A Remote Sensing Approach for Exploring Ancient Traffic

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Abstract

Ancient landscapes of movement are challenging to conceptualize. Moving agents did not leave much material evidence behind other than their continuous use of pathways and roadways –unless the road was intentionally built. Under special morphological conditions, this repetitive practice carved the landscape in such a way that the proof of past movements survived until today. In one of these cases, the Early Bronze Age road network in Upper Mesopotamia provides ample evidence for a reconstruction of landscapes of movement. In realization of this opportunity, this study aims to explore ancient traffic through satellite remote sensing. Particularly, the study pushes the agenda for not only mapping the road network, but also understanding the volume of traffic. To accomplish this, the methodology relies on Normalized Difference Vegetation Index (NDVI) data for the investigation of the relationship between soil compaction and vegetation health. It is hypothesized that variations in the ancient traffic differentially changed soil physical characteristics so that past variation is still detectable in modern environmental data, albeit only through the study of proxy variables. Comparison of NDVI values over the Early Bronze Age roads suggests differential use. Results of the study also open a new research avenue for studying the morphology of ancient roads with the same proxy data.

1. INTRODUCTION

Ancient roads reflect motivations and needs behind social, economic, political and religious relations of past societies; paths of movement imposed order on agricultural production [1], facilitated trade [2], enabled transportation of bulk-goods [3], mediated hegemonic power [4], provided social integration [5], and shaped military strategies [6]. Furthermore, everyday actions of individuals contributed to the formation of roads, and in return, roads sustained individual (and societal) relations. Due to the historicity of these relations, roads can be regarded as unique despite the fact that they are (cross-culturally) linear anthropogenic features. This proposed uniqueness should be the most visible for the volume of movement; two morphologically similar roads might have carried different traffic due to the agent variations creating that traffic. Therefore, considered not only as the container of action (i.e. the 2D layout of a road system), but the action itself (i.e. the traffic), ancient road has much more to say.

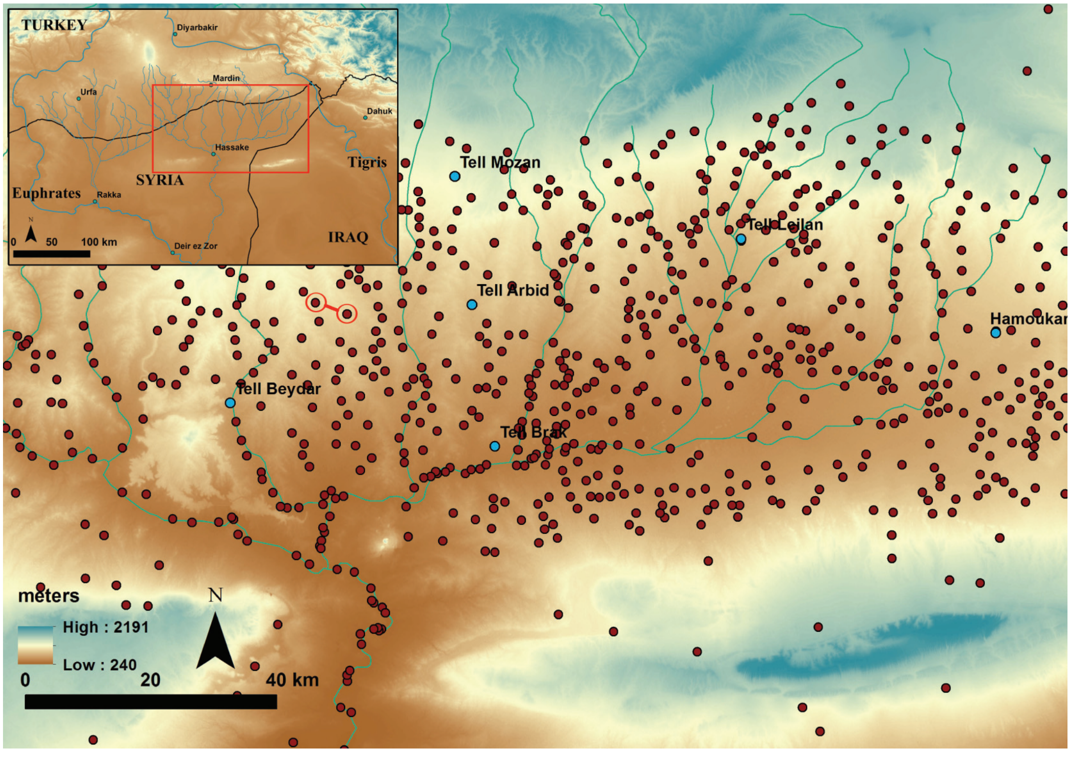
This paper investigates Early Bronze Age (Third Millennium BCE) road systems in Khabur Basin, Upper Mesopotamia. At this space-time continuum, the movement praxis embedded within the agricultural and pastoral economies as well as the socio-political life significantly contributed to the formation of hollow ways. In pursuit of this phenomenon, the methodology follows a satellite remote sensing approach to model Early Bronze Age traffic variations. Thus, the study aims to surpass the current archaeological knowledge on locations and dimensions of roads -the container-, and builds an analytical framework for the ancient traffic -the action-.

1.1 Study Area

Upper Mesopotamia is the vast area between the banks of the Tigris River in the east and the Euphrates River in the west. To the north, it is bounded by high altitude Taurus-Zagros Mountains. To the south, the desert conditions forms an impermeable boundary where precipitation levels critically drop under 200-300mm/year. Other than large ancient settlement mounds and two major anticlines, called Jebel Sinjar (920 meters) and Jebel Abd al-Aziz (1480 meters), there are no significantly obtrusive features in the physical landscape. Basaltic plateaus in the area (Ur and Wilkinson 2008) are only slight modifications in the gentle geomorphology.

Khabur River, which is the main tributary of the Euphrates, forms the basin. North-south aligning valleys drain to the basin. Although irrigation projects altered the hydrological landscape, flow levels are still determined by the amount of precipitation. Khabur is also the area in which significant developments of Early Bronze Age manifested themselves the most; mainly the rapid urbanization period and intensification of agricultural production. Khabur Basin is dotted with ancient mounds, all of which were possibly occupied during Early Bronze Age at some point of their habitation histories. Considering the large number of settlements in the area the study focuses on only two of these settlements and investigates ancient traffic in detail (Fig.1.).

Figure 1. Distribution of EBA settlement mounds in Khabur Basin, Upper Mesopotamia Two of these mounds (in red circles) are further investigated for their traffic levels.



1.2 Archaeological Background and Previous Work

In Upper Mesopotamia, roads — also called hollow ways [7] or roadways [8] are linear depressed features, running across the landscape. They are usually hard to detect on the ground [9], but aerial [10] and satellite imagery [11] provide significant opportunities to document the remnants of ancient movement.

Upper Mesopotamia preserves evidence of past mobility in significant clarity since land-use has shifted only between sedentary agriculture and pastoral nomadism [8]. This minimized the damage in archaeological record due to low level land-use intensity. Only in recent times, irrigation agriculture, power dams, and other large-scale state projects have started to change archaeological landscapes drastically. Therefore, Upper Mesopotamia is a region where the evolution of road systems can be studied in the archaeological record in great detail. Furthermore, relatively flat topography of the area suggests that the environment imposed little constraints on the formation of roads and it was the politico-economic landscape, but not the physical landscape provided prime determinants of the location, direction, and the volume of traffic.

Hollow ways were formed over a considerable span of time [9]. In Iraqi Jazira, investigating settlement patterns in relation to hollow ways suggest that ancient road systems were most probably in use as early as the 4th millennium BCE (ibid.). The alignment of the Third and early Second Millennium sites along hollow ways provides temporal information for their use. Later on, (e.g. Neo-Assyrian, Sassanian and Islamic times) new hollow ways were formed and/or existing ones were reutilized.

Despite the complexity in dating hollow ways, it has been widely suggested that most of the road network -as apparent today- was part of the Early Bronze Age sociopolitical and economic system [8], (also see Casana [12]). Especially, radial hollow ways emanating from tell-based nucleated sites are securely dated to the Early Bronze Age [7]. Ur [11] also suggests only a small portion of roads can be dated to Antique or Early Islamic periods as these later systems were usually narrower and more focalized (i.e. structurally different) in comparison to wide Early Bronze Age hollow way system.

One can further refine the dates for hollow ways. Urban Early Bronze Age populations, concentrated in tell settlements must have had the capacity to provide the necessary volume which generated broad hollow ways. In earlier and later times, settlements were morphologically more dispersed on the landscape, forming complex low mounds [9,13]. Such settlement typology is less likely to be responsible for the formation of deep hollow ways. Likewise, flat settlements dominated occupational styles in Roman and Islamic times [14]. So, it can be suggested that later settlements had lower population densities per unit area, and thus, were limited in the ability to concentrate and funnel movement. Without a significant volume of traffic no such hollow way could have been formed [15]. Therefore, it seems plausible to hypothesize that hollow ways were mainly in use during urbanized mid-to-late Early Bronze Age.

First documented by Poidebard and later examined by van Liere and Lauffray, studies on these linear features stayed in dormant state up until Wilkinson's work where he identifies these features as the remnants of a system of ancient roadways. He also immediately realizes the importance of the mechanics behind the formation of hollow ways and explores movement with hypothetical volumes of traffic flow. Later, Wilkinson expands his study to relate hollow ways with the economic structure of Early Bronze Age states.

Since then only a handful of studies further investigate hollow ways from a remote sensing, geoarchaeological, and archaeological perspectives. These studies altogether provide a strong case for the significance of hollow ways in the making of everyday life. But, no research exists to date (other than Wilkinson's pioneering work) which dwells into the making of the roads; the traffic flow itself.

1.3 Classification of Hollow Ways

Initial observations on Early Bronze Age hollow ways suggest that they were morphologically and spatially diverse [9], [11], [15], [16]. This is not to say ancient roads had mutually exclusive functions, but rather they were intertwining and multifaceted [17]. For a morphological classification, Ur [8] observes hollow ways as wide as 100 meters and as deep as 2 meters. He also notes their lengths ranging from a hundred meters to more than 5 kilometers. Wilkinson and Tucker [9] report the widest hollow way is to be around 200 meters. The average depth is 1.0 meter while they can be (but rarely) as deep as 4 meters.

The main topological separation remains in between radial and long-distance systems [9]. Radial hollow ways emanate from an Early Bronze Age settlement and can reach ~3 kilometers in length. Wilkinson [18] suggests that radial hollow ways were used for controlled transportation of flocks from settlements to open pasture land. While moving, livestock were kept in groups to minimize crop damage and when the agricultural production boundary was passed, flocks were dispersed in the open land. As a result of continuous use by animals and humans, linear depressions around settlements were formed and the evidence for ancient movement still survives today [11].

Inner-regional routes connect settlements together and reveal evidence of local settlement connectivity. In some cases, they also appear as parts of a larger movement network. These inter-regional routes cut the landscape in long distances and highlight a different mode of transportation. For instance, in Syrian Jazira there is evidence for the exchange of luxury goods and animals and visits by the city representatives between important centers of the plain [24]. Epigraphical evidence also suggests that rulers, established themselves in larger settlements were visiting smaller towns [25].

Some scholars argue that a hollow way is the result of a hydro-compaction process where the rupturing of fine soil material initiates the formation of shallow gully [19]. Others argue that these depressions were components of man-made drainage systems [20]. However, geoarchaeological [21], environmental [22], and landscape studies [23] in Upper Mesopotamia suggests that these radial route systems were indeed the artifacts of past movement.

2. METHODOLOGY

The methodology involves mapping hollow ways and exploring productivity levels along hollow ways as proxy information for the variations in the volume of ancient movement. In the first part, CORONA imagery is used to document hollow ways and to create an initial inventory of a road system, belonging to two Early Bronze Age settlement mounds. In the second part, documented hollow ways are investigated for their soil structure in relation to crop productivity; proposed model axiomatizes that variations in the volumes of ancient movement resulted in quantifiable differences in soil composition, texture, hydrological characteristics, and thermal capacities of soil. And, the effects of ancient movement are still reflected on modern soils of Upper Mesopotamia. In this paper, the focus is solely on investigating metrics for exploring variations in crop health and density of green area.

Soil physical and chemical properties form a truly complex natural phenomenon. These properties are spatially correlated and modeling the response of soil variables is a demanding task. Due to this complexity, large-scale investigations are usually reductionist and are based on physical theories when empirical data is scarce or collection of such data is infeasible. Let alone the study area (located in modern day Syria) is not open to researchers due to current political instability. Therefore, there is a need for developing an innovative remote sensing methodology.

Variation in modern crop productivity due to ancient soil compaction is the variable in the model; soil compaction inversely affects crop productivity. A remote sensing product which is called vegetation index (VI) is used to study productivity, and in return, should provide information on soil compaction. Ratio of vegetation indices which are calculated for hollow way soils and adjacent "non-traffic" soil matrix is considered as a proxy for the volume of ancient movement: lower index values (less healthy vegetation) on hollow ways indicate more compaction, and thus, higher volume of movement.

2.1 Mapping Hollow Ways

The CORONA spy-satellite system was developed as part of the US intelligence program in the Cold War era [26]. In this time period, a large number of CORONA missions were run with different camera characteristics. Due to its high spatial resolution, temporal coverage, and stereoscopic capability, CORONA images are widely used in archaeological studies of the Middle East (e.g. [27], [28], [29], and [30]).

CORONA images were obtained before massive scale constructions, industrial agriculture, and urban expansion in the Middle East. Considering the problems in obtaining historic aerial photographs in the Middle East, the value of high resolution CORONA imagery as a snapshot of the study area before landscape transformations is beyond doubt. Furthermore, large spatial coverage enables researchers to document past landscape at a wider scale. CORONA also offers high temporal resolution. Areas of Upper Mesopotamia were usually visited by more than one CORONA mission at different times of year. Since the visibility of archaeological features depends on geographic, geological as well as local weather conditions, multiple images from different dates increase the detection probability of archaeological features.

In Upper Mesopotamia, ancient settlements and their road networks appear on CORONA imagery in exclusive forms (Fig.2.). Remnants of the hollow ways have differential water retention capabilities. Drainage at the edges of hollow ways is more when compared against the centers of hollow ways, and thus, they appear in bright colors due to high reflectivity while the center portions appear in darker forms [11]. Furthermore, hollow ways are usually elongated, and they are differentiated from other natural phenomenon, such as wadis and relic river beds. In other words, hollow ways have a unique spatial-spectral combination which raises the potential for employing feature detection on CORONA images.

For mapping purposes, two EBA sites are selected. The main road network is composed of hollow ways emanating from these two settlements (Fig. 2, white arrows). Conforming to previous studies, these radial hollow ways have an average length of 2.5 km. A single hollow way is also located connecting these two settlements together, completing the road network (Fig. 2, red arrow). In total, ~30km of

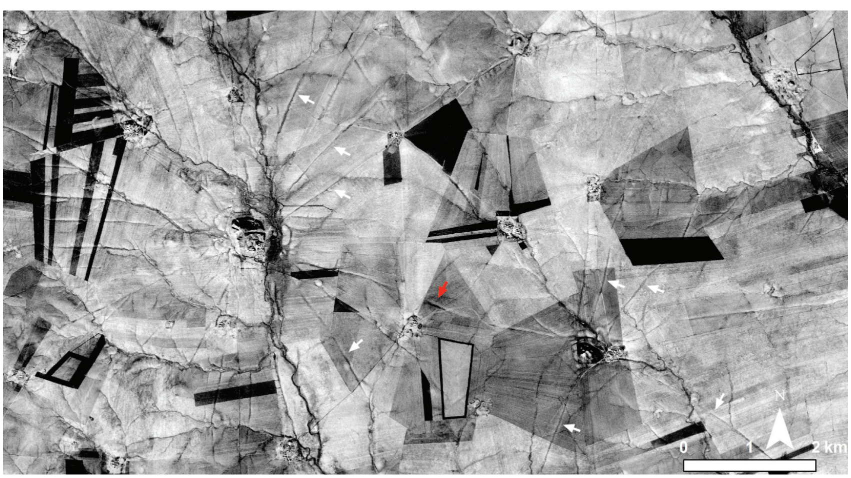


Figure 2. Hollow ways radiating from settlement mounds are clearly visible on CORONA imagery (white arrows). Another route is detected in between these two settlements connecting one another (red arrow)

hollow ways are mapped and prepared for the vegetation index analysis.

2.2 Modern Proxies for Ancient Movement: Vegetation Indices for Soil Compaction

Studying vegetation spectral characteristics in order to determine vegetation type and other biophysical properties is one of the main focus areas of remote sensing. Vegetation health, growing conditions, and the amount of vegetation biomass can be modeled by exploring the electromagnetic spectrum [31]. Vegetation characteristics and the ways in which these characteristics are reflected on the electromagnetic spectrum are variable. Optimum conditions for measuring vegetation properties via satellite sensors is distorted if vegetation is planted at different times in their growth cycles, which results in variations at canopy level. Also, even if the biological structure of the biomass is compatible in a given area, different crop management strategies, such as weed control, row spacing and field orientation have an impact on the relations between the vegetation and how it is detected on the sensor [32]. In order to normalize for external factors and to maximize sensitivity to plant biophysical parameters, a set of vegetation indices are used in the remote sensing.

A vegetation index may be considered as a proxy for buried archaeological features. Ancient ditches, pits, or canals may get filled with topsoil and they retain more water than the surrounding matrix. As a result vegetation growing on these features becomes healthier than other vegetation around. In a similar fashion, walls, burials or floors may reduce soil nutrients and decrease water retention capabilities. It is very likely that the vegetation growing on these features will be less healthy. Therefore, by measuring green material characteristics vegetation indices indirectly provide information on the location, size, and type of an archaeological anomaly.

Hollow ways are filled with sediments or were cut through runoff [8]. These transformations create variances in vegetation growth. Specifically, in the spring soil on hollow ways can have more abundant crops. Furthermore, during the summer and fall months a green steppe weed, generally called Prosopis, grows disproportionately on these ancient features [21]. These variations are –hypothetically- detectable on satellite data by using vegetation index datasets.

The methodology considers these variations in modern crop production due to ancient soil compaction [33,34]. Thus, vegetation indices measuring modern crop conditions have the potential to inform about the levels of past compaction. In this regard, the variation in "health levels" of modern crops is a proxy for ancient traffic volumes.

There is a plethora of vegetation indices used in remote sensing studies. These indices include, but not limited to EVI (Enhanced Vegetation Index), NDVI (Normalized Difference Vegetation Index), TSAVI (Transformed Soil Adjusted Vegetation Index), and SARVI (Soil and Atmospherically Resistant Vegetation Index). In this paper, the methodology relies on the NDVI as it is the most commonly exploited index; yet emerging studies also suggest the potential use of other indices as well [35].

2.3 NDVI Datasets

In order to generate NDVI values, Landsat 7 ETM+ is employed. The sensor provides multispectral data at 30 meters spatial resolution. The choice of ETM+ is due to two main reasons. First, the data is available to researchers at no cost while providing extensive global coverage. Second, it has a wide temporal depth, making frequent visits to areas of interests since 1999. This historicity is of immense importance since it provides NDVI users with the opportunities for matching satellite remote sensing data with high temporal resolution precipitation values; an important variable for the detection (un)healthy vegetation growth. In lieu of this relationship, time-series data from weather stations in the Khabur Basin are generated for the years between 1999 and 2003. The time series was cut for the years after 2003 since a system failure in late May 2003 makes the use of ETM+ data a challenging task. In consideration of the precipitation values, Landsat data is acquired for the peak vegetation growth month (May) to observe vegetation under stress in 2000 (ID: LE71710342000137SGS00) and under the abundance of rain in 2003 (ID: LE71710342003129EDC01).

In the next step, 8bit digital numbers are transformed into reflectance values, using metadata accompanied to each Landsat scene. First, the transformation involves conversion from digital numbers to radiance, using:

$$L_\lambda = (Gain_\lambda * DN_\lambda) + Bias_\lambda$$

where L_λ is the radiance of the band λ, $Gain_\lambda$ is the band specific gain, and $Bias_\lambda$ is the band specific bias. The conversion from radiance to reflectance is through:

$$R_\lambda = [\pi * L_\lambda * d^2] / [E_{sun,\lambda} * \sin(\theta_{SE})]$$

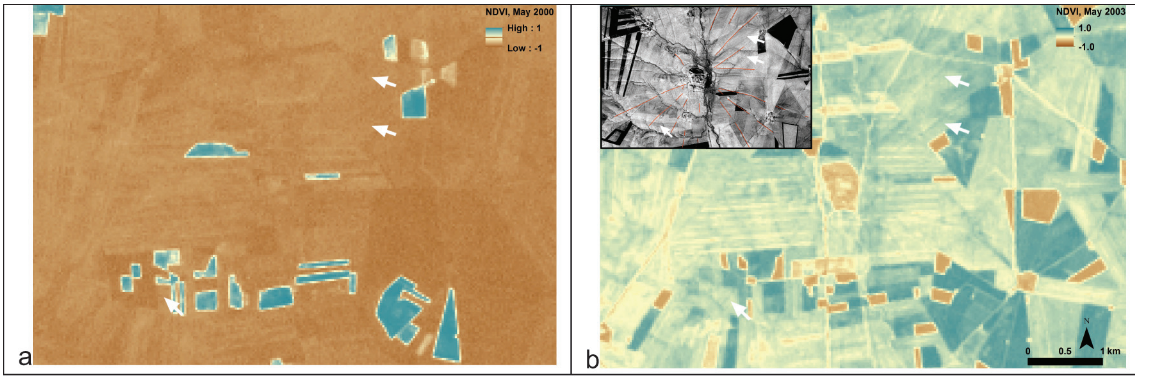
where R_λ is the reflectance of the band λ, d is the earth to sun distance in astronomical unit, $E_{sun,\lambda}$ is the band specific radiance, and θ_{SE} is the solar elevation angle. NDVI values are obtained after:

$$NDVI = (R_{\lambda,4} - R_{\lambda,3}) / (R_{\lambda,4} + R_{\lambda,3})$$

where $R_{\lambda,4}$ is the near infrared band of Landsat ETM+ and $R_{\lambda,3}$ is the red band.

Two NDVI datasets from low precipitation May, 2000 and high precipitation May, 2003 season reveals drastic differences (Fig.3.). Hollow ways are hardly visible in the NDVI2000 dataset. It appears as the agricultural production was at minimum levels and green material was concentrated in areas where irrigation was practiced. On the contrary, NDVI2003 provide ample evidence for the location and size of hollow ways, despite the fact that Landsat ETM+ has coarser resolution (30m) in comparison to CORONA imagery (~1.8m at nadir). Therefore, 2003 data has the potential to further evaluate Early Bronze Age traffic and exploration is focused solely on this date.

Figure 3. A comparison of NDVI results for the study area (a) Year 2000 (b) Year 2003. Due to low precipitation levels in 2000, rain-fed agricultural production was ceased, greatly reducing the visibility of existing hollow ways.



2.4 Data Explorations

After the selection of the appropriate NDVI dataset, the next step is to explore manifestations of hollow ways for their NDVI values. To accomplish this, 12 main hollow way chunks at the eastern road network is thoroughly investigated using transects which are running orthogonal to the roads at each 20 meters (Fig.4.). Transects are 300 meters long, leaving equal distance (i.e. 150 meters) on either side of hollow ways. Considering the previously reported dimensions of Early Bronze Age road systems, the selected transect length is long enough to fully cover hollow ways while leaving extra space for the comparison of "trafficked" and "non-trafficked" soils. The length of transects, moreover, compensate for the spatial and resolution mismatching between CORONA image and Landsat data.

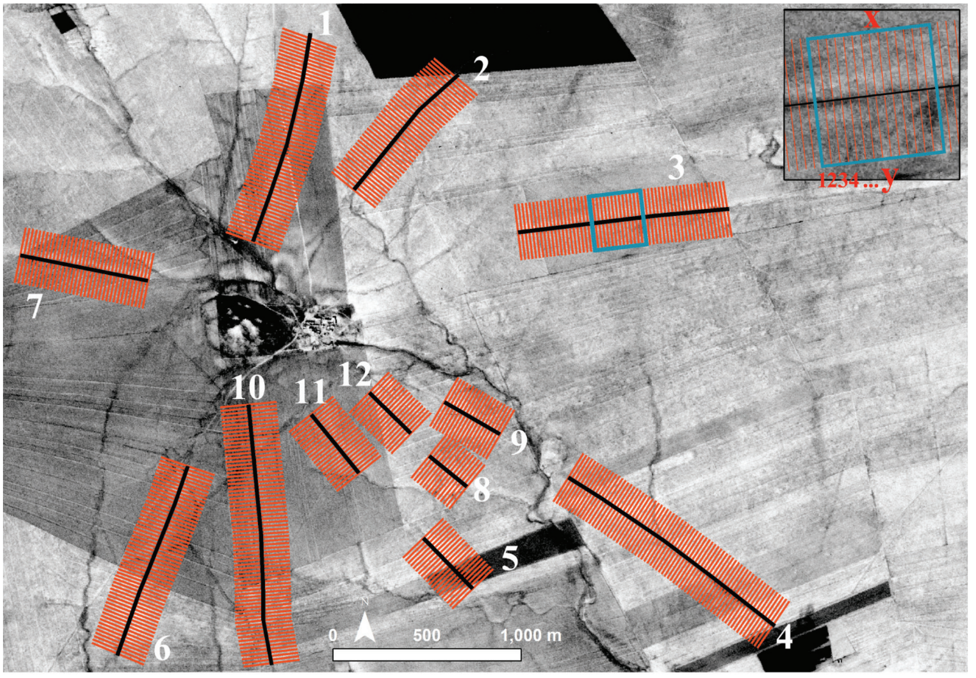


Figure 4. Transects overlaid on hollow ways in order to extract NDVI profiles running the road network orthogonally.

To initialize the process, NDVI data with 30 meters resolution (after vectorization) is imported to Matlab 2014b environment in order to perform interpolation on grid data. An interpolated NDVI value is extracted for every meter on each transect so that profiles become easier to decipher. To evaluate the process, a sample of 15 transects (Fig.4. blue box) are treated with the workflow described above. Next, profiles are visually investigated for possible patterning of transect data.

The sample transect set reveals a broad range of profiles (Table 1). Considering the age of hollow ways, such wide variance is expected due to ever-going taphonomic processes, yet some patterning still exist. The general tendency for NDVI values around 150 meter mark is to be lower in comparison to immediate environs; in some profiles (#2, #3, #4) more significant than others (#11, #12, #13). This observation comes as a support for soil compaction due to ancient traffic lowers the productivity of soils accumulating over. Of particular interest is the NDVI peak around 150meters mark which represents the center of hollow ways as mapped on CORONA images. This peak suggests relatively healthier vegetation along the mid-point of hollow ways, as discussed before. It is highly possible that topsoil from immediate vicinities of hollow ways accumulated in these areas, making the soil more productive while also collecting drainage due its morphology. This comes in the expanse of lowering the nutritional and humidity content of soils immediately around (#3, #4, #5, #6, #7, and #8 for

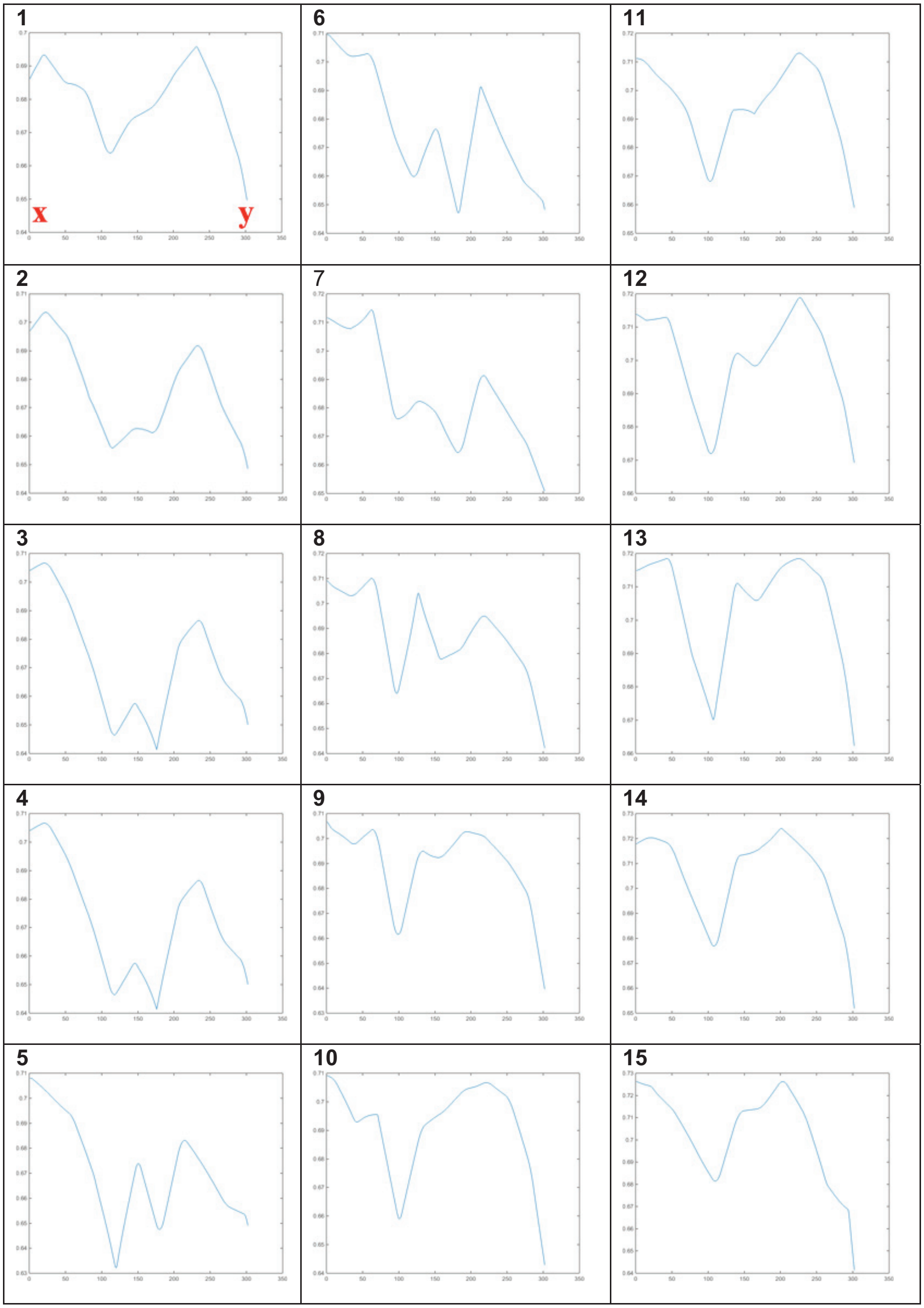


Table 1. A sample set of transects overlaid over a portion of Hollow Way #3. Transects are incremented from west to east and the profile runs from north to south.

their sharp drops as approaching to the center). In other profiles (#10, #14, and #15), 150 meters mark still exist albeit in more subtle forms.

To put these multispectral observations into perspective it is necessary to further investigate the morphology of hollow ways under the light of remote sensing. The information comes from the only geoarchaeological study of hollow ways, by Wilkinson *et al.* [21]. In their study, three hollow ways at Tell Brak are investigated in detail, suggesting hollow ways had been deeper and later filled with fine-grained sediments over time. Hollow way WP040 reveals that the profile of original road (before the filling) is asymmetrical; also proposing asymmetrical soil accumulation. This could also explain the non-symmetric NDVI profiles #11, #12, #13, #14 in comparison to #2, #3, #4, and #5, assuming no other post-depositional processes had taken place. Soil micromorphology readings from sample columns indicate hollow ways have been acquiring material from immediate vicinities [21: 762] which conforms to the low NDVI readings around the focal points of hollow ways. Furthermore, column samples also indicate the main hollow way fill is located in between 60-120 cm below the surface level. This is critical as the main crop in the area, barley, has a rooting depth as low as 160 cm, and thus, directly affected from hollow way soils. It gets even more critical when the plant roots hit the Early Bronze Age hollow way surface as the penetration depends on the compaction levels which must have been determined by the ancient traffic.

To further explore this hypothesis, a large set of transects overlaid on documented hollow ways and their profiles are investigated (Fig.4.). In order to follow the discussion above for the NDVI interpretation, profile readings which propose similar symmetrical post-deposition (#3, #4, #5, and #6) are selected for further analysis. In consideration of the large number of transects to be evaluated for its data series, a number of rule-sets are defined in Matlab 2014b based on the classification of local minima and maxima values distributed around 150m mark. This approach greatly reduces the time for visual investigations and provides further potential for exploring larger areas and studying more hollow ways.

None of the transects over hollow ways #8, #9, and #12 (Fig.4.) produces the target NDVI series (Table 2.). # 8 and # 12 (as parts of the same hollow way) have declining indices, potentially indicating complete asymmetrical hollow way morphology. The drop in #9 bounces back after the 150 meter mark. This behaviour might be explained by the relic river in the vicinity of hollow way, providing soil moisture and thus, increasing crop productivity.

Once the conforming NDVI series are averaged into a single series, one can qualitatively compare the results. Hollow ways #2, #3, and #11 appears to be the most trafficked as the gradients fall rather steep towards hollow ways. This is also to say vegetation growing over these hollow ways is significantly less healthy (even at the 150 meter peaks) suggesting more soil compaction. #10 also suggest large amount of traffic. However, the eastern bound of the series lacks a local maxima so that the magnitude of change is unknown. Hollow ways #1 and #4 have similar NDVI values with their immediate surroundings, possibly suggesting the ancient traffic was not high enough to alter soil physical characteristics. Hollow ways #5 and #7 are anomalous in the sense that the vegetation growing over these roads has significantly larger index values. It is probable that these hollow ways drained more water than other hollow ways or they are morphologically off another category. Finally, hollow way #6 might have some asymmetrical structure, but the resulting NDVI series do not provide a clear argument for its potential traffic load.

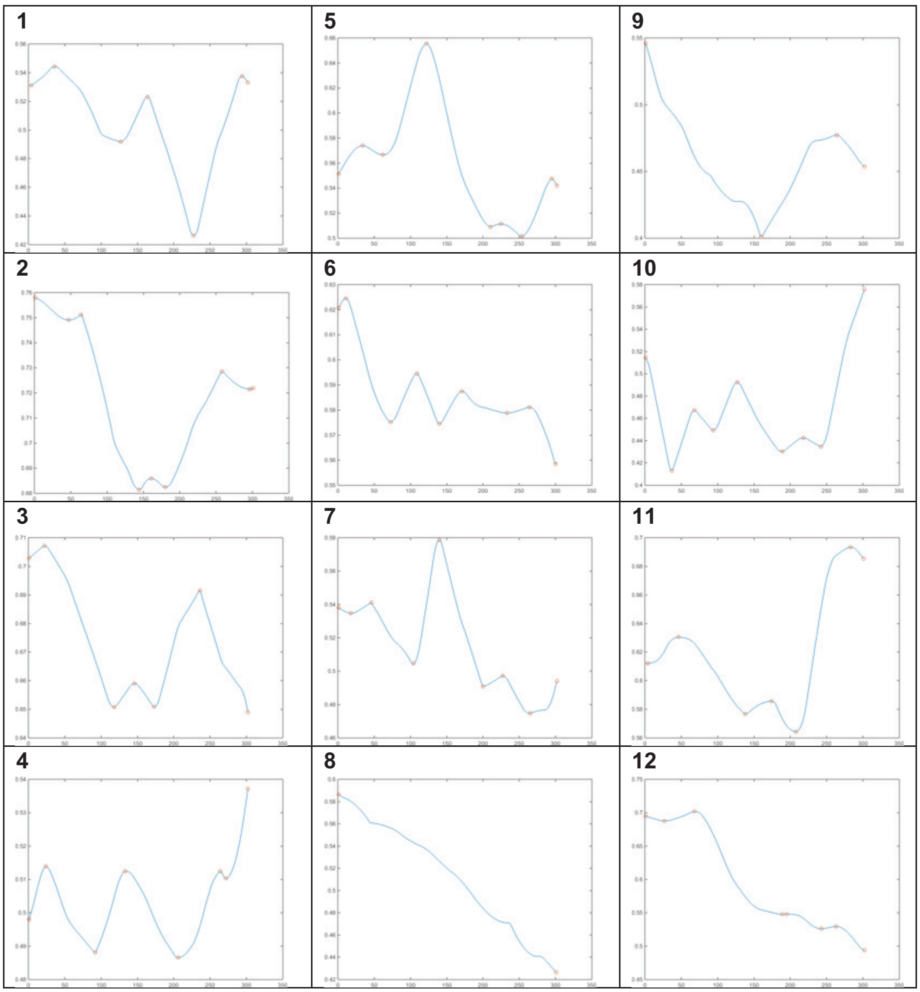


Table 2. Evaluated NDVI transects over hollow ways of an Early Bronze Age site

3. RESULTS

This study aims to explore Early Bronze Age traffic levels through the investigation of Normalized Difference Vegetation Index (NDVI) values. Results suggest some hollow ways might have been used more frequently than others since the vegetation growing over these hollow way fills produce lower values in comparison to their immediate areas. Some hollow ways, on the other hand, do not differ from their vicinities in terms of their NDVI composition, suggesting little to no structural change.

Some hollow ways have completely different configuration of NDVI series. This might be due to the asymmetrical morphology of hollow ways, and thus, due to differential post-deposition processes. Therefore, the study has the potential for further classification of hollow ways. As expected, some hollow ways cannot provide much information based on their NDVI analysis. Nevertheless, the study is replicable and can be extended to cover larger areas. Therefore, it has the potential to understand the landscapes of movement in its entirety in Upper Mesopotamia during Early Bronze Age.

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