Open Archaeology 2020; 6: 2–18 DE GRUYTER

Original Study

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On the Lookout: Directional Visibility Cones and Defense in the Nebo Region, West-Central Jordan

https://doi.org/10.1515/opar-2020-0002
Received October 3, 2019; accepted December 18, 2019

Abstract: This article uses directional visibility analysis to assess the defensibility of two Iron Age (9th–8th cent. BCE) sites from the Nebo region of west-central Jordan: the fortified town of Khirbat al-Mukhayyat and its adjacent watchtower at Rujm al-Mukhayyat. Directional visibility cones illustrate how the improved viewsheds afforded by the watchtower at Rujm al-Mukhayyat were needed to establish line of sight between Khirbat al-Mukhayyat and other settlements located higher up on the Transjordanian plateau. Without the addition of the watchtower, Khirbat al-Mukhayyat would have been cut off from direct communication with nearby towns at Hesban and Ma'in. Despite the increased visibility provided by the watchtower at Rujm al-Mukhayyat, Khirbat al-Mukhayyat retained limited capacity to monitor movement to the south in the vicinity of Ma'in. Further, it could not establish direct visual contact with the important urban centre at Madaba to the southeast. These findings may have implications for understanding the military strategy adopted by the Moabite king Mesha in his mid-9th century BCE campaign against the Town of Nebo, identified with Khirbat al-Mukhayyat.

Keywords: GIS; Viewshed Analysis; Directional Visibility; Iron Age Watchtowers; Transjordan

1 Introduction

This article uses directional visibility analysis to demonstrate that the Iron Age watchtower at Rujm al-Mukhayyat (hereafter, Rujm Mukhayyat)[1] was purposely built to enhance the defensibility of the nearby fortified settlement at Khirbat al-Mukhayyat (hereafter, Kh. Mukhayyat), identified as the Town of Nebo mentioned in the mid-9th cent. BCE Mesha Inscription.[2] Situated on a steep ridge along the western edge of the Transjordanian plateau, Kh. Mukhayyat had commanding views to the west towards the north shore of the Dead Sea, the Jordan Valley, and the eastern slopes of the Judean Hills, but it lacked direct line of sight with settlements at higher elevations on the surrounding plateau to the north, east and south (Figure 1).

1 Glueck (1939) noted a distinction between *rujms* and *qasrs*, the former being associated with rounded watchtowers while the latter corresponded to rectilinear structures. However, these terms are often used interchangeably (Kletter, 1991), and they are used solely to designate watchtower installations.

2 For a discussion on the identification of Khirbat al-Mukhayyat as Nebo, see Musil, 1907; Noth, 1944; Saller & Bagatti, 1949; Simons, 1959; Van Zyl, 1960; Abel, 1967; Ottosson, 1969; Baly, 1974; Kallai, 1986; Holladay, 1989; Miller, 1989; Piccirillo, 1990; Harrison, 1996; Piccirillo & Alliata, 1998; MacDonald, 2000; Foran, Dolan & Edwards, 2015; Edwards, Foran & Dolan, 2016; Dolan & Foran, 2016; Foran, Dolan & Edwards, 2016; Edwards, 2019.

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This rendered the town vulnerable along three of its flanks, as it was cut off from communication relays and had limited capacity to directly monitor movement. Located on a hill overlooking Kh. Mukhayyat to the southeast, Rujm Mukhayyat could have potentially alleviated some of these defensive vulnerabilities, as it was better positioned to establish communication links with neighbouring settlements.

Despite previous allusions to Rujm Mukhayyat's role in the broader communication and defensive networks of west-central Jordan, until now no systematic visibility analysis has been carried out at the site. In this paper, I make use of directional visibility cones to calculate the incremental improvements in the viewsheds of both Kh. Mukhayyat and Rujm Mukhayyat at four elevation offsets: 5 m, 7.5 m, 10 m, and 12.5 m. These offsets correspond to the reconstructed height of observation platforms at both sites. Through the use of directional visibility cones, I am able to demonstrate that a watchtower measuring 12.5 m would have enabled Rujm Mukhayyat to significantly improve its visibility to the north, northeast, east, and south, and to establish direct communication links with the nearby fortified towns at Hesban and Ma'in.

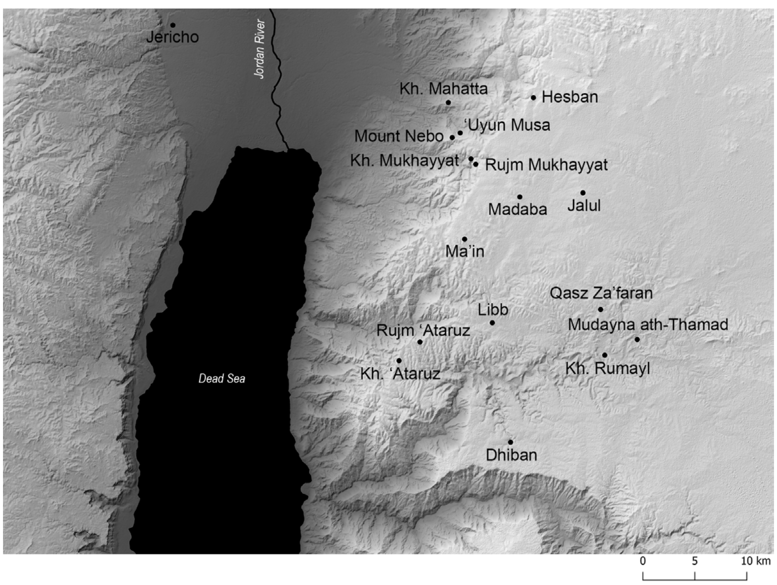

Figure 1: Map showing the locations of sites mentioned in the text.

2 Territoriality in Northern Moab

In recent years, Finkelstein and others (2000; Finkelstein & Lipschits, 2010; Finkelstein, Lipschits & Sergi, 2013; Finkelstein & Römer, 2016; Edwards, 2019) have articulated a suite of architectural features attributable to the territorial expansion of the Northern Kingdom of Israel into Transjordan. The product of the powerful Omride dynasty, this enterprise centred on the founding of heavily fortified compounds situated at key points along Israel's borders. In the Madaba Plains of west-central Jordan, the sites most frequently associated with the Omrides are Ataroth and Jahaz, typically identified with Khirbat 'Ataruz and Mudayna ath-Thamad. Together these sites are thought to demarcate the boundary between Israelite and Moabite territory in the mid-9th century BCE (Finkelstein, 2011).

In a previous article (Edwards, 2019), I suggested that the Iron Age remains at Kh. Mukhayyat exhibited several elements consistent with Omride architecture. The northern half of the site included a rectangular casemate compound built atop an elevated podium, while a rock-cut moat was observed along the southern edge of the mound. The construction of an isolated watchtower at Rujm Mukhayyat mirrored the defences at Omride sites further to the south. Khirbat 'Ataruz has previously been linked to the nearby watchtower at Rujm al-'Ataruz (Ji, 2016), while Mudayna ath-Thamad has been linked to several watchtowers, including Rujm ar-Rumayl and Qasr Za'faran (Daviau, 1997). Based on these parallels, I argued that the addition of isolated watchtowers formed part of the Omride building program in west-central Jordan serving not only to buttress Israel's border defences, but also to expand its inter-site communication and defensive capacity within the region (Edwards, 2019).[3]

3 The Iron Age Watchtower at Rujm al-Mukhayyat

The fortified town of Kh. Mukhayyat, situated about 6 km northwest of Madaba, is flanked by Wadi Mukhayyat to the west and Wadi Afrit to the east. These wadis meet at a confluence south of the site, where they form a new wadi, Wadi Jadidah, that flows in a westerly direction toward the Jordan Valley (Figure 2). The Iron Age occupation at Kh. Mukhayyat was first noted by Glueck (1935) during his visit to the site in 1934, when he attributed some of the surface pottery to the Iron I and II (11^{th}–8^{th} cent. BCE), especially along the southwest part of the site and the upper mound. In the 1990s, Michel (1998) exposed Iron Age walls and several ashen layers with pottery that she called Samarian Ware. Most recently, parts of the Iron Age fortification system have been excavated by the Khirbat al-Mukhayyat Archaeological Project[4] (Foran, Dolan & Edwards, 2016) at various points along the site, attesting to the significant Iron Age occupation on the mound.

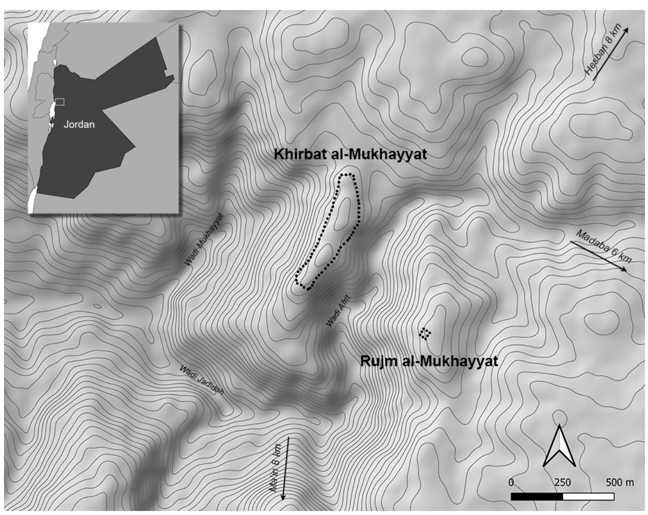

Figure 2: Map showing the locations of the fortified Iron Age town of Khirbat al-Mukhayyat and its adjacent watchtower at Rujm al-Mukhayyat. The dotted areas show the extents of each site. The boundaries of the study region are indicated in the upper left inset.

Rujm Mukhayyat is located about 0.6 km southeast of the main settlement at Kh. Mukhayyat, atop a steep ridge (Figure 3). The only excavations at the watchtower to date were carried out by Ripamonti over the course of two seasons in the 1960s. Unfortunately, the results of Ripamonti's work have never been published, and the material has been lost.[5] A brief summary of this work, including a schematic plan of the architecture were provided by Benedettucci and Sabelli (1998). They posited an Iron Age date for the site based on surface collections, and this date was subsequently corroborated during a brief survey of the site by the Tell Madaba Archaeological Project (Graham & Harrison, 2001, as cited in Foran, Dolan & Edwards, 2015, p. 2).

3 Bennett (1978) refers to one of these watchtowers, Rujm ar-Rumayl, as a "signal station," underscoring its function as a beacon for intersite communication.

4 This project is occasionally referred to as the Town of Nebo Archaeological Project.

5 Ripamonti published a report concerning the excavation of Iron Age tombs in the vicinity of Kh. Mukhayyat (Ripamonti, 1963; but see also Saller, 1966), but this volume does not provide further details of his operations at Rujm Mukhayyat.

Figure 3: Oblique aerial view of the Iron Age watchtower at Rujm al-Mukhayyat (Kennedy & Bewley, 2007; APAAME_20070417_DLK-0137).

Rujm Mukhayyat has roughly a square layout, measuring approximately 10 m per side (Figure 4). At its centre was a rectangular courtyard measuring 4.5 x 3.6 m, itself flanked by secondary rooms measuring approximately 1.5 x 1.0 m. Four rooms were positioned to the south and to the east, with either three or four rooms on the north and west sides. While the general plan of the structure is discernible, its poor state of preservation makes it difficult to provide more precise details without further excavation. The southwestern corner of the building is particularly poorly preserved, where the bedrock slopes more steeply and remains of terracing support walls along the perimeter are visible (Benedettucci & Sabelli, 1998). Benedettucci and Sabelli (1998) surmise the defensive nature of the edifice at Rujm Mukhayyat, suggesting that it functioned primarily as a watchtower with commanding views to the south. The ruins of the structure still stand to a height of approximately 5 m, though most of the extant architecture remains partly buried under considerable wall tumble (Figure 5). Until now, however, the viewsheds of both Kh. Mukhayyat and Rujm Mukhayyat have never been assessed systematically, owing in large part to the dearth of published information about the sites.

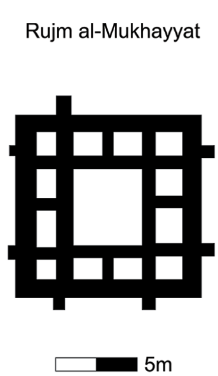

Figure 4: Schematic plan of Rujm al-Mukhayyat (after Benedettucci & Sabelli, 1998, p. 130, Figure 3).

Figure 5: Detail of the architectural remains along the north side of the watchtower at Rujm al-Mukhayyat (photo by S. Edwards).

4 Methods

4.1 Visibility Analysis and Directional Visibility Cones

A number of recent studies have applied visibility analysis to the investigation of ancient defensive systems and specifically to watchtower networks (Earley-Spadoni, 2015; Topouzi et al., 2002, to name just a few). Fundamentally, visibility analysis measures what can be seen from an observation point—usually a site—and this information is used to address questions relating to site placement, communication, and defensibility (Bongers, Arkush, & Harrower, 2012; Marsh & Schreiber, 2015; Murphy, Gittings, & Crow, 2018). Typically, visibility analysis entails calculating the viewsheds of one or more sites, and determining lines of sight between pairs of sites. Recently, more sophisticated applications have been developed, including cumulative viewshed (Wheatley, 1995; Lake, Woodman, & Mithen, 1998; Wright, MacEachern, & Lee, 2014) and fuzzy viewshed analyses (Fisher, 1994; Rášová, 2014), though calculating simple viewsheds and assessing line of sight between objects remain ubiquitous. This type of research is normally carried out in a GIS environment, with the output taking the form of a binary raster map indicating which cells are visible or invisible from the observation point. The introduction of affordable and easy-to-use GIS tools has helped contribute to a proliferation of visibility focused studies across a range of periods and regions (Paz & Birkenfeld, 2017), but examples of pre-digital visibility studies are also attested (e.g., Parker, 1987).

The present study asks how much of the surrounding landscape and which sites within that landscape could have been visible from two observation points: Kh. Mukhayyat and its adjacent watchtower at Rujm Mukhayyat. These sites are situated on the western edge of the Transjordanian plateau, overlooking the Dead Sea and Jordan Valley. Consequently, the viewsheds of both sites naturally exhibit strong westerly biases. This gives the impression that the defensive functions of both sites were oriented towards monitoring sites and movement to the west, but this impression is highly skewed by the local topography. To account for these biases, I incorporate directional visibility cones into my analysis in order to assess the relative changes in visibility across eight cardinal directions (north, northeast, east, southeast, south, southwest, west, and northwest). These directional cones allow a better understanding of how different watchtower heights would have impacted visibility across specific viewing directions. While increasing visibility in any direction would be important for Rujm Mukhayyat, even a slight increase in visibility to the north, east, or south would have been critical for integrating Kh. Mukhayyat into the broader communication and defensive networks in west-central Jordan.

Directional visibility cones have been applied across a range of case studies (for example, see Turchetto & Salemi, 2017; Murrieta-Flores, 2014; Wheatley & Gillings, 2000). The procedures for carrying out this type of visibility analysis have been described in detail elsewhere (Turchetto & Salemi, 2017). The present analysis builds on these previous studies by focusing especially on comparing viewsheds at variable elevation offsets. Specifically, I model the viewsheds for both Kh. Mukhayyat and Rujm Mukhayyat at four different observer offsets: 5 m, 7.5 m, 10 m, and 12.5 m. These offsets correspond to the hypothetical reconstructed heights of observation platforms.[6] The underlying assumption in this approach is that a watchtower's functionality depended in large part on the improvements in the visibility it offered, and that this entailed a height threshold that achieved certain practical objectives with regards to monitoring terrain or communicating with neighbouring sites. Determining precisely what the optimal watchtower height would have been is made possible by calculating multiple viewsheds at progressively increasing offsets. In this case, I have opted to start at 5 m, and increase the offset by intervals of 2.5 m, up to a maximum offset of 12.5 m.

4.2 Data Acquisition and Procedures

The visibility analysis presented in this study was carried out using GRASS GIS 7.6.0. The digital elevation model (DEM) used was based on the ASTER GDEM V2 data.[7] This data is suitable for the present analysis given that it is freely available, has relatively high spatial resolution (30 x 30m) (Kirk, 2017), and is especially accurate in mountainous terrain (Zhao et al., 2011).

Visibility analyses were carried out within the GRASS GIS environment. Viewsheds were calculated using GRASS' r.viewshed module, which resulted in a binary raster map showing which cells were visible from each site at specifically determined offset elevations. This map was then superimposed on a shaded relief map of west-central Jordan. Directional visibility cones were generated in GRASS following the protocols outlined by Turchetto and Salemi (2017), and these were applied for each of the four offsets measured at both sites.

Locational data for the sites included in the analysis were acquired primarily from the MEGA Jordan archaeological database,[8] which is curated by the Department of Antiquities of Jordan and free to use for research purposes. Site coordinates were double-checked against recent Google Earth imagery for accuracy. Most sites were easily detected in this imagery, including small, isolated watchtowers like Rujm Mukhayyat.

4.3 Determining Tower Heights

The poor state of preservation of many Iron Age watchtowers in west-central Jordan makes it difficult to estimate what their actual heights would have been based solely on extant architectural remains. The ruins at Rujm Mukhayyat rise about 5 m above the surrounding terrain, but most of its masonry remains heavily obscured by wall tumble (Figure 6). A similar, albeit larger Iron Age watchtower at Qasr az-Za'faran—about 20 km southeast of Kh. Mukhayyat—has walls that still stand 6.2 m. The original tower would have been much taller, perhaps as much as 14–15 m. Another Iron Age watchtower at Rujm al-'Ataruz, 19 km south of Kh. Mukhayyat, stands at least 3.6 m (Ji, 2016), though it is currently in a poor state of preservation. Together, this evidence strongly suggests that watchtowers in west-central Jordan could have easily reached as high as 10 m. Volumetric analyses of the rubble heaps that frequently surround these sites offers one

6 In this study, observer and target offsets were set at the same value.
7 Jointly released by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA).
8 http://www.megajordan.org/

possible solution to more accurately estimating watchtower heights, though this may be rendered more difficult considering that many Iron Age watchtower sites were heavily quarried or modified in subsequent periods (Daviau et al., 2006).

In their study of Greco-Roman tower tombs from Syro-Mesopotamia, Silver et al. (2015) modelled tower heights as high as 30 m. Kirk (2017), on the other hand, adhered to a "conservative minimum" (after Seifried, 2015) of just 3 m in his study of defensive strategies in post-Medieval Sicily. This latter approach aims to limit overestimations of visibility by modelling offsets that reflect the height of extant structures in addition to the height of an average human observer, usually about 1.5 m. Earley-Spadoni (2015) used an offset elevation of 15 m in her study of Early Iron Age fire-beacon communication networks in Urartu. By adopting a maximum offset of 12.5 m, the present analysis falls well within accepted values for Iron Age watchtower heights. At 12.5 m, the watchtower at Rujm Mukhayyat would have stood just more than double its current height, which seems reasonable considering the amount of wall tumble surrounding the structure. Mazar (1990) has suggested that these towers might have been topped by timber superstructures, lending further height to their uppermost viewing platforms, but such additions have not been considered in the present analysis.

Figure 6: The ruined watchtower at Rujm al-Mukhayyat as seen from the north (photo by S. Edwards).

4.4 Determining Visibility Radius

Another important parameter to consider in visibility analysis is search radius. Visibility studies frequently assume ideal conditions regarding weather, time of day, and visual acuity of the observer, and this can lead to an overestimation of the distance limits for search radii (Rua, Gonçalves, & Figueiredo, 2013). Recognizing that visibility will inevitably decay over distance due to a wide range of factors, fuzzy viewshed analysis has developed as a means to statistically account for this decline in detection rates (Fisher, 1994; Rášová, 2014; Ogburn, 2006; Murphy, Gittings, & Crow, 2018). Despite the advances presented by fuzzy viewsheds, there remains considerable variability in the selected values for search radii in visibility studies, which can range from 4 km (Turchetto & Salemi, 2017) to 60 km (Murphy, Gittings, & Crow, 2018). The present study adopts a search radius of 20 km, which most analyses seem to agree represents the maximum effective distance at which people and landscape features can be discerned (Rennell, 2012; Llobera, 2007).[9]

9 For a recent review of the problems relating to distance and object recognition in visibility analysis, see Fábrega-Álvarez & Parcero-Oubiña (2019).

5 Results

Table 1 summarizes the results of the visibility analysis for both Kh. Mukhayyat and Rujm Mukhayyat by indicating which settlements would have been visible from each site at offsets of 5 m, 7.5 m, 10 m, and 12.5 m, corresponding to the reconstructed height of observation platforms. Though there is no evidence of a watchtower at Kh. Mukhayyat with comparable dimensions to the structure at Rujm Mukhayyat, both sites were nevertheless analysed at all four offset elevations for consistency.

Table 1: Sites visible from Khirbat al-Mukhayyat and Rujm al-Mukhayyat at 5 m, 7.5 m, 10 m and 12.5 m observer/target offsets.

	Khirbat al-Mukhayyat				Rujm al-Mukhayyat			
Sites Visible / Offset:	*5m*	*7.5m*	*10m*	*12.5m*	*5m*	*7.5m*	*10m*	*12.5m*
Kh. al-Mukhayyat	n/a	n/a	n/a	n/a	Yes	Yes	Yes	Yes
Rujm al-Mukhayyat	Yes	Yes	Yes	Yes	n/a	n/a	n/a	n/a
Ma'in	No	No	No	No	No	No	No	Yes
Hesban	No	No	No	No	Yes	Yes	Yes	Yes
Madaba	No	No	No	No	No	No	No	No
Mt. Nebo (Ras Siyagha)	No	No	No	No	No	No	No	No
'Uyun Musa	No	No	No	No	No	No	No	No
Mahatta	No	No	No	No	No	No	No	No

Figure 7 shows the maximum viewsheds of both Kh. Mukhayyat and Rujm Mukhayyat calculated using an observer offset of 12.5 m. Visibility from Kh. Mukhayyat was clearly restricted along most directions apart from the west (Figure 7a). Rujm Mukhayyat also had good visibility to the west (Figure 7b), but this was supplemented by considerably expanded views to the north, northeast and east. These maps highlight the dramatic improvements in visibility offered by the watchtower at Rujm Mukhayyat, despite its proximity—just 0.6 km—to the main fortified settlement at Kh. Mukhayyat. Again, it should be reiterated that the viewsheds depicted in Figure 7a for Kh. Mukhayyat assume the existence of a 12.5 m high observation

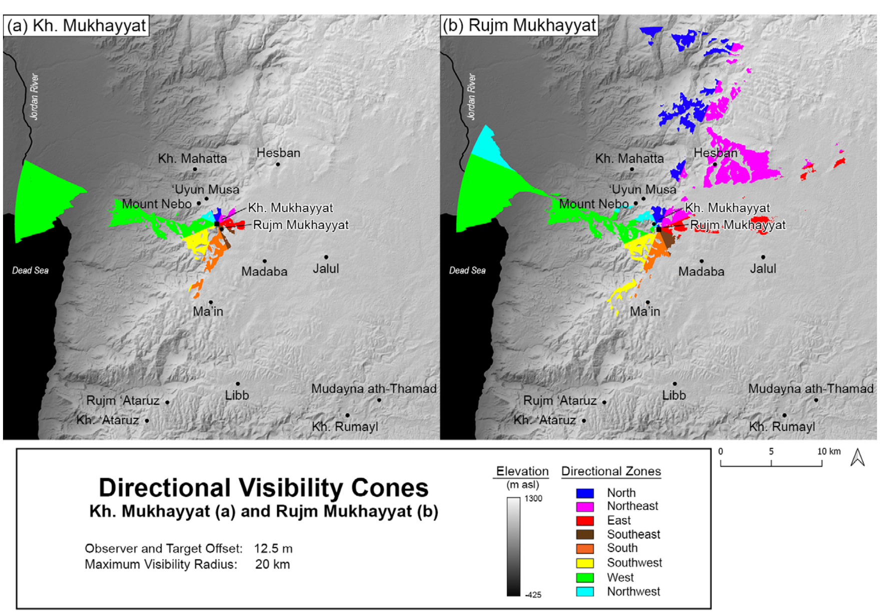

Figure 7: Comparative viewsheds of Kh. Mukhayyat (a) and Rujm Mukhayyat (b), as measured from the maximum observer/target offset of 12.5 m, with a maximum search radius of 20 km. Visible regions are indicated by the colored regions, whose distinctive colors correspond to their respective visibility cones.

platform in antiquity. To date, there is no evidence for any such structure at that site, meaning that the viewsheds presented here probably represent an overestimation, and in reality the viewsheds at Kh. Mukhayyat would have been more restricted.

Even at a maximum reconstructed height of 12.5 m, Kh. Mukhayyat would have been unable to establish direct line of sight with contemporaneous Iron Age sites to the north, east and south, and as a result it could not directly observe or communicate with important settlements like Hesban, Madaba and Ma'in. This is illustrated in Figure 8a–d, which shows the relative viewsheds of Kh. Mukhayyat at the four measured offsets. Here, each of the eight directional visibility cones is indicated by a distinct colour. These maps highlight not only the site's impressive views to the west—represented by the bright green wedge—but also its considerably restricted views in essentially every other direction. Moreover, these maps demonstrate the negligible improvements to Kh. Mukhayyat's overall viewsheds at the reconstructed offsets.

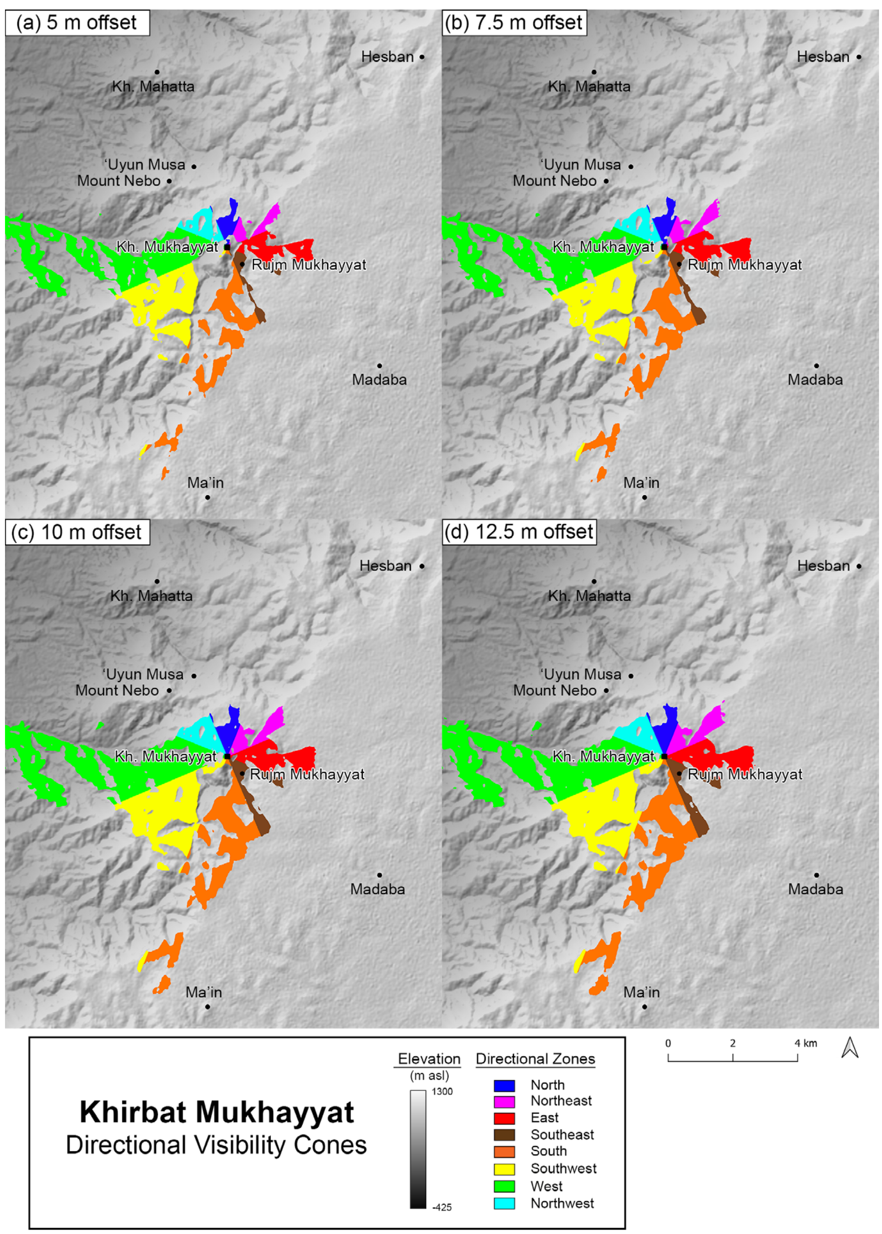

Figure 8: Map showing the directional visibility cones as measured from Khirbat al-Mukhayyat. Panels correspond to the observer/target offsets used in the generation of each viewshed raster map: (a) 5 m; (b) 7.5 m; (c) 10 m; (d) 12.5 m. Panels show only a detail of the central region of the viewshed. For the full extent of the viewshed at the maximum observer/target offset, see Fig. 7(a).

Despite the relative proximity of neighbouring settlements, the restricted visibility at Kh. Mukhayyat underscores the necessity of the adjacent watchtower at Rujm Mukhayyat for improving site intervisibility. However, the utility of Rujm Mukhayyat as a signal station or defensive watchtower depends largely on its reconstructed height, as the present analysis shows.

At an offset elevation of 5 m (Figure 9a), Rujm Mukhayyat provided superior viewsheds to the north and northeast compared to Kh. Mukhayyat. The important settlement at Hesban would have been visible, even if barely so, from a 5 m high watchtower at Rujm Mukhayyat (Figure 9a, inset). The intervening territory between Rujm Mukhayyat and Hesban, on the other hand, remained largely invisible. Likewise, major sites to the southeast like Madaba and Jalul remained out of view. Improved viewsheds emerge when modelling a 7.5 m offset (Figure 9b), particularly to the northeast near Hesban, with significantly more of the intervening territory being visible. However, even at 7.5 m and 10 m offsets (Figure 10a), much of the land to the south remained out of view, including the settlement at Ma'in.

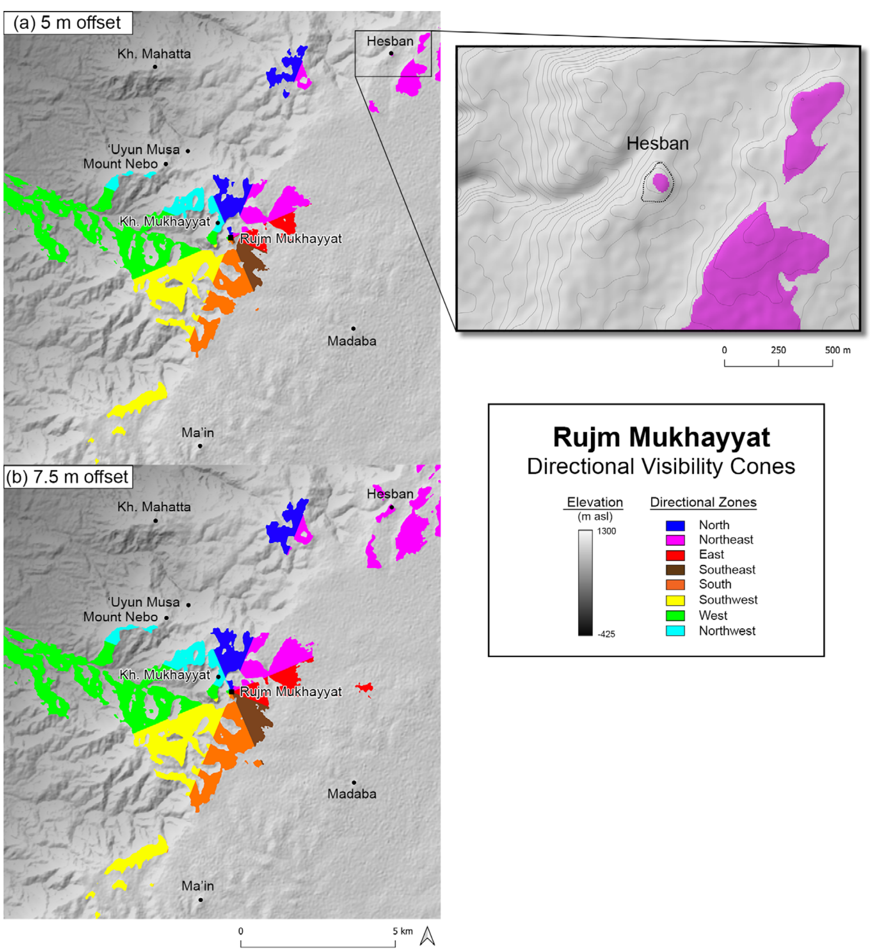

Figure 9: Map showing the directional visibility cones as measured from Rujm al-Mukhayyat using observer/target offsets of (a) 5 m and (b) 7.5 m. Panels show only a detail of the central region of the viewshed. For the full extent of the viewshed at the maximum observer/target offset, see Fig. 7(b). The inset at the top right shows a detail view of Hesban, which is just visible from Rujm Mukhayyat at an observer/target offset of 5 m.

Figure 10a–b shows a detailed map of the viewshed from Rujm Mukhayyat at reconstructed tower heights of 10 m and 12.5 m. Only at an offset of 12.5 m would Rujm Mukhayyat have been able to establish direct line of sight with Ma'in (Figure 10b, inset). Madaba and Jalul, the major sites situated southeast of Rujm Mukhayyat, remain out of view even at this level. To the west, Rujm Mukhayyat retains commanding views of the Wadi Jadidah, the north shore of the Dead Sea and parts of the Jordan Valley in the vicinity of Jericho. In contrast to the viewsheds of Kh. Mukhayyat at the same reconstructed height, the watchtower would have significantly increased visibility to the north and northeast. Smaller improvements are also observed in visibility to the east and south. To the northeast, Hesban is visible already at an offset of just 5 m, but at the maximum measured offset of 12.5 m much of the intervening territory becomes visible, meaning that movement between both sites could have been monitored from Rujm Mukhayyat. Note that Ma'in is only visible at the maximum offset, while much of its surrounding territory is out of view, suggesting that the ability to monitor movement around Ma'in from Rujm Mukhayyat would have been severely limited regardless of watchtower height.

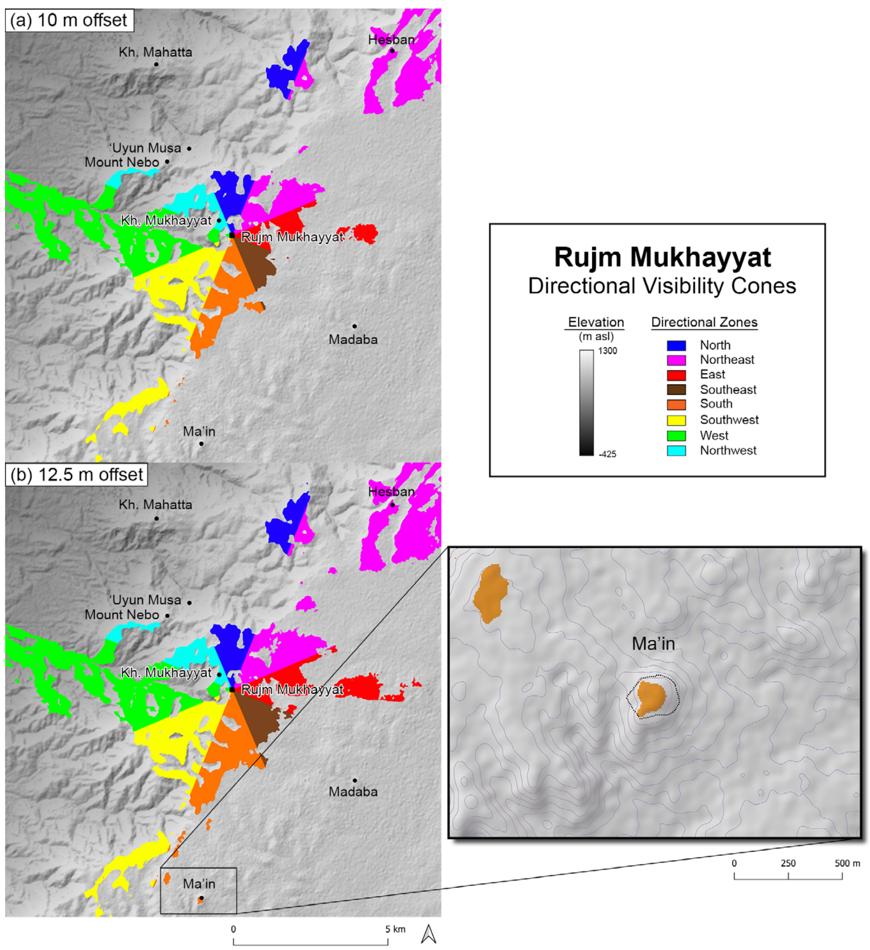

Figure 10: Map showing the directional visibility cones as measured from Rujm al-Mukhayyat using observer/target offsets of (a) 10 m and (b) 12.5 m. Panels show only a detail of the central region of the viewshed. For the full extent of the viewshed at the maximum observer/target offset, see Fig. 7(b). The inset at the bottom right shows a detail view of Ma'in, which is just visible from Rujm Mukhayyat at an observer/target offset of 12.5 m.

Table 2 summarizes changes in the percentage of visible area at both sites, across all eight directions, and at the four measured offsets. In order to appreciate the impact of increasingly higher observer offsets, it is important to consider not only the total change in area, but also the overall percentage increase in visible area within each directional zone. For example, at Kh. Mukhayyat (Table 2a), the total visible area is greatest to the west at all measured offsets. At a reconstructed observer offset of 12.5 m, 28.35% of the area within the west directional zone is visible. This is not surprising given the local topography, where the surrounding hills obscure much of the visibility along nearly all the other directional zones except to the west. The next most visible zones at Kh. Mukhayyat are found to the south (2.74% at 12.5 m offsets) and southwest (2.65% at 12.5 m offsets), while the least visible zones are found to the north and northwest, in the direction of Mount Nebo.

Table 2: Table showing the percentage of total visible area within each directional visibility cone for (a) Khirbat al-Mukhayyat and (b) Rujm al-Mukhayyat. The two columns on the right indicate the total change in visible area and the percentage increase in visible area as measured from the lowest to highest offset elevations (5 m to 12.5 m).

(a)	**Khirbat al-Mukhayyat**					
	Total Visible Area within Directional Zone (%)				*Total Change in Visible Area (%)*	*Increase in Visible Area (%)*
	Offset					
	5m	*7.5m*	*10m*	*12.5m*	*5m→12.5m*	*5m→12.5m*
Directional Zone						
North	0.27	0.32	0.35	0.40	0.13	48.15
Northeast	0.32	0.42	0.50	0.59	0.27	84.38
East	0.72	0.83	0.95	1.06	0.34	47.20
Southeast	0.31	0.42	0.51	0.60	0.29	93.55
South	1.64	2.04	2.4	2.74	1.10	67.07
Southwest	1.94	2.21	2.46	2.65	0.71	36.60
West	24.63	25.97	27.17	28.35	3.27	15.10
Northwest	0.41	0.47	0.53	0.56	0.15	36.59

(b)	**Rujm al-Mukhayyat**					
	Total Visible Area within Directional Zone (%)				*Total Change in Visible Area (%)*	*Increase in Visible Area (%)*
	Offset					
	5m	*7.5m*	*10m*	*12.5m*	*5m→12.5m*	*5m→12.5m*
Directional Zone						
North	6.07	7.70	9.18	10.64	4.57	75.29
Northeast	7.79	11.02	14.55	18.36	10.57	135.68
East	0.63	0.91	1.92	4.46	3.83	607.94
Southeast	0.54	0.73	0.88	1.07	0.53	98.15
South	1.50	1.77	2.06	2.51	1.01	67.33
Southwest	2.66	3.03	3.39	3.80	1.14	42.86
West	26.94	28.21	29.34	30.35	3.41	12.66
Northwest	3.9	4.58	5.18	5.66	1.76	45.13

If one considers how much more area is visible as the offset is raised from 5 m to 12.5 m—that is, from the minimum to maximum measured tower heights—it is evident that some directional zones are affected more than others. For example, at 28.35%, the percentage of visible area to the west of a 12.5 m high tower at Kh. Mukhayyat is only 3.27% more area than a 5 m tower looking in the same direction. Thus, the overall increase in visible area for a 12.5 m high tower compared to a 5 m high tower is only 15.10%, at least along the west directional zone. Comparing that to the 93.55% increase in visible area to the southeast makes it clear that certain directional zones would have witnessed dramatic improvements in overall visibility compared to other directional zones that otherwise had greater visibility in general.

This is especially significant for understanding relative increases in visibility along certain directional zones at Rujm Mukhayyat (Table 2b). Like Kh. Mukhayyat, the directional zone with the highest total visible area at Rujm Mukhayyat is found to the west. A total of 30.35% of the west directional zone would have been visible from a 12.5 m high tower at Rujm Mukhayyat. However, note that the greatest overall percentage increase in visible area along any directional zone would have been to the east. Along this direction, a 5 m tower would only have been able to see about 0.63% of the land, but a 12.5 m high tower would have been able to directly monitor about 4.46% of the land. This represents a 607.94% increase in the visible area, which far outpaces the improvements in visibility along all other directional zones. Notably, the next highest-ranking directional zones, in terms of percentage increase in visible area, are to the northeast (135.68%) and southeast (98.15%), which correspond to the locations of Hesban and Ma'in, respectively. Thus, the results in Table 2 imply that despite the west directional zone having the best overall visibility, the relative improvements in visibility offered by a 12.5 m high tower at Rujm Mukhayyat significantly improved that site's ability to observe land along key directional zones oriented toward important neighbouring settlements.

6 Discussion

Directional visibility analysis reveals that, above all, the Iron Age town at Kh. Mukhayyat had exceedingly poor viewsheds to the north, northeast, east, southeast, and south. Regardless of the reconstructed height of an observation platform at the site—whether 5 m or 12.5 m—Kh. Mukhayyat could not directly establish line of sight with important contemporary nearby settlements like Hesban, Madaba, and Ma'in. Only with the supplemental viewsheds provided by an approximately 12.5 m tall watchtower at Rujm Mukhayyat could the town be linked to the broader communication and defensive networks higher up on the Transjordanian plateau. The results of the viewshed analysis presented here strongly suggest not only that a watchtower installation at Rujm Mukhayyat was purposely built to increase the monitoring capacity of Kh. Mukhayyat, but also that the watchtower itself must have been approximately 12.5 m in height. A shorter tower would have been insufficient to establish line of sight with Ma'in. In addition to advancing our understanding of site placement in the Nebo region of west-central Jordan, these findings have important implications for the context surrounding Kh. Mukhayyat's role in the mid-9th century BCE conflict recorded in the Mesha Inscription between the Moabite king Mesha's forces and those of the Israelites under the Omride dynasty.

6.1 Communication Networks and Defensibility

Defensive systems can only function properly if the individual sites in the network are visible by at least one other site (Kay & Sly, 2001). The defensibility of a site is partially determined by its ability to monitor approaches, especially roads, from elevated vantage points (Martindale & Supernant, 2009). Without the watchtower at Rujm Mukhayyat, the town at Kh. Mukhayyat would have been unable to directly communicate with sites higher up on the plateau. Likewise, with limited visibility along three of its flanks, Kh. Mukhayyat would have had little advance warning in the event of an attack from a hostile force approaching from the north, east or south.

At a maximum reconstructed height of 12.5 m, Rujm Mukhayyat could monitor the routes emanating from the Hesban region to the northeast, at least to a limited degree, and this would have provided a strategic advantage in the event of military conflict involving armies coming from that direction. Notably, visibility to the northwest remained limited, as neither Ras/Siyagha, 'Umm Musa, or Mahatta were within line of sight of Rujm Mukhayyat.

Though visibility is increased to the east and southeast, further signal relays—potentially through Ma'in—would have been necessary to communicate with Madaba and Jalul to the southeast, as these sites remained out of view. To the south, Ma'in would have been visible from Rujm Mukhayyat, but only if the watchtower was at least 12.5 m in height. On the basis of functionality alone, this implies that the watchtower at Rujm Mukhayyat must have been at least this high, otherwise its usefulness would have been considerably reduced. Yet, even with a 12.5 m watchtower, the elevated mound at Ma'in remained barely visible, while the territory surrounding that site was almost completely out of view. None of the approaches from Ma'in to Kh. Mukhayyat could have been monitored to any significant degree from Rujm Mukhayyat, meaning that military activity stemming from the south posed a major threat even though Ma'in itself was within line of sight. This suggests that intervisibility between Rujm Mukhayyat and Ma'in was oriented toward remote signalling for communication. As a result, advance warning of an impending attack could have been relayed to Kh. Mukhayyat by smoke or fire signals, but Kh. Mukhayyat itself was incapable of monitoring advancing armies approaching from the south. This vulnerability is potentially significant in light of the details provided in the Mesha Inscription regarding Mesha's attack on Nebo.

6.2 Mesha's Campaign Against Nebo

The results of the visibility analysis carried out in this study show that Kh. Mukhayyat's eastern and southern flanks were particularly vulnerable to attack due to the limited viewsheds in those directions. This information is especially relevant for understanding the context of Mesha's sacking of Nebo as described in the Mesha Inscription. Mesha makes a point of noting that he advanced on Nebo in the night, after which he fought against the town from dawn until midday (Mesha Inscription lines 14–15). This detail is noteworthy for two reasons. The first is that it implies that had Mesha moved against Nebo during the day, his advance would have been more easily detected, and he would have lost the element of surprise. The second is that it suggests that the route taken by Mesha to reach Nebo would have been along a path that was at least partially visible from the watchtower at Rujm Mukhayyat. This could have taken place near the edge of the escarpment, in the vicinity of Ma'in. So long as no advance warning signal was sent from Ma'in, a night approach from the south would have been fairly secure. Alternatively, the approach could have emanated from the east, which appears to have effectively been a blind spot in Kh. Mukhayyat's defences.

Archaeological evidence of an Iron Age conflagration at Kh. Mukhayyat is possibly attested by ashen layers documented by Michel (1998) in her excavations west of the Church of St. George on the upper mound at Kh. Mukhayyat. More recent excavations along the western edge of the northern part of the site have exposed parts of the defensive wall, but further evidence of an Iron Age destruction is still lacking.

Admittedly, the interpretations presented here cannot be corroborated without further archaeological or documentary data, and it is hoped that the ongoing excavations at Kh. Mukhayyat will shed further light on the destruction and abandonment of the Iron Age town. Nevertheless, visibility analysis, and especially the use of directional visibility cones, offers new data for interpreting the overall defensive strategies employed by the Iron Age occupants of the Nebo region. Specifically, the watchtower installation at Rujm Mukhayyat appears to have been deliberately constructed to provide greater observational capacity and communicative potential for Kh. Mukhayyat, which itself retained rather poor visibility. A 12.5 m high tower would have, at the very least, allowed for direct line of sight to be established with Hesban and Ma'in, but the Nebo region nevertheless remained vulnerable to hostilities emanating from further up on the plateau, particularly to the south and southeast, in the vicinity of the core Moabite territory and its capital city at Dhiban.

7 Conclusions and Future Work

This study has focused primarily on the comparative viewsheds of two sites: Kh. Mukhayyat and Rujm Mukhayyat. Analysis of these viewsheds reveals that a watchtower was necessary to link Kh. Mukhayyat to the broader communication and defensive networks of the west-central plateau. However, there are a range of Iron Age sites dotting the Madaba Plains of west-central Jordan, from humble watchtowers to major urban settlements. Future work will aim to establish the broader network of interconnectivity between these settlements as expressed through intervisibility. Understanding the communication systems and defensive networks that tied these sites together will contribute significantly to our understanding of socio-political organization during the Iron Age, especially as it relates to the formation and dynamics along the perceived boundaries of prominent states like Moab, Ammon and Israel.

Directional visibility cones provide a useful avenue for detecting the subtle yet significant changes in visibility along certain cardinal directions. When coupled with comparative viewshed analysis that models visibility at different elevation offsets, directional visibility cones can shed light not only on the strategic placement of watchtowers within a defensive landscape, but also on their reconstructed heights.

Acknowledgements: This research was made possible by the generous support of the American Center for Oriental Research in Amman and the Burton MacDonald-Rosemarie Sampson Fellowship. Further backing was provided by the Khirbat al-Mukhayyat Archaeological Project, for which I served as Survey Director from 2012 to 2016. Additional support was also provided by the Department of Antiquities of Jordan, and for that I am extremely grateful.

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