

Virtual Survey on North Mesopotamian Tell Sites by Means of Satellite Remote Sensing

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1 The role of Virtual Survey

The study of “tells” is a fundamental category of archaeological research. At present, most of our knowledge of the distribution of these ancient settlement mounds derives from ground survey. This paper is a progress-report on a project aimed at examining whether we can begin to detect them more or less at will, from the kinds of information which are becoming available to us from space, from data sources such as multi-spectral imagery, digital elevation models, or high resolution scenes with wide spatial and temporal coverage. Since in many areas tells are disappearing rapidly in agricultural improvement schemes or the growth of modern settlements, and since the data collected from space are constantly improving in resolution, we aim at elaborating methods for what we may reasonably call “virtual survey”: From the settlement mounds we know, we derive mathematical descriptions within the digital data, and then systematically search the Earth’s surface for phenomena with similar properties. With luck, most of what turns up should indeed be prehistoric settlement mounds (rather than, for instance, piles of road-stone awaiting distribution). Although only “ground-truthing” through a site visit can confirm this, we will present an approach to such a systematic evaluation of remotely sensed data in the following, in particular by relying on data of the SRTM digital elevation model. This approach is not a substitute for traditional methods, but

may become a valuable supplement to them.

Tells are a specific form of settlement-choice¹ over a well-defined area, from eastern Hungary to northern India, in places where mudbricks were used for building. Tell-formation is also characteristic of specific social and historical circumstances, since it is a phenomenon of a particular period in pre- and early history and closely related to the advent of urban settlement systems. In cases in which sites lasted over millennia – and especially in which they achieved urban status – their size can be very impressive. Therefore it is not surprising that such sites have been the object of intensive investigation for decades.

Unfortunately, even the locations of large and important tell sites occur in the archaeological literature with unknown reliability (accuracy) and precision. It is not uncommon to find significantly different co-ordinates being given for the same site in different sources, referring to geographic coordinate systems of any origin and any epoch (and not necessarily accompanied by this relevant reference). Even when the suggested co-ordinates do not plot in the sea (as some of the entries in archaeological gazetteers have been known to do), we are seldom sure whether they are intended to give merely a generalised indication of position, or a precise location. Thus, providing accurate co-ordinates for some very well-known mounds is one useful contribution of the present work. However,

¹Rosenstock, Tells in Südwestasien und Südosteuropa.

these major sites are only prominent representatives of a whole distribution of settlement mounds, still visible in wide areas in the Near East.

The major desire to interrogate the landscape for potential tells is that we have no clear idea how representative our current distribution maps really are. Naturally, they represent the cumulative result of several kinds of survey, which differing intensity and at different points in time. But the question arises whether these have been deployed in such a way as to sample the total pattern in a representative way, or are they just arbitrary and involuntarily self-confirming visits to the same places over and over again? (This is a characteristic problem of distribution maps, summarised in the aphorism that “archaeological distribution maps are maps of the distribution of archaeologists”). Do archaeological distributions really stop at international borders, as they uncannily seem to do on certain maps? While we cannot answer this question for finds of archaeological material (for instance particular categories of artefacts), we nevertheless can begin to do so for physical phenomena such as hills of a certain size and shape. Thus, providing comprehensive overviews of both their spatial and physical distributions, together with an accurate estimate of the “cut-off point” beyond which the smaller ones cease to be recognisable by current methods, is the major incentive for the present work.

So, how could this be achieved?

In the following we will briefly review the remote sensing of tells (section 2) and will describe the (semi-) automatic tell detection strategy which allows the virtual survey, and present first quantitative results on the distributions of tells in northern Mesopotamia (section 3). Finally, we will evaluate both the results qualitatively in a detailed case study and illustrate how the virtual survey on the SRTM model can be extended easily by other means of remote sensing (section 4).

2 Remote Sensing of Settlement Mounds

From a simple physical point of view, tells are features of 5 to 50 m in height, 50 to 500 m in diameter, and usually

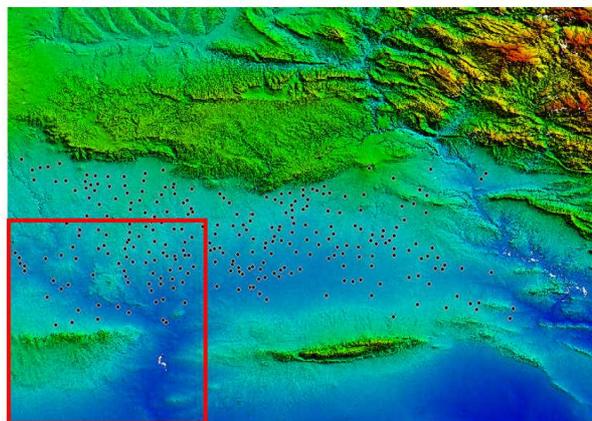


Figure 1: The Khabur basin with settlement mound positions indicated (black dots). Tells of the southwestern SRTM tile (bordered red) were confirmed by archaeological survey and serve as test sites.

of conical shape. Also, they primarily consist of loam and mud-based materials. Both features might be used in the identification of tell sites (Fig. 2).

High resolution satellite imagery allows the resolution of objects even on a scale of meters or less (e.g. SPOT 10 m, ICONOS 1 m). They provide information similar to standard aerial images and can often be interpreted without ground control. Providing views onto scenes of the 1960s, before much of the modern transformations took place², declassified CORONA imagery is used to study ancient sites in the Near Eastern landscapes³. Multi-spectral imagery, e.g. LANDSAT or ASTER data, are a standard tool in the classification of ground cover and soil types⁴ (Fig. 6). In the detection of settlement mounds they are potentially helpful to identify the often un-vegetated and eroding tell sites⁵. Investigation of tells from a three dimensional perspective is provided by digital elevation models (DEM) (Figs. 2, 3). At

²Intensified agricultural activities, but also increasing industry and transport lead also to the destruction of ancient sites and landscape features shaped in antiquity.

³Kennedy, *Declassified Satellite Photographs and Archaeology in the Middle East*.

⁴Fowler, *Satellite Remote Sensing and Archaeology*

⁵Altaweel, *The Use of ASTER Satellite Imagery in Archaeological Contexts*.

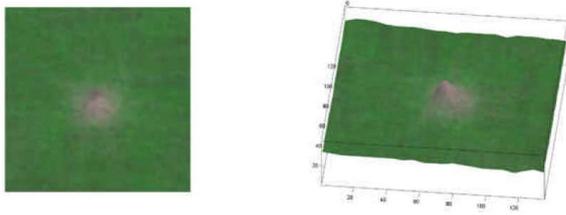


Figure 2: Average of the digital elevation model and of the LANDSAT Image of 133 tell sites from the Khabur. The majority of the tells is in direct vicinity to modern settlement which is visible from the bright central spot.

a resolution of 3-8 m, the stereo views of CORONA imagery also allow to generate highly resolved elevation models⁶, but only with considerable effort and within limited regions. The potential usefulness of data from the Shuttle Radar Topography Mission (SRTM) in the search for tells was identified shortly after the data were released⁷. With uniform coverage at a global basis and a high spatial resolution, it provides for the first time an opportunity to observe topographic phenomena at the scale of tell settlements: Representing well-defined anomalies in the flat lowland landscapes in which they are typically situated, these artificial mounds can easily be “spotted” in the DEM⁸.

A wide, supra-regional survey sets certain constraints on the data which is being used. First, the availability of the data is a relevant issue. While high resolution and complete coverage is so far only available from commercial suppliers, also the use of “low cost” data products, such as CORONA or ASTER, amounts to considerable sums, when a surveying wide regions is desired. Second, a high degree of automation in the routine work is required, to relieve the operator in the processing of voluminous data and to obtain a high objectivity and reproducibility in the analysis. It is also a basic necessity in

⁶Gheyle et al., Evaluating CORONA.

⁷Sherratt, Spotting Tells from Space.

⁸This elevation model also provides insights to landscape evolution in alluvial environments, which was recently discussed by C. Hritz and T.J. Wilkinson (Hritz and Wilkinson, Recognition of Ancient Irrigation Channels in Mesopotamia using digital terrain data.)

an complete analysis of complex information, i.e. high dimensional multi-spectral imagery. While a detailed spatial analysis of monochrome scenes still lies beyond the means of current image processing, methods for a machine-based evaluation of the (multi-) spectral information are readily available.

Consequently, in this stage of our survey we restrict ourselves to LANDSAT ETM+ and SRTM data. The favoured reliance of CORONA and ASTER data will be restricted to a regional case study, due to their limited availability, but also due to labour-intensive manual effort required in the registration of the CORONA images and heterogeneous data quality of raw ASTER data. Unfortunately, by itself, the spectral signature of known tells has so far proven too unspecific to serve as a diagnostic characteristic in an automated detection (e.g. Fig. 6). Thus, our search for tell sites is primarily based on the processing of the DEM data, only with the ancillary use of the satellite imagery and other geo-referenced information⁹. In the automation of this task, an algorithm for the evaluation of local elevation pattern has been tailored to the search of small conical mounds^{10 11}.

Automated Tell Detection

The SRTM data used in Menze et al.¹² is derived from a test area in the north of Mesopotamia (Figs. 1, 7)¹³. The upper Khabur catchment has a long settlement history, and witnessed the major expansion of nucleated settlements in the third millennium B.C., a region which is still in the focus of current research¹⁴. The basin is covered by six SRTM one-degree tiles (36 N to 38 N; 38 E to 41 E) at three arc-second resolution (90 m). As part of ongoing archaeological investigation of this region, 133 sites with an indication of settlement activity had been

⁹I.e. detailed military topographic charts where eye-catching features in the huge Mesopotamian plains are carefully mapped for orientation and tactical purposes offers a fertile source of additional material to be considered.

¹⁰Menze, Ur, and Sherratt, Detection of Ancient Settlement Mounds.

¹¹Menze, Kelm, and Hamprecht, From Eigenspots to Fisherspots.

¹²Menze, Ur, and Sherratt, Detection of Ancient Settlement Mounds.

¹³When implementing a machine-based search algorithm, a reliable ground truth is highly relevant both in the design of the algorithm (“training”) and the critical assessment of its performance (“test”).

¹⁴Ur, Urbanism and Society in the Third Millennium Upper Khabur Basin. Lawler, Archaeology: North Versus South, Mesopotamian Style.



Figure 3: Evidence for a tell from LANDSAT, topographic maps and the SRTM elevation model, shown is Tell el Bazari, as used in the definition of the training data set.

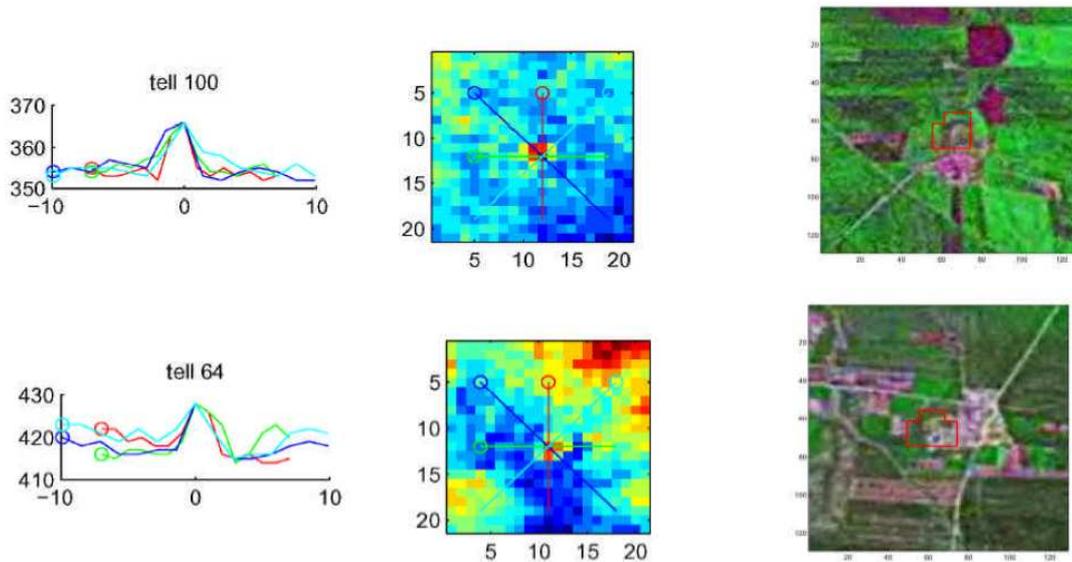


Figure 4: Principle of point detection. The characteristic height profile of a tell site generates a typical point-like pattern in the DEM. Under the resolution of the SRTM DEM, their elevation is often of nearly conical shape (height profiles left, as indicated in the DEM image patch, center). The sidelength of the DEM patches is approx. 2km, they also show the natural elevation pattern.

recorded within the tile 36 N, 38 E. The tell sites had been identified from CORONA images and several seasons of fieldwork associated with excavation projects¹⁵. These tells ranges from one to 60 ha in area and from less than 5 m to more than 50 m in height.

In order to keep this validated data as an independent test set in the comparison between archaeological ground survey and computer based DEM survey, a second data set was acquired for the training of the classification algorithm. For this purpose the remaining SRTM tiles of the Khabur were visually searched for presumed settlement mounds. By means of LANDSAT ETM+ images and topographic maps¹⁶ it proved possible to identify a further set of 184 settlement mounds¹⁷ (Fig. 3).

Within the DEM data, these mounds usually appear as small contrasting spots (Fig. 4). Although the geographic region under study is a relatively flat plain, natural variation of the land surface exists on different scales, ranging from slowly varying slopes to steep canyon walls (Fig. 1), a variation which is superimposed on the characteristic point-like pattern of the tells. Following techniques developed for face recognition (“eigenface” subspace filters with a subsequent nonlinear classifier), a classifier was trained from the second set of the 184 tells which discriminates between the typical spot pattern of a mound in the DEM and the variation in its background¹⁸. Applied to new data, the classification algorithm is able to provide ranked lists of positions with decreasing settlement mound probability.

On the SRTM test tile¹⁹, it was possible to detect 85 out of the 133 test sites at a threshold, which results in 327 false positives for the 600*1200 pixels of the test region (northern half of the test tile, Fig. 1); most of the undetected sites were lower than 5 to 6 m in the DEM (Fig. 5). False positives were mostly either due to natural elevations resembling tells in height and size, which occur frequently in the undulating slopes of Jabal Abd al-Aziz and Jabal Sinjar, or they were due to artefacts caused by the presence of water surfaces. Obviously the first of

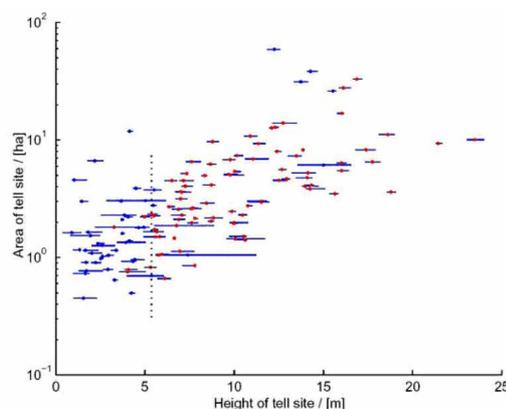


Figure 5: On the test set of 133 tells of the south-western Khabur basin, nearly all major sites higher than 6m can be detected (blue: missed, red: detected). Exceptions are due to “unusual” height/area ratios, which have not (yet) been learned from a training data set.

these error sources sets natural limits to the presented application. A subsequent tool allows to study these sites in detail and to register any available information: names and further evidence from the map, position in the DEM (and thus the height), extensions in the satellite imagery.

Virtual Survey

The developed algorithm is able to guide an investigator to elevations which are most probably tells with high sensitivity and specificity and under objective criteria. Nevertheless, other sources of (digital) information can be used to rule out obvious false positives and to increase the confidence in positions proposed by the classifier. Topographic maps and LANDSAT imagery are primary sources of this information. Topographic maps reveal typical place-names (i.e. “Tell”, “Tall”, “Tepe”, “Höyük”) or in some regions even indicate a settlement mound with an appropriate symbol. LANDSAT, but also commercial satellite imagery such as CORONA, Ikonos, Quickbird and Spot give a direct view onto sites and serve as the first component for their visual inspection²⁰, e.g. in the exclusion of natural elevations in mountainous areas or simply

¹⁵Ur, Settlement and Landscape in Northern Mesopotamia; Wilkinson, Archaeological Landscapes of the Near East.

¹⁶Soviet topographic maps, 1:100 000, U.C. Berkeley map collection.

¹⁷Menze, Ur and Sherratt, Detection of Ancient Settlement Mounds; Menze, Virtual Survey.

¹⁸Menze, Kelm, and Hamprecht, From Eigenspots to Fisherspots

¹⁹Menze, Ur and Sherratt, Detection of Ancient Settlement Mounds

²⁰Wilkinson, Archaeological Survey of the Tell Beydar Region.

to identify recent “tell-like” elevations (such as the piles of road-stones mentioned above). At a resolution which is more than five times higher than the one of the SRTM, and in conjunction with information from maps or based on the prior knowledge of the human operator, it also enables – to some degree – the detection of tell sites which are either too small to be seen in the DEM or which are missed by the algorithm, as they e.g. do not have the typical elevation pattern as a tell in the Khabur.

Technically the proposed “virtual survey” is organized as follows: The classifier marks positions which are above a predefined “tell mound probability” within an SRTM patch (Fig. 13). By means of comparison with maps and satellite imagery which cover the same area, a human expert is able to mark any of these positions which appear to him as probable tell sites. A software tool allows to study these sites in detail and to register any available information: names and further evidence from the map, position in the DEM (and thus the height), extensions in the satellite imagery. A final comparison against names and positions from the nearest known tell sites, as obtained from external data sets²¹, links the results of the virtual survey against real ground truth. Tell sites not yet documented in any of such data sets can then be further investigated, either by the purchase of high-resolution imagery, or in the field (Fig. 11).

3 Survey Results

Northern Mesopotamia

So far, 60 one-degree SRTM tiles in the region between 33 E and 48 E and 34 N and 39 N have been surveyed (Fig. 7), comprising the territory of south-eastern Turkey, parts of northern Syria and the Iraq, but also parts of the Lebanon and Iran. In all, 2148 probable tell-sites were recorded.

The *spatial distribution* of the recorded mounds shows a high degree of regularity (Figs. 7,9), a feature which can be observed both in the western and in the eastern region. A high number of the mounds lie on a hexagonal

²¹e.g. Hours, Atlas des sites du Proche Orient; Ur, Settlement and Landscape in Northern Mesopotamia, Rosenstock, Tells in Südwestasien und Südosteuropa; Lehmann Bibliographie der archäologischen Fundstellen und Surveys in Syrien und Libanon.

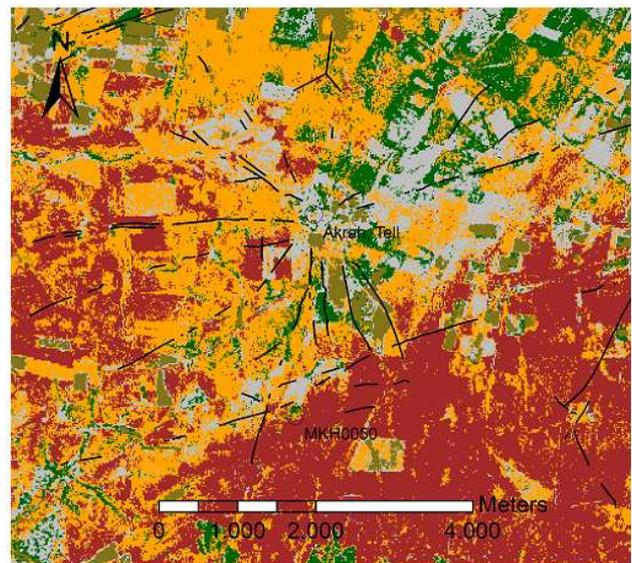


Figure 6: Supervised classification of multi-spectral ASTER imagery of Tell Akrah (21.5.2001). Grey areas are without plant cover, red and orange areas have a sparse vegetation (seasonal or permanent), dark green areas indicate wadis. The superimposed black lines show linear hollows from the visual inspection of the ASTER image.

grid as expected under “ideal” conditions. Alternatively, they line up along rivers or wadis. Such observations had been recognised earlier²² for other regions, but can now be studied in more quantitative terms.

To obtain the *height of a mound*, a plane was fit repeatedly to selected reference points in its surrounding. The elevation was assessed as the maximal difference between the surface of the mound and the plane. The accuracy of this procedure was in the range of metres, depending on the size of the mound and the topography of its environment²³. While some of the mounds reach considerable heights of more than 50m – even at DEM resolution²⁴ – small (or low) sites predominate in the distribution of the recorded mounds (Fig. 10), peaking little above the detec-

²²E.g. Adams, Nissen, The Uruk Countryside, 19, Fig. 8.

²³Menze, Ur and Sherratt, Detection of Ancient Settlement Mounds

²⁴Elevations in the SRTM are quantities averaged over nearly one hectare; therefore the base-to-top height of the mounds might be somewhat higher in reality.

tion limit²⁵) and (relative) vertical accuracy of the SRTM model of c. 5 m²⁶.

When resolving the height analysis to spatial subregions (Fig. 10), two tendencies can be observed: First, mounds at the “outward margin” of the fertile crescent, in the direct vicinity to the Antilebanon and the Tauros mountains, tend to be higher than mounds at the inward regions with less precipitation (Figs. 7, 8). Second, a decrease in the number of minor sites can be observed from east to west (Fig. 10). While a test for significant differences²⁷ reveals that the height distribution of sites above 10 m is identical in all three areas indicated in figure 7, the number of smaller mounds decreases significantly from east to west.

It is observed that rank-size-distributions of settlement systems (“Zipf’s law”) fulfill characteristic rules²⁸. When testing whether this relation also applies to the distribution of tell-settlement heights, it is observed (Fig. 10, right) that a strict linear relationship might hold on the upper tail of the distribution, but a linearity cannot be assumed on the full distribution of mound heights.

Summing the heights of all recorded “tell-like” mounds on a spatial grid, one might be tempted to interpret the resulting map as a proxy to tell-specific settlement activity (Fig. 8). However, turning a distribution of *characteristic mounds* into a map of verified *settlement mounds* remains the objective of further work. A detailed analysis of further satellite imagery is one way to obtain a more reliable assessment of a sites, which was pursued for an exemplary region in the south eastern part of our north Mesopotamian survey region.

²⁵Menze, Ur and Sherratt, Detection of Ancient Settlement Mounds

²⁶The distribution of the recorded heights can be approximated by a gamma distribution with shape parameter 2.70 (+/- 0.08) and rate 0.29 (+/-0.01).

²⁷Wilcoxon rank test at 0.01% level

²⁸Gabaix and Ioannides, The Evolution of City Size Distributions; Nitsch, Zipf zipped, also see references therein.

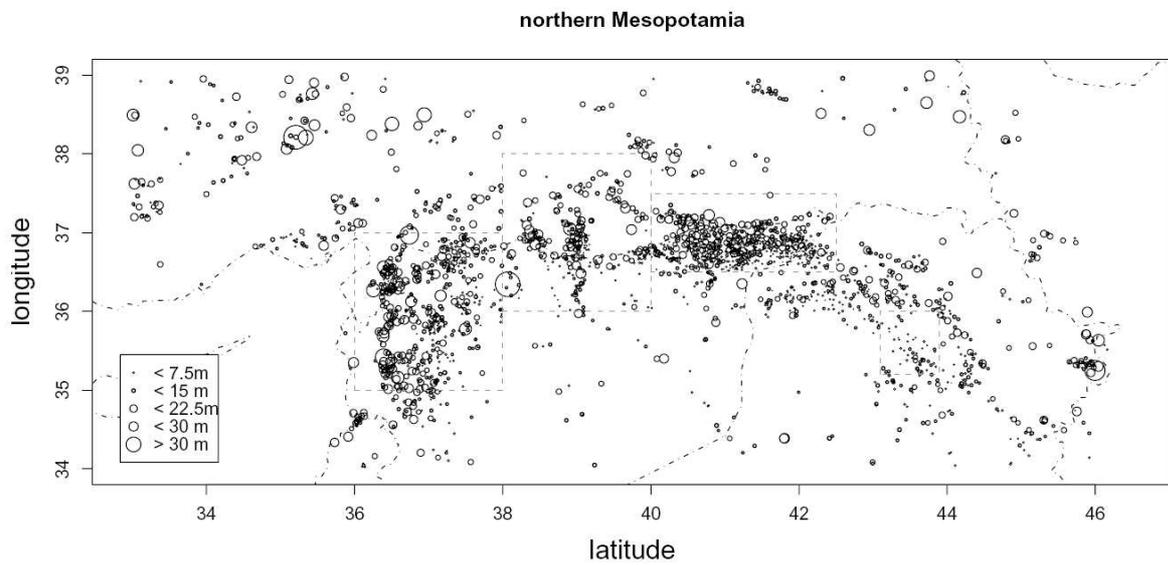


Figure 7: Detected sites in northern Mesopotamia, heights of the mounds indicated by circels. Coastlines and borders of modern territories of Turkey, Syria, the Lebanon, the Iraq and Iran are indicated. The three survey test regions (Fig. 9) and the region of the case study (Makhmur plain) are indicated by dashed gray boxes.

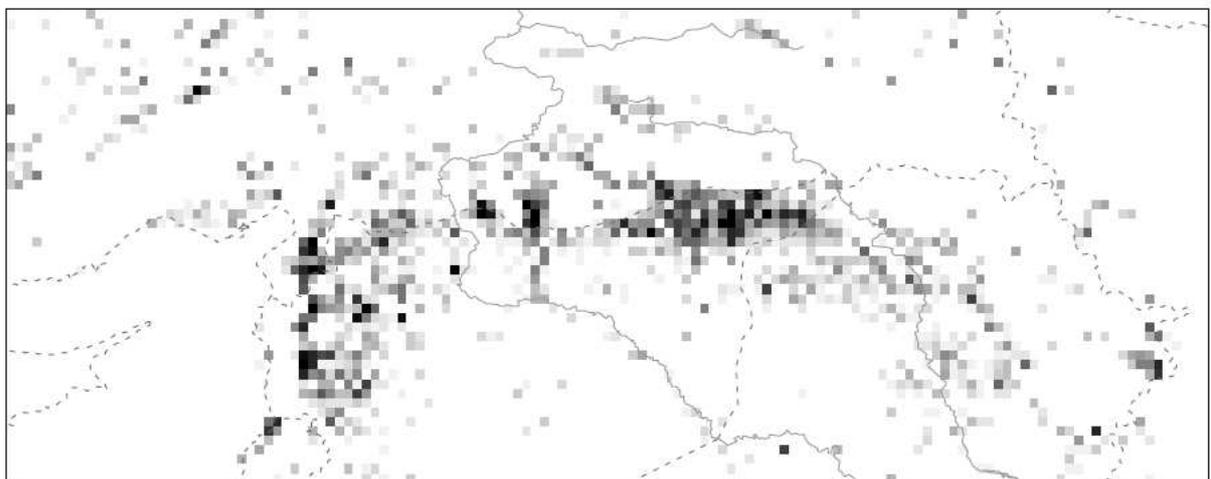
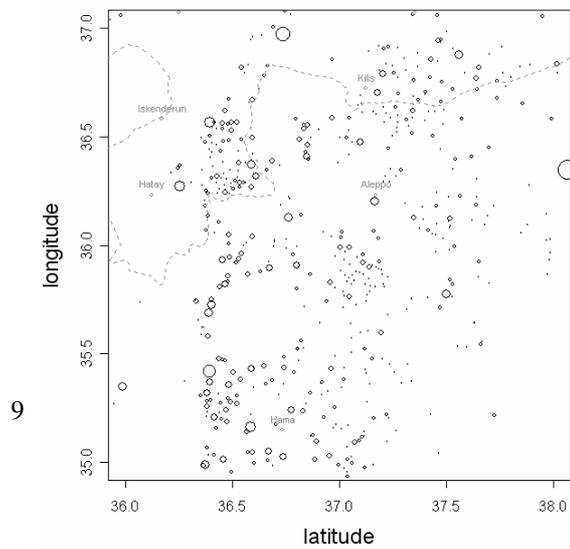
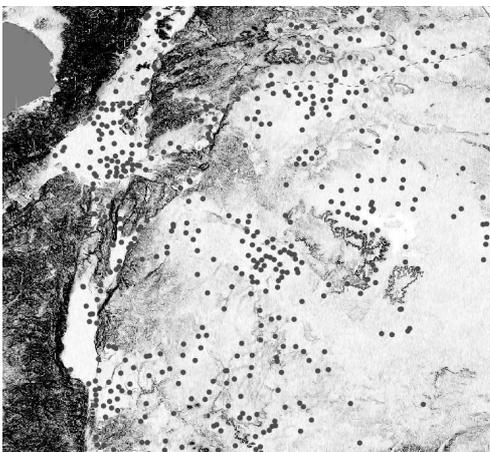
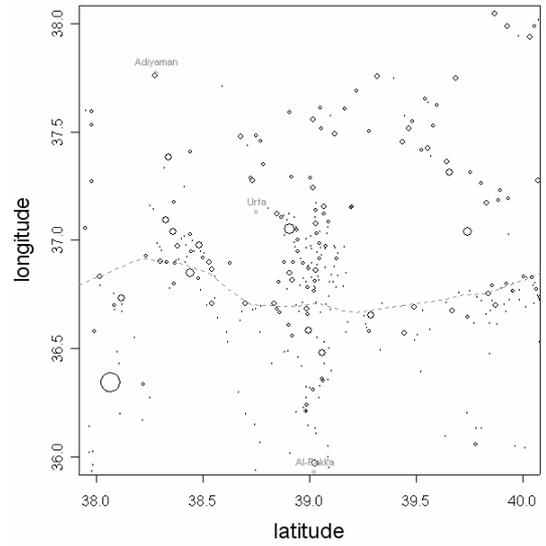
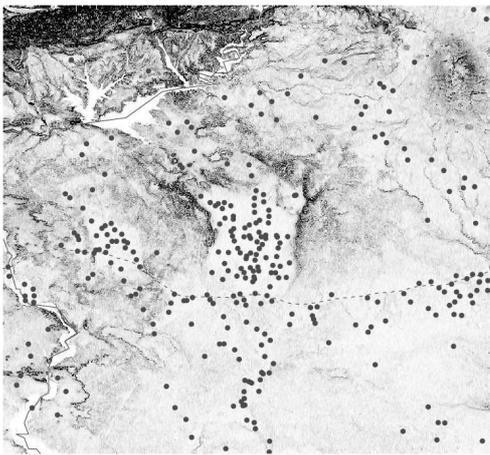
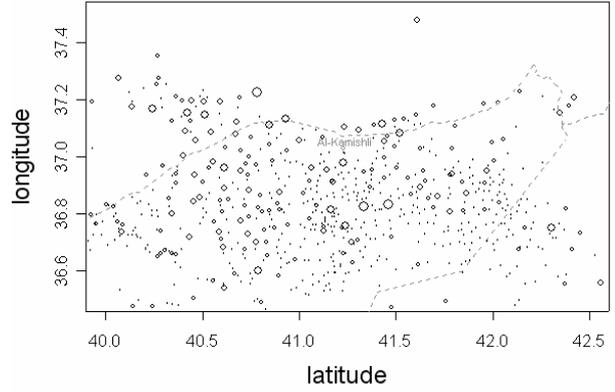
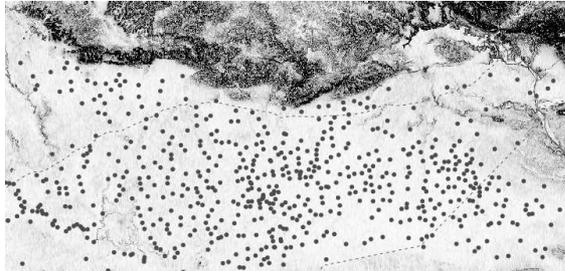


Figure 8: Cumulation over all heights of all recorded mounds within the area of the indicated pixels. Black pixels indicate a high number of mounds and / or the presence of high mounds. Compare to fig. 7.



9

Figure 9: Detected mounds in the eastern, central and western test regions (from top to bottom: Khabur, Galih, Antilebanon). Borders of modern territories, coastline and rivers are indicated, symbols as in fig. 7. Parts of the western Khabur plain also served as test bed in the design of the classifier.

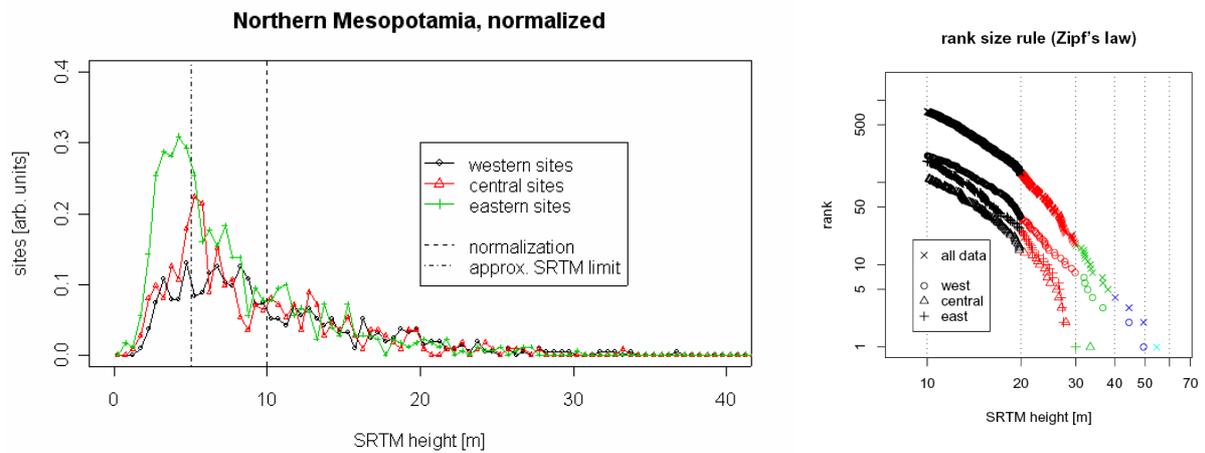


Figure 10: Left: Size distribution of the recorded mounds. While the distribution of mounds higher than 10m do not differ in the three test areas (disregarding a normalization constant), the eastern region (Khabur) is characterized by a high number of small mounds, which still are above the approximate SRTM detection limit of 5m. Right: Relationship between the height of a mound and its rank (log-log) within the whole distribution of sites (“Zipf’s law”); for all sites in northern Mesopotamia and in the three defined test regions of Fig. 9.

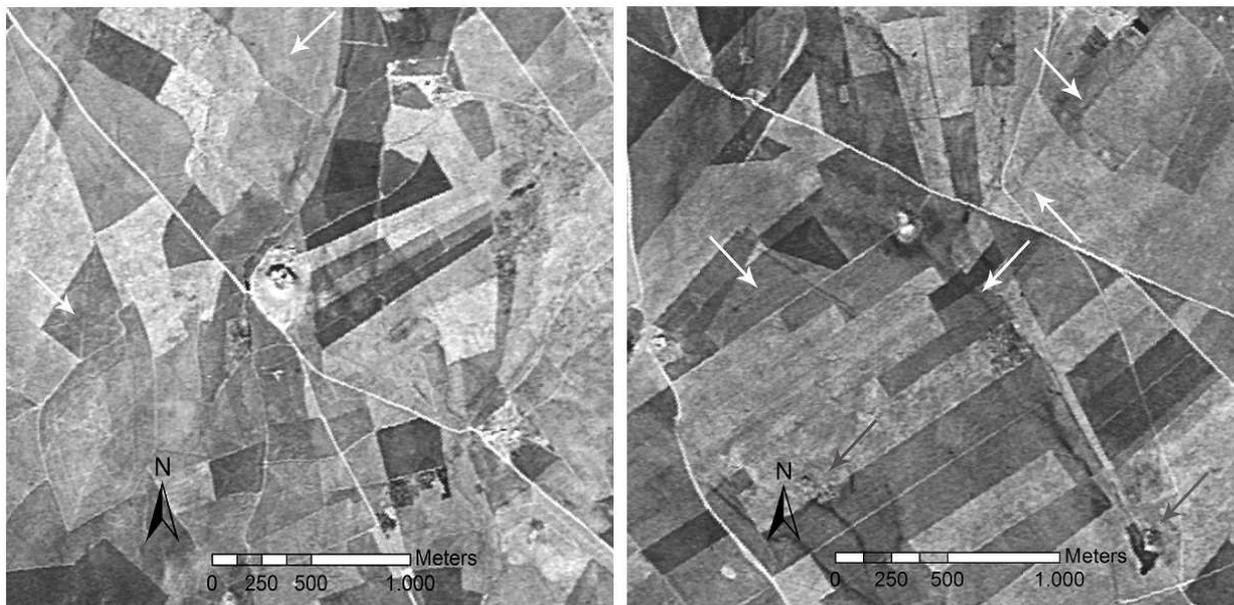


Figure 11: Radial hollows visible on CORONA imagery. Left: Tall Aswad (06.12.1969). Right: Tulul al-Nawwar (16.8.1968). Radial hollows are indicated by white arrows, grey arrows point to remains of smaller settlements.

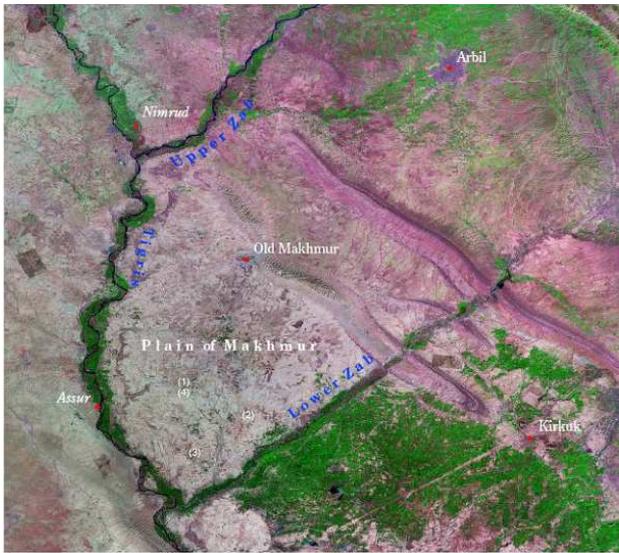


Figure 12: The Makhmur Plain; 1. Tall Akrah, 2. Tall Aswad, 3. Tulul al-Nawwar, 4. MKH0050.

4 Case Study

The Plain of Makhmur

In the case study we concentrated on the area east of Ashur, the first capital of the Assyrian state, cult centre and seat of the highest god of the Assyrian pantheon, Ashur. The plain of Makhmur is located in the triangle framed by the Upper Zab in the north, the Qara Chauq mountains in the west, the Lower Zab in the south and the river Tigris in the west, belonging to the heartland of the Assyrian state (Figs. 12, 7).

The region provides the interesting opportunity to show the relation between settlements, climate and dependence on the accessibility of water resources. The north-eastern part of this plain lies within the 200-250 mm precipitation belt, which forms the fluid border between the Fertile Crescent, where dry farming is possible²⁹, and the Syro-Arabian steppe, where the western part strongly depends

²⁹It is to keep in mind that these values underlie strong annual fluctuations (cf. Wirth, *Agrargeographie des Irak*, 19-20). Efficiency of dry farming in relation to socio-economic, political and environmental developments had been pointed out by Wilkinson (*Linear hollows in the Jazira, Upper Mesopotamia*, 549).

on irrigation with water from the river Tigris. Huge irrigation projects dating back to the Middle-Assyrian, Neo-Assyrian, Parthian/Sasanian, but also Early Islamic periods can still be traced on the ground and are clearly visible on satellite images (Fig. 14)³⁰.

Amazingly little is known about this area. Although anciently important routes directly linking major centres like Ashur, Arba'ilu (modern Arbil) or Arrapkha (modern Kirkuk) crossed the plain, only single sites had been investigated, most of them situated close to the Tigris³¹. Important work in the inland has been conducted by M.E.L. Mallowan and M. El-Amin who opened soundings at Kaula Kandal, Old Makhmur (Tall Ibrahim Bayis) and Tall Akrah showing the importance of this region³², but also by W. Bachmann who mapped and described sites he visited during his work at Ashur and Kar-Tukulti-Ninurta, posthumously published by R. Dittmann³³. A screening of the western part with remote sensing methods has been conducted by M. Altaweel³⁴. Due to this rather limited number of ground surveys, a "ground truth" in its classical meaning is hard to achieve. Fortunately, another possibility is offered by the remains of ancient routes and ways itself which are traceable by means of air photography, satellite imagery, respectively satellite photography, and to some degree on the ground³⁵.

Hollow ways or more descriptive linear swales are depressions in soft ground through prolonged usage for intersite and interregional traffic (Fig.11). Furthermore they also had been used for reaching the fields in the surroundings of a site, the closest sphere of activities³⁶. From

³⁰E.g. Altaweel, *Land of Ashur*, 108-120, 129-32; Wilkinson et al, *Landscape and Settlement in the Neo-Assyrian Empire*, 27-32.

³¹Like Tall Kushaf, Kar-Tukulti-Ninurta, Ashur or Tall al-Naml. The river and the area close to it is still a major route from north to south. Archaeologists and travellers of the 19th and early 20th century mainly focused on the huge capitals of the Neo-Assyrian Empire which flank the Tigris. The main route to Arbil and then to Kirkuk and Baghdad started in Mosul where Ninive could be visited along the way. So there was no incentive to cross the Makhmur Plain, which was partly deserted and pasture of nomadic tribes, and hard to cross (cf. Andrae, *Das wiedererstandene Assur*, 275; Wirth, *Agrargeographie des Irak*, map F).

³²Mallowan and El-Amin, *Soundings in the Makhmur Plain: Part I*, 145-153; *Soundings in the Makhmur Plain: Part II*, 55-68.

³³Dittmann, *Ruinenbeschreibungen der Machmur-Ebene aus dem Nachlass von Walter Bachmann*, 87-102, Fig. 1.

³⁴Altaweel, *The Land of Ashur*.

³⁵Ur, *CORONA Satellite Photography and Ancient Road Networks*, 104-106; Oates, *Studies in the Ancient History of Northern Iraq*, pl. 1a.

³⁶Wilkinson and Tucker, *Settlement Development in the North Jazira*,

the air these features are distinguishable from the soil by darker colour than the surrounding area. This is due to infillings of soil wash and continuous agricultural activity. Differences in vegetation³⁷, resulting from a drainage effect can also be recognised at wadis which are filled by plough wash (Figs. 6, 11). While on CORONA photographs they appear as lines distinguishable from the surrounding terrain by their dark colour³⁸, additional multi-spectral ASTER images can complete the picture as they visualize hollows which are just apparent in the near infrared spectrum (Fig. 14)³⁹. Ideally, these hollows allow to identify former settlement sites indirectly.

Especially radial hollows concentrating around central tell sites are interesting for verifying a tell-like mound in the DEM. Critical voices could argue that not every site or tell site shows linear hollows in its proximity. This might be due to “short term” occupation, lower population density and little agricultural activities (in comparison to the larger Bronze Age centres), soil erosion through recently intensified agriculture possible by making use of fuel pumps for intensified field irrigation, and of modern harvesting machines. However, this will primarily affect very small tell settlements and low mounded sites, not visible in the DEM, and the presence of linear hollows in the vicinity of tell-like elevations still remains a positive indicator of a settlement mound.

Mounds in the DEM

Compared to the upper Jazira, which is known for its high number of tell settlements, the concentration of sites visible in the DEM is relatively low. Most of them can either be found in the centre or in the southern part of the plain (Fig. 13). Some examples of those sites shall be discussed in the following.

Out of these, the biggest settlement mound (in the

Iraq; Wilkinson, *Linear hollows in the Jazira, Upper Mesopotamia*; for a brief introduction of the investigation and interpretation of hollow ways in the Near East see Ur, *CORONA Satellite Photography and Ancient Road Networks*, 102-104.

³⁷For example obvious differences in the heights of the natural cover or grain (see Oates *Studies in the Ancient History of Northern Iraq*, pl. 1a).

³⁸Ur, *CORONA Satellite Photography and Ancient Road Networks*, 106.

³⁹Altaweel, *The Use of ASTER Satellite Imagery in Archaeological Contexts*, 153-157.

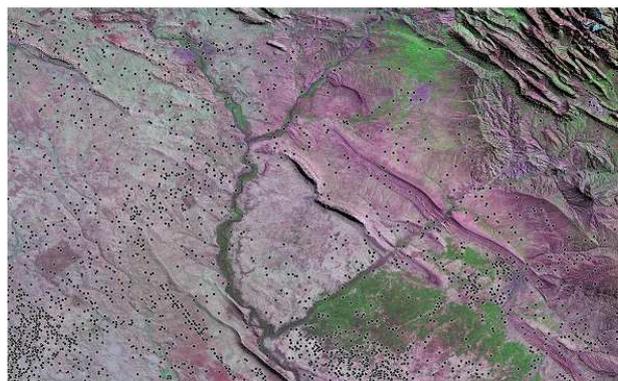


Figure 13: Positions of “tell like” mounds in the Makhmur plain, as detected by the classifier. Clearly visible are regions where the natural topography prohibits a search for settlement mounds in the DEM.

means of the height of its debris in relation to its probable outline⁴⁰) spotted by the classifier is Tall Akrah which is supposed to be the Old-Assyrian *Ekallatum*⁴¹ (Fig. 12 no. 1). On CORONA images, the radial hollow lines centred around Akrah (white arrows), are clearly visible, as well as a bigger hollow (black arrows) leading from the eastern bank of the Tigris opposite to Ashur straight to a col through the southern Qara Chauq in the east⁴². The circular shape of this site and its sharp slope within a plain terrain, features typical for tells in the upper Jazira, offers ideal conditions for the automated screening. Tall Aswad (Figs. 12 no. 2, 11 left), 16.5 km south east of Tall Akrah, is also characterised by its round shape and a hard slope. Just a few traces of radial hollows coming from north and from west are visible on CORONA images. Tulul al-Nawwar (Figs. 12 no. 3, 11 right) is a site consisting of two elevated spots. Four radially hollow lines are traceable. One coming from the south-east might

⁴⁰Altaweel, *Land of Ashur*, 164.

⁴¹Dittmann, *Ruinenbeschreibungen der Machmur-Ebene aus dem Nachlass von Walter Bachmann*, 100-102.

⁴²This longer distance road would strengthen the identification of Tall Akrah with Ekallatum which is known to have lain close to a royal road hūr šarri (Schoeder, *Keilschrifttexte aus Assur verschiedenen Inhalts*, VAT 9658 (+) VAT 9626: 9; Kataja and Whiting, *SAA XII 1:9*); to “royal roads” see Kessler, “Royal Roads” and other Questions of the Neo-Assyrian Communication System, 129-136; Altaweel, *The Roads of Ashur and Niniveh*, 222, 224-225.

links this site with another one which could have been occupied during a time span when al-Nawwar was also inhabited. Complex sites like MKH0050 (Figs. 12 no. 4, 15) consisting of a group of mounds which are positioned close to each other appearing as an unified elevated structure in the SRTM model. Nevertheless, this “unified” mound, as well as all mounds described above, were reliably detected in the DEM by the “tell spotting algorithm” and could easily be identified as tells when checking the proposed sites with maps and LANDSAT data.

A high number of false positive hits are present in the northern part of the Makhmur plain, in vicinity to Qara Chauq. Here the lower quality of the data, but also the natural topography which is dominated by distorting wadis (Fig. 13) yields a variation of the DEM which results in a high number of erroneously proposed sites, prohibiting a reliable analysis of results from the automated screening, although tell sites are known in this part of the Makhmur⁴³.

5 Discussion

The proposed survey on the SRTM model allows to record a high number of sites on a supra-regional scale. According to supplemental information of LANDSAT imagery and topographic maps, the detected sites are likely to represent artificial mounds of characteristic tell-like shape, most of them of rather moderate height and therefore representing minor sites. Mapping these mounds together with relevant physical parameters, such as height in the present step, spatial extension of the site in a next, represents the major contribution of the proposed “virtual survey”.

The survey has, so far, been applied to plains of northern Mesopotamia. Limits arise both from the natural topography and the data quality. While in the northern planes also a considerable number of mounds could be identified which do not surpass a height of 5 m in the DEM, but which stand clearly from the ground, the quality of the data deteriorated towards the south yielding a

⁴³For example Tell Kushaf at the estuary of the Upper Zab to the Tigris or Tell Ibrahim Bayis at the Husain al-Ghazi pass leading through the Qara Choq (Sarre and Herzfeld, *Archäologische Reise im Euphrat- und Tigris-Gebiet*, 210-212; El-Amin and Mallowan, *Soundings in the Makhmur Plain* 2, 55-60).

“rough” SRTM surface model, resulting in a high number of false positive hits. The presence of geologic features resembling settlement mounds in height and size (in the DEM) also limited the usefulness of the SRTM in some regions. As a result, our survey is so far limited to north Mesopotamian plains and adjacent landscapes, where the link between tell-like elevation and real settlement mound might be allowed with the highest probability.

Overall, decisions about a presence of a tell-like elevation remains subjective to some degree. Thus, a more systematic evaluation of other sources of information is indicated to ease this decision and to increase the quality of the maps of the recorded mounds. Beside the demonstrated usefulness of a detailed but time-consuming interpretation of CORONA imagery, it is the analysis of spectral data which, differently from mono-colour images, provides patterns which potentially are also interpretable in an automated, computer-assisted fashion. Although spectral imagery has proven to be an unreliable source in a rather global search over wide areas so far, it might yield valuable information on the local evaluation of a site in a further extension of the “virtual survey”.

A final ground truth can only be obtained by real ground control. Linking the recorded co-ordinates with known and published information remains the ultimate step to verifying the mounds and to obtaining a temporal dimension for distribution maps as in figures 7 and 8. However, the present results already allow the opportunity to further analysis, such as a study of the the spatial point pattern of the identified mounds or their correlation with other (geo-) physical parameters such as distance to river systems, precipitation, soil characteristics, to name just a few. The supra-regional data set resulting from the survey on the SRTM model might also serve as basis for either predictive⁴⁴ or generative⁴⁵ modeling approaches.

6 Conclusions

It has been demonstrated how the globally available SRTM elevation model can be used for archaeological re-

⁴⁴e.g. Brand, Groenewoudt and Kvamme. *An Experiment in Archaeological Site Location*; or: Mehrer and Wescott, *GIS and Archaeological Site Location Modeling*

⁴⁵Manrubia and Zanette, *Intermittency model for urban development*, and references therein.

mote sensing of wide areas. This considerably extends the current application of satellite imagery in restricted survey regions.

In general, we envisage a program of archaeological “virtual survey” for settlement mounds over a large part of the Near East, making use of a combination of automated and quantitative methods which are indispensable in a systematic screening of large amounts of complex data. The present work offers a methodology which increases our ability to screen for relevant sites, and to detect and evaluate rapidly and objectively any tell-sized mound within the SRTM elevation model. Further extensions of the survey to other parts of the Fertile Crescent not so far systematically subjected to ground-survey will incorporate new forms of analysis of multi-spectral data where necessary to overcome limitations associated with the particular topography and data quality of specific regions.

This ability to “virtually survey” tell sites over a huge geographical area provides unprecedented opportunities to uncover an enormous amount of information about the early history of human habitation in tell-building areas on a uniformly detailed scale. When calibrated chronologically it has the potential to tell us much about the formation and evolution of settlement patterns and the growth and reconfiguration of urban systems in a crucial part of the Old World.

Acknowledgement

BHM and SM gratefully acknowledge financial support by the MFG Steinbuch award. We thank Paul Yule, Susan Sherratt and Peter Miglus for valuable comments.

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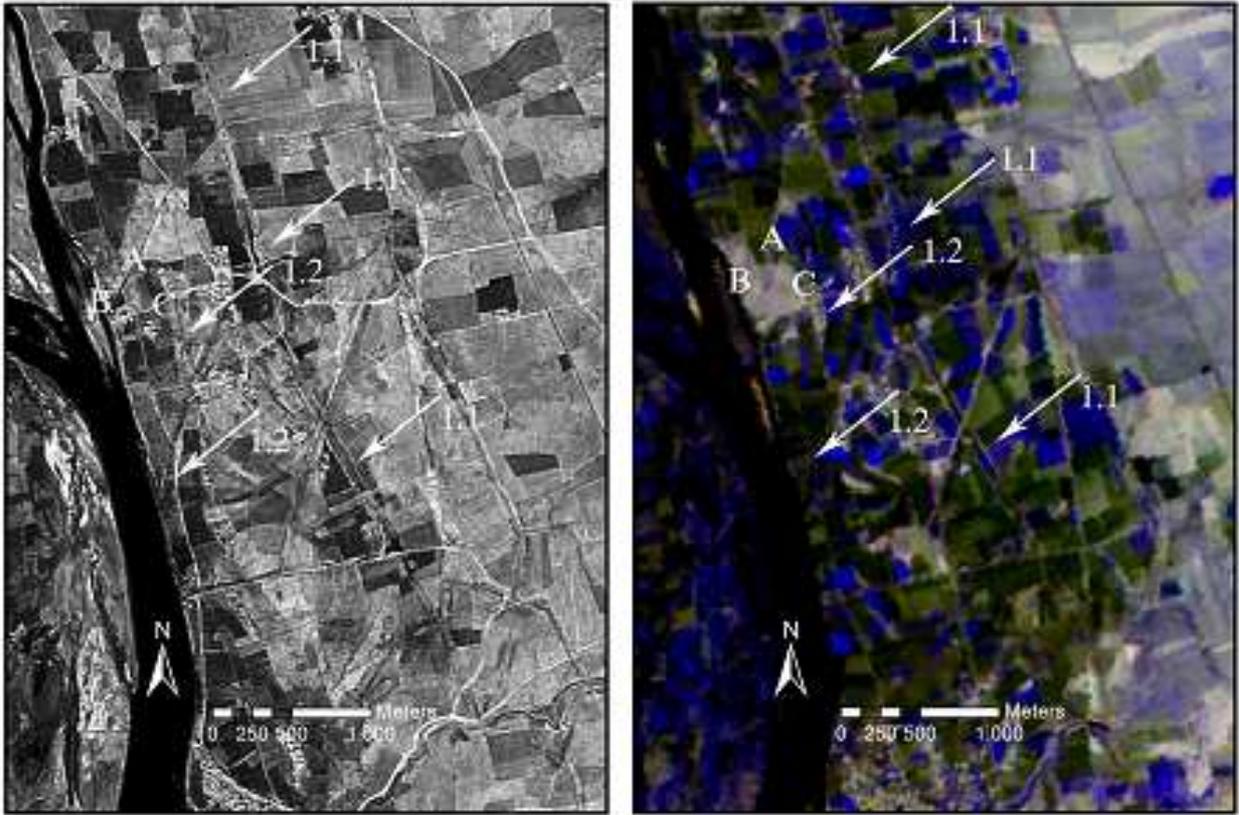


Figure 14: Western part of the Makhmur plain. 1.1: Main branch of the Middle-Assyrian pattu meshari (cf. Bagg, *Assyrische Wasserbauten*, 41-43.); 1.2: Off-take of the pattu meshari flowing through the northern part of Kar-Tukulti-Ninurta and draining to the Tigris in the south; letters are indicating architectural features (left: CORONA, 16.8.1968; right: ASTER 05.3.2002).

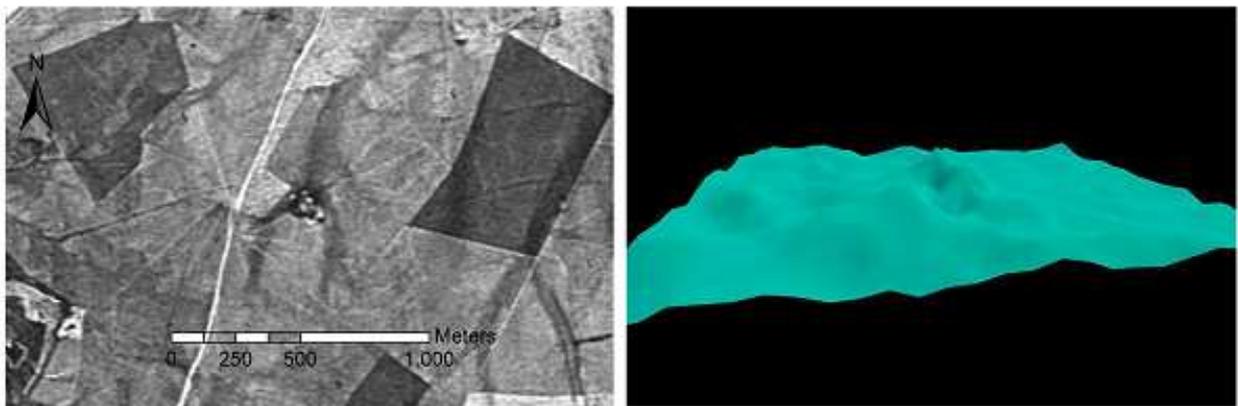


Figure 15: The site MKH0050 south of Tall Akrah. Hollow ways are clearly visible on the CORONA photograph (on the left; 16.8.1968) while the tell's physical features are visible on exaggerated SRTM (on the right).

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