sorphi and also further to the south in the upper valleys marked on the map with single blue lines. Establishing their current condition, use and dating is crucial, but cannot be judged without targeted field verification.

There are other remains that should also be visited and checked. They seem to be some unnamed or presently poorly documented smaller

temples. These are marker #22 and similar features between Sorphi and Trapeang Ta, digitised as red rectangles in blue ones because they show the typical prasat layout.

REGION 8

Features of region 8 show traces of large scale landscape modifications. Around Prasat Kraham, Damrei, Khna and many others there are innumerable signs of former or current dams, embankments, even with traces of grids (markers #29 and #24). On the other side of the local watershed (marker #24) the Prasat Bak and Neang Khmau areas down to Prasat Pram have many embankments and reservoirs. The examiner also feels that this kind of landscape continues to the south as well, beyond the lidar survey area. There are interesting features and miniature networks (marker #28), but their dating should be verified because they are highly questionable because of their exceptional condition.

Grids of ponds east (marker #25) and southeast of Neang Khmau are also interesting because while the ponds do seem to be present there are no easily recognisable marks of the usual linear features around them. When examining the distribution and configuration of linear features, Prasat Chen and its surroundings are similar to Andong Preng and archaeological findings there may be worthy of comparison. Geophysical tests are also recommended in this area because of the high density of visible structures.

Prasat Krap (marker #26) is another example of what Banteay Pir Choan was for its eroded grid.

CLASSIFYING SITES BY ORIENTATION

The orientation of built-up structures was the first analysis done on the result of the lidar survey. We selected the features from the coverage representing the regular network elements.

Assuming the usual rectangular layout of khmer landscape structures we applied certain simplifications. All azimuth values of the lines have been rotated to the first quarter of a cartesian coordinate system. The method of this simplification can be followed on Figure 11.

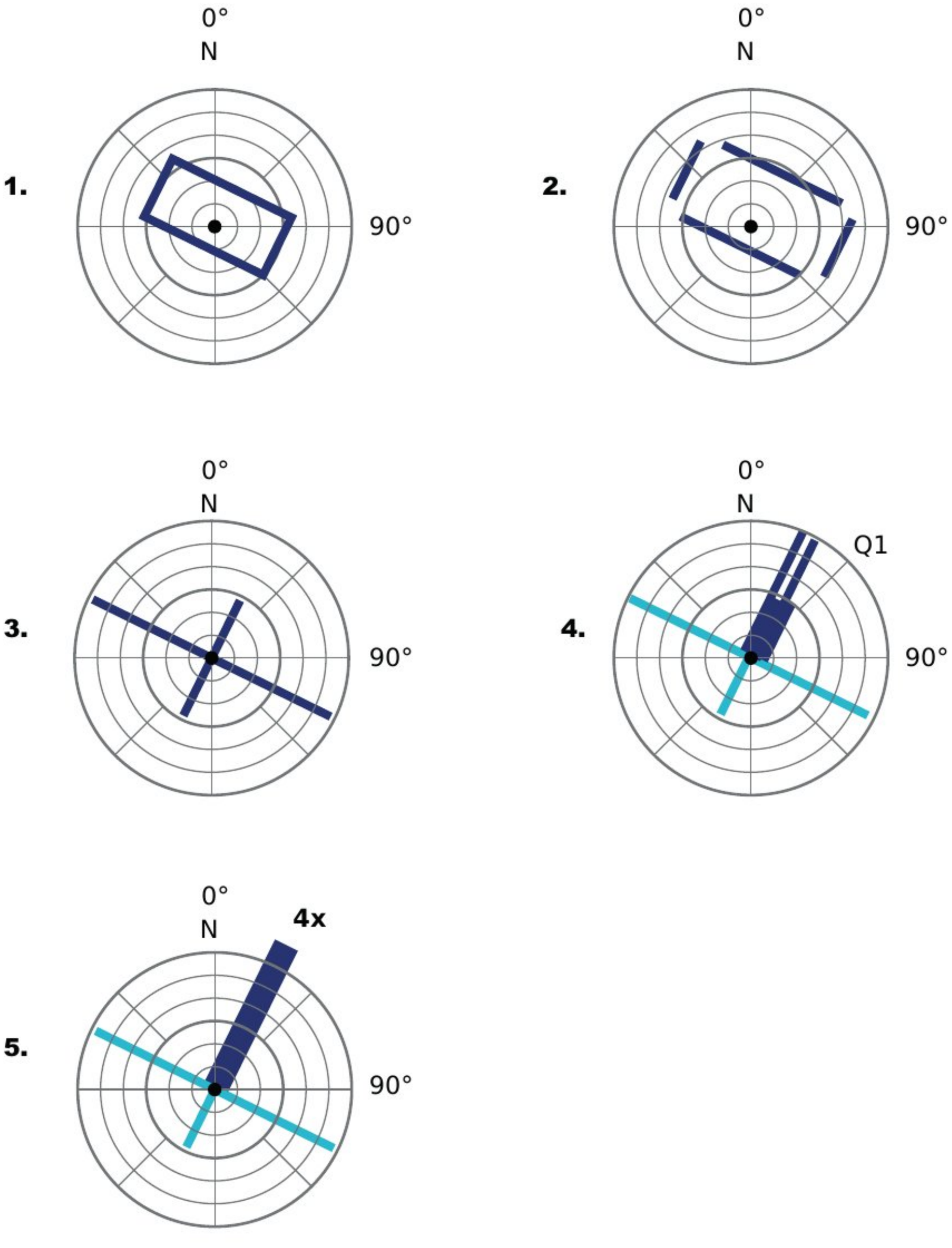


Figure 11: Simplification process for rectangular features.

- Step 1: There is a random rectangular layout on the landscape.
- Step 2: Its edges are separated theoretically to behave independently of each other.

- Step 3: When digitizing lines in a GIS system, the azimuth of the line is usually random. This azimuth value is technical and it can be calculated from the endpoint coordinates of each line segment. An East-West line (road, wall) has no real-life direction. It could also be said to head West-East, for example. In this way, each line has its own technical azimuth. In our example all four line segments head in different directions.
- Step 4: Taking into consideration the above it is all the same if we say East-West or West-East. Since Khmer layouts are rectangular and we consider the structure as a whole, when talking about the orientation of the whole structure segments having a right angle rotation also share the common orientation. This is why right angle rotation is also enabled. In step 4 we rotated all segments to the first quarter azimuth range (0<= azimuth < 90). Theoretically, for the same reason, 90° is also the same as 0°.
- Step 5: If we have all four segments of a rectangular feature then at the end we will have four segments in the first quarter of the plane heading at the same angle. The length of digitized line is not taken into consideration, neither as a weight factor, nor a threshold value indicating what to use later or what not to use in our further calculations.

The clear advantage of the simplification described above is the elimination of the necessity of analysing the role of the structural elements, their hierarchy or of identifying the line of the main orientation, which, for example, could be the opening direction of the main sanctuary, if any. This method could be fully automated once we have the indentified anthropogenic lines digitized.

Usually, not all the segments of ancient features are identifiable, even on lidar images. The presented simplification method also enables us to take partly identified features into consideration. Partly identified features are when we see one, two or three sides of a suspected rectangular feature but without the visible presence of the fourth edge, its line cannot be digitized.

Doing statistical analysis on hundreds of such identified and digitized network elements, we tried to calculate clusters of orientation. Orientation here refers to the technical azimuth values of line segments rotated into the first quarter of the plane.

CLUSTER ANALYSIS

We used the R statistical language for further calculations. Histogram plotting of azimuth values confirmed the previously known fact that in

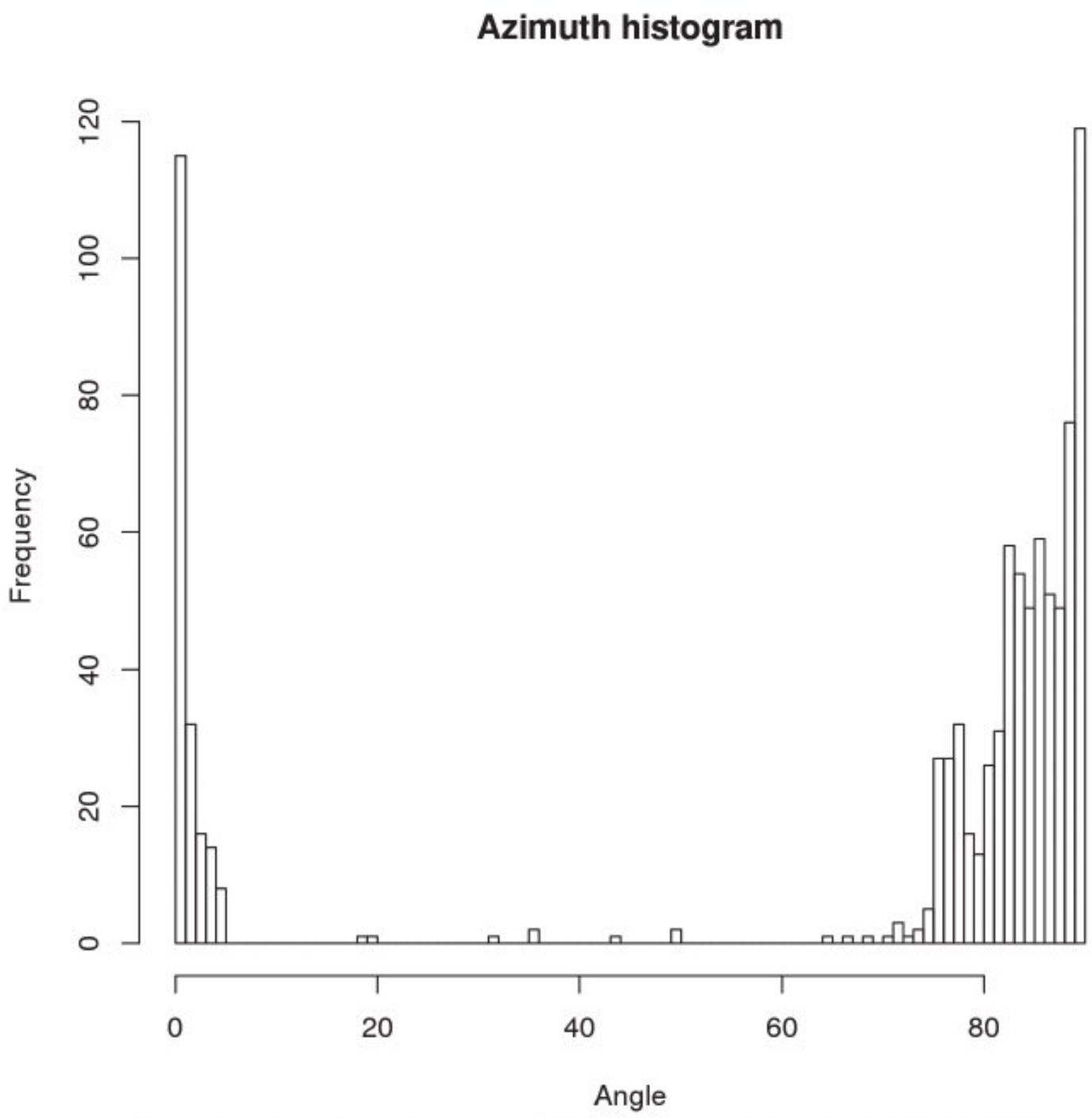


Figure 12: Histogram of the distribution of first quarter orientation angles.

Koh Ker many features are rotated 14° - 15° from the ideal East-West orientation,while others follow the East-West line just as they do in Angkor.

Treatment using degree values in statistical software is not self evident. In our example the azimuth values are limited to the [0°;90°) range**1**. However, 0° and 90° are essentially the same values for our purposes, since they cover the same orientation of a structure in practice. Even estimated density plots fail as they cannot see the 'identity' of 0° and 90° values.

Examining the values of the first histogram on Figure 13 we were able to see that azimuth values are concentrated around 0° degrees (=90°) and 74° -76°. This latter is the manifestation of the ~14° -16° well known difference of some layouts.

This concentration enables us to make a second rotation to move our degree values into a continuous range where statistical calculations treat the values according to our needs. The second rotation was -45°,

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[1] Left closed, right open interval meaning azimuth values are between 0° and 90°, including 0° but exluding 90°.

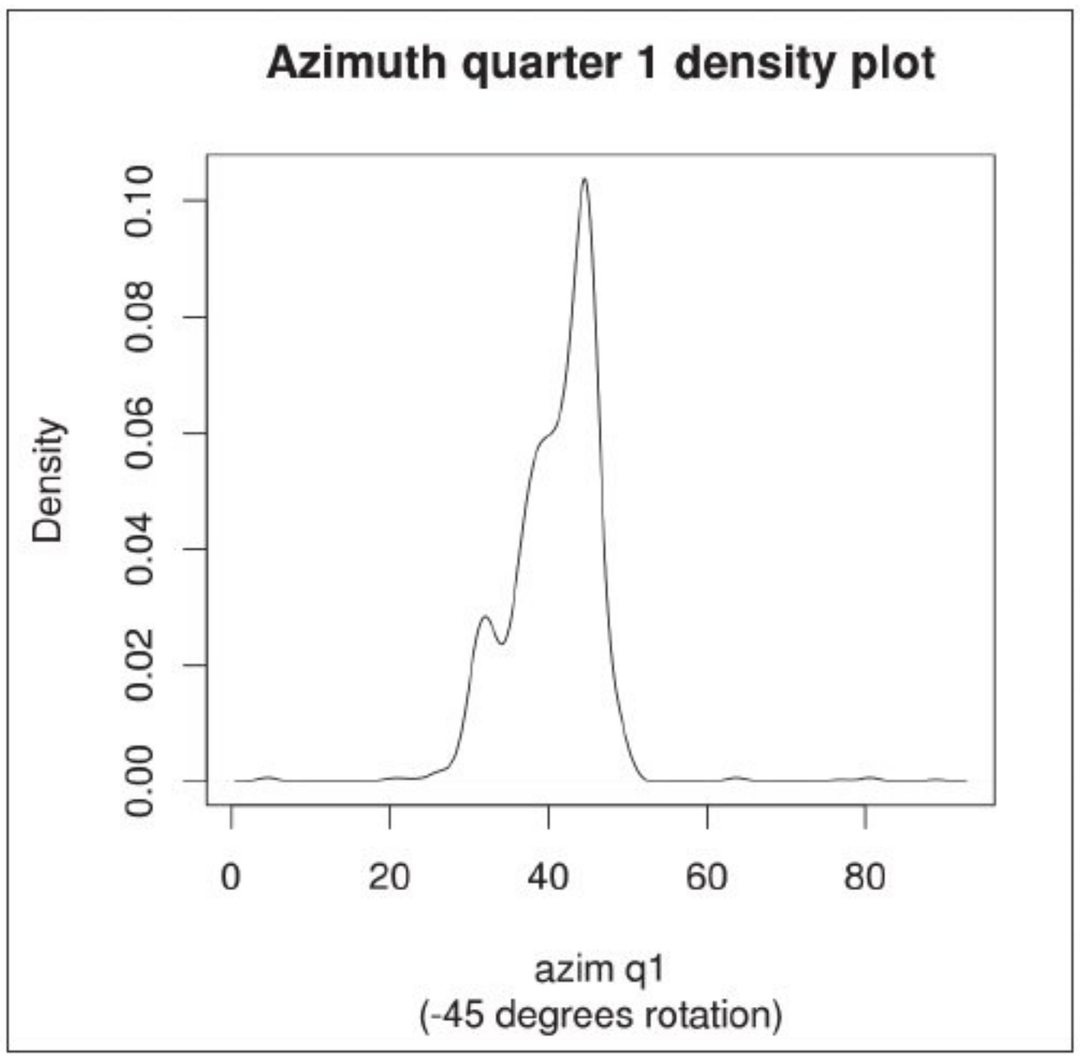


Fig 13: Estimated density plot of orientation angles in first quarter following the 45° rotation.

so values around 0° and 90° degrees have been adjusted to around 45° and other values are also rotated respectively.

Creating the estimated density plot provided by the R language packages a new discovery emerged.

In addition to the East-West (45° on the plot) and ~14° groups (~30° on the plot) a third group appears at around 39° - 40° (which represents a 5° - 6° degree deviation from the ideal East-West orientation).

Checking our theory in a statistical manner, a K-means cluster analysis has been applied to the vector of rotated azimuth values. The three close and related accumulation points identified on the histogram indicated that the ***k*** value could be 3 for the analysis.

The K-means cluster analysis provided the following result:

Cluster #	**Cluster centers in rotated azimuth**	**Real azimuth values**	**Interpretation**
1	31.17048	76.17048	~14° Rahal, Prasat Thom, etc.
2	38.90987	83.90987	**~6°** **New group**
3	45.24634	0.24634	Idealistic East-West

Figure 14 – Table of clustering results

Using the clusters a map was created showing the regular network elements coloured by the cluster they belong to.

It is clearly visible that all the three groups have a certain spatial pattern. East-West orientation exists all around the surveyed area. The group of ~14° deviation is formed around Prasat Thom or Rahal, indeed.

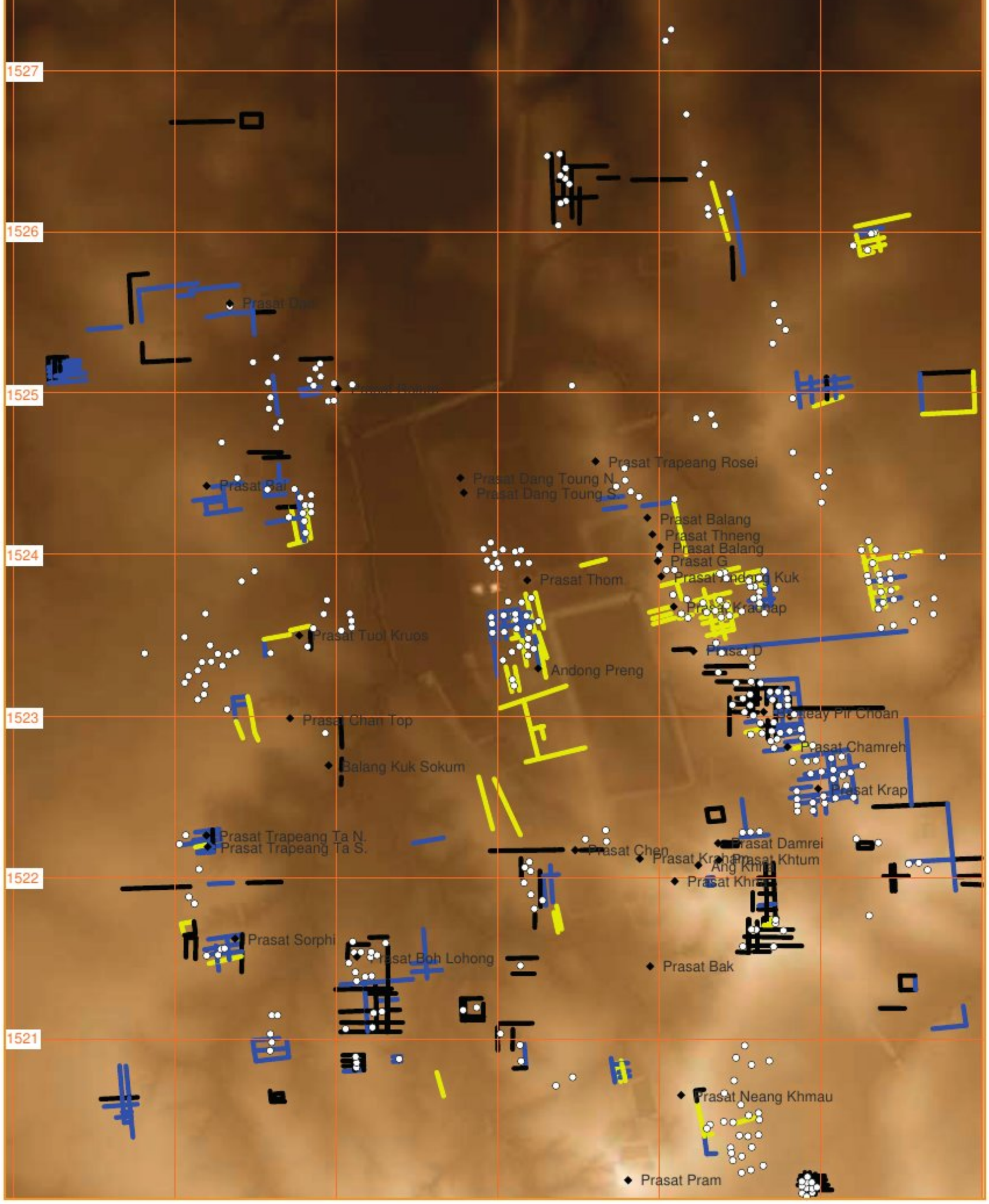
The newly separated ~6° deviation group is spread widely on the area and mostly shows remnants of what is probably an older network of local grids. These locations seem to be rebuilt, especially in the example of Banteay Pir Choan where the two different orientations coexist.

Koh Ker orientation groups

0 500 1000 1500 2000

meters

WGS '84 UTM Zone 48N, grid 1000m each



◆ named sites

Lines coloured by orientation group

○ Ponds

Figure 15 Orientation lines coloured by cluster groups (black: ideslistic E-W, blue: ~6°, yellow: ~14°).

SUMMARY

At first-glance the examination of the lidar images with the pseudo shaded technique revealed new observations and questions about Koh Ker.

1. Built structures are placed on watersheds, sometimes really precisely. Pseudo shaded images show hills and valleys but in real life the level differences in Koh Ker are minimal. The landscape seems to be plain when one stands in it.
2. Even when using our basic classification several zones or zone types could be separated. These are:
   a) Agricultural
   b) Water management (protection, storage, irrigation)
   c) Actual habitation (ritual and other functions)
3. In the case of Koh Ker these zones follow each other like shells starting from the centre and are largely affected by local topographic facilities at each local features.
4. Orientation of built-up structures seems to be affected by many factors
   a) At first glance, the orientation of built-up structures seems to be in conjunction with the orientation and angles (and their right angles) of the watersheds they are built on.
   b) Following a statistical analysis it seems that different orientation groups could be identified as independent of local topography and following other, possibly theoretical rules.

Summarizing all the information above, the following conclusion could be made regarding patterns and orientations.

Orientation is usually ruled by the intention of the builders, following religious or other traditions. Wherever topography or the capability of safe control of water needs guidelines given by divides and valley bottoms are precisely followed by larger structures like the Rahal. Built-up structures and local grids then follow the orientation of these main contemporary features as well.

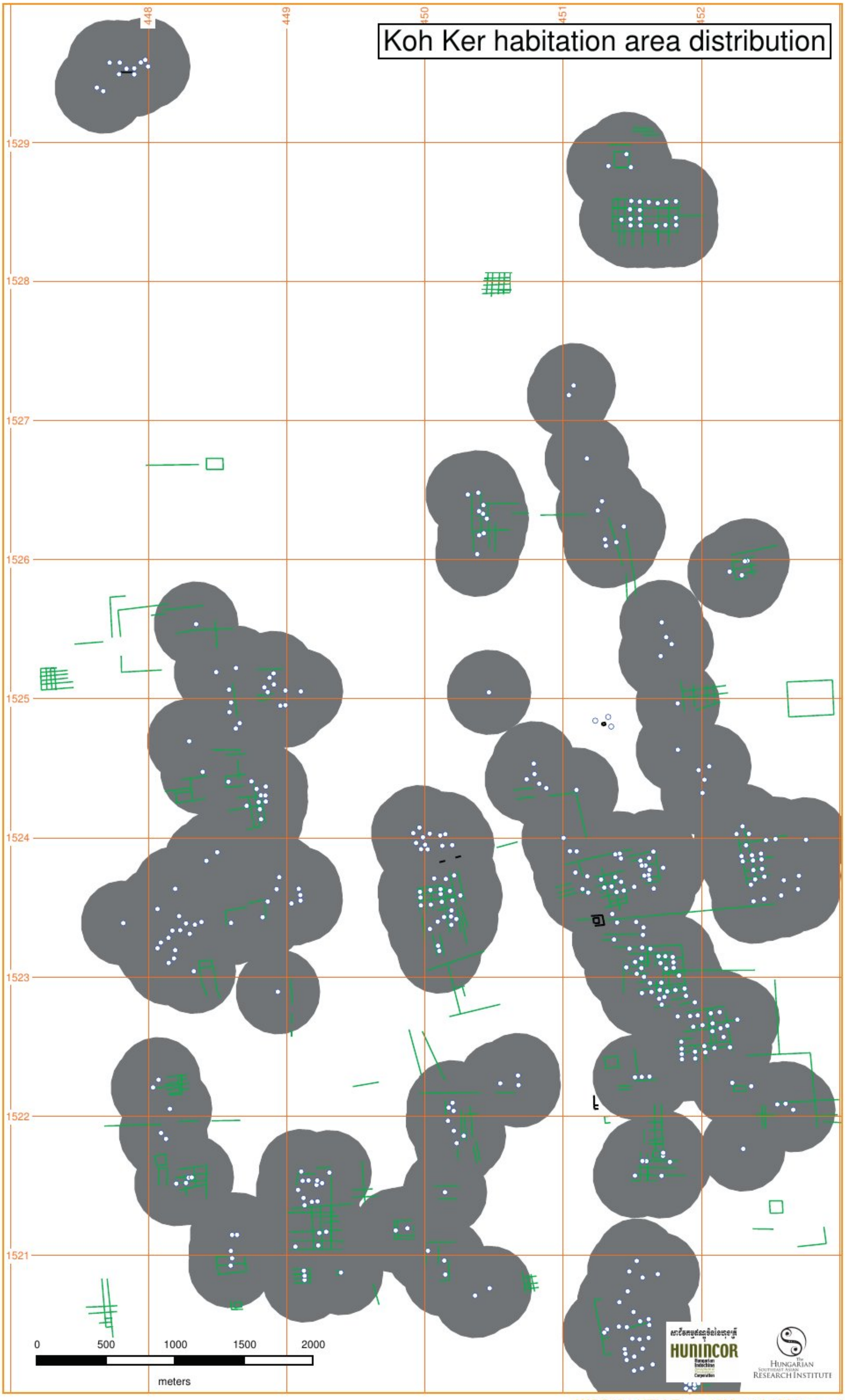


Figure 16: Locations of ponds and grids are in gray while 'empty' areas are places for water (infrastructure) management and cultivation