Developing a Collaborative Strategy to Manage and Preserve Cultural Heritage during the Libyan Conflict. The case of the Gebel Nāfusa

Marco Nebbia[1], Anna Leone[1], Ralf Bockmann[2], Mftah Hddad[6], Hafed Abdouli[5], Ahmed M. Masoud[3], Nader M. Elkendi[3], Hassan M. Hamoud[3], Salah S. Adam[4], Moncif N. Khatab[4]

[1] *Department of Archaeology, Durham University, UK*

[2] *Deutsches Archäologisches Institut – Rome Department, Italy*

[3] *Department of Antiquities of Tripolitania – Centre for Documentation and Digitalization of Heritage, Libya*

[4] *Department of Antiquities of Cyrenaica, Libya*

[5] *Department of History, Faculty of Arts of the University of Sfax, Tunisia*

[6] *Department of History, Tarhuna University, Libya*

Abstract

The paper discusses the potential of a collaborative scheme for the development of a protocol for recording and managing the cultural heritage in Libya. The critical political situation in the country urges the development of cultural heritage management policies in order to protect it more thoroughly and consistently. Moving on from the numerous international initiatives and projects dealing with a mostly "remote" approach to the issue, the project here presented is trying to engage with staff members of the Department of Antiquities (DoA) in the elaboration of a joint strategy for the application of remote sensing and Geographical Information Systems (GIS) to the preservation and monitoring of the Libyan cultural heritage. A series of training courses resulted in an initial development of new ways of recording and analysing field data for a better awareness of the full range of threats that the archaeology, of the country, is subject to. Focussing on the case of the Jebel Nafusa the training involved the assessment of site visibility of satellite imagery, the analysis of high resolution satellite datasets for archaeological mapping, the creation of a GIS spatial database of field data, the mapping of risks and threats to archaeology from remote sensing data. This led to

the elaboration of risk map showing the areas that will be next affected by a number of threats, thus giving the DoA a tool to prioritise future fieldwork to keep the assessment of site damage up to date. Only a collaborative approach can lead to a sustainable strategy for the protection of the invaluable cultural heritage of Libya.

Current situation of ancient site management in Libya

The past and present political situations in Libya have left the country without specific policies or programmes for controlling and preserving ancient sites (Abdulkariem and Bennett 2014). These sites are under threat for numerous reasons, such as: recent destruction targeting religious buildings, including marabouts; quarrying activities threatening and demolishing ancient traces in the landscape as well as larger sites; and the expansion of modern urban centres that compromise the survival of pre-Roman and Roman cities. In recent years, research projects have investigated and surveyed Libyan territories on a local scale, demonstrating the importance of recording archaeological evidence into a GIS platform (Sterry and Mattingly 2011; Mattingly and Sterry 2013). Moreover, since the start of the conflict a series of meetings addressing the issue of Cultural Heritage have been organised and provided a forum for discussion in particular on the issue of recording sites in the landscape and managing them (Cultural Heritage in Libya – Tripoli 2013 and the very recent UNESCO-ICCROM meeting held in Tunis in April 2016). Since the conflict goes through phases of expansion of Isis (the Islamic State) and reconquest, the areas under threat and unaccessible often changes. Therefore, the recording system, in the field, changes according to the presence or absence of the conflict. A good example is offered for instance by the important Punic and Roman city of Sabratha, which has been under the control of Isis for a period and has now been freed again. The conflict developed in particular since 2013, the political situation is very complex and sees several groups in oppositions, as well as the expansion of Isis

In this panorama of political instability and constant threats directed at national cultural heritage, there is an urgent need to develop a more centralised GIS recording system for the entirety of Libya, so that the status of sites can be constantly monitored and maintained by the relevant Departments of Antiquities (both Tripolitania and Cyrenaica). This project is working towards this goal through a series of specifically targeted training courses and joint work with the Departments of Antiquities. The aim is to build a toolset that local authorities can use on a daily basis to record and monitor archaeological sites and to plan future fieldwork, following a risk-prioritised schedule. It is the heritage management aspect of the project that this paper will concentrate on by discussing two examples from Jebel Nāfusa.

Aims and objectives

In 2014, a joint project was initiated between Durham University (UK), the Deutsches Archäologisches Institut in Rome, the University of Sfax (Tunisia), and the Department of Antiquities of Libya (now of Tripolitania and Cyrenaica) – Centre for Documentation and Digitalization of Heritage (CDDH - Tripolitania). The project has two principal aims:

1. To understand the impact of the Arab conquest on Tripolitania and, from a wider perspective, the whole of North Africa. The region in fact played a key role in the Arab conquest of North Africa, bridging East and West. The project therefore intends to track the transition from the Byzantine into the Arab period up to the 15^{th} c. when a substantial restructuring of the landscape took place.
2. To develop a shared protocol for site recording and management within the territory investigated in the project. This goal is developed in co-operation with the Libyan Departments of Antiquities and Susan Kane (Oberlin College - USA) in order to initiate a long-term plan for the management and preservation of multi-period archaeological sites

Landscape Archaeology in Libya

Over the last few decades GIS applications and landscape studies have developed a more complex system of viewing archaeology within the contextual landscape. Sites are not considered individually, but as parts of an interconnected network in which archaeological evidence results from societal complexities, and each agent's actions can affect the whole system (Bentley and Maschner 2003: 5). This condition requires a more comprehensive approach in order to untangle different agents/features from the cumulative palimpsest of archaeological traces left in the landscape and to establish their diverse contributions to the encompassing system. In this view, even ephemeral traces of an economic landscape, such as relict field systems, can give insightful contributions to an understanding of the functions and roles of related settlements and sites (Sterry and Mattingly 2011: 112).

As much as archaeological research and cultural heritage management developed innovative methods and interpretations in Western countries (UNESCO World Heritage Centre 2008; Gullino and Larcher 2013), the cultural heritage preservation and management in Libya is still bound strongly to more traditional ways of conceiving sites as only archaeological monuments to be monitored and protected.

This paper will show how the concept of archaeological evidence developed in Landscape Archaeology could be considered on the agendas of institutions involved in the management and protection of cultural heritage in the North African country.

The theoretical approach is reflected in the methodology adopted by this project, which relies on two main sources of data combined together: field survey and remote sensing.

The current Libyan political condition prevents systematic fieldwork in the country, especially by foreign archaeologists, and this makes collaborations with local authorities hard to carry out. In fact, recently a number of projects have been developed that use remote sensing to map and control archaeological sites, such as: EAMENA (http://eamena.arch.ox.ac.uk/), focussing on the territory of North Africa and the Near East; the Mega-Jordan project (http://megajordan.org/) aiming to catalogue all of the archaeological sites in Jordan; and the recently started ATHENA project at the Remote Sensing Science Center for Cultural Heritage (http://athena2020.eu) foccused on creating a centre of excellence for remote sensing application to cultural heritage, to mention just a few. The originality of this project is the opportunity to work closely with the Libyan Department of Antiquities, which granted the possibility of integrating remote sensing analysis with data collected in the field and constant monitoring and recording. This provides information otherwise unachievable solely by satellite imagery mapping, such as chronological references, states of preservation of sites, and recording of the smaller and more ephemeral archaeological evidence not visible by satellite. From this perspective, full collaboration with the Departments of Antiquities towards the development of a standardised procedure of site recording and monitoring, primarily with the use of remote sensing and GIS, appears necessary.

Recording sites and the definition of archaeological record

Site recording and the way in which data have been acquired are illustrated here using specific case studies, in order to clarify and highlight the full potential of the applied methodology. The methodology has been developed during training courses during which theoretical and methodological approaches have been discussed and combined with the reality of the field archaeology experience of the DoA.

The training

Three intensive training courses have been organized between Durham University and Deutsches Archäologisches Institut on one side and the Libyan DoA on the other. The courses built up progressively the expertise in Landscape Archaeology, GIS and remote sensing, for six members of the DoA of Libya, which have been chosen among the staff of the former CDDH. The two-week

courses have been held at the Faculty of Arts of the University of Sfax in Tunisia (a destination easy to reach by all the participants). In the first course the basics of GIS and remote sensing and their varied applications in archaeology have been presented to the attendees. Despite the short time and the complexity of the topic DoA staff appreciated the usefulness of these techniques and agreed on moving on with discussing their specific applications to Libyan archaeology. Therefore, the second two courses have been focussing on the application of GIS and remote sensing to a set of data that the DoA has been collecting on the ground in the Jebel Nāfusa region. The use of fieldwork data directly collected by some of the participants and other staff of the DoA was fundamental for the learning experience as the deep knowledge of the archaeological data benefitted the whole collaborative strategy. In fact, the combination of ground knowledge of what kind of archaeology needs to be recorded, monitored and protected, and the integration with a landscape perspective resulted to be the best approach to tackle the conservation of the Cultural Heritage of the region.
Durham University provided with possible new operational tools the DoA who in turn provided with a real case study of great historical importance.
To follow are the results of this collaboration.

Field survey data – the current case study: Jebel Nāfusa

In the spring of 2014 a field survey was carried out by staff members of the CDDH in different areas in the Jebel Nāfusa, around the towns of Kabaw, Haraba, Tendimira, Hawamed, Sherwes, Tamzin, and Giosh. The area is located on the mountain range that runs from Homs (Libya) to Gabes (Tunisia), near the Tunisian border by the major city of Nalut (Fig. 1).

A total of 126 sites, ranging from forts to fortified settlements, mosques to small graves, have been recorded. The field walking mainly involved rural areas around towns and villages (Fig. 2). On the ground, sites were located and recorded with handheld GPS devices, and material (mainly potsherds, but also metal objects) collected for dating purposes. A photographic documentation of monuments accompanied the survey. Information regarding site types, preliminary chronology, states of preservation, geo-morphological settings, and current and foreseen threats for each archaeological remain were entered into a database.

The DoA designed the structure of the database and during the first training course we worked out together how to store the information contained in a way that can be integrated with everyday management procedures. Field data were imported into a GIS geo-database with a consistent list of coded values, thus homogenizing data sourced from different surveys and eliminating information redundancies. In this way it was possible to handle the entire field survey dataset and combine it with data recovered from remote sensing mapping (Fig. 3). The choice of adopting a GIS data model as a database was driven by the fact that compared to other platforms commonly used in cultural heritage management (like ARCHES[1]), the geodatabase allows us to perform spatial queries and spatial analysis, and favours the integration of data with the imagery. Overall, it seemed the best option in order to develop a tool and protocol that can be adopted easily by the DoA in its management tasks, both desk-based and in the field.

Remote sensing analysis

The second main source of data was satellite imagery; as already stressed, it is fundamental to understand the potential of satellite mapping, as it depends on many variables such as shape and size of the site, nature of the site, location of the site, contrast between land use of the surroundings and of the site itself, state of preservation of the site, spatial and spectral resolution of the image, time of acquisition of the image, and differences in satellite sensors. The potential for recovering archaeological sites from remote sensing data has been tested in other areas of the country, like Central Fezzan in the Saharan region (Sterry and Mattingly 2011: 104-107). Nevertheless, a careful assessment of the full spectrum of archaeological evidence visibility on satellite imagery has never been published. Therefore, we proceeded with a systematic evaluation of all sites surveyed during the fieldwork.

Along with standard and freely-available datasets such as Landsat 8 OLI, we used two different types of high-resolution imagery: Orbview-3 (panchromatic 1 m resolution, acquired between 2000 and 2001) and Pleiades (4 bands: Blue, Green, Red and Near Infrared – pan-sharpened to 0.5 m resolution, acquired between 2013 and 2014). A geo-database of features representing potential archaeological sites has been produced on the basis of intensive photo-interpretation of the territory covered by satellite images (Fig. 3).

The data stored describe each mapped feature and provide information on site location, the imagery used to map the feature, feature shape, the appearance of the feature on the image (spectral signature), the type of anomaly, and a first interpretation along with the level of certainty of the interpretation.

The aim of the database is to have a full set of information regarding the potential for recovering archaeological sites in an area currently inaccessible due to on-going conflicts. This helps prioritising and planning future fieldwork in territories where archaeological remains are more

[1] http://archesproject.org (accessed on 06/03/2016)

likely to be found. It is also intended to support the creation of a risk map of areas under threat due to the expansion of modern centres or the uncontrolled exploitation of natural resources. One of the great advantages of remote sensing is the possibility to contextualise a site within its surroundings.

Sherwes: a landscape view

The site of Sherwes, southwest of the modern town of Haraba, represents a key case study for defining a more complex conception of archaeological records within a *landscape* perspective. Photo-interpretation revealed a number of features defining a system, which comprises the main settlement, traces of roads/pathways, and field systems (Fig. 5).

The main settlement consists of four major neighbourhoods. The central one hosts a fortified building (*gasr*) and several other structures surrounding it on the mound slopes, including storing installations. From the survey data we know that in the middle of the site there is a mosque, and in the northeast quarter a synagogue (Basset 1899; Hirschberg 1974). From the satellite image, it was possible to map traces of a pathway (partially still in use) that leads from the settlement to the *wadi* valley bottom and goes upstream. The written sources tell us that the *wadi* was one of the main routes that linked the upland plateau of the *jebel* to the coast in the north, and that the valley bottom was cultivated at the time of the occupation of the settlement in the 10^{th}-11^{th} centuries (Warfalli 1981, 119; Ibn Hawqal, *Súrat al-ard: Opus geographicum*, ed. Kramers, Leiden 2014: 94-95). Extraordinarily, some remains of a fossil landscape of field systems are still visible on the images, alongside the main *wadi* in areas where the valley opens up; these structures are visibly abandoned nowadays but it is clear that they were part of an agricultural system linked to the near Islamic settlement of Sherwes.

The evidence shows the need for recording, monitoring, protecting, and preserving not just a single building or site, but the whole contextual landscape as part of cultural heritage. A Landscape approach has never been considered for cultural heritage management purposes before, by the DoA, therefore there is not a specific protocol on how to record and preserve *landscape features*, but the training courses expose the staff of DoA (who showed extreme interest) to these problematic for the first time. It is still a work in progress, but further courses and workshops will provide new insights on the best operational strategy to adopt in the field.

Mapping risks and integration with archaeological data in Jebel Nāfusa

Results of the field investigation show how the predominant threats to archaeological sites in this area are water erosion and vandalism (Fig. 6). Water erosion is mostly due to the proximity of the sites to steep areas where the friable soil is more affected by the running water. Vandalism has been recorded more frequently in the area West of Kabaw and mostly regards the use of archaeological remains as overnight shelters where fires are set for heating and rubbish left in the monuments; this is mainly occurring in still upstanding or semi-collapsed structures. It is hard to estimate how this will affect the preservation of the historical buildings, but the first step for the DoA is to map and record this, in order to have a full quantitative and spatial awareness of its magnitude across the landscape.

We, therefore, focussed our attention on mapping these two major risks recorded from the ground assessment and on the threat derived from the approaching urban sprawl. Urban encroachment has not been mentioned in the overall list of primary threats to the archaeology of the Jebel Nāfusa recorded in the field, as it is not an easy assessment to do from the ground. In this sense, in fact, the Landscape perspective has not only been applied to the understanding of the complexity of the archaeological record, but also to the thorough evaluation of the full spectrum of on-going hazards to the archaeological remains. Thanks to the analysis and evaluation of satellite imagery, we agreed to include urban sprawl as one of the major hazards endangering the cultural heritage in the area of Jebel Nāfusa.

Relying on the latest enhanced land elevation dataset (released on September 2014) generated from the Shuttle Radar Topography Mission (SRTM), at 30 metres resolution, it was possible to automatically reclassify and extract the steepest slopes along the cliff line for the surveyed area in Jebel Nāfusa.

These areas, displayed by a number of polygons, are affected by wind erosion, water erosion, and landslides, which represent natural hazards to archaeological sites located in a buffer zone along the cliff line (Fig. 7).

Moreover, by using a series of historical Landsat imagery, covering a time span of 40 years (Landsat 1 MSS from 1972, Landsat 5 TM from 1987, and Landsat 8 OLI from 2015), it was possible to map the growth of urban centres located in the survey area and the main connecting road network (Fig. 7).

The results, comparing the size of urban areas between 1972 and 2015, show different levels of progressive expansion, from minimal increase (e.g. Tendimira, 10%) to a considerable rise in the extension of the urban area of 250% (e.g. Kabaw), to the extreme of a major town like Nalut that grew by 540% over the period considered. Moreover, by looking at the road network it is clearly observable how in most cases the expansion of modern towns occurs along the main routes of communication, especially on the Jebel uplands, whereas on the northern plain the growth of settled areas is more isotropic. The field survey data analysis has shown that 27% of the recorded sites are located within 1 km of towns and are, therefore, endangered by urban expansion (although only 15% of these are located along main roads).

Topographic position is another indicator of endangerment at archaeological sites. A GIS analysis considering elevation levels showed that 65% of the surveyed sites are situated within 200 m of steep slopes (either uphill or downhill) and are therefore threatened by wind and water erosion, as well as landslides. Unfortunately, due to limited spatial resolutions and georeferencing inaccuracies of the satellite imagery commonly available, it was not possible to undertake a calculation of historical rates of erosion in steep areas.

Overall, 20 % of the recorded sites are affected by both urban expansion and natural erosion.

The GIS environment allows for the integration of different maps representing hazards into a single raster dataset, indicating the different levels of risk for archaeological remains in the territory under investigation. The quantitative analysis of each hazard can be represented with a raster image, where each pixel value represents the level of risk for that hazard at a specific point. A predictive map of high risk zones for cultural heritage has been generated utilising four hazards: (1) steep areas, (2) urban expansion, (3) vicinity to main routes, and (4) vandalism. The first three variables were mapped from satellite imagery (as described above), whereas vandalised areas have been considered by a *kernel density estimation* (Okabe et al. 2009) based on collected field data. The encroachment of each hazard (represented as polygons) has been calculated as a series of Euclidean multi-buffers, predicting areas potentially affected by each hazard. The reclassification of the four raster datasets into a risk gradient scale has produced four images that have been integrated, using a fuzzy approach, into a single weighted risk map. Each variable has been weighted taking into consideration its potential contribution to the predictive model; as such, a percentage of influence has been assigned to each hazard. On the basis of the analysis of the historical expansion of the urban centres discussed earlier, a proportional encroachment has been predicted (50 year time lapse) for each town with an overall contribution of 30% assigned to the variable. A 10% contribution has been assigned to the route network because there is an overall trend of urban expansion along the main road system. A 30% contribution was also assigned to the last two variables, taking into consideration the vicinity to steep slopes and the vicinity to areas affected by vandalism. The weighting of the different threats has been agreed with the DoA, as the previously unrecorded urban sprawl resulted to be among the major hazards, and equally dangerous, for the archaeology as the natural erosion and the on-going vandalism are. The estimate of how much each hazard has to be weighted is a work in progress, as more fieldwork will provide further data to evaluate the effect that each threat has overall. For this reason we agreed on giving an equal weight to natural erosion, urban sprawl and vandalism, as this seems to be the current situation. Routes systems have been assigned a smaller weight, as their contribution is, in this case, considered strictly related to the urban sprawl and a higher weight would have falsely affected the overall prediction of cumulative risks. Areas nearby roads, but far from modern settlements do not seems particularly endangered at the moment.

The resulting map (Fig. 8) represents the areas where the overall threat to cultural heritage is higher and therefore can assist in developing a more targeted site recording strategy.

Moreover, the level of risk can be 'inherited' by the points, thus giving and overview on the representativeness of the surveyed sample. The risk level for the different areas has been mostly calculated on the basis of remote sensing mapping (only the vandalism has been derived from field data), but the fieldwork has been carried out without the knowledge and the spatial awareness of where the most endangered areas are. It is clear from Fig. 8, in fact, that only few sites are classified as high risk (red) because the field survey was not planned according to the risk map and the majority of areas at high-risk level have, indeed, not been surveyed. Areas like the town of Kabaw and its surroundings are most certainly at high risk and should be next surveyed and recorded.

One of the major contributions of a GIS-based landscape approach is that it can help prioritizing future fieldwork in areas like Jebel Nāfusa, and in general the country of Libya, characterized by limited access due to on-going conflicts.

Results

Overall, only 47% of the archaeological sites surveyed in the field are visible on satellite imagery (mid-high/high visibility). Furthermore, if we compare the visibility of sites between the two sets of high-resolution imagery, counting on similar variability of site types, background surroundings, and state of preservation in both datasets, the results show that 24% of sites on Orbview-3 have a mid-high/high visibility, whereas on Pleiades the number is 62%.

Smaller sites such as graves, small cisterns, or wells are not visible in the images at all, for a number of reasons: first, the small dimensions of these objects prevent them from being displayed by more than a few pixels, so that they are practically invisible; moreover, the land use of the sites does not contrast with their surroundings; and finally, the objects do not have a sufficient topographical expression to produce shadows that can be detected in the images.

Structures like mosques or small buildings are indeed visible on both images, although better defined on Pleiades as the spatial resolution is higher and the colours make such objects more visible; however, the certainty of sites being archaeological remains is still rather low as the general state of preservation is quite good, so it is hard to distinguish them from modern buildings that are in use.

Bigger and more complex sites, such as different sorts of fortifications (e.g. Sherwes) and hilltop sites, are quite distinguishable on the satellite imagery due to their dimensions, shape, and topographical expression, although sometimes not clearly visible as the natural topography can obscure their presence (Table I).

The case of Sherwes shows that the use of remote sensing, if not integrated with fieldwork, does not provide enough information to fully understand the complex landscape. Apart from dating visible features, the details of individual sites are missing and do not allow a full understanding of the settlements. It is therefore seen as mandatory, even in difficult conditions, to work in association with local authorities who can provide ground control and data collection. Site recording and risk mapping have limited value if not integrated into a specific, controlled, managed, co-operative plan.

Discussion

The advantage of covering vast areas with remote sensing is still a great potential for archaeological mapping for conservation purposes; moreover, applications of satellite imagery allow for a more thorough monitoring of sites, landscapes, and changing environments that might affect the preservation of archaeological remains (Banerjee and Srivastava 2013).

In the current digital era, data storage and management have become a priority on the agenda of cultural heritage science, so that bespoke procedures may be developed in order to have both a more complete and accurate database and a fine-tuned tool-set to be used in the everyday workflow by local authorities in charge of cultural heritage management.

Many methods and techniques have been developed over the last decades specifically to tackle archaeological applications, and standard procedures of data collection have been updated.

Within the framework of cultural heritage management new methodologies to record archaeology as well as to map threats have been established (Hesse 2015; Wang 2014; Risbøl et al. 2014). For imposing monuments, 3D recording is already a common practice that guarantees the complete storage of every detail of a building (Yastikli 2007; Remondino 2011).

Predictive modelling has also been developed on a large scale both for research and conservation purposes, but has been devoted mainly to predict those areas that might contain archaeology (Verhagen and Whitley 2012). Fewer applications of predictive modelling have been focused on mapping areas that will be affected by hazards such as urban sprawl (Danese et al. 2013), but these are considered fundamental for areas like Jebel Nāfusa where this particular hazard has been already classified as imminent. "Remote" assessments quantified site damages by defining new ways of tackling big areas (Cunliffe 2014). New ways of predicting which areas will be next affected by damage to archaeological remains has been developed using remote sensing data and GIS analysis (Agapiou et al. 2015). The challenge here presented is to make these tools available to, and adoptable by, staff members of the Libyan DoA, so that can be used for regular recording and monitoring procedures.

The contribution of new technologies and methodologies to archaeological data collection and recording has to be flanked by close interactions with stakeholders and local authorities that are in charge of cultural heritage management and responsible for its preservation (Abdulkariem and Bennett 2014). A form of interaction is exemplified in this paper. The results are the outcome of a series of GIS and remote sensing training courses, in which methods and practices have been developed and discussed (and not simply taught) with staff members of the Department of Antiquities of Libya, to favour a thorough understanding of the full spectrum of potential of the applied methodologies.

The importance of field survey data for cross-validating remote sensing potential and interpretation has been fundamental to work out the best strategy for recording and managing sites at a medium scale. More training courses will follow in order to discuss and establish procedures enabling the accurate recording of archaeological remains at the site level.

Overall, the collaborative strategy here presented shows how the development of a procedure that allows local authorities monitoring and protecting their archaeological landscapes, also provides the possibility to generate "freshly" recorded data to be used for the research project. This is the only way to generate ready-to-use primary datasets from a country that results difficult, if not impossible, to access to, in the current political situation. The participation of the DoA in the design of the training courses is fundamental for the development of a standard protocol of site recording and monitoring, thus giving an active scope to the application of technologies like remote sensing and GIS for the cultural heritage preservation, as it has been shown to have been successful in other disciplines (Ghose and Huxhold 2001).

The approach here presented even if based on the specific case of the Jebel Nāfusa, can find a wide spectrum of applicability whenever there is the willingness from the research institutions to engage with local authorities in countries and areas where the physical access is limited due to unstable political situations. More technically speaking, the methodology has wide application to a variety of archaeological contexts and environments, as it is highly adaptable to the specific necessities of the different regions. Clearly the assessment of the potential of remote sensing and field data could is fundamental to establish the sustainability of the protocol to follow that can vary from context to context.

Acknowledgements

Support for the development of this project has been given by Prof. Susan Kane (Oberlin College) and the Ambassador Funds for Cultural Heritage. Gratitude is due to the Faculty of History, University of Sfax for their hospitality, facilities, and support provided during the training courses. The training courses have been funded by Durham University and Deutsches Archäologisches Institut – Rome Department and the Society for Libyan Studies (London).

A great thanks is due to the two anonymous reviewers whose invaluable comments made it a better paper. The authors are the only responsible for any errors.

References

Abdulkariem, A., and P. Bennett. 2014. "Libyan Heritage under Threat: The Case of Cyrene." *Libyan Studies* 45 (November 2014): 155–61. doi:10.1017/lis.2013.1.

Agapiou, A, V Lysandrou, D D Alexakis, K Themistocleous, B Cuca, and A Argyriou. 2015. "Cultural Heritage Management and Monitoring Using Remote Sensing Data and GIS: The Case Study of Paphos Area, Cyprus." *Computers, Environment and Urban Systems Journal* 54: 230–39. doi:10.1016/j.compenvurbsys.2015.09.003.

Banerjee, R., and P. K. Srivastava. 2013. "Reconstruction of Contested Landscape: Detecting Land Cover Transformation Hosting Cultural Heritage Sites from Central India Using Remote Sensing." *Land Use Policy* 34. Elsevier Ltd: 193–203. doi:10.1016/j.landusepol.2013.03.005.

Basset, R. 1899. "Les Sanctuairws Du Djebel Nefousa." *Journal Asiatique*, 5–83.

Bentley, A. R., and H. D. G. Maschner. 2003. *Complex Systems and Archaeology: Empirical and Theoretical Applications*. Salt Lake City: The University of Utah Press.

Cunliffe, E. 2014. “Remote Assessments of Site Damage: A New Ontology.” *International Journal of Heritage in the Digital Era* 3 (3): 454–73.

Danese, M., N. Masini, and B. Murgante. 2013. “Archaeological Risk and Spatial Analysis. How to Compare Urban Sprawl and Archaeological Sensibility Maps.” In *EARSel Proceedings*.

Ghose, R., and W. E. Huxhold. 2001. “Role of Local Contextual Factors in Building Public Participation GIS: The Milwaukee Experience.” *Cartography and Geographic Information Science* 28 (3): 195–208. doi:10.1559/152304001782153017.

Gullino, P., and F. Larcher. 2013. “Integrity in UNESCO World Heritage Sites. A Comparative Study for Rural Landscapes.” *Journal of Cultural Heritage* 14 (5). Elsevier Masson SAS: 389–95. doi:10.1016/j.culher.2012.10.005.

Hesse, R. 2015. “Combining Structure-from-Motion with High and Intermediate Resolution Satellite Images to Document Threats to Archaeological Heritage in Arid Environments.” *Journal of Cultural Heritage* 16 (2). Elsevier Masson SAS: 192–201. doi:10.1016/j.culher.2014.04.003.

Hirschberg, H.Z. 1974. *A History of the Jews of North Africa, Vol. 1. From Antiquity to the 16th C*. Leiden: Brill.

Mattingly, D. J., and M. Sterry. 2013. “The First Towns in the Central Sahara.” *Antiquity* 87 (336): 503–18. doi:10.1017/S0003598X00049097.

Okabe, A., T. Satoh, and K. Sugihara. 2009. “A Kernel Density Estimation Method for Networks, Its Computational Method and a GIS-Based Tool.” *International Journal of Geographical Information Science* 23 (1): 7–32. doi:10.1080/13658810802475491.

Remondino, F. 2011. “Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning.” *Remote Sensing* 3 (6): 1104–38. doi:10.3390/rs3061104.

Risbøl, O., C. Briese, M. Doneus, and A. Nesbakken. 2014. “Monitoring Cultural Heritage by Comparing DEMs Derived from Historical Aerial Photographs and Airborne Laser Scanning.” *Journal of Cultural Heritage* 16 (2). Elsevier Masson SAS: 202–9. doi:10.1016/j.culher.2014.04.002.

Sterry, M., and D. Mattingly. 2011. “DMP XIII: Reconnaissance Survey of Archaological Sitesin the Murzuq Area.” *Libyan Studies* 42: 103–16.

UNESCO World Heritage Centre. 2008. “Operational Guidelines for the Implementation of the World Heritage Convention.” *Operational Guidelines for the Implementation of the World Heritage Convention*. http://whc.unesco.org/archive/opguide08-en.pdf.

Verhagen, P., and T. G. Whitley. 2012. *Integrating Archaeological Theory and Predictive Modeling: A Live Report from the Scene*. *Journal of Archaeological Method and Theory*. Vol. 19. doi:10.1007/s10816-011-9102-7.

Wang, Jieh-Jiuh. 2014. “Flood Risk Maps to Cultural Heritage: Measures and Process.” *Journal of Cultural Heritage* 16 (2). Elsevier Masson SAS: 210–20. doi:10.1016/j.culher.2014.03.002.

Warfalli, M. S. M. 1981. “Some Islamic Monuments in Jabal Nafusa.” School of Oriental and African Studies. doi:10.1038/143019a0.

Yastikli, N. 2007. “Documentation of Cultural Heritage Using Digital Photogrammetry and Laser Scanning.” *Journal of Cultural Heritage* 8 (4): 423–27. doi:10.1016/j.culher.2007.06.003.

Figures captions:

Fig. 1. Location of the survey area in the Jebel Nāfusa, Libya.

Fig. 2. Distribution of sites mapped during the field survey conducted by the Department of Antiquities in Spring 2014 in the Jebel Nafusa territory.

Fig. 3. Sample of the geodatabase entries derived from data collected during the field survey imported in the GIS platform.

Fig. 4. Coverage of satellite imagery used for the project in the Jebel Nafusa and distribution of sites surveyed.

Fig. 5. Mapping of archaeological features from the complex site of Sherwes. (Pleiades 4-bands multi-spectral image – 0.50m res).

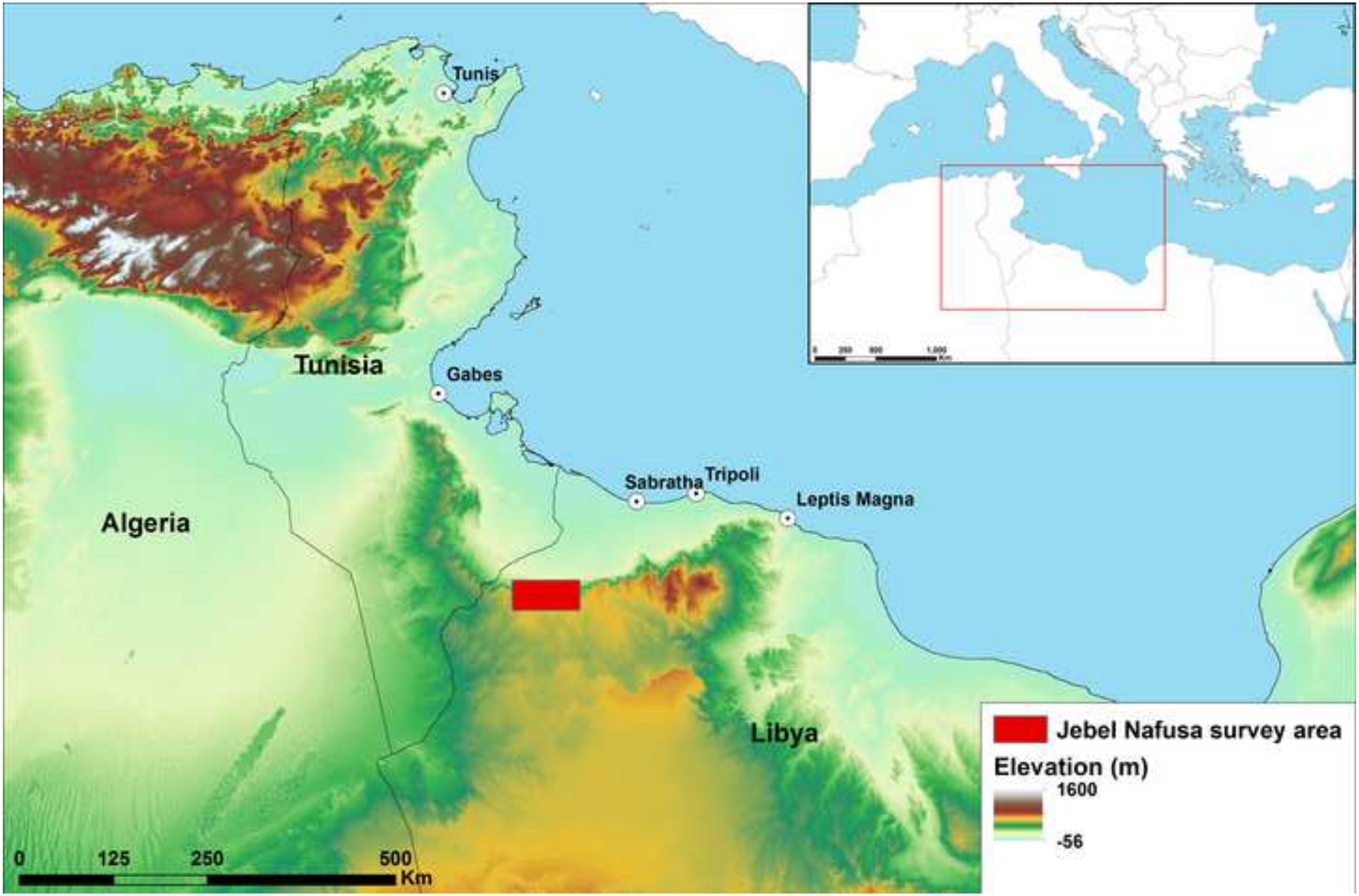
Fig. 6. Barplot showing the primary threats recorded during the field survey in the Jebel Nafusa.

Fig. 7. Mapping risks and hazards for the archaeology in the Jebel Nafusa.

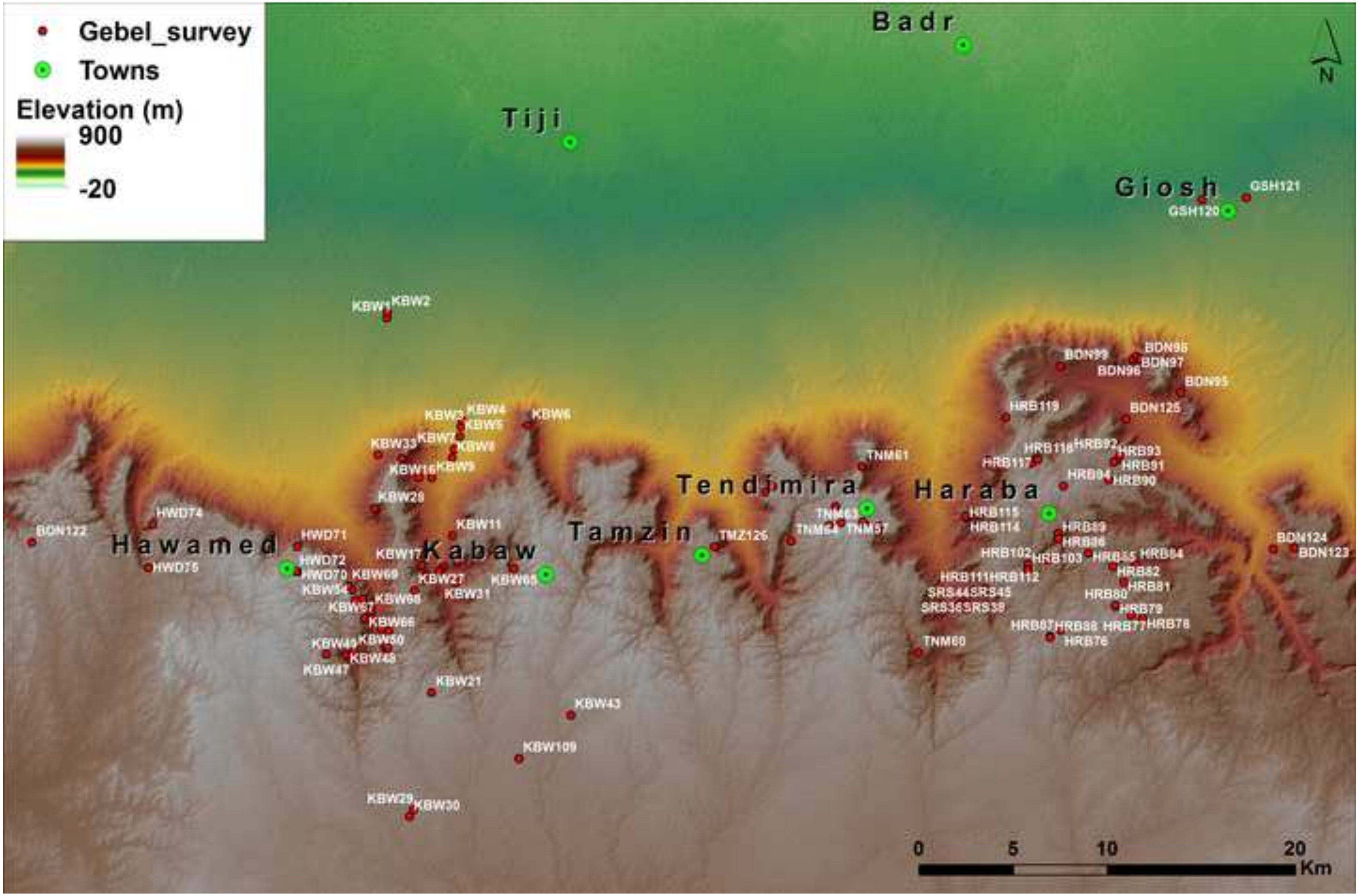
Fig. 8. Risk map showing areas potentially threatening archaeological sites.

Table I. Comparative table showing the visibility of the archaeological remains on satellite imagery.

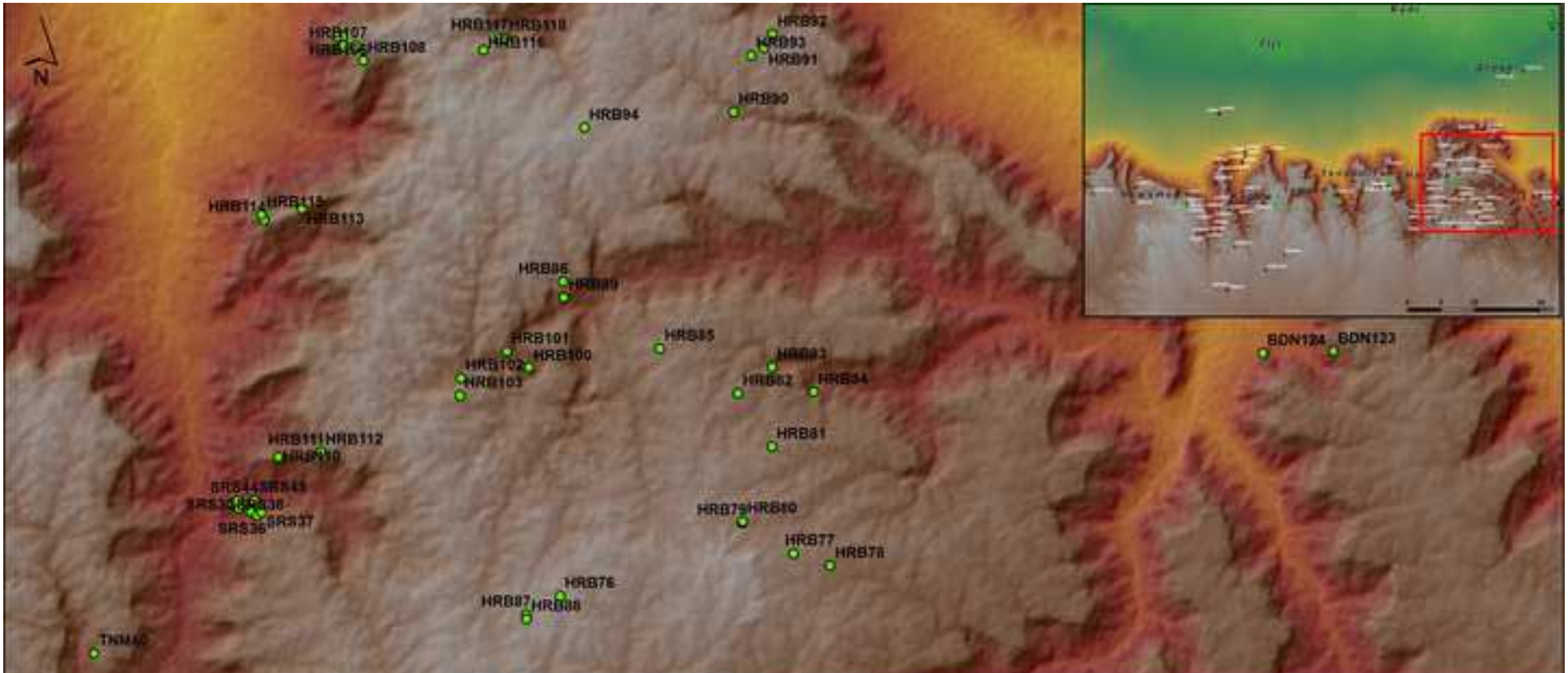
Click here to download Figure Fig.1 NEW.jpg



Click here to download Figure Fig.2 NEW.jpg



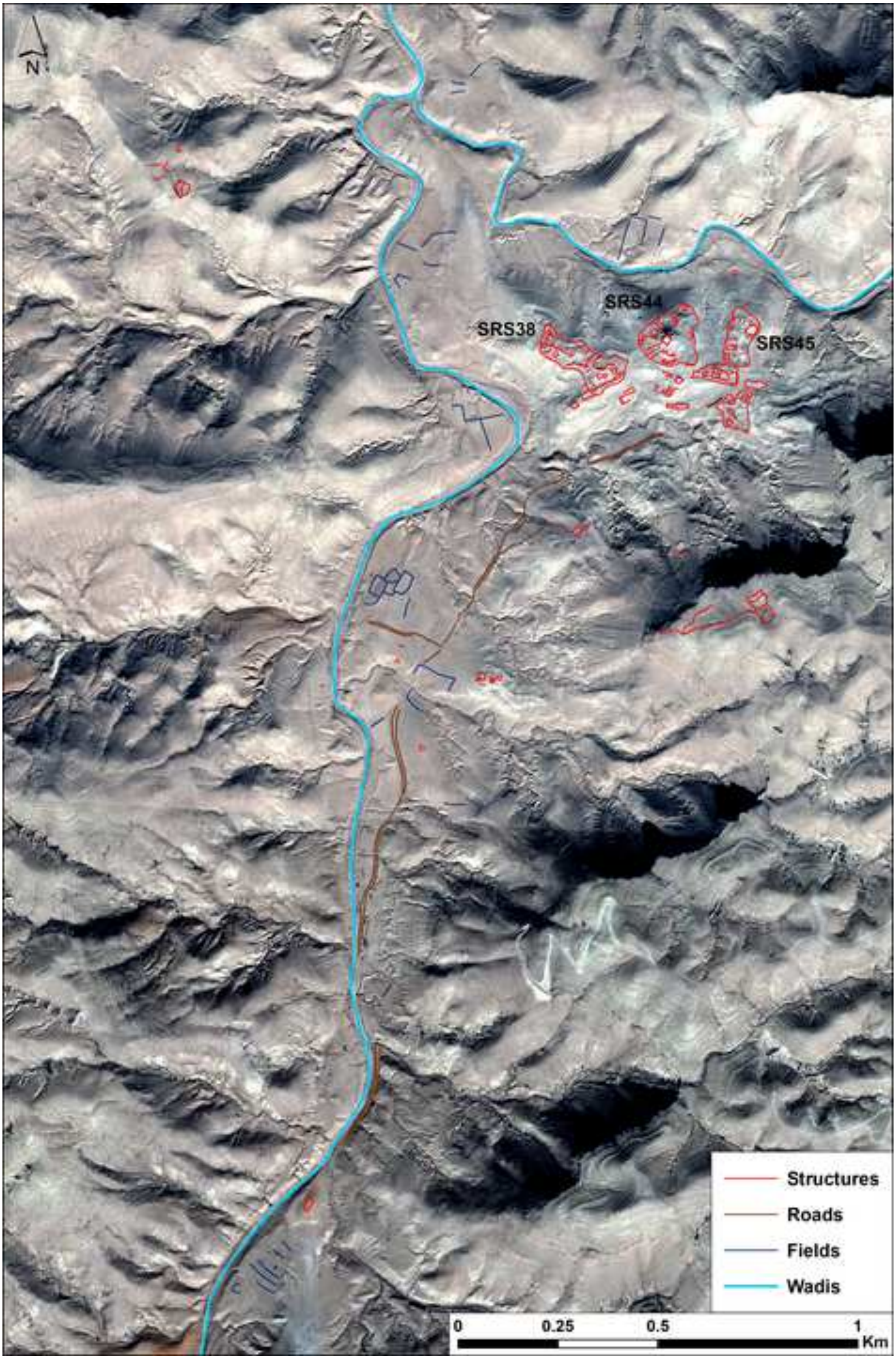
Click here to download Figure Fig.3 NEW.jpg

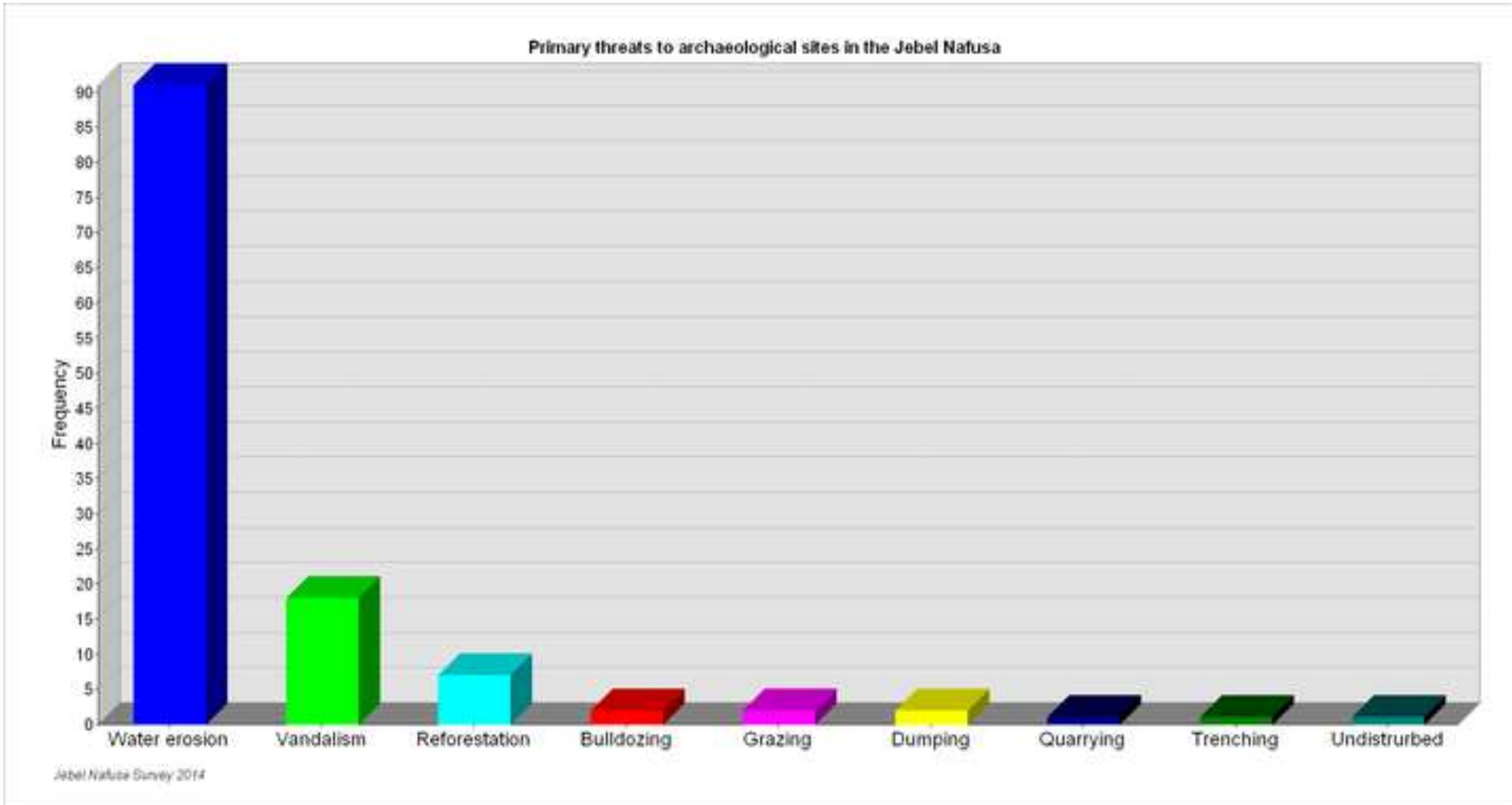


OBJECTID *	Shape *	رقم_التسلسل	رمز_الموقع	الرمز_الطب	رمز_الفترة	الاختلالات
1	Point	KBW1	Well	Valley bottom	Islamic	Bulldozing
2	Point	KBW2	Grave	Wadi bank	Unknown	Vandalism
3	Point	KBW3	Cave	Wadi bank	Prehistoric	Dumping
4	Point	KBW4	Mosque	Hilltop	Islamic	Vandalism
5	Point	KBW5	Settlement	Hilltop	Islamic	Pipeline
6	Point	KBW6	Palace	Mountain top	Islamic	Water erosion
7	Point	KBW7	Grave	Hilltop	Unknown	Ploughing
8	Point	KBW8	Grave	Hilltop	Islamic	Vandalism
9	Point	KBW9	Public building	Plateau	Islamic	Vandalism
10	Point	KBW10	Public building	Hilltop	Islamic	Water erosion
11	Point	KBW11	Habitatio/Military	Hilltop	Islamic	Water erosion

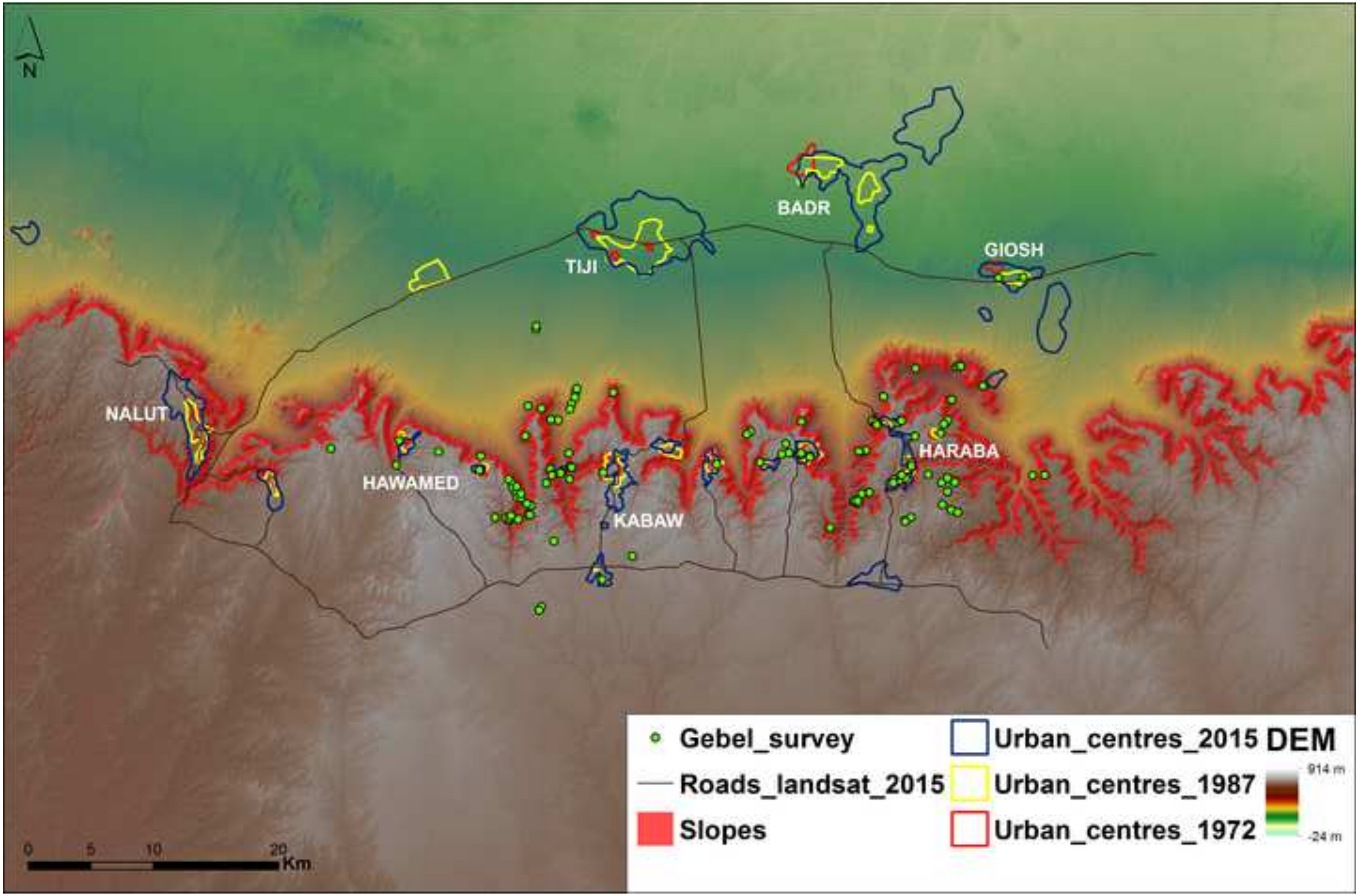
Click here to download Figure Fig.4 NEW.jpg

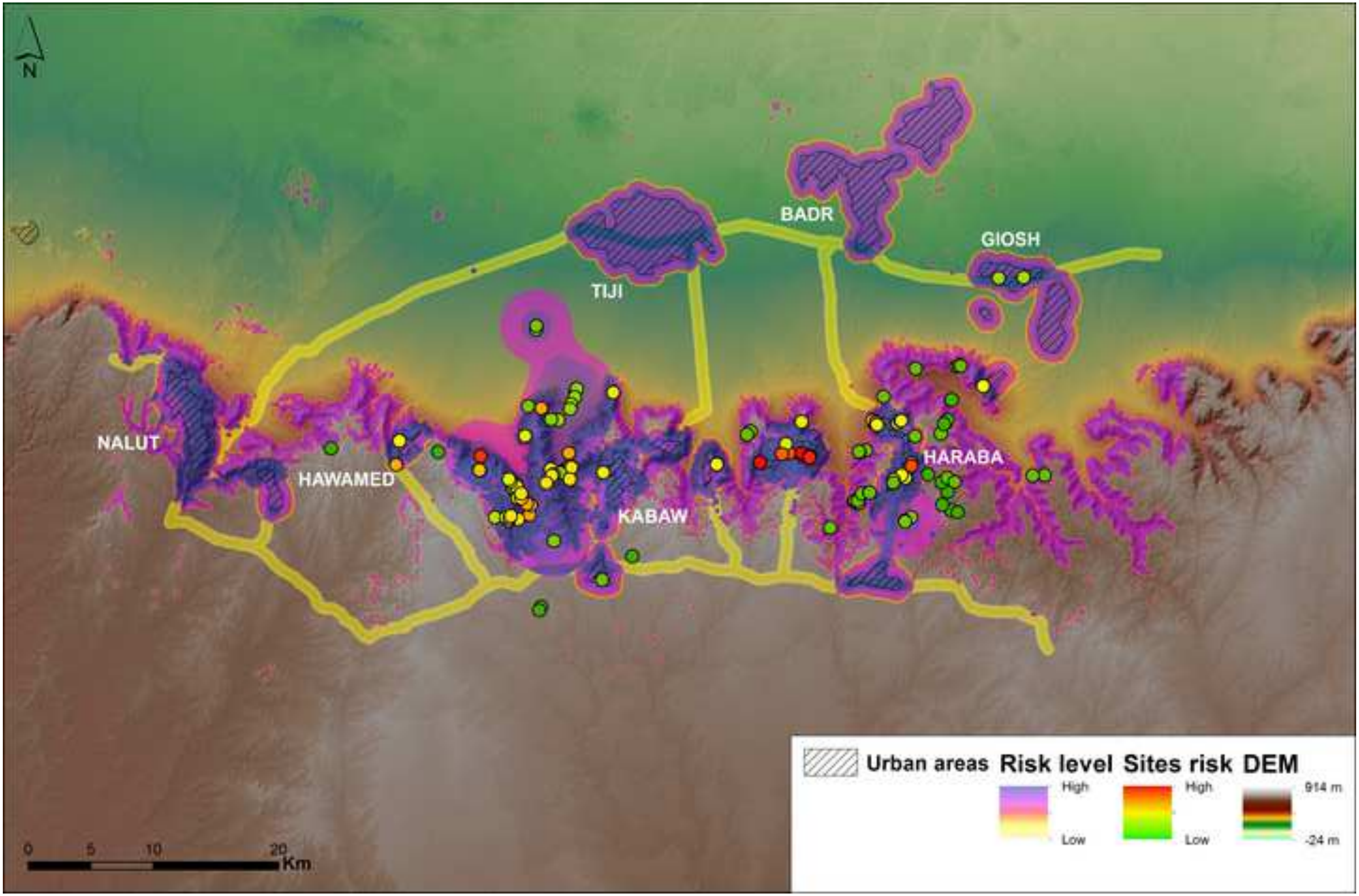
Click here to download Figure Fig.5 NEW.jpg



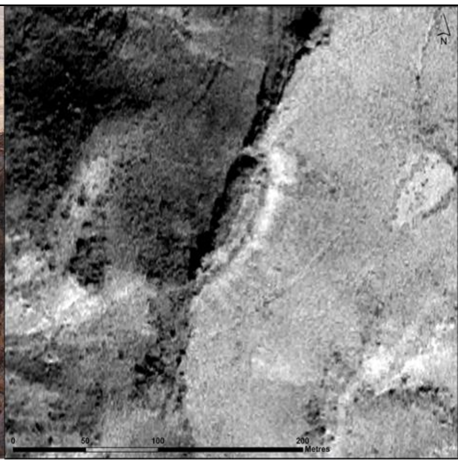
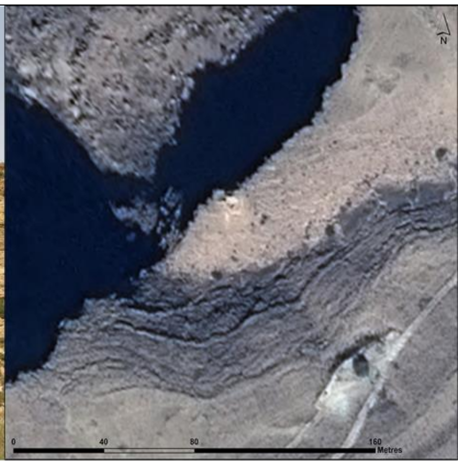
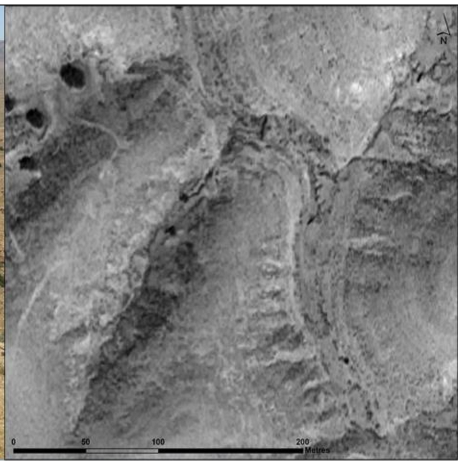

Primary threats to archaeological sites in the Jebel Nafusa
Frequency
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Water erosion
Vandalism
Reforestation
Bulldozing
Grazing
Dumping
Quarrying
Trenching
Undistrurbed
Jebel Nafusa Survey 2014

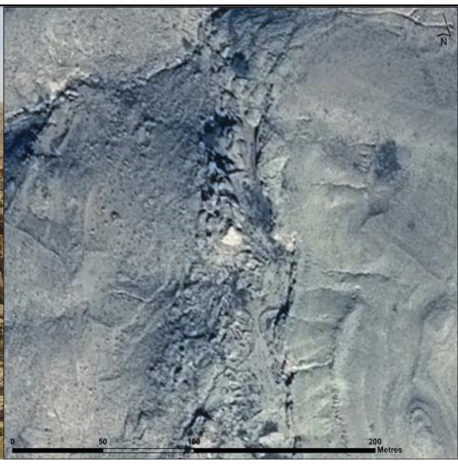
Click here to download Figure Fig.7 NEW.jpg




N
BADR
GIOSH
TIJI
NALUT
HAWAMED
KABAW
HARABA
Urban areas
Risk level
High
Low
Sites risk
High
Low
DEM
914 m
-24 m
0
5
10
20
Km

 	BDN99 – Large Islamic fortification with structures for storage situated on a hilltop north of the town of Haraba. The site is highly visible on the satellite image. The location of the structure is easily detectable and the nature of the site determinable. (*4-bands multi-spectral images Pleiades 2013 - 0.50m res*).
 	HRB77 – Islamic watchtower located on a mound in the uplands south of Haraba. The small structure is highly visible on the satellite image, as well as the mound where it sits. Part of the building plan can be detected. (*4-bands multi-spectral images Pleiades 2013 - 0.50m res*).
 	HRB100 – The urban settlement located in the surroundings of Haraba dates back to the 10th-12th century. The entire plan of the settlement is clearly visible on the satellite image. The complexity of the site is detectable on the satellite image. (*4-bands multi-spectral images Pleiades 2013 - 0.50m res*).

		KBW28 – Islamic small fortification with structures for storage situated in the northwest of Kabaw at the edge of the uplands area. The location of the site is guessable on the image although the anomaly could also be referred to a rock formation. (*Panchromatic OrbView-3 images 2006 – 1m res*).
		TNM58 – Large Islamic fortification located on a mountain top northwest of Tendimira on the edge of the upland area. The upstanding structure is visible on the satellite image; the extensive collapsed buildings are not detectable. The largest part of the site cannot be mapped and the interpretation could be biased. (*4-bands multi-spectral images Pleiades 2013 - 0.50m res*).
		BDN122 – Undefined structure located on a hilltop between the towns of Nalut and Kabaw. The site shows a considerable complex structure from the ground visit photos, although chronology and function are unclear. The extensive standing structures are totally invisible on the satellite image. (*Panchromatic OrbView-3 images 2006 – 1m res*).

 	HRB84 –Islamic watchtower located east of Haraba, overlooking a wadi valley. The shape of the building, which preserves tens of metres high walls, is disguised by the topography of the terrain. The structure appears like a rock formation in the satellite image. (*4-bands multi-spectral images Pleiades 2013 - 0.50m res*).
 	TNM60 – Islamic watchtower with storage structures, located south of Tendimira. The structure is situated at the edge of a mid-slope terrace. The site visibility on the satellite imagery is prevented by the topography of the terrain . (*4-bands multi-spectral images Pleiades 2013 - 0.50m res*).