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Mobile peoples - permanent places : the construction and use of stone-built architecture by nomadic communities in the Jebel Qurma region of the Black Desert (Jordan) between the Hellenistic and Early Islamic periods.

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Citation

Huigens, H. O. (2018, November 22). *Mobile peoples - permanent places : the construction and use of stone-built architecture by nomadic communities in the Jebel Qurma region of the Black Desert (Jordan) between the Hellenistic and Early Islamic periods*. Retrieved from <https://hdl.handle.net/1887/67087>

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Issue Date: 2018-11-22

2 The Natural Environment of the Jebel Qurma Region

2.1. INTRODUCTION

The Jebel Qurma region is highly diverse in terms of its natural environment and hosts a large number of archaeological remains from prehistoric until recent times, together comprising a diverse series of archaeological landscapes. While its archaeological remains are presented in Chapters 3 to 5, the aim of this chapter is to describe the natural elements of the study area and the methods employed to study them. Although natural and cultural elements of archaeological landscapes are always entwined to some degree, archaeological remains are always fixed in an environment largely created by natural forces. This natural base of the archaeological landscape provides a good starting point in the study of nomadic landscapes.

This chapter is more, however, than simply a description of the types of natural landscapes encountered in the study area. Additionally, it presents the results of a number of digital modelling procedures that will be important in understanding the structure of the nomadic landscape, as discussed further on in this dissertation. In order to do so, datasets containing information on the physical environment, such as geological maps, topographic maps, and satellite imagery, needed to be transformed in

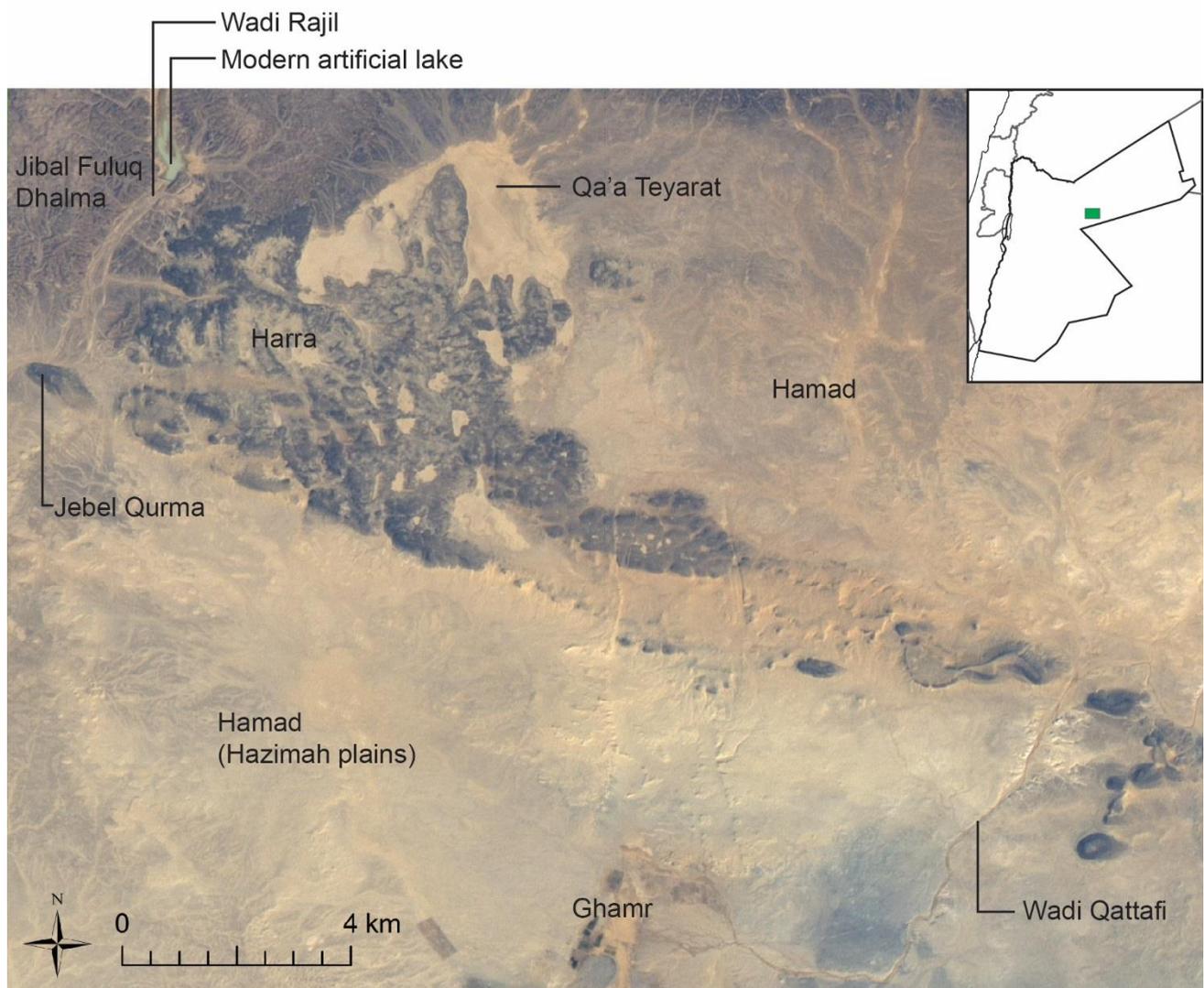


Figure 2.1: Satellite photograph of the Jebel Qurma region, with relevant features indicated (insert: location of the study area (green) in Jordan). Base map: Landsat 7, true colours.

such a way that it could be used for later quantitative and qualitative analyses. For example, although a satellite photographs may provide the observer a sense of what the physical environment is like, it requires classification in such a way that the image is analytically useful. Therefore, for this study, a number of datasets on the natural environment – mostly remote-sensing data – were digitally processed for later analyses. Furthermore, published literature on the Black Desert in general and, to a lesser degree, on the Jebel Qurma region in particular were consulted.

The study area of the Jebel Qurma Archaeological Landscape Project was set out at the onset of the project in 2012. This was done on the basis of a number of major topographic boundaries such as wadi courses and hills. The study area is situated between UTM (Zone 37R) coordinates 323020 E, 3522870 N and 343985 E, 3506805 N – an area of 336 km² large. It is roughly bordered on the west side by Wadi Rajil, on the east and south side by Wadi Qattafi (Fig. 2.1).

2.2. REGIONAL SETTING

The Black Desert derives its name from the seemingly endless blanket of dark basalt boulders and cobbles that covers a low limestone plateau. This basalt surface cover has been formed through the weathering and breaking-up of solidified lava flows (Fig. 2.2), which erupted from the earth's crust mostly between 8.9 and 0.1 million years ago (Bender 1968, 106).

Jordan's Black Desert generally witnesses hot summers with maximum temperatures of between 35 and 38 °C on average, with absolute maxima exceeding 46 °C. In winter the average minima are between 2 and 9 °C, although occasionally it may freeze. Westerly winds predominate year-round (Al-Homoud et al. 1995, 58-9). The climate of the Jebel Qurma region can be characterised as a hot desert climate – or BWh in the Köppen climate classification system (Allison et al. 2000, 354).



Figure 2.2: A *harra* surface in the Jebel Qurma region showing a dense packing of angular basalt rocks. Photo by author.

Today, the Black Desert receives between 150 to 200 mm of average annual rainfall in the north to less than 50 mm in the south, which makes this an arid region unsuitable for large-scale rain-fed agriculture. The Jebel Qurma region is situated in an area that receives less than 50 mm of annual rainfall. Precipitation usually only occurs from November through May, although most of it falls from December through March, and usually in the form of short but heavy storms (Al-Homoud et al. 1995, 58). It should be noted, however, that such precipitation trends are averages and can greatly vary between one year and the next. Rainfalls may be very localised in desert regions, and may thus result in the presence of surface water in one region while a neighbouring area located only a few kilometres away may remain



Figure 2.3: Two conditions of Wadi Rajil: completely dry showing steeply carved out banks; and filled with fast flowing water after torrential rains. Photos by P. Akkermans.

dry (Laity 2008, 56). Also, long periods of drought may occur. In fact, short-term dry spells lasting a few decades may occur in the Middle East (e.g. Cook et al. 2016; Enzel et al. 2003), which have severe repercussions for an environmentally marginal area such as the Black Desert, possibly resulting in rendering certain regions completely dry for years on row. The availability of surface water and the degree of soil moisture are equally erratic. Runoff rates are usually high as well given the low permeability of soils in the Black Desert and the widespread presence of desert pavements. Water from rainfall is thus quickly carried off, either to major wadis (Fig. 2.3) or, in many cases to mudflats. A mudflat (or *qa'a* in Arabic) occurs at the bottom of a so-called endorheic or closed basin where runoff water is contained on the surface as a shallow temporary lake until evaporated (Fig. 2.4). Silts carried within the water are deposited here to form a mudflat. Mudflats also occur in wadis if the wadi gradient is limited, in which case the mudflat is called *marab* rather than *qa'a* (Allison et al. 2000, 362).



Figure 2.4: A mudflat before and after heavy rainfall. Photos from the Jebel Qurma region by author and P. Akkermans.

As a consequence of the hydrological conditions of the Black Desert at large, surface water may be transported from areas of high rainfall to comparatively dry regions. This has major consequences for the Jebel Qurma region as it receives surface water from rainfall occurring dozens of kilometres away. The Jebel Qurma region is located on the border of three water drainage systems (Fig. 2.5), all of which are endorheic basins. The largest of these systems is the Azraq basin, covering an area of over 10,000 km². At its centre lies the Azraq oasis which contains permanent water year-round – even though nowadays artificial maintenance of the springs is required to counter large-scale modern pumping activities. One of the major wadis of the Azraq basin is Wadi Rajil, which originates on the slopes of Jebel Druze in Syria. Wadi Rajil runs through the northwest part of the Jebel Qurma region and, importantly, may carry large amounts of water through the region.

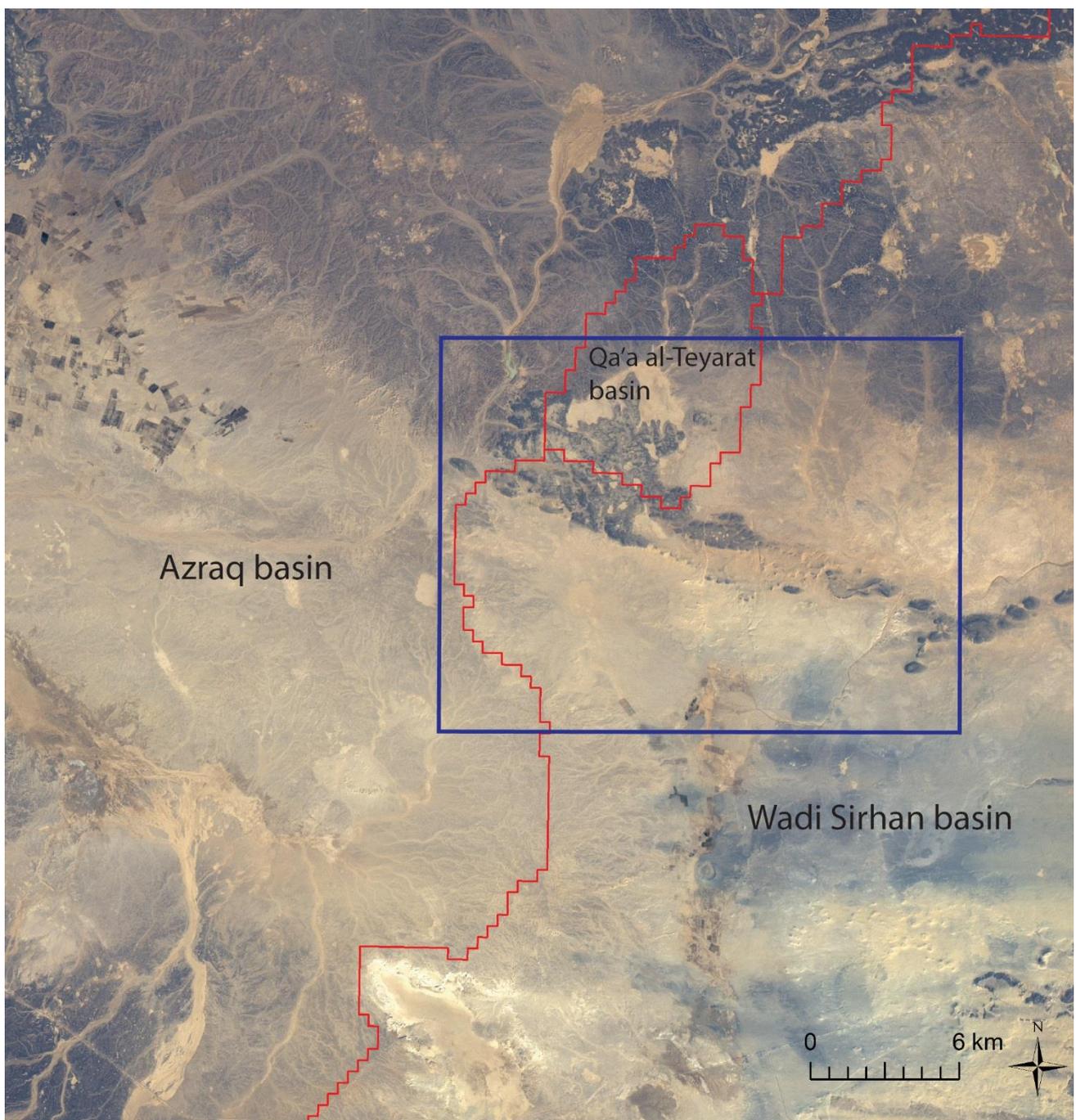


Figure 2.5: The Jebel Qurma region, outlined in blue, is part of three drainage basins whose borders – or watersheds – are indicated in red. Base map: true colour Landsat 7 image. Watershed boundaries are based on HydroSHEDs data.

The second drainage basin that is partially situated in the research area is part of the Wadi Sirhan system which is a low-lying area comprising multiple drainage basins distributed over a northwest-southeast axis. A major wadi of the Sirhan system is Wadi Qattafi which runs through the Jebel Qurma region and culminates at the small oases of Ghamr, situated in the south of the research area, and further south at Hazim, which is known already from historical times because of the presence of wells. The Wadi Qattafi drainage system is mostly situated to the northeast of the Jebel Qurma region. The catchment area of the Wadi Qattafi is much smaller and situated in a more arid region in comparison with the Wadi Rajil catchment area, and thus carries smaller amounts of water through the Jebel Qurma region.

The third drainage basin is a relatively small, localized endorheic basin of about 65 km² with at its centre an extensive qa'a that is locally known as the Qa'a al-Teyarat (or *Flat of the Airplanes* – derived from its use as an airstrip in the colonial past), where surface water from local rainfall may collect in wet seasons.

There are a few places situated at the fringes of the Black Desert where water is available permanently, such as at the larger oasis towns of Azraq in Jordan and Jawf in Saudi Arabia. Additionally, there are a number of small pools — sometimes artificially created in the past — such as at Wisad and Burqu' in Jordan, and at Nemara in Syria.

The dry, stony basalt region that makes up the Black Desert is bordered to the northwest by the Hauran region. This is also a basalt-covered region but receives much more rainfall annually which makes it a highly fertile region suitable for agriculture. To the north, east, and west, however, extend the vast and dry plains of the *hamad*, covered by limestone gravel and, in places, by a desert pavement of flint that eroded from the limestone substrate. Together the *harra* and *hamad* make up a larger desert region known in Arabic as the *Badiyah as-Sham*, or in western terminology as the Syrian Desert. It is bordered in the north by the Euphrates river and in the south by the Nefud desert in central Arabia. The latter also forms the southern boundary of the *Harrat al-Sham*. It is also here, on the border between the *harra* and the Nefud, that the historically relevant oasis of Jawf is situated. The Jebel Qurma region is situated on a border zone between *harra* and *hamad*. To the north extend more *harra* landscapes that continue almost uninterrupted into southern Syria. To the west, south, and east, however, *hamad* landscapes stretch out comprising gravel plains and low, flint-covered hills.

In terms of vegetation, the Black Desert lies in the Saharo-Arabian desert vegetation zone, in which Al-Eisawi (1985) has defined four sub-zones based on soil types, including *harra* soils, gravelly (*hamad*) soils, wadi soils and saline (mudflat) soils. Each of these sub-zones hosts a number of plant species. Large shrubs such as *Tamarix*, and *Retama raetam* mostly grow in wadis whereas smaller shrubs, such as *Artemisia herba-alba*, *Atriplex*, *Astragalus* and other may also occur in gravelly soils beyond wadis. Annuals such as *Anthemis deserti* and *Asteriscus pygmaeus*, as well as grasses, are entirely restricted to the *harra* landscapes where they may quickly grow in the event of rainfall. Mudflats host a number of salt-tolerant species such as *Nitraria retusa* but also large *Tamarix* shrubs (Cordova 2007, 104-6; Al-Eisawi 1985).

To what degree the climate and environmental conditions in the Black Desert may have differed in the past is at this point difficult to say. There are hardly any published palaeoclimatological or environmental proxies in the Black Desert from the Late Holocene. The presence of nomadic camel- and shepherders that is attested in the region based through the Safaitic inscriptions and petroglyphs suggests that that environmental conditions may have resembled present-day conditions, although only to a very limited degree. This would suggest strong seasonal fluctuations in the availability of resources vital to a pastoralist economy — most notably water and pastures — which is corroborated by epigraphic sources from the region itself (see Chapter 1). Nevertheless, the region may also have been affected by changes in climatic conditions that occurred during the Late Holocene in the eastern Mediterranean region. Such oscillations can be observed in climatic proxies from regions further to the west,

such as the Dead Sea, Soreq Cave near Jerusalem, and the eastern Mediterranean (Bar-Matthews & Ayalon 2004; Bookman et al. 2004; Migowski et al. 2006; Neumann et al. 2007; Orland et al. 2009; Schilman et al. 2001; 2002). Whereas much of the first millennium BC is generally associated with relatively arid conditions, with precipitation rates much lower than today (Bar-Matthews et al. 1998; Roberts et al. 2011), a more humid phase seems to have started sometime towards the end of the millennium. Climatic data from lake sediments of the Dead Sea indicate that this humid phase started somewhere between ca. 500 and 200 BC (Bookman et al. 2004; Migowski et al. 2006; Neuman et al. 2007), whereas proxies from Soreq Cave and the eastern Mediterranean date the starting point to ca. 50 BC (Schilman et al. 2002). This humid period seems to have lasted until about AD 700, although the Dead Sea proxies indicate that it may have been interrupted by a period of aridity between ca. AD 50 and 400 (Migowski et al. 2006). Others have dated this intermediate dry spell in the Levant between ca. AD 300 and 470 (Izdebski et al. 2015). The onset of increased aridity around AD 700 is well attested at the Dead Sea, Soreq Cave and eastern Mediterranean cores, and seems to have continued until about AD 1100 (Bar-Matthews & Ayalon 2004; Izdebski et al. 2015; Migowski et al. 2006; Schilman et al. 2001; 2002). Although the various proxies are not conclusive about the exact chronology and magnitude of these climatic oscillations they seem to represent fairly well established trends for the Levantine region. However, to what degree and how climatic conditions affected more localized environmental conditions is much more difficult to ascertain, as the climatic effects on environmental conditions vary from region to region and are hard to predict. More detailed information on environmental conditions and oscillations therein regarding the Black Desert during Classical and Late Antiquity therefore remain scarce. One notable exception in this respect is a recent study on pollen samples from the Azraq oasis, from which it was concluded that Azraq and its surroundings were dominated by a Saharo-Arabian vegetation type between ca. AD 600 and 1400 (Woolfenden & Ababneh 2011), which is comparable to today's vegetation type (see above).

Other issues that remain unresolved is how reliable environmental conditions were in the Black Desert, and the degree of fertility of its soils. Nowadays, the timing and amount of rainfall in the region is highly unpredictable. In some years, no rain at all may fall, while in other years short but heavy storms may cause flooding of wadis. Furthermore, in times of rainfall the high water runoff rates prevent moist absorption by soils and the growth of vegetation. Although it is not unthinkable that soils of much higher fertility may have been present in the region in the past (Rollefson et al. 2014; Rowan et al. 2015), any evidence for this is at this point unavailable. Also, if and to what degree rainfall was more predictable in the past is currently unknown.

2.3. MODELLING THE PHYSICAL GEOGRAPHY OF THE JEBEL QURMA REGION

Having discussed the regional setting of the Jebel Qurma region, the physical geography of the study area itself will now be presented in more detail. While studies of the physical geography of the Black Desert in general abound, more detailed information on the Jebel Qurma region itself is much more scarce. Part of what is presented below therefore represents new data that has been acquired through satellite remote sensing, and landscape models that were created based on these data, especially in terms of topography, surface cover, and visibility.

2.3.1. Data acquisition and processing

The discussion of the physical characteristics of the study area below is based on a variety of datasets. What follows is a brief description of these datasets and the way in which they were digitally processed to be incorporated and analysed in a Geographic Information System (GIS). The GIS software package

used in this study is ArcGIS. Detailed descriptions of data processing and modelling procedures, including the steps followed and tools used in ArcGIS, can also be found in Appendix A.

Hardcopy maps

Topographic maps of the study area that were obtained from the Jordanian Natural Resource Authorities for the purpose of the project included four 1:50,000 scale hardcopy maps (sheets 3453 I to IV) that were digitally scanned and mosaicked. Geological maps covering the Jebel Qurma region with the same sheet numbers were obtained and processed in a similar way. These geological maps were published together with short but insightful reports (Abdelhamid 1999; Rabba' 1998; 2005). The features from these maps, including geological and geomorphological units, were then digitally traced in ArcGIS. Comparisons with more recent satellite imagery, however, indicated that the accuracy of these maps is fairly limited, and additional datasets on local geological conditions were thus required.

Satellite imagery

Different types of satellite imagery were obtained that were able to provide information on local geology, topography and hydrology. The first are Landsat images, which are low-resolution satellite images that are freely accessible online through the United States Geological Survey. Landsat is the name of a long-term satellite photography mission that started in 1972 with the launching of the Landsat 1 satellite and has since launched seven more earth observing satellites. Three of these satellites are still oper-

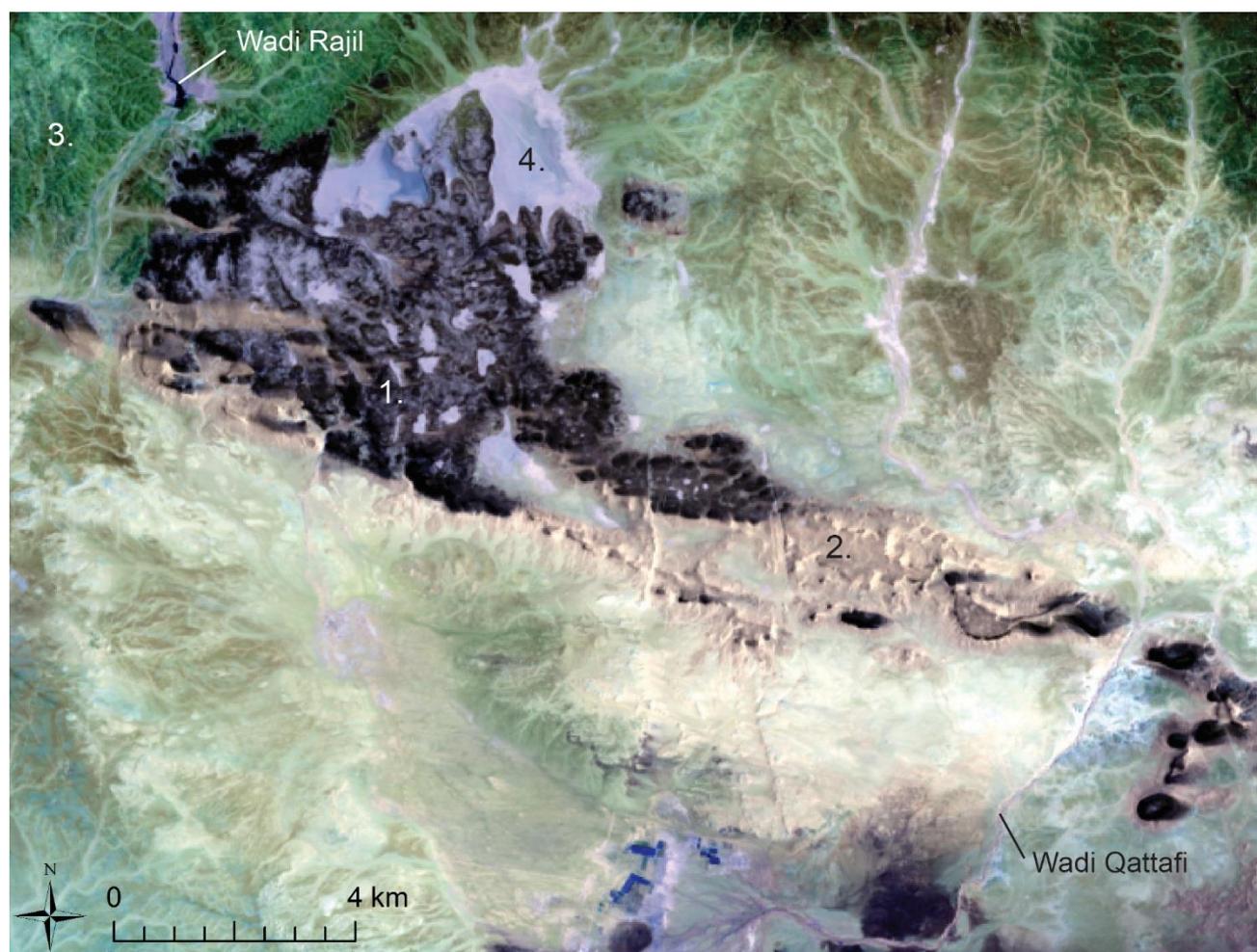


Figure 2.6: The Jebel Qurma region on false colour Landsat 8 imagery (bands 7-6-5), highlighting lithological differences on the surface, such as (1) basalt, (2) sand covering basalts, (3) chert and (4) mudflats.

ational at this moment (Landsat 5, 7 and 8). The cameras on these satellites are multispectral, meaning that they record different wavelengths of light including those that lie beyond what can be recorded with the human eye, such as infrared (IR) and near-infrared (NIR) wavelengths. The spatial resolution of the imagery varies between 120 m and 15 m, depending on the recorded wavelength. The imagery is thus not suitable to detect small archaeological features. Rather, their advantage lies in combining different bandwidths to study specific phenomena, such as water bodies, vegetation, or other types of surface cover. Furthermore, through their digital availability free of cost, as well as the frequent updates of imagery, Landsat images can be used to study relatively rapid developments on the earth's surface, including developments in surface water and vegetation (cf. Parcak 2009, 58-64).

Another type of optical satellite imagery used for this study is Ikonos imagery. This was originally a product of the commercial satellite company GeoEye, and the Ikonos satellite has produced optical imagery of the earth's surface between 1999 and 2015. The imagery has a high spatial resolution, i.e., of about 0.8 m. Also, the imagery has five bands: panchromatic, blue, green, red, and NIR. Ikonos imagery was acquired from the Jordan Oil Shale Company (JOSCO) as a derived product, meaning that all processing was done by JOSCO prior to acquisition. The imagery had been orthorectified using a 30 m ASTER GDEM and 12 ground control points, and pan-sharpened in 80 cm resolution. The imagery could be directly imported in ArcGIS.

Although hardcopy geological maps were available for the study area, these proved to be of limited spatial accuracy. Therefore, Landsat 8 imagery was used to model the surface cover in the Jebel Qurma region. A combination of bands 7 and 6 (shortwave infrared light) and 5 (near-infrared light) was used to classify the Landsat imagery based on surface cover. This band combination highlights lithological differences on the imagery, as different rock or soil surfaces reflect different wavelengths of light that especially fall in the shortwave infrared and near-infrared light spectra (Leverington & Moon 2012). The resulting imagery (Fig. 2.6) was classified following a Supervised Classification procedure in ArcGIS (see Appendix A). Signature polygons were created on the basis of high resolution Ikonos imagery and geological maps, on which different land cover areas could be identified, while the actual signatures were derived from the Landsat composite raster containing the near- and shortwave infrared bands. On the basis of these signatures the Landsat raster covering the complete study area was classified in terms of surface cover.

Satellite imagery containing information on the topography of the entire study area included Shuttle Radar Topography Mission (SRTM) images, which consist of elevation data in a ca. 90 m resolution raster. More accurate elevation data includes WorldDEM radar data that was obtained from Airbus Defense & Space. WorldDEM data is of much higher spatial resolution, i.e. 0.4 arc-second or ca. 12 m per pixel, and is based on imagery from the TerraSAR-X and TanDEM-X satellites. Both SRTM and WorldDEM data could be used to produce Digital Elevation Models (DEMs) of the study area, which were subsequently used to create other topographic models. WorldDEM data was only available for the western part of the study area (see Fig. 2.7), and subsequent use of this data in landscape modelling procedures is therefore confined by this data extent (see, e.g., Figs. 2.14 & 2.20). Such modelling procedures included the calculation of slope degrees and profile curvatures in the study area (see Appendix A), and the creation of a Hillslope Position Classification (HPC) raster in ArcGIS, based on WorldDEM data. In an HPC raster topographic features are classified according to three different variables: slope degree, profile curvature, and relative elevation (following Miller 2014; Miller & Schaetzel 2015). On the basis of these variables a differentiation was made between topographic lows, modest slopes, steep slopes, shoulders (or ridges), and topographic highs (see Appendix A for digital modelling procedures).

The WorldDEM raster was further used to carry out a number of analyses related to visibility. It was used to define areas in the landscape that are visually more prominent than others, such as hilltops, extensive plains, and so on, i.e., locations that can be observed from many points within the landscape.

Less prominent locations are areas that are often hidden from view, i.e., secluded areas such as deep valleys and depressions in the landscape. In order to differentiate between different degrees of visual prominence a cumulative viewshed was created of the area covered by the WorldDEM dataset (see Appendix A). In a viewshed, the visibility of each cell of a DEM from one or multiple locations in the landscape – or ‘observer points’ – is calculated. The value of each cell of a viewshed raster indicates from how many observer points the cell is visible. In a cumulative viewshed, the values of multiple viewsheds are summed. In a cumulative viewshed a differentiation is made between locations in the landscape that are generally more visible than others. It thus calculates the degree of visual prominence of each location in the landscape.

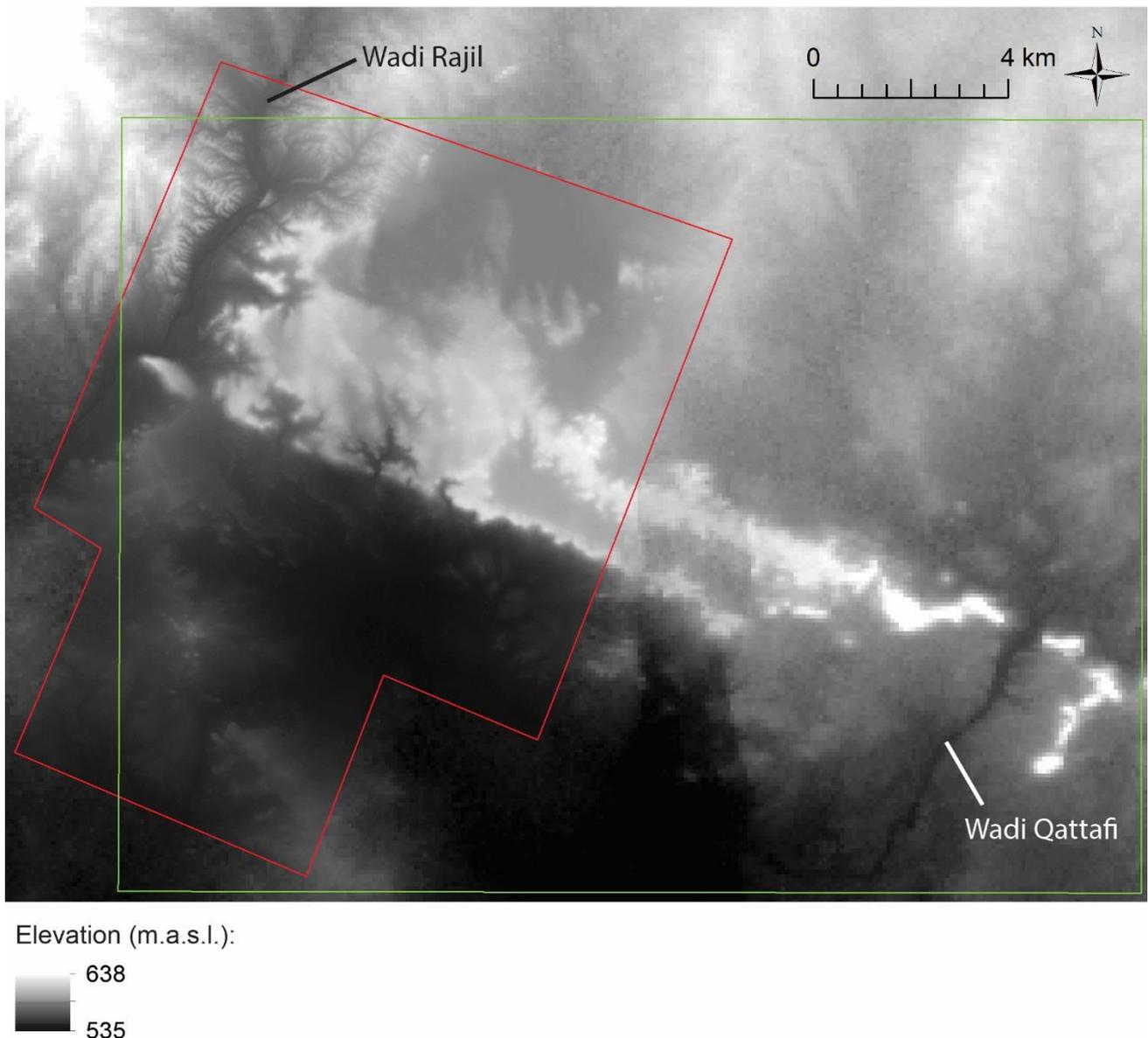


Figure 2.7: A 90 m resolution SRTM DEM of the Jebel Qurma region (green) overlain by a 12 m resolution WorldDEM (red).

The WorldDEM data was also used to define locations in the landscape that represent dominant features along the horizon. Although what is visible along the horizon depends largely on the location of an observer, it is possible to differentiate between parts of the landscape that are more often visible along the horizon than others. These features represent the ‘skyline’ of a landscape which, although not visible from every location in the landscape, are visible on the horizon more often than other features.

The 'Skyline' tool in ArcGIS was used to create such skylines, and was specifically calculated using observer points placed in areas representing topographic lows, following the Hillslope Position Classification (see Appendix A). By doing so, a map was created showing features that are most dominant along the horizon when looking around from low-lying areas in the landscape.

Furthermore, the surface cover classification derived from Landsat 8 imagery and the slope degrees derived from WorldDEM data were combined to create a cost surface raster, in which the relative costs of movement through a particular area are calculated. In this model, cost of movement is based on two parameters, being the degree of slope and surface cover of the terrain. This is based on the assumption that passing over steep slopes is more costly than over flat areas, and passing through rough surfaces, such as basalt is more costly than passing over even surfaces, such as limestone/sandstone. Slope and surface cover classes were scaled from 1 to 10 and compared, resulting in a cost surface raster that represents relative costs of movement (see Appendix A).

Satellite data on the hydrology of the study area included HydroSHEDs data, which is a derivative of SRTM imagery compiled by the WWF Conservation Science Program. HydroSHEDs is an abbreviation of 'Hydrological data and maps based on Shuttle Elevation Derivatives at multiple scales' and contains hydrological information on, for example, drainage networks and watershed boundaries on a large geographic scale. For hydrological modelling on a local scale, i.e. the scale of the study area, WorldDEM data was used. On the basis of WorldDEM data the Hydrology toolbox in ArcGIS was used to model wadi courses and drainage basins in the study area, as well as to model tributary valley systems and endorheic basins (see Appendix A).

2.3.2. Geology

The Jebel Qurma region hosts a variety of geological formations and fault lines that form the basis of its geomorphology, topography and hydrology. These formations (Fig. 2.8) will now be further discussed in chronological order.

The oldest formation in the Jebel Qurma region is the Umm Rijam Chert-Limestone formation, which is a marine bottom formation dated to the Lower to Middle Eocene. It consists of whitish to beige limestone with beds of red-brown or grey to black chert. The formation is between 30 and 85 m thick (Abdelhamid 1999, 10-12; Rabba' 2005, 5). The geological maps of the study area indicate that it is mostly present at the surface in its northwest and northeast corners, as well as on some isolated hills within Wadi Rajil.

The Umm Rijam formation is covered in placed by the Wadi Shallala Chalk formation, which dates to the Middle Eocene and is also a sedimentary marine bottom deposit. It is characterised by white-grey to yellow chalk, and thin beds of chert. This formation is up to 28 m thick (Abdelhamid 1999, 12; Rabba' 2005, 5-6). The geological maps indicate that it is mostly present in the east part of the Jebel Qurma region.

Covering parts of the Umm Rijam and Wadi Shallala formation is a particular type of basalts that are part of the Wisad group. These basalts date between ca. 13 and 8 mya and are mostly grey to light grey in colour (Rabba' 2005, 11-12). They are mostly present in the central southern parts of the Jebel Qurma region. A particular basalt formation that is part of the Wisad group is Wadi as-Subhi basalt, which is typically formed in large plates, and may have been an important building material. It is therefore important to note that these basalts of the Wisad group cannot be found in the study area, but only in regions further to the east. In the Jebel Qurma region, non-platy Wisad basalts are found in a relatively small area in the southeast part of the region.

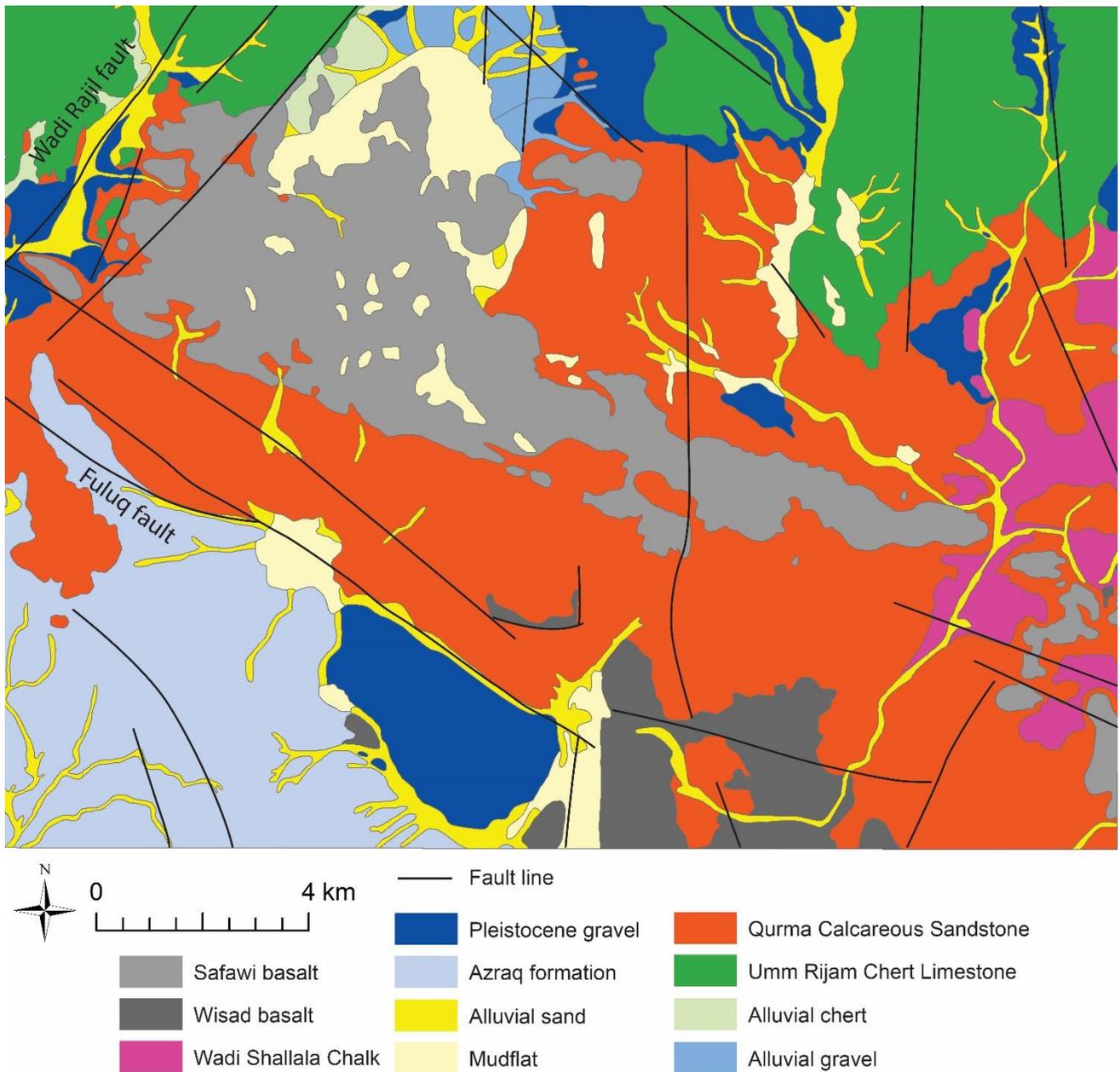


Figure 2.8: Geological map of the Jebel Qurma region. Adapted from Abdelhamid (1999) and Rabba' (1998; 2005).

Another sedimentary formation, this time slightly younger than the Wisad basalts, is the Qurma Calcareous Sandstone formation, dated to the Late Miocene. It overlies the Wadi Shallala and Wisad formations. The Qurma formation consists of sandstones of various colours – from white to pink to reddish brown – and is often covered by light grey to beige quartzites. This formation is up to 29 m thick (Abdelhamid 1999, 12-14; Rabba' 2005, 5-6). In the Jebel Qurma region it is found mostly in the central and southeast areas.

The main body of basalts in the study area are part of the Safawi group, which dates to ca. 8.9-8.7 mya, and is slightly younger than the Wisad basalts and the Qurma Calcareous Sandstone formation. These basalt also overlie the Wadi Shallala formation in places. The Safawi basalt flows are between 10 and 50 m thick, although they are usually heavily weathered into irregularly shaped angular blocks of a dark blueish grey to brownish or black colour. Their texture is usually relatively dense, although more vesicular basalts may occur in places (Abdelhamid 1999, 5; Rabba' 1998, 7; Rabba' 2005, 14). Safawi

basalts are centrally located in the Jebel Qurma region, almost like an island of basalt, surrounded by sedimentary formations.

A relatively young sedimentary formation, dated to the Plio- and Pleistocene, and thus post-dating the Safawi basalts, is the Azraq formation. It is lacustrine formation and consists of a mixture of sedimentary rock types, including sandstone, limestone, gypsum, but also loose sands, silts and gravels, although the upper, exposed parts mainly consist of limestone and sandstone (Abdelhamid 1999, 14-15; Rabba' 1998, 12). The Azraq formation mostly occurs in the southwest corner of the study area.

Covering large parts of the Jebel Qurma region is a series of what are described as superficial Quaternary deposits, and may cover the older formations to a large extent. These deposits consist of two main components, being Pleistocene gravels and Holocene alluvial deposits. The Pleistocene gravels consist of a combination of chert, limestone and basalt clasts. These gravels often form a desert pavement with a distinctive dark colour. The Holocene alluvial deposits consist of sandy deposits in wadis, where the sands also contain cobbles and pebbles of chert and limestone, and mudflat deposits composed of silt, silty clay and fine sand. Additionally, Holocene deposits include alluvial fans running down eroded hillslopes (Abdelhamid 1999, 15; Rabba' 1998, 12; Rabba' 2005, 9). In the Jebel Qurma

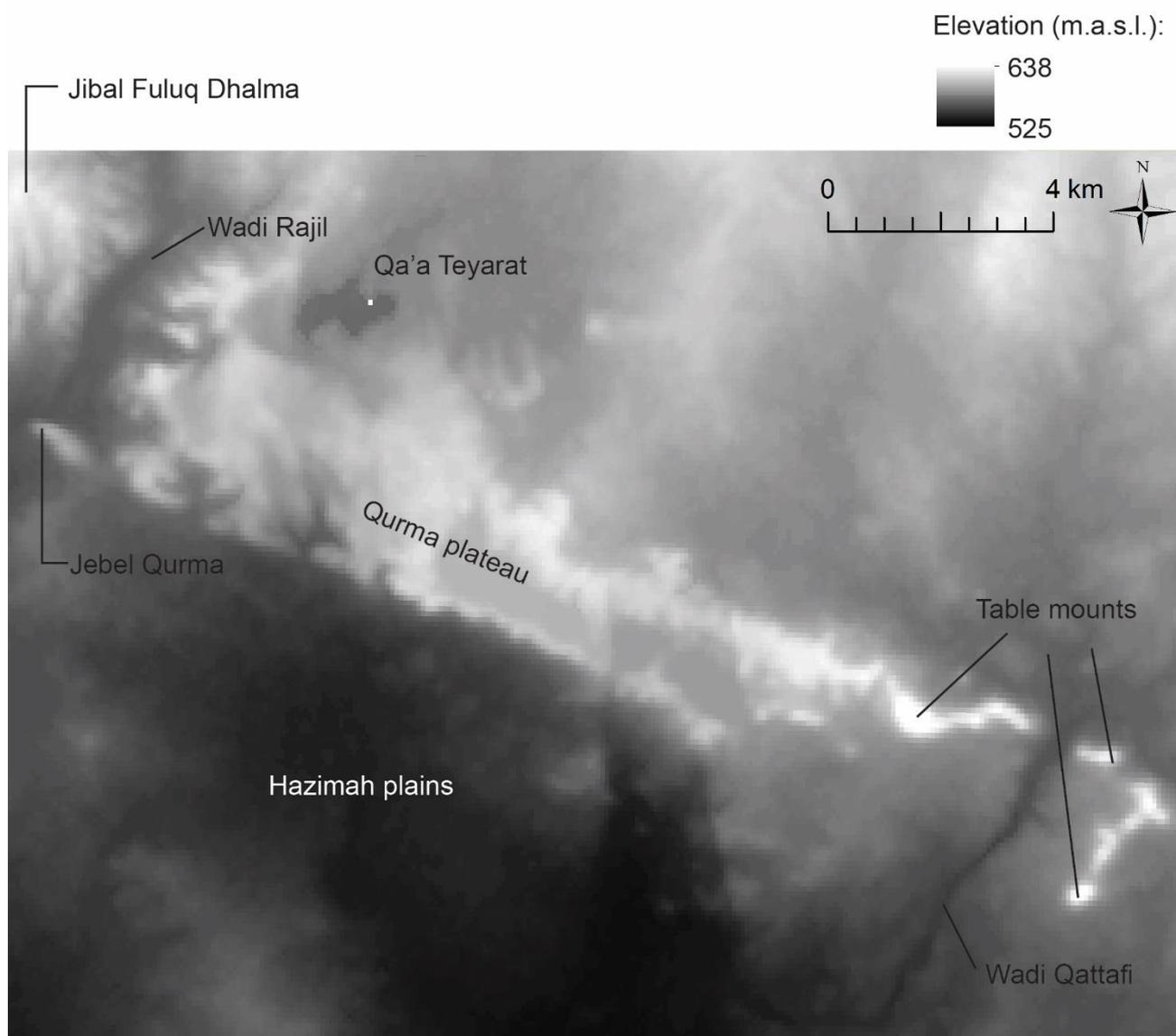


Figure 2.9: Elevation map of the Jebel Qurma region with relevant topographic features indicated. Base map: SRTM DEM.

region Pleistocene desert pavements mostly occur around a number of major wadis in different parts of the study area, whereas Holocene alluvial deposits are found within wadis and mudflats. Mudflats are mainly situated in endorheic basins but also within a number of wadis.

In addition to rock formations a number of major fault lines are also depicted on the geological maps of the Jebel Qurma region. These have influenced the topography of the study area to a large degree. The first of these is the Fuluq fault, which runs in a arc in a more or less NW-SE trajectory through the Jebel Qurma region, and has resulted in the formation of a steep escarpment, dividing the region into a relatively high region to the north of this fault, and a low region to the south (see below). Another major fault line is the Wadi Rajil fault, which runs in a NE-SW trajectory through the region and has contributed, as its name suggest, to the formation of Wadi Rajil.

2.3.3. Geomorphology

In this paragraph the geomorphology of the Jebel Qurma region is presented, including its topography and surface cover. This is partially based on the description of the geology of the study area presented above, but also on additional datasets including satellite data.

Topography

The Jebel Qurma region is characterised by a variety of topographic features including table mounts, valleys, ridges and plains (Fig. 2.9). A chain of topographic highs, comprising hills, plateaus and table mounts, is situated in the centre of the study area running in a roughly NW-SE direction. These hills were formed through tectonic uplift associated with the Fuluq fault that runs parallel to this chain (see above). On the east and west part of the study area this chain is dissected by two major wadis – Wadi Rajil in the west, associated with the Wadi Rajil fault and Wadi Qattafi in the east. The central chain of hills reach a maximum absolute elevation of 648 m above sea level. Relative to the plains surrounding this upland, these hills are up to about 75 m high. The upland can be roughly divided into three elements. The first of these is the range of hills known locally as the *Jibal Fuluq Dhalma* (Fig. 2.10). These hills are dissected by numerous wadis that resulted in a large number of ridges, slopes and small valleys.

This type of topography also occurs on the east bank of Wadi Rajil,



Figure 2.10: The Jibal Fuluq Dhalma in the Jebel Qurma region featuring low flint-covered hills intersected by deep, narrow wadis. Photos by P. Akkermans.



albeit only in the northern part of the study area. The second upland terrain is the Qurma plateau (Fig. 2.11) consisting of an elevated plateau bounded by steep slopes on its south and west side. On the north side most of the plateau's slopes are much gentler. A limited number of broad, deep valleys are situated at the edges of the plateau, especially on the south and west side. These valleys are not very long – typically between 0.5 and 1.5km. The top of the plateau is not flat but undulating, featuring low rolling hillocks, smaller valleys, as well as a number of endorheic basins. The third type of topographic highs consist of table mounts, i.e., individual hills with steep slopes and relatively flat, wide tops (Fig. 2.12). A concentration of such table mounts occurs in the eastern part of the study area where the Qurma plateau seems to break up into individual mounts, known locally as *Jibal Qattafi*. More table mounts are situated along Wadi Rajil in the west part of the study area. The most prominent of these is *Jebel Qurma* from which the toponym of the study area was derived.

To the south of the central upland extends a low-lying area known as the Hazimah plains. This is a largely flat area with scattered undulations such as hillocks, low plateaus and table mounts with a relative height between 5 and 25 m (Fig. 2.13). Similar plains extend to the north of the central hilly chain, although the absolute elevation of these northern plains is

Figure 2.11: The Qurma plateau with steep slopes leading up to an extensive upland from which broad valleys run down. Photos by P. Akkermans.



Figure 2.12: Table mounts in the Jebel Qurma region, including Jebel Qurma (top) and an aerial view table mount near Wadi Qattafi (bottom). Photographs by P. Akkermans (top) and Don Boyer (bottom; courtesy of APAAME).

Figure 2.13: Extensive gravel plains and low isolated hillocks in the Hazimah area of the Jebel Qurma region. Photos by author.

higher than the Hazimah plains. These plains also feature scattered elevated terrains.

In addition to the rather undulating terrains described thus far there are a number of areas in the study area that are almost completely flat. These areas are present at the bottom of endorheic basins where silts brought in by runoff water have accumulated to form mudflats. Several small flats are present on the Qurma plateau. The much larger Qa'a al-Teyarat is situated on the northern edge of the plateau (Fig. 2.4).

A classification of the topographic features of the western part of the Jebel Qurma region was created following a Hillslope Position Classification procedure (see above), the result of which is depicted in Figure 2.14. This model shows a relative classification of the topography rather than an absolute one, which has a number of advantages. First of all, it allows for the identification of topographic high places not only in absolute terms, but also in relative terms, i.e., relative to an area's direct surrounding. The HPC model thus shows the presence of local topographic highs, consisting of low plateaus and table mounts, in the Hazimah plains – a region that is a low-lying area in absolute terms. The model furthermore highlights topographic lows, consisting of shallow basins and valley floors, within the Qurma plateau – an upland area in absolute terms. The model furthermore highlights different slope classes – modest and steep ones – which are largely situated on the south and west side of the Qurma plateau but also in the Fuluq hills and Hazimah plains. Finally, well pronounced ridges are present on many of the border zones between slopes and topographic highs. Most of the area for which the HPC was produced – restricted by the extent of the WorldDEM data – was classified as a topographic low (Fig. 2.15), covering large parts of the Hazimah plains but also part of the Qurma plateau. Topographic highs comprise the second largest class. In many cases high and low areas are not separated by substantial slopes.

Modest and steep slopes cover about 12% of the area, while well pronounced ridges are even more scarce as they cover less than 2% of the area – mostly on the southern and western sides of the Qurma plateau.

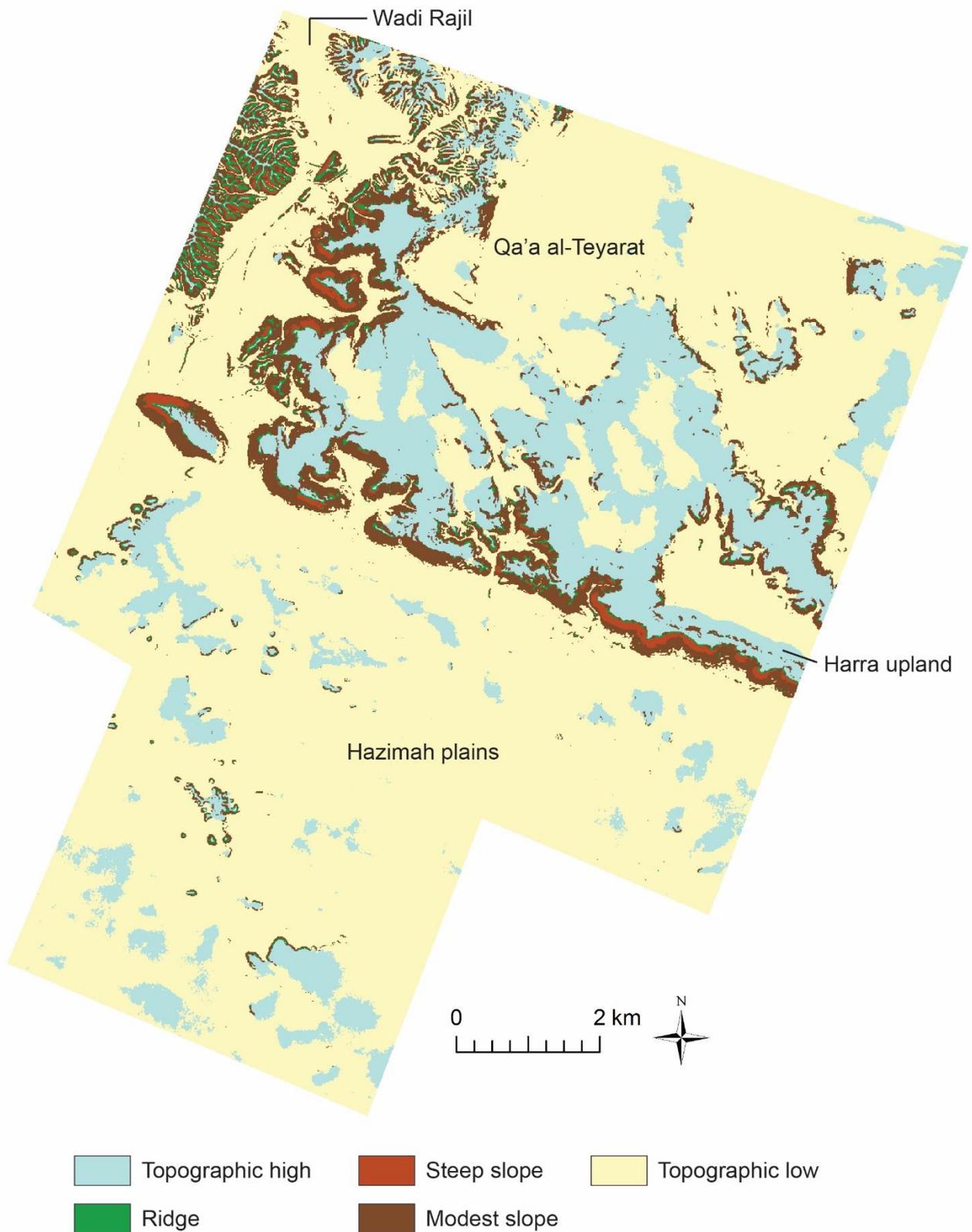


Figure 2.14: Result of a Hillslope Position Classification, which differentiates between various topographic features based on slope degree, elevation, and surface curvature.

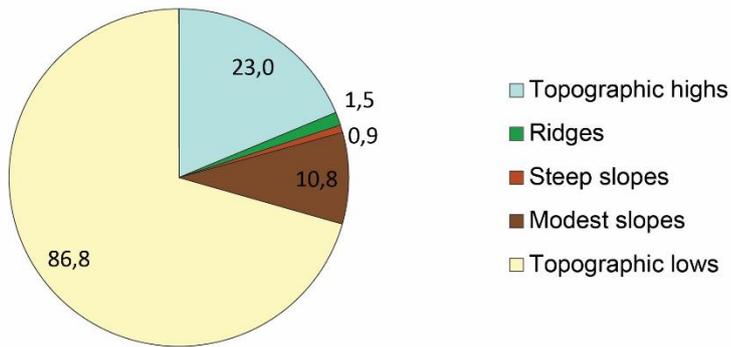


Figure 2.15: Proportion of topographic features in the western part of the Jebel Qurma region, based on the Hillslope Position Classification. Absolute area sizes (in km²) are indicated.

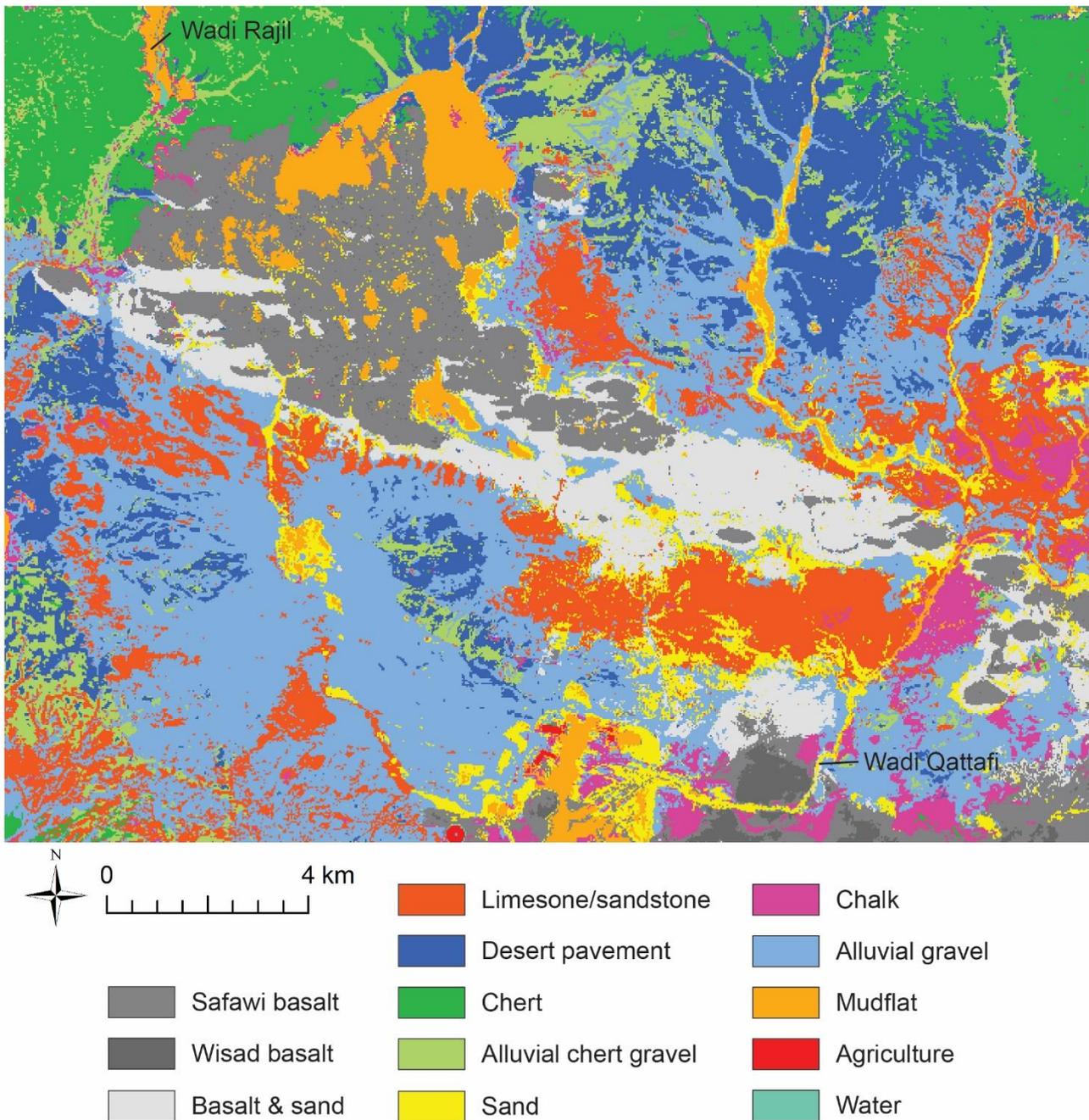


Figure 2.16: Surface Cover Classification of the Jebel Qurma region based on Landsat 8 imagery (see Fig. 2.6).

Surface cover

Surface cover in the Jebel Qurma region is largely governed by the geological formations described above, given the scarce amount of vegetation, surface water, buildings and infrastructure in the area. However, the distribution of lithological formations as depicted on the geological maps is not very accurate, and sometimes even incomplete. For a more accurate representation, the Surface Cover Classification (SCC) based on Landsat imagery was created, as described above.

For the SCC (Fig. 2.16) 13 different classes were defined based on geological formations and observations on high resolution Ikonos satellite imagery. In addition to the geological formations described above, three more classes were defined, including surface water which was only present in small quantities behind the Wadi Rajil dam, agriculture – as observed in a small part of the Ghamr oasis in the south – and basalts partially covered by sands. These sands, which are probably of aeolian nature (cf. Kempe & Al-Malabeh 2010, 49; Rosser 2002, 17), were not depicted on geological maps but were clearly visible on Landsat imagery as mottled brownish areas. Observations on the ground further corroborated the existence of such surfaces (see also Fig. 2.20). For the sake of clarity, these 13 classes can be divided into three general categories, namely *harra* surfaces (basalts), mudflats, and *hamad* surfaces (other non-basalts), of which *hamad* surfaces cover the largest area by far (Table 2.1). These surfaces surround the *harra* landscapes on most sides. Numerous small mudflats can be found within the *harra* landscapes as well, although the largest one by far – the Qa’a al-Teyarat – actually lies on a border zone between the *harra* and *hamad*, in the northern part of the study area.

The area sizes per surface cover are given in Figure 2.17, which shows that Holocene alluvial grav-

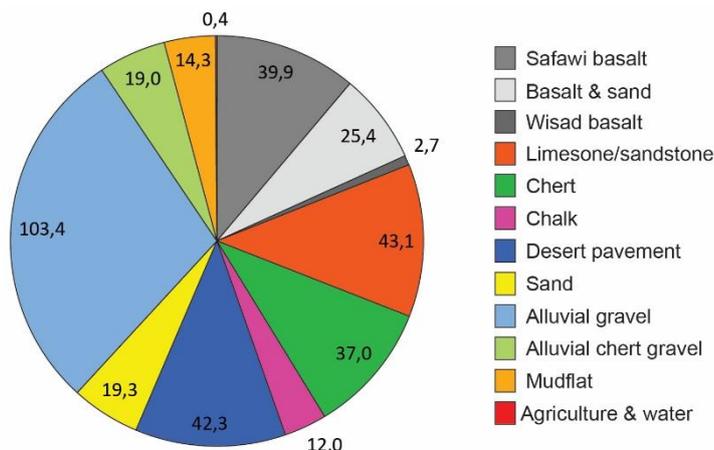


Figure 2.17: Proportion of different types of surface covers in the Jebel Qurma region, based on the Surface Cover Classification. Absolute area sizes (in km²) are indicated.

Surface type	Area size (km²)
<i>Harra</i>	64
<i>Hamad</i>	259
Mudflats	13

Table 2.1: Area size per surface type in the Jebel Qurma region, based on Surface Cover Classification.

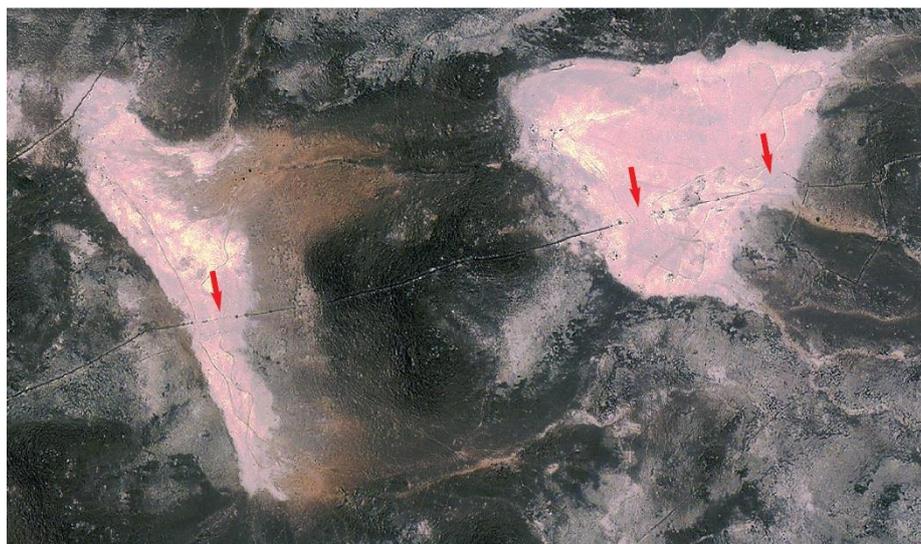


Figure 2.18: Mudflat sediments (pink) in the Jebel Qurma region that appear to have partially buried a wall feature (indicated by the arrows). Base image: Ikonos satellite photo.

els form one of the largest classes, covering more than 100 km², or almost a third of the study area. Since these deposits are broadly dated to the Pleistocene and Holocene (see § 2.3.2.), it cannot be excluded that archaeological remains are buried underneath them. The same may hold for mudflats. Although detailed information about when exactly they developed and how quickly is not available, aerial photographs show that archaeological features are sometimes partially buried by mudflat sediments (Fig. 2.18). Sands may obviously also have covered archaeological remains (Fig. 2.19), although it is again not known exactly when they were deposited. In general terms, it may be surmised that only about half of the surfaces in the study area predate the Holocene, whereas the other half, consisting of alluvial and aeolian deposits, may have been deposited during that period, although when exactly is unknown. This may have implications for the visibility of archaeological remains – something that needs to be tested or at least acknowledged when studying the archaeological data.

The distribution of surface covers can now also be compared to local topography. Basalts mostly occur on the hills and plateaus in the centre of the study area, although only on the Qurma plateau and the adjacent table mounts, rather than on the Fuluq hills. Many sands have accumulated between the basalts particularly in the eastern part of the *harra* landscape, while this has also occurred to some extent in the western part. Wisad basalt is present in the central south, as was indicated on geological maps. As for *hamad* surfaces, it appears that chert gravel surfaces are mostly present in the northern part of the study area, including on the Fuluq hills, and that in the plains more varied desert pavements and alluvial deposits mostly occur. The limestone/sandstone and chalk outcroppings that also occur in these plains largely represent the local topographic highs, i.e., the hillocks, plateaus and low table mounts present here. Mudflat deposits occur in topographic lows representing basins, but also in wadi courses where apparently still standing surface water may be present in wet periods.

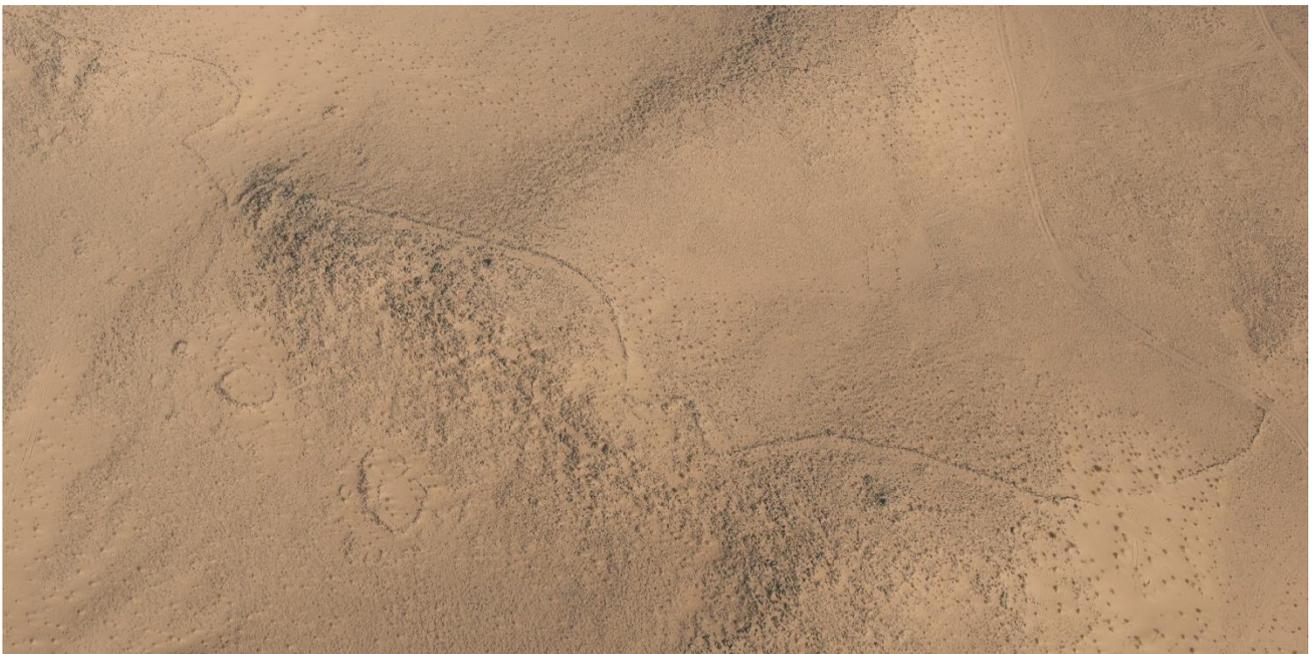


Figure 2.19: Windblown sand deposits in the Jebel Qurma region partially covering a number of archaeological features. Photo by David Kennedy, courtesy of APAAME.

Natural boundaries and corridors

Another issue of importance in terms of geomorphology is the presence of natural boundaries and corridors, as these impact the relative cost of movement through the landscape to potential visitors. In terms of movement, boundaries may be impassable cliffs or water bodies, while corridors may be relatively flat areas or areas with an even, compact surface. Thus, two principle parameters of cost of

movement in the landscape are slope degrees (Fig. 2.20) and surface cover (see above). As shown above, these aspects were calculated and a combination of the two models results in a model that gives insight into relative costs of movement (Fig. 2.21). This model shows, perhaps not surprisingly, that movement is restricted mostly in the basalt covered upland and least restricted in the low lying plains. Steep slopes covered by basalt form the most severe boundaries in terms of movement – although these boundaries are not absolute – while corridors are formed by valleys in which non-basaltic surface covers as well as more gentle slope gradients occur.

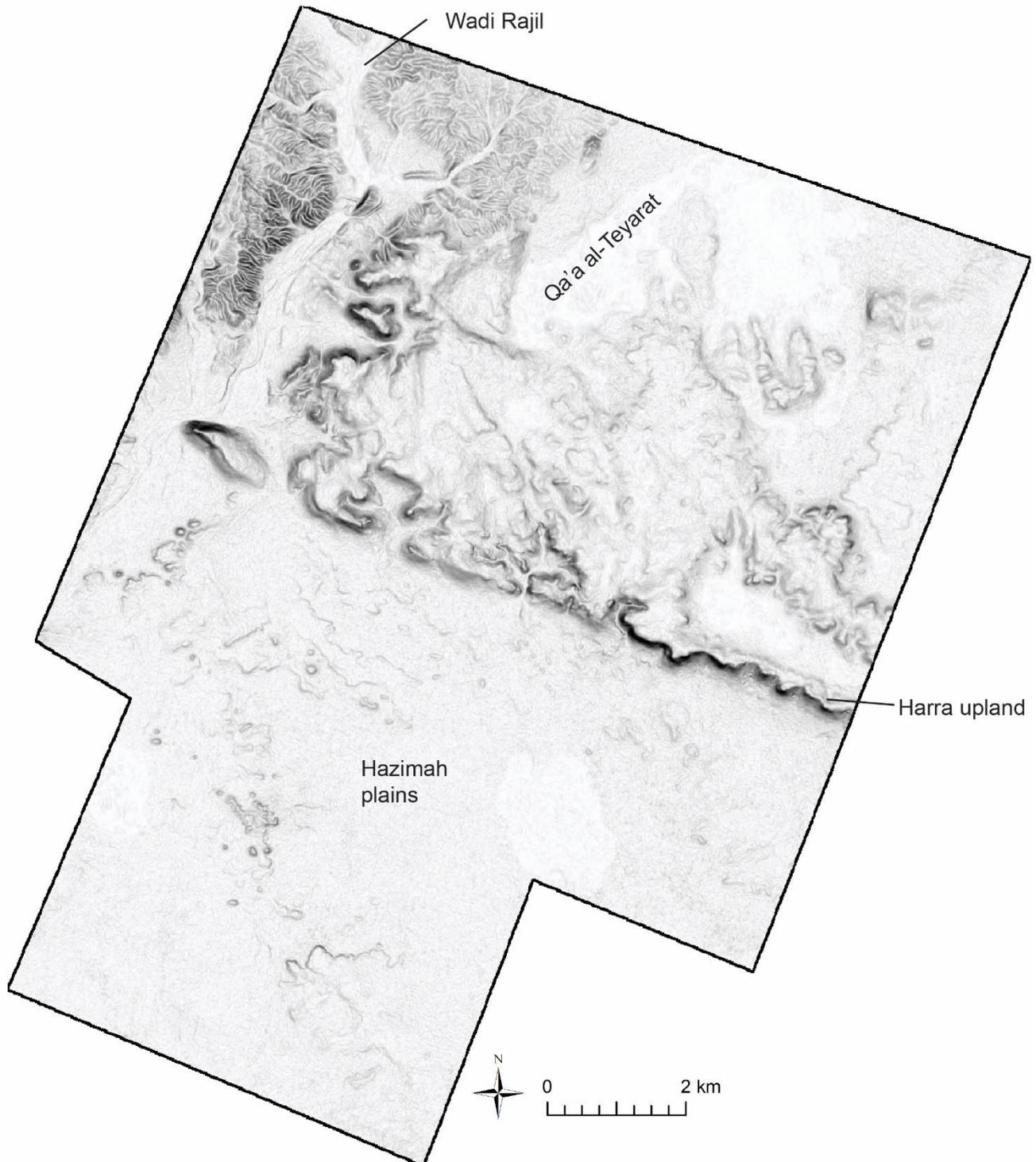


Figure 2.20: Relative degree of surface slope in the western part of the Jebel Qurma region. Darker shades indicate steep slopes while lighter shades indicate gentler slopes. Based on WorldDEM.

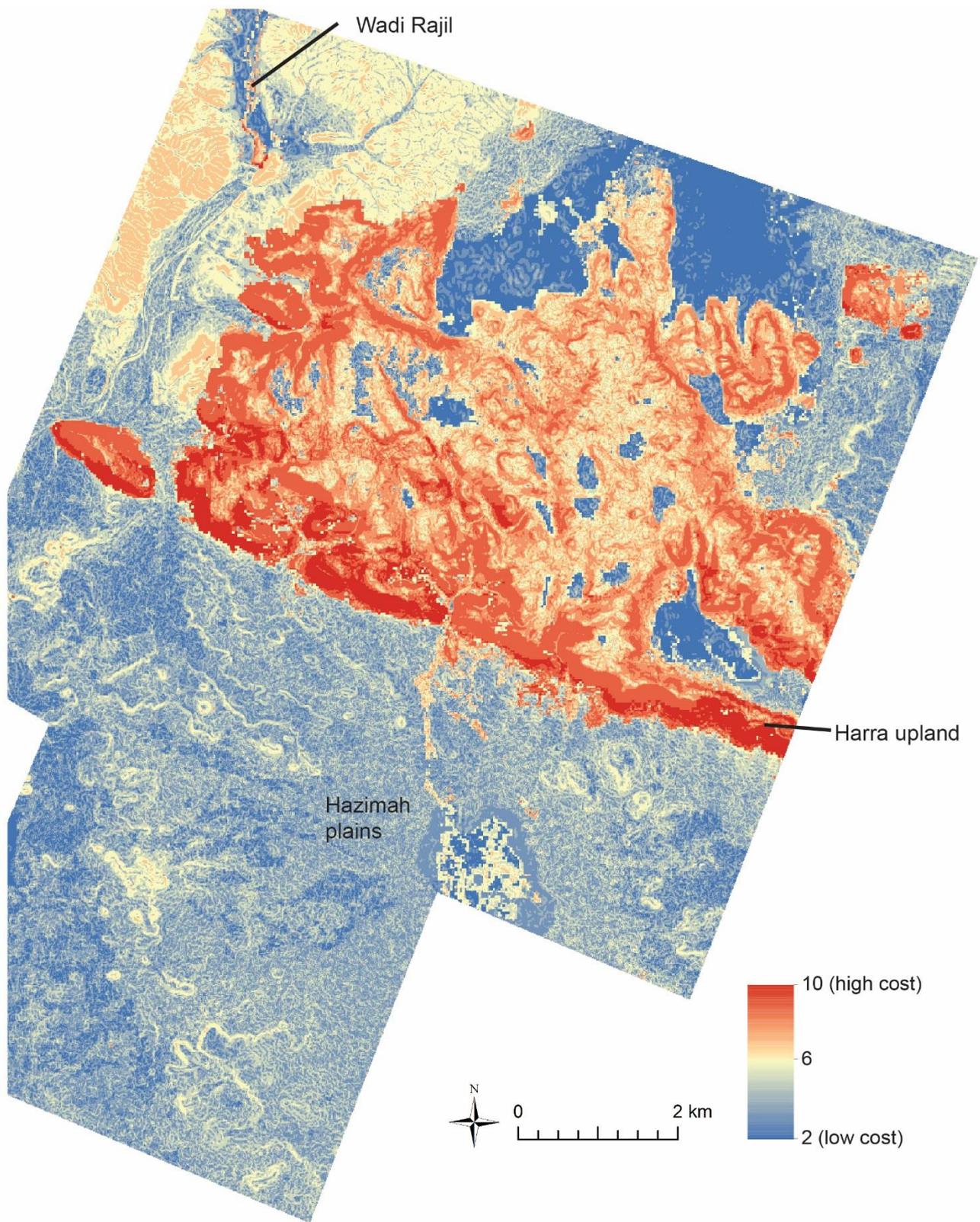


Figure 2.21: Cost Surface Raster showing the relative cost of movement on a scale of 2 (low cost) to 10 (high cost) through the western part of the Jebel Qurma region based on slope degree and surface cover.

2.3.4. Drainage systems

As was noted above (§ 2.2) the Jebel Qurma region sits on the border between two large drainage systems, i.e. the Azraq and Sirhan systems, as well as a third more localized system culminating in the Qa'a al-Teyarat. Numerous wadis are present in the Jebel Qurma region that form the local surface drainage system. The courses of these wadis were modelled (Fig. 2.22) on the basis of WorldDEM data (see above). These wadis stand dry for large parts of the year but may contain water in times of rainfall. Some of the smaller wadi systems are tributaries of larger wadis, such as Wadi Rajil, which eventually debouches in the Azraq oasis. However, a number of small wadis also run into local mudflats.

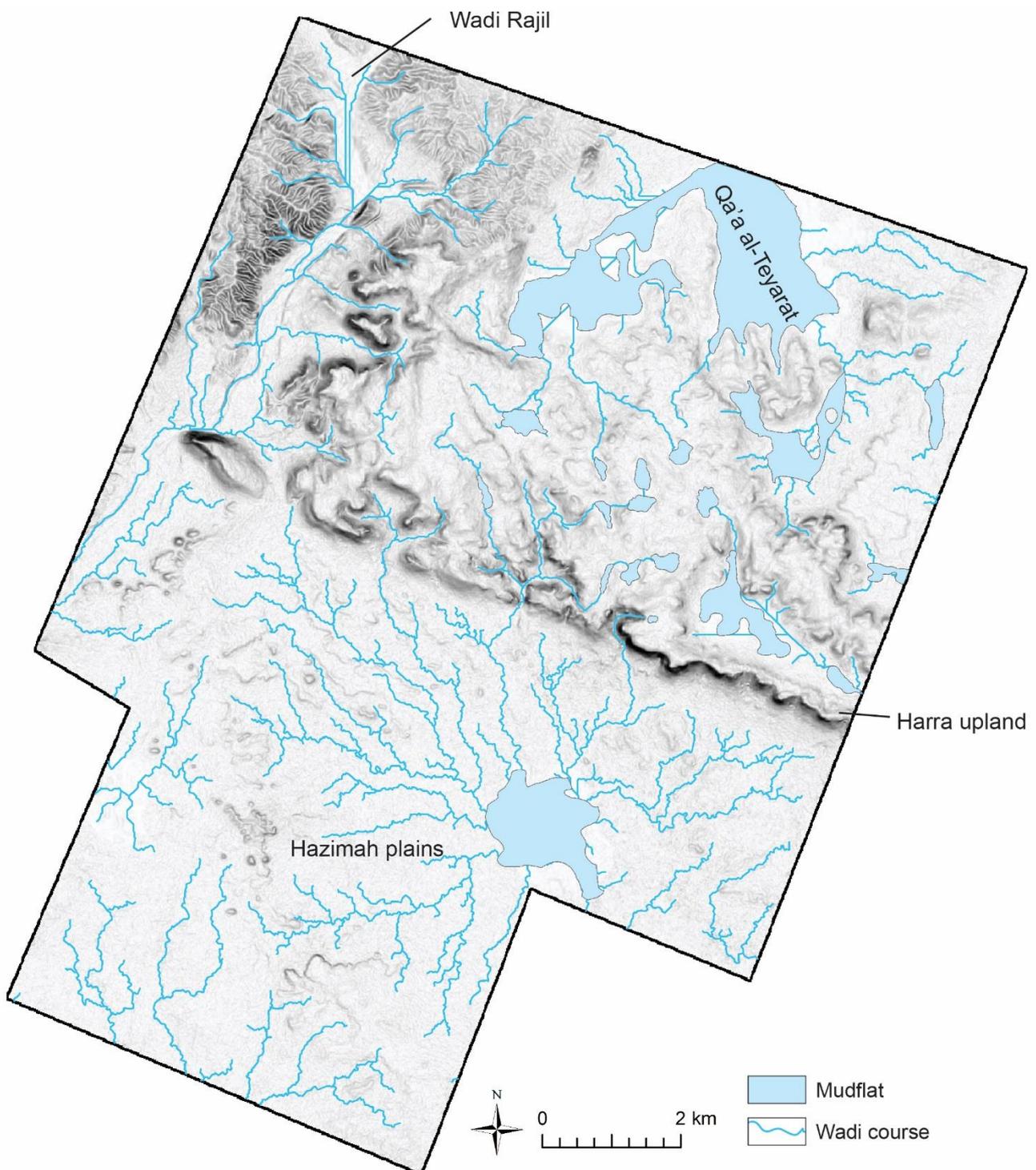


Figure 2.22: Drainage patterns in the western part of the Jebel Qurma region, showing wadi courses as modelled based on WorldDEM data and mudflats indicated on topographic maps. Base image: WorldDEM slope map.

The major watershed boundaries in the Jebel Qurma region, related to the three drainage basins described above, were modelled on the basis of WorldDEM data. Of importance in this respect are the smaller, tributary drainage basins represented by valley systems that run down from the Qurma plateau, as well as a number of small endorheic basins on the plateau itself. The watershed boundaries of these systems were calculated on the basis of WorldDEM data (see § 2.3.1.) and are depicted in Figure 2.23. This figure shows the presence of eleven tributary- or valley systems that run down from the cen-

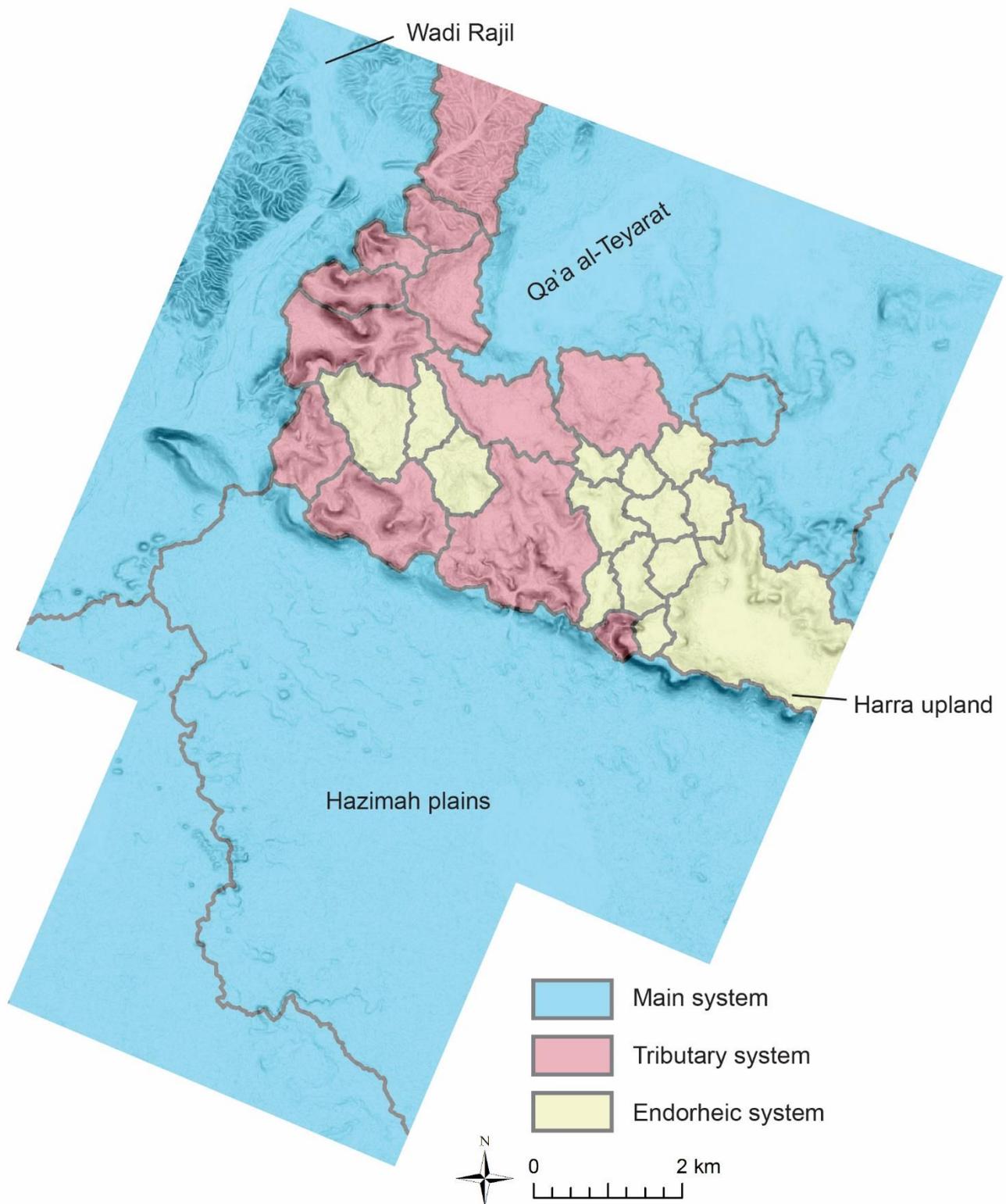


Figure 2.23: Classification of different drainage systems in the western part of the Jebel Qurma region. Base image: WorldDEM slope map.

tral plateau , covering an area of ca 17 km² in total. The individual sizes of these valleys lies between ca. 0.3 and 3.3 km², when taking into account only the ones of which the full extent is known. In addition to these tributary systems, a number of small endorheic systems were defined. These cover a total area of 7.7 km², again taking into account only the ones for which the complete extent is known. The individual sizes of these basins lies between 0.25 and 1.25 km², and are characterised by the presence of a small mudflat on the bottom of the basin. All of these endorheic systems are situated in the Qurma plateau, and are completely surrounded by *harra* surfaces. These basins are therefore the most poorly accessible areas in the region as they are enclosed by basalt surfaces and bounded by slopes on all sides.

2.3.5. Vegetation

Specific information on the type and distribution of vegetation in the Jebel Qurma region is currently not available. While there are ways of studying vegetation systematically through remote sensing, their application for sparsely vegetated areas such as the Jebel Qurma region is problematic. Multispectral satellite imagery, such as Landsat imagery, has been used to gain information on healthy vegetation, especially by studying the amount of red and near-infrared light that is reflected by green leaves. These reflectance values have been used to calculate a Vegetation Index (VI), which is a mathematical equation based on reflectance values based on different spectra of light (Rouse et al. 1974). The most commonly used VI is the Normalized Difference Vegetation Index (NDVI). Hammer (2012), for example, used NDVI to locate pasture zones and compared these to distributions of nomadic campsites and other features. A drawback of VI is that in sparsely vegetated areas the reflectance of soil rather than healthy vegetation can greatly disturb its outcome. While a number of equations have been proposed to compensate for soil reflectance (e.g. Huete 1988; Qi et al. 1994) their success has proved to be limited, especially in areas where vegetation cover is less than 30% (Ren & Feng 2015). The use of VI is therefore unsuitable for studying vegetation in a sparsely vegetated area such as the Jebel Qurma region.



Figure 2.24: Perennial vegetation in various wadis in the Jebel Qurma region. Photos by P. Akkermans.

While direct and systematic ways of studying vegetation patterns in the Jebel Qurma region is thus problematic, some remarks of a more general nature can be made based on inference. Aerial photographs and observations on the ground have indicated that there are numerous areas in the Jebel Qurma region where vegetation occurs, either seasonally or year-round. Large, permanent shrubs are often present in major wadis such as Wadi Rajil and Wadi al-Qataffi, but also in smaller wadis that run down from the basalt plateau (Fig. 2.24). Smaller shrubs are also present in the *harra* and *hamad* landscapes. Furthermore, seasonal vegetation of grasses and weeds may start to grow after the occurrence of heavy rainfall, as was observed in the field during the 2016 campaign, which took place shortly after a period of rainfall. Relatively lush vegetation was present in the *harra* landscape in April 2016, not only in the wadi valleys but also on the slopes and top of the Qurma plateau (Fig. 2.25), where the basalt boulders offer seedlings some protection against the wind and sun (cf. Rowe 1999, 358). By ways of inference, then, it may be suggested that wadi systems are areas that are generally most densely vegetated, probably because part of the runoff water seeps into the wadi beds and is contained there for prolonged periods of time. Other parts of the landscape may become green as well, but only after the occurrence of heavy rainfall.



Figure 2.25: Annual/biennial vegetation in various landscapes of the Jebel Qurma region. Photos by P. Akkermans.

2.3.6. Visibility

Much of the Jebel Qurma region is dominated by undulating terrains, which creates high variability in terms of visibility, i.e., what can be seen from different locations in the landscape. Visibility in the Jebel Qurma region is largely restricted by the topography of the landscape. Vegetation, at least nowadays, is too restricted to significantly influence what is visible and what is not. The topography, on the other hand, is highly variable and includes high locations in the landscape offering extensive views as well as ranges of hills shielding extensive areas from view. Indeed, some locations in the study area represent highly prominent places in the landscape – areas that can be observed from relatively many locations – while other areas, such as valleys, are much more secluded and are only visible from a few locations situated nearby.

This is illustrated in the Visual Prominence Classification (Fig. 2.26), which shows that the central southern part of the study offers mostly locations that are highly exposed, including the southern ridge of the basalt plateau and the Hazimah plains at its foot. Also prominent are some major hills on top of the basalt plateau and along Wadi Rajil. These are high places that can be seen from many locations in the landscape. Much more secluded locations include many low-lying areas confined by high slopes, including Wadi Rajil itself and its tributary valleys, as well as the bottoms of valleys running down from the south of the plateau.

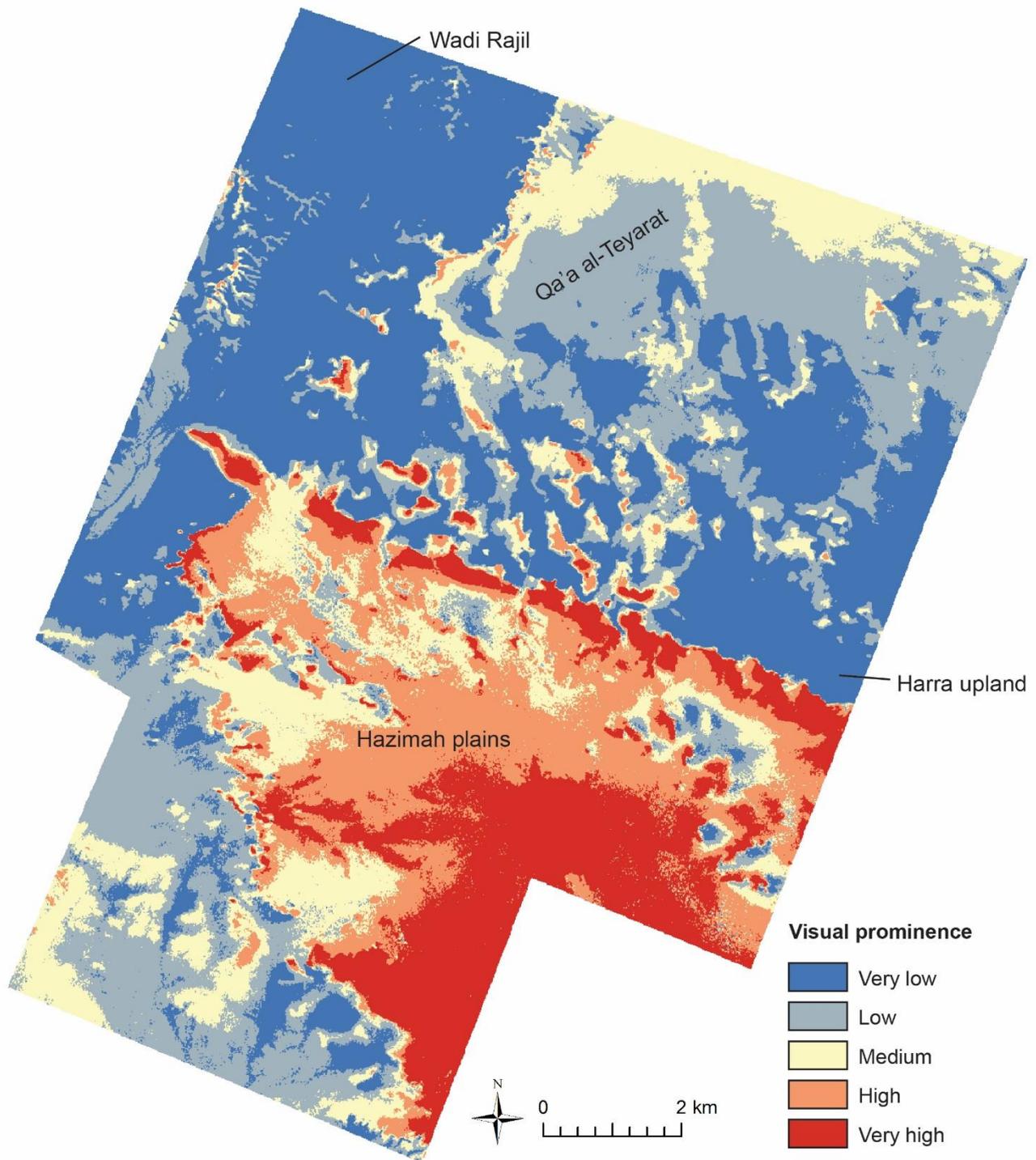


Figure 2.26: Visual Prominence Classification of the western part of the Jebel Qurma region.

Dominant features on the horizon in the Jebel Qurma region, as indicated through the Skyline analysis map (Fig. 2.27) include most of the ridges and hilltops of the undulating terrain that characterise the study area. These ridges and hilltops often define the boundaries of visibility in the study area. The horizons visible from low lying areas, such as the Hazimah plains or the floor of Wadi Rajil, were dominated by high places (Fig. 2.28).

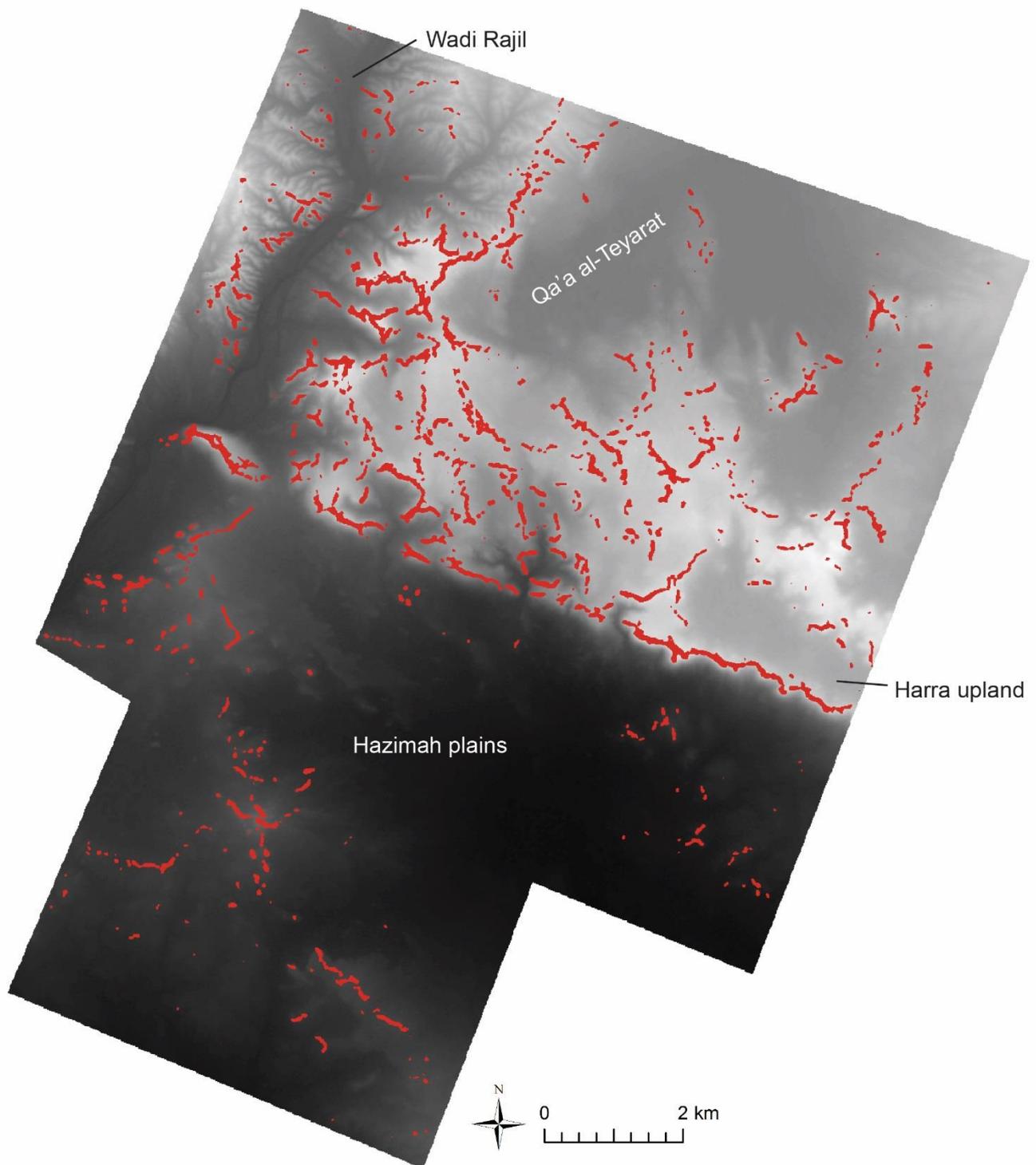


Figure 2.27: Result of a Skyline analysis of the western part of the Jebel Qurma region. Landscape features that are most dominantly present on the horizon are indicated in red. Base map: WorldDEM.

2.4. CONCLUDING REMARKS

In this chapter I have discussed the physical geography of the Black Desert and presented several landscape models of the Jebel Qurma region. On the basis of these models the physical environment of the study area was classified into different environmental zones on different scales, based on different parameters. These classifications will be compared to the archaeological remains in the landscape in Chapters 4 and 5.



Figure 2.28: Examples of dominant skylines in the landscapes of the Jebel Qurma region. Photos by P. Akkermans.

The Jebel Qurma region hosts a wide diversity of natural environments that offer various potentials for nomadic communities. Sources of water and vegetation are unequally distributed across the region, as are locations of varying visibility and seclusion. Similarly, some areas are easily accessible to potential visitors while other places are much more difficult to reach, related to the nature of the terrain. These issues will be taken into account when trying to understand the structure of the nomadic landscape in the course of this study.

Another important issue that has emerged from this chapter is the presence of Holocene deposits in the study area, such as alluvial and windblown deposits, that have potentially obscured archaeological remains. To what degree this may have been the case will be further studied in the next chapters as well, as this is relevant in the reconstruction of nomadic activities in various parts of the landscape.