



# An integrated GPR and geoinformatics approach for assessing potential risks of flash floods on high-voltage towers, Makkah, Saudi Arabia

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## Abstract

Makkah city is considered as a geologically transitional region that combines topographic and terrain features of the Sarawat Mountains to the east and the coastal plain of the Red Sea to the west and it is consisted of a semi-circular plateau cut by several structural valleys that were defined by faults and cracks. The surface runoff resulting from the rainstorms over the mountainous areas lead to the occurrence of flashfloods that debouch into the tributaries of valleys towards estuaries that encompass residential areas and municipal infrastructures. The present study assesses the negative impacts of flash floods on under-construction high-voltage towers in the valleys surrounding Makkah city using topographic analysis, Ground Penetrating Radar (GPR) surveys and field checks. Topographic modeling was implemented to delineate risky zones that are vulnerable to flash floods at the intersections between major valleys in Wadi Numan and Wadi Al Sharaya Basins and high voltage power lines. The GPR results showed the presence of three geological layers of sedimentary rocks: the first surface layer (A) is composed of alluvial sediments of fine to coarse sand with a thickness of 2 m. Followed by the second layer (B) of sand and gravel, which attains 3 m thickness. The third layer (C) consists of alluvial sediments mixed with rock fragments (diorite and quartzite diorite) and extend to a depth of more than 10 m. The GPR sections indicated that the concrete tower bases are different in thickness and depth from site to other. Different protection measures for the tower bases were suggested to avoid the adverse impacts of the flash flood. The measures varied from site to site and included the establishment of soil barriers, implementation of rocky hills, the defensive collision nets system and the concrete walls system.

**Keywords** GPR · Risk assessment · Flood hazards · Geoinformatics · Saudi Arabia

## Introduction

Linked to global climate changes, the mountainous regions in Western Arabia currently witness enhanced precipitation (Almazroui et al. 2012). The unique geological and

topographic settings of Makkah city between rugged mountainous terrains in the east and a low-laying coastal terrain in the west (Fig. 1) has generated a series of structurally controlled valleys with a complex topography (Smith 1980). The surface runoff resulting from the occurrence of rainstorms over the mountainous areas generates a torrential flow with intensive flash floods and other natural hazards that could jeopardize human lives and infrastructures (Othman et al. 2020). The tributaries of valleys towards the basin outlets are usually interspersed with residential neighborhoods and major infrastructures. The torrential flows are usually loaded with crumbs and rocky debris, which increases their strength to erode and shovel surface components of the soil and increase their destructive effects on the facilities that stand in their way, which represent a real danger to lives and the destruction of private and public properties (Dawod et al. 2012).

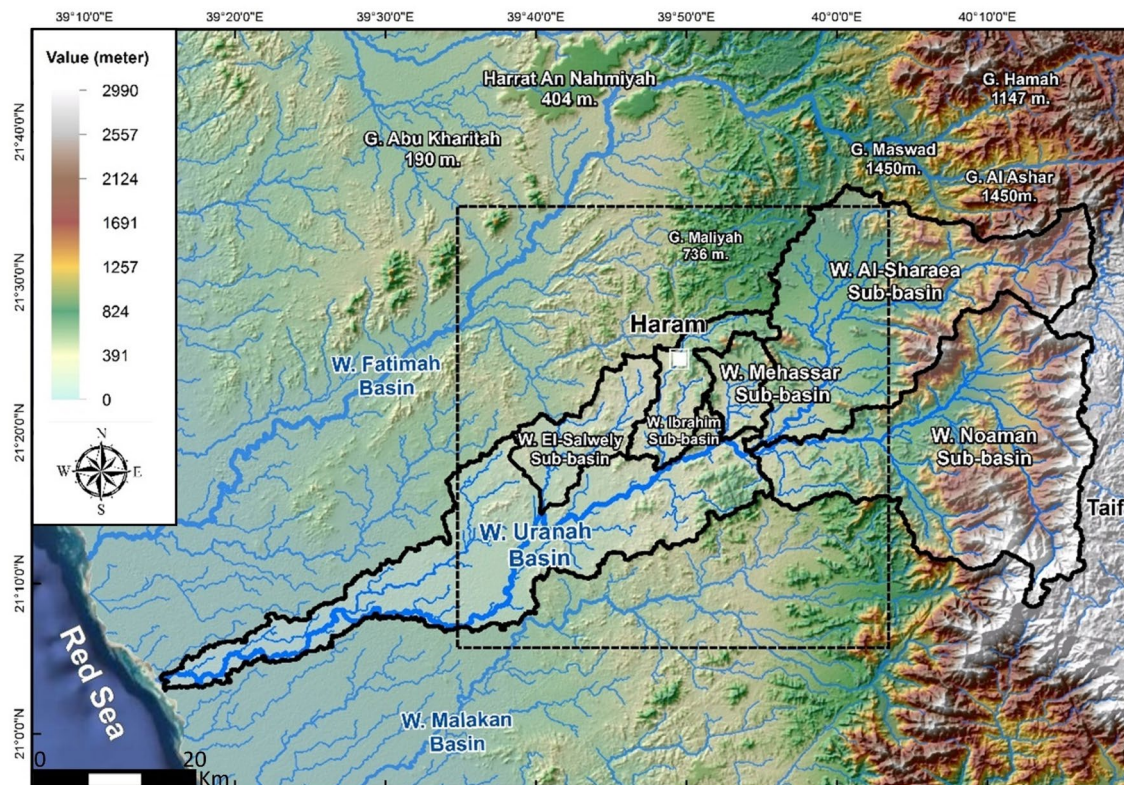
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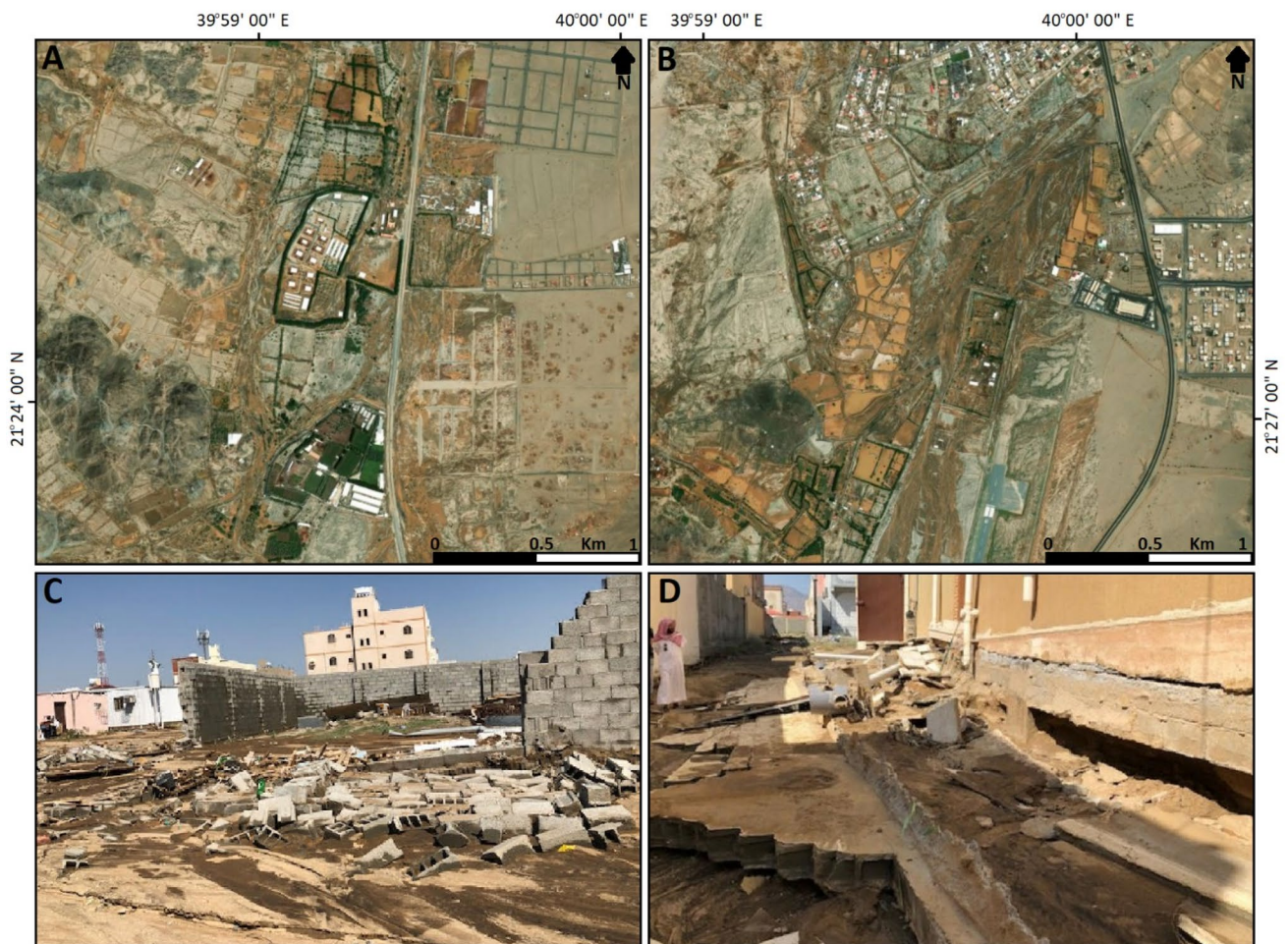


**Fig. 1** Location map of Makkah city superimposed over a digital elevation model (DEM) showing the central region of Makkah and the main and subsidiary drainage basins affecting it

It has been noticed recently that some of the infrastructure installations of the power lines between Makkah and Jeddah cities have been affected by the flash floods in the valley tributaries (Al Harbi et al. 2012), which led to uncovering the bases of power lines along the valley sides. Therefore, it is necessary to identify the vulnerable areas, with electrical infrastructure installations such as transformers and towers of high-volt networks, for the erosional hazards of the flash floods and to evaluate the current protection measures and suggest future precautions to mitigate the adverse impacts of flashfloods on the infrastructures in Makkah city and similar megacities in the Arabian Peninsula. The characteristics of torrents are mainly controlled by many natural factors such as the pattern and intensity of rainfall, size and geometry of the drainage basin, slopes and longitudinal profile of the valleys, soil types and the landcover units (e.g., urban and agricultural lands) (Mohamed et al. 2015; Borouba 2007; Fred and Mostafa 2008). The development of construction operations and the establishment of new urban settlements along the main streams of the catchments surrounding Makkah city (Fig. 2) add more complexity to mitigating the negative impacts of the flash flood events. Thus, torrents resulting from moderate-intensity storms have become noticeably destructive in response to the change in

surface runoff coefficients that accompany urban expansion processes. Consequently, many public and private properties and infrastructure installations for power lines are threatened by torrents.

The economic growth during the past 50 years in many countries in the Middle East and the Arabian Desert has steered the establishment of major urban and industrial centers along the desert fringes of megacities that suffer from severe shortage in surface water resources and infrastructure (Hutchinson and Herrmann 2008). The ability to pump deep aquifers and desalinate seawater and brackish groundwater offset the lack of surface water resources (Wojcik and Maadah 1981). Urban expansion and its utility networks occur at the expense of the surrounding landforms that differ in their geological and hydrological relief systems. The low relief areas for alluvial fans, canyon beds, and piedmont lines represent the most favorable locations for urban development (Dunne 1991). In addition, these areas in the basin outlets usually contain potential aggregate resources and raw deposits for building materials as well as groundwater resources fed by rainstorms and occasional floods (Blair and Macpherson 1994; Abotalib et al. 2019). The development of sudden floods is controlled by many different climatic and morphological



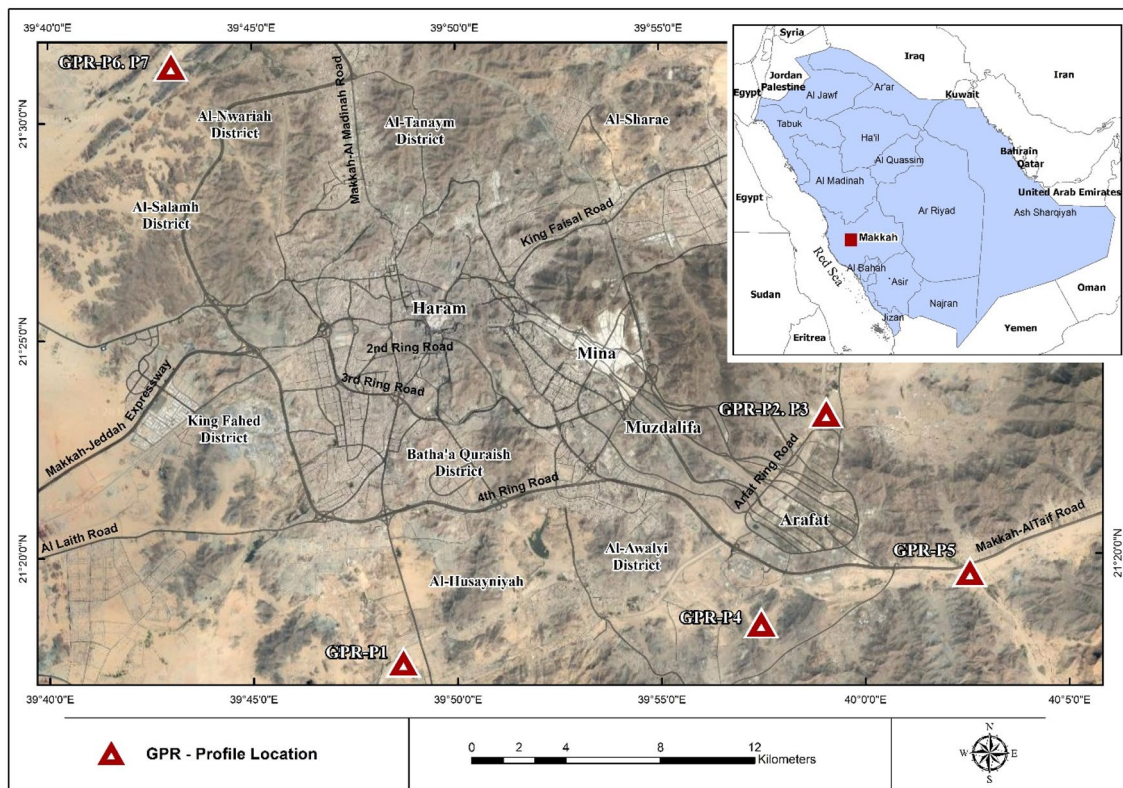
**Fig. 2** Satellite imagery and photographs of the study area after flash floods showing damages. Constructions and new urban areas in the interior of valleys Northeastern Makkah city covered the natural dis-

closures of valleys' soils which prevent the infiltration of water into the ground and increase surface runoff

factors with high spatial and temporal changes (Embabi 2004). Therefore, the negative impacts of rapid floods can vary from watershed to another and even within the same catchment relying on the dominant land use units and the attenuation of discharges and sediment loads associated with each event (Bastawesy et al. 2009).

The present study integrates readily available hydrological data, remote sensing data together with field and GPR surveys to assess the vulnerability of power lines infrastructures to erosion associated with torrential floods in Western Arabia. The integrated approach takes advantage of the spatial analysis to correlate different basin-scale hydrological parameters with small-scale geophysical measurements to define the characteristics of infrastructure foundations within valleys vulnerable to flashflood events and hence enables the recommendation of protection measures along the basin scale. The presented approach is transferrable and can be applied to similar settings in the Saharan-Arabian Desert. In order to achieve the study

objectives, the following tasks were conducted: several sites at wadi Auranah, Wadi Fatma, Wadi Nuaman, wadi Rahgan and Arafat plain Fig. 3. The tasks include the following: (1) Highlighting the effect of development activities on the paths of active valleys in the central region of Makkah, that cause increasing the rates and quantities of runoff for torrential water, the effect of this on increasing the risk levels on the plans and vital installations located at the end of the natural drainage basins during rain fall events. (2) Using the ground penetrating radar technique to study the stratigraphic sequence and the quality of sediments at the dangerous areas on high-voltage towers. (3) Determining the thickness and extension of the concrete bases of the old and newly constructed high-voltage towers in different places and conditions. (4) Monitoring and evaluating the traditional current means of protecting the infrastructure of electricity from the risk of torrential torrents.



**Fig. 3** Location map of the studied sites showing the locations of the GPR profiles

## Characteristics of the study area

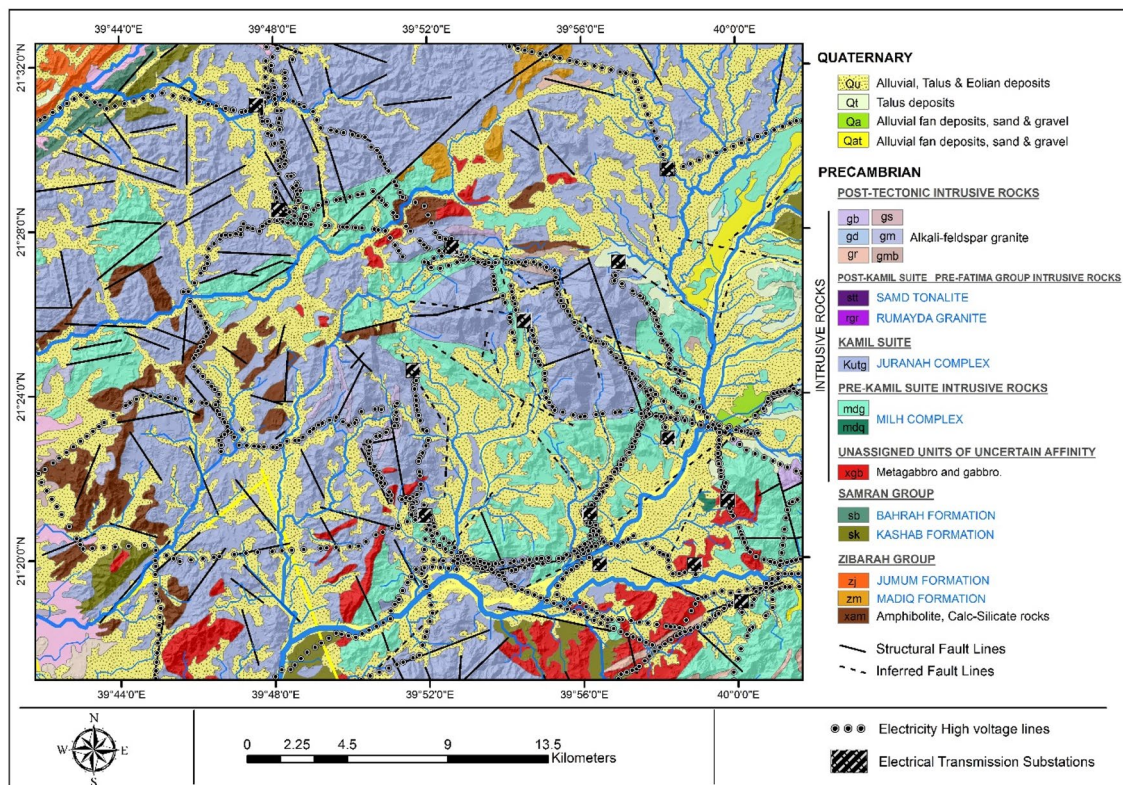
### Site description

The central region of Makkah extends between longitudes  $45^{\circ}39'$ – $40^{\circ}39'$  east and latitudes  $15^{\circ}21'$ – $35^{\circ}21'$  north. The city is considered as a transitional region that combines topographic and terrain features of the Sarawat Mountains to the east and the coastal plain of the Red Sea to the west. Altogether, the surface of Makkah is a semi-circular plateau crossed by several structural valleys that were defined by faults and cracks (Fig. 4).

The urbanization of Makkah city takes a radiant extension pattern in longitudinal directions inside those valleys and their tributaries around the original city center. As a result of the limitations of suitable areas for urban expansion due to the geological and geomorphological structure of Makkah, modern urban expansion has favorably advanced towards the downhill of the mountainous areas. As many new residential neighborhoods and many schemes have been constructed in the interior of these valleys, this necessitates providing these areas with electricity infrastructure and extending high-voltage lines.

## Geological and structural settings

Geologically, Makkah city is located in the west-central part of the Proterozoic Arabian Shield, which comprises different types of igneous, metamorphic and sedimentary rocks. The Pre-Cambrian rocks spread in many regions in the mountains of Makkah, where they mainly consist of schist, gneiss, and amphibolites in sequences of symmetrical folds (Greenwood et al. 1976; Smith 1980; Moore and Al-Rehaili 1989) (Fig. 4). These rocks are interspersed with many metagabbro dikes, in addition to some granite dikes. The rock groups of the Proterozoic rocks in Makkah are divided into the following: (1) the Zubara Formation group, which is the oldest rock unit in Makkah and it consists of quartz-schist and transformed quartzite and amphibolites; (2) the Pre-Kamel group, which consists of diorite rocks, gabbro, metagabbro and gneiss-granodiorite, and finally (3) the Kamel group, which is the most widespread group in Makkah and is composed of that diorite quartz, tonalite and granite-mononite. The main structural trends in Makkah region include the following: a Pre-Cambrian northeast to north-northeast trend and a Tertiary tectonic



**Fig. 4** The geological map of Makkah region, produced by the Saudi Geological Survey in 1989

phase associated with the Rd Sea rifting with a northwest trend (Greenwood et al. 1976; Othman et al. 2020).

The uplift of the Arabian-Nubian shield during the Cenozoic in response to the Red Sea opening (Abotalib and Mohamed 2013; Othman et al. 2018) resulted in intensification of the hydrological processes and associated weathering and thus incision of deep channels in the Pre-Cambrian rocks with thick alluvial sediments filling the stream course of major valleys.

The valleys of Numan, Al-Shara'i, Auranah, Muhasar, Ibrahim and Wadi Al-Mansouriya are among the most important valleys in Makkah, which embrace most urban groups and residential neighborhoods (Fig. 4). The valley-filling alluvial deposits are represented by sand, gravel and clays in addition to aeolian materials that accumulate along the valley channels or on the hillsides facing the prevailing winds (Mirza et al. 2005).

### Data acquisition and analysis

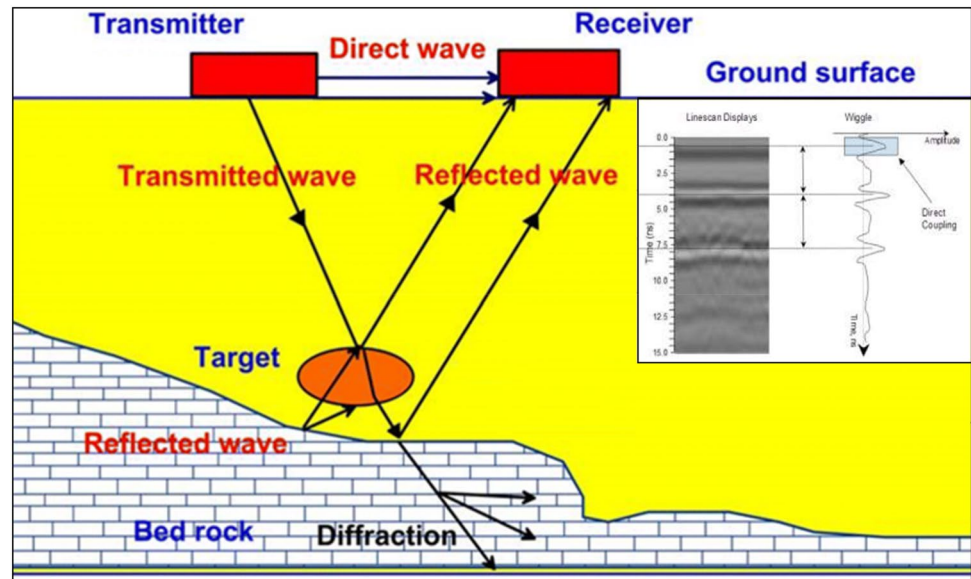
GPR is a high-resolution geophysical method, in which the propagation of high-frequency electromagnetic waves (Fig. 5) leads to imaging different structures in the subsurface in response to the changes in dielectric properties of these structures and surrounding materials. There are many

subsurface voids that might represent engineering concerns and it is necessary to get information on the size, subsurface geometry and depths of voids and karsts before building or reconstruction operations proceed. In the present study, GPR has been employed to detect the dimensions of the high-voltage tower foundations, the subsoil characterization at these installations. During GPR survey, transmission of radar waves takes place through a surface antenna, followed by receiving the reflected signals from buried discontinuities and finally measuring the elapsed time (Ardekani 2013; Daniels 1996; Davis and Annan 1989). Since GPR maps can be produced immediately after data acquisition, they can be used to plan the excavations, without delay.

Among geophysical methods, GPR is an electromagnetic technique primarily designed for location of objects or interfaces buried beneath the earth's surface or located within a visually opaque structure (Daniels 1996).

An important area of application for GPR is the localization of water content areas (Afshar et al. 2015; Bowling et al. 2005; Mahmoudzadeh et al. 2012; Lunt et al. 2005) and formations related to karst phenomena, such as cavities and buried sinks (Abbas et al. 2005; Afshar et al. 2015; Gómez-Ortiz and Martín-Crespo 2012; Pueyo Anchuela et al. 2009; Sevil et al. 2017; Pueyo-Anchuela et al. 2009) codified the main features of GPR for some karst-related morphologies

**Fig. 5** The GPR's Concept, after (Daniels 1996)



(i.e., sediment-filled cavities, landing and ancient collapse evidence). They proposed a “guide” for identifying these shapes in surface-acquired GPR profiles and describing the expected engineering relationships between electromagnetic reflectors (i.e., geometry in the winding, disciplined reflectors, folded reflectors, or side-side sudden changes in electromagnetic properties).

The GPR method has been proposed and used to assess cracking and mechanical damage in the tunnel prior to excavation, in both civil and mining frameworks, providing high-resolution images around the materials behind the drilling face. Compared to seismic methods used for the same purposes, GPR provides higher resolution data, but lower depth (Li et al. 2017). In particular, in mining environments, while mining design and mining exploitation, detailed knowledge of the rock mass produced by

GPR can be really helpful. For example, in this context, GPR has already been used to detect the presence of fractures (e.g., Kovin 2011; Abdel Hafez et al. 2006; Porsani et al. 2006; Shaaban et al. 2013) and infer the presence of small cracks and assess the quality of the rock mass (such as Dérobert and Abraham 2000; Orlando 2003; Wai-Lok Lai et al. 2018; Aldas et al. 2006) suggested a method for using GPR to obtain subsurface images of rock outages in order to improve the detonation pattern design.

The acquisition has been carried out using compact and integrated radar unit GSSI System Model SIR-3000. The utilized system was attached to compatible GSSI 100 MHz antenna. The survey has been accomplished along separate profiles at five selected sites: The path of Wadi Auranah in Al-Husayniyah region, Arafat plain district, Wadi Numan path, west of Umm Al-Qura University, Al-Abdiya and the



**Fig. 6** Field survey at new constructed High-voltage Towers using GPR System Model SIR-3000 and Antenna 100 MHz of GSSI Company

intersection of Wadi Rahjan with Wadi Numan and Fatima Valley path, west of the study area (Fig. 6).

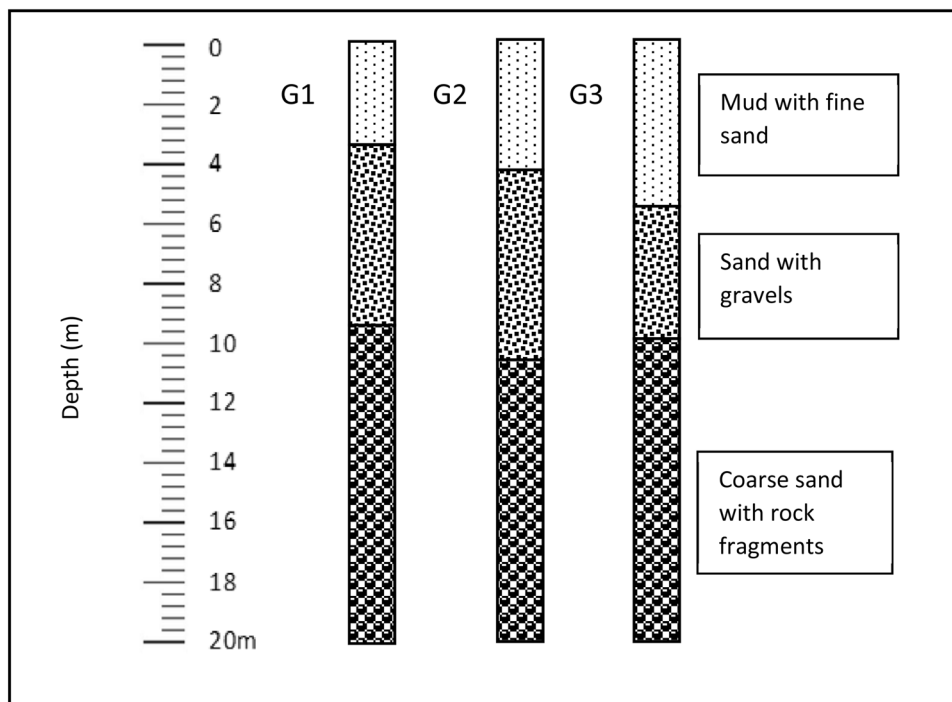
The collected data have been processed using program Radan 7.0 (RADAN 7 2017) to remove the embedded noise due to outside effects and to enhance the GPR traverses.

The general applied processing steps included the following: (1) Static correction to correct the start time; a corrected Time Zero provides a more accurate depth calculation because it sets the top of the scan to a close approximation of the ground surface. (2) Background removal; background Removal is a filter, formally called a Horizontal Background Removal FIR Filter, which removes horizontal bands of noise. Sometimes these bands are caused by ‘real’ horizontal reflectors, but they can also be caused by low-frequency noise such as antenna ringing. (3) FIR Filter (25, 200 MHz for the central frequency 100 MHz antenna); this option offers multiple data filters. FIR filters have a finite-duration impulse response and, when encountering a feature in the data, are guaranteed to output a finite filtered version of that feature. This property makes it possible to design filters that are perfectly symmetrical and have linear phase characteristics. FIR filters will, therefore, produce symmetrical results so reflections will not be shifted in time or position. (4) IIR Filter; IIR filters are a holdover from analog circuits and function much the same way as FIR filters. It is a simpler and potentially cruder type of filter than the FIR filters, which is often used to remove noise, but may change the waveform

shape. When an IIR filter encounters a feature in the radar data, it produces an output that decays exponentially towards zero but never reaches it, hence the name “infinite.” IIR filters are not necessarily symmetrical and while they achieve excellent amplitude response, their phase response is non-linear and so they can cause slight phase shifts in the data. (5) Range Gain (Energy decay); Range Gain offers a way of changing the gain curve at different points and using different methods. This is helpful if a portion of the data is under or over gained during data collected. (6) Migration; the radar antenna radiates energy with a wide beam width pattern such that objects several feet away may be detected. As a consequence of this, objects of finite dimensions may appear as hyperbolic reflectors as the antenna detects the object from far off and is moved over and past it. Deeper objects are likely obscured by shallower ones that appear as interfering hyperbolic reflectors. Steeply dipping surfaces will also cause diffracted reflections of radar energy. This energy can obscure other reflections of interest and cause misinterpretation of subsurface geometry of the investigated objects. (7) Time/depth conversion.

Some soil probes were also used in the study areas, which give information about the classification thickness and type of soil in these areas (Fig. 7); these probes indicated that the topmost layer consists of mixture of mud and fine sand with about 5-meter thickness, the second layer represents sand sediments with average thickness of 6 meters, while the third one is a mixture of sand and rock fragments extended to the maximum depth of the probe (20 m).

**Fig. 7** Soil succession as deduced from some soil probes (G1, G2 and G3) for construction purposes in some locations within the study area



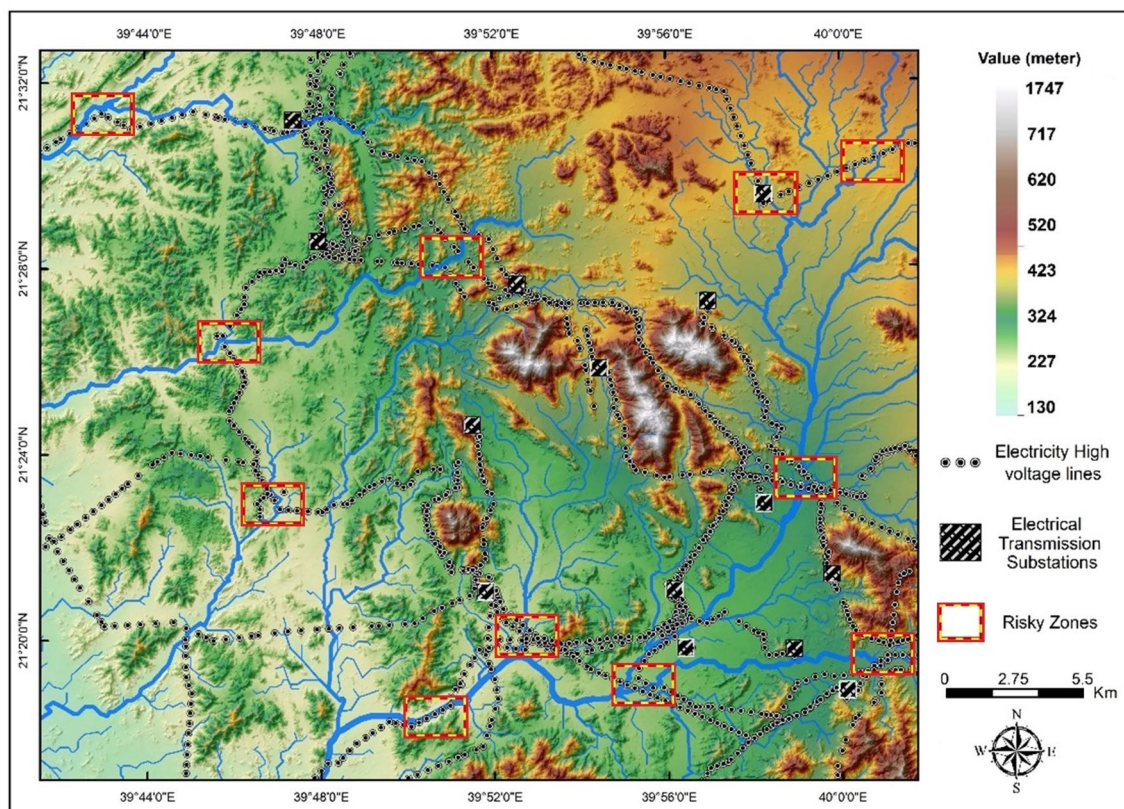
## Result and discussion

### GIS and Field monitoring

The hydrological investigations and data in desert environments are still sparse and insufficient to provide a better understanding of the hydrological processes and associated natural hazards, where all available hydrological models are not properly calibrated (El Bastawesy et al. 2009). Moreover, most of these data are also limited and collected by individuals or entities during independent case studies with no regional project or a monitoring network to sustain a synchronous and continuous measurements, and, in general, do not represent spatial and temporal diversity within dryland settings and operations (Robinson 1994; El Hames and Richards 1998). As a result, sudden floods often lead to destruction, and the risk of wastewater increases gradually (White 1995). The regional intensification of these hydrological hazards necessitate the collection of more relevant data to assess and examine the interaction between urban development, construction operations, hydrogeological processes and land use planning (Walling and Gregory 1970).

The digital elevation model (Fig. 1) has been deduced for the study area; this map also was used to illustrate risky zones of valley stream intersection with the high-voltage power lines (Fig. 8). The research focuses on the areas where torrents' effect on the electricity infrastructure in Wadi Numan and Wadi Al Sharaya Basins in particular (Fig. 9), because of their direct impact on the central area of Makkah and its surrounding villages and extensions of new residential areas. This study focused on the areas of electrical installations such as high-voltage towers that have been constructed in the valleys or on its edges, which makes them vulnerable to the risk of torrents. This work aimed to assess the geological situation in those areas and determine the dimensions and appropriateness of establishing the high-voltage towers for these conditions as well as evaluating the various protection methods used for those constellations.

Desert countries face major challenges in managing hydrological stresses, given the lack of appropriate information about the hydrological processes (Arzani 2010; El Bastawesy et al. 2013). In such arid/hyper-arid conditions, the availability of water resources controls the urban extension and the characteristics of infrastructure installations as well as the different land use units (Rubin 1991; El-Baz et al. 2000; Tooth 2000).



**Fig. 8** Digital elevation model with the main valley's streams cutting the study area and the electricity high-voltage lines





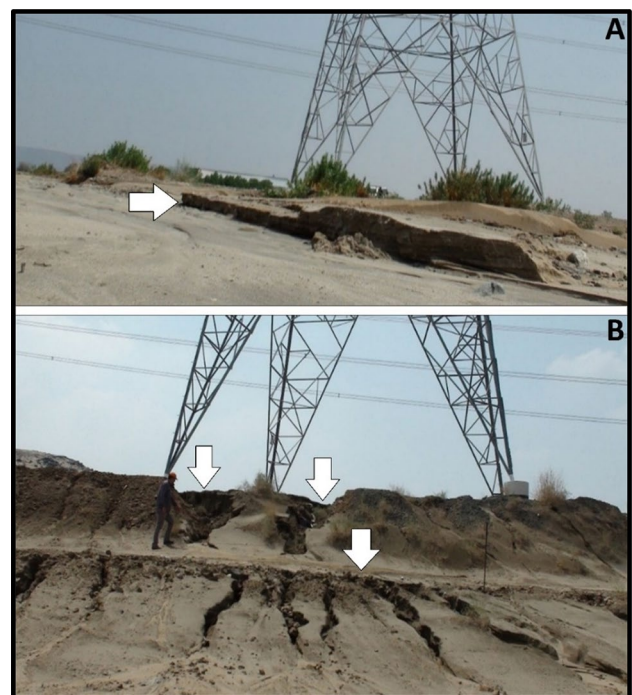
**Fig. 9** A pictures from the study area, Al-Wadi Al-Akhdar road in Wadi Arana on 12 August 2019, showing the effect of floods on high-voltage towers located in the interior of the valley, the erosion activity of the streaming water on the soil

The means of protection used for the basics of high-voltage towers against the risks of torrents in the vicinity of the central region varied from site to other. It was possible to monitor these methods through multiple field trips to the study area, wherever the field investigations have been done to evaluate the protection tools means used for the basics of high-voltage towers against the risks of torrents in the vicinity of the central region. These tools varied from one site to other: Al Auqom “soil barriers, the rocky hills, the defensive collision nets system and the concrete walls system.

The responsible organization for constructing high-voltage electric lines, used the hard-rocky hillside, on the edges or inside the paths of valleys as a platform to install the bases of high-voltage towers on it. This mechanism is the best to protect the base of the tower from being exposed to torrent erosion. However, it was possible to monitor some sites consisting of sedimentary or cumulative sedimentary hills showing have been influenced by the effect of erosion due to the streaming torrents, which may expose the site to collapse (Fig. 10).

### The GPR results

After the data acquisition and processing, some radar records were analyzed and interpreted to obtain the geological and geotechnical situation at the studied targets. It is worthy to mention that the lithological information obtained from the



**Fig. 10** Photographs showing the effects of erosion caused by sweeping torrents on the sedimentary hills that were used as platforms to install some bases of high-voltage towers

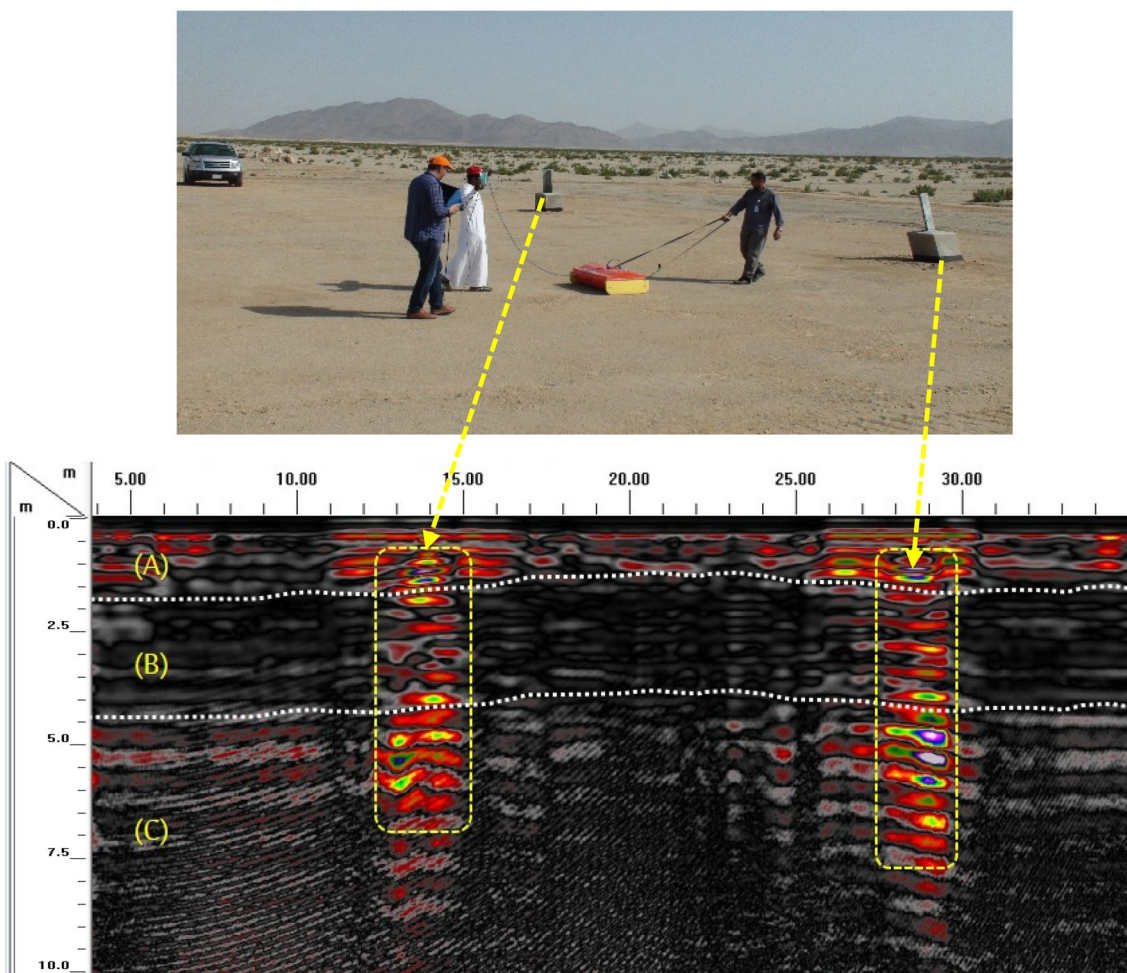
soil probes with the radar wave amplitude changes have been used as an assistant factor/key for the GPR record interpretation. When the wave encounters materials with varied dielectric permittivity, such as magmatic intrusive bodies in the soil profile, as well as different soil water content, this will be reflected in a change of the amplitude, frequency and phase of the GPR signals. The water content of a soil has a significant effect on the relative soil dielectric permittivity. The dielectric permittivity is a complex function with real and imaginary components and is related to the conductivity of the medium (Zabala et al. 2019; Ardekani 2013).

In the case of GPR measurements, which commonly have frequencies ranging from 100 MHz to 2 GHz, most soils do not show dielectric relaxation and low conductivity. In soil profiles, which are composed of a mixture of water, air and minerals, the dielectric permittivity is determined by the relative contributions of these components. Because the dielectric permittivity of minerals (from 2 to 5) and air (equal 1) are less than that of liquid water (81), the soil dielectric

permittivity is controlled by the presence of water in the soil (Scudiero et al. 2012).

- **GPR records P2&P3 at Arafat plain district**

Figures 11, 12 represent parts of the GPR sections P2 and P3, which were measured in the Arafat Plain area. These sectors show the presence of three layers of sedimentary rocks: the first surface layer (A): consisting of valleys sediments of coarse sand mix with fine sand have a thickness of 2 m. Followed by the second layer (B): It consists of valleys deposited of sand mixed with gravel and its thickness reaches 3 m. Then the third layer (C): It consists of valleys sediments mixed with rock fragments (diorite and quartzite diorite) and extend to a depth of more than 10 m. These GPR sections indicated that the four concrete tower bases are about 2 m thick with a vertical extension of approximately 6 m below the ground surface, and the horizontal distance between them is 15 m. It is worthy to mention that these bases represent



**Fig. 11** Part of the GPR record conducted along profile No. 2 (from H.D 5 m to 35 m) at Arafat plain district

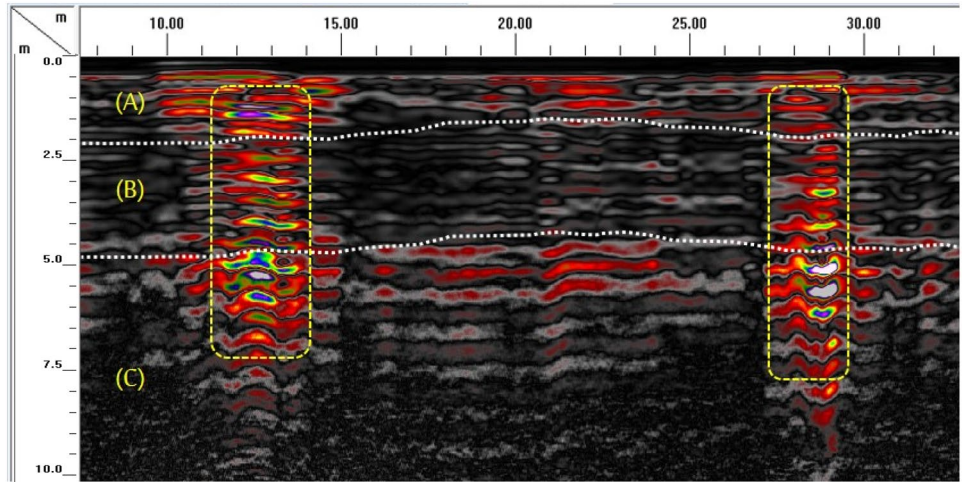
new towers under construction in the area in preparation for the conversion of the old track.

- **GPR record P4**, Wadi Numan path

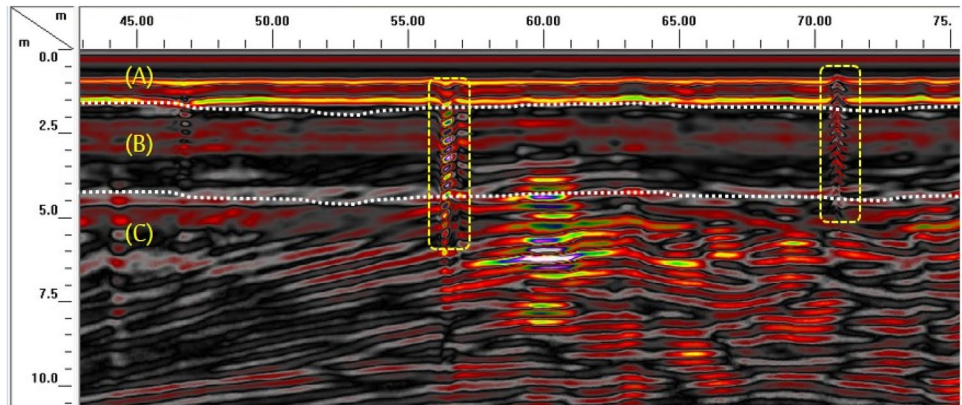
Figure 13 represents parts of the GPR sections P4, which were measured in Wadi Numan path, west of Umm Al-Qura University. This section shows the presence of three layers of sedimentary rocks: the first surface layer,

(A), consisting of valley sediments of coarse sand mixed with fine sand having a thickness of 2 m. Followed by the second layer, (B), it consists of valleys deposited with sand mixed with gravel whose thickness reaches 3 m. Then the third layer, (C), it consists of valley sediments mixed with rock fragments (diomite and quartzite diomite) and extends to a depth of more than 11 m. These GPR

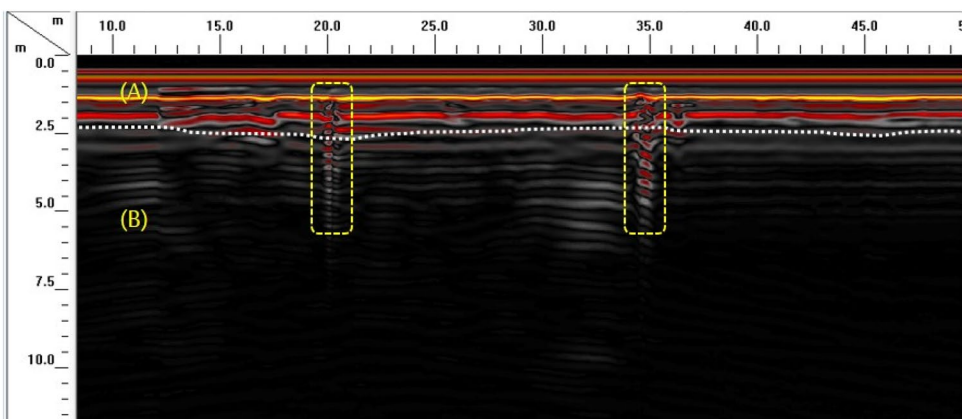
**Fig. 12** Part of the GPR record conducted along profile No. 3 (from H.D 8 m to 32 m) at Arafat plain district



**Fig. 13** Part of the GPR record conducted along profile No. 4 (from H.D 45 m to 75 m) at Wadi Numan path, west of Umm Al-Qura University



**Fig. 14** Part of the GPR record conducted along profile No. 5 (from H.D 10 m to 50 m) at the intersection of Wadi Rahjan with Wadi Numan



sections indicated that the four concrete tower bases are about 1 m thick with vertical extension of approximately 5 m below the ground surface and the horizontal distance between them is 15 m. These construction characteristics consider minimal for 38 kV high-voltage towers.

- **GPR record P5, the intersection of Wadi Rahjan with Wadi Numan**

Figure 14 represents part of the GPR sections P5, which were measured in the intersection of Wadi Rahjan with Wadi Numan. This section shows the presence of two layers of sedimentary rocks: the first surface layer, (A), consisting of valleys' sediments of coarse sand mixed with fine sand having a thickness of 2 m, followed by the second layer, (B), which consists of valleys deposited with alluvial clay and fine sand, which extends to the maximum depth of wave penetration about 13 m. It is noted that the radar waves suffering an attenuation as a result of increasing the clay minerals in the soil is due to decreasing the flow velocity at the confluence of the two valleys, which led to an increase in the sedimentation rate of the clay materials.

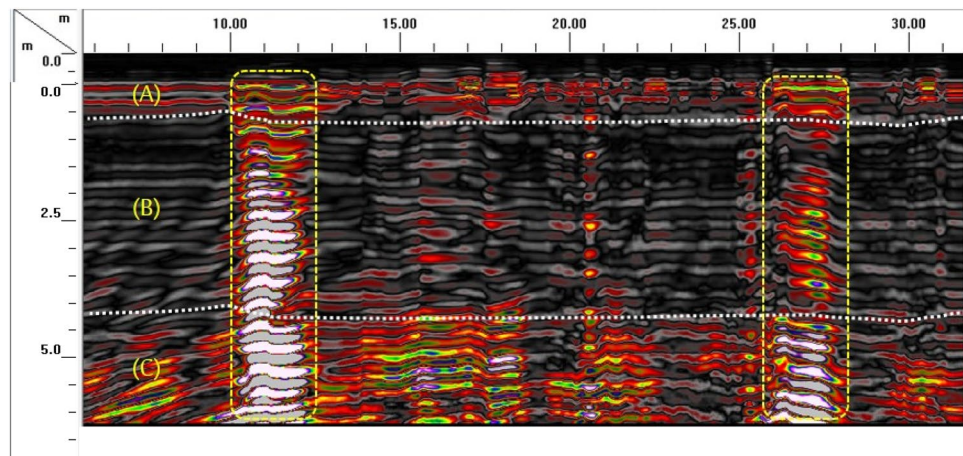
These GPR section indicated that the four concrete tower bases are about 1 m thick with vertical extension of approximately 4.5 m below the ground surface, and the horizontal distance between them is 15 m. These construction characteristics consider minimal for 38 kV high-voltage towers.

The radar records, No.4 and 5, obtain the disadvantages of the dimensions of the high-voltage tower basis at this region, which is characterized by the loose clayey sediments and accumulations of water at the intersection of Wadi Rahjan with Wadi Numan. So, we believe that officials have fixed this problem and improved the specifications of the new tower basis as noticed from radar records No. 2 and 3.

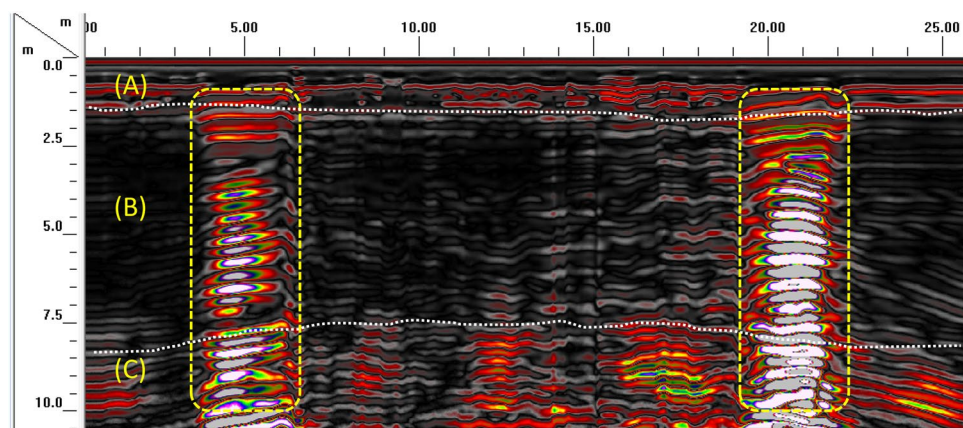
- **GPR records P6 and p7, Fatima valley path**

Figures 15, 16 represent a part of the GPR sections P6 and P7, which was conducted in the fourth location west of the study area in the path of Wadi Fatima. Field observations revealed a recent consolidation of the concrete bases of this tower that was confirmed from the results of GPR survey. These sections show the presence of three layers of sedimentary rocks: the first surface layer (A):

**Fig. 15** Part of the GPR record conducted along profile No. 6 (from H.D 5 m to 32 m) at Fatima Valley path



**Fig. 16** Part of the GPR record conducted along profile No. 7 (from H.D 0 m to 25 m) at Fatima Valley path



consisting of valley sediments of coarse sand mixed with fine sand has a thickness of 1.5 m, followed by the second layer (B) that consists of valleys deposited with muddy sand mixed with gravel and its thickness reaches 3.5 m. Then the third layer, (C), consists of valley sediments mixed with rock fragments (diorite and quartzite diorite) and extends to a depth of more than 9 m. This sector has shown that the two concrete pillars are about 2 m thick, with an extension of approximately 7 m below the ground surface; the horizontal distance between them is 15 m.

- **GPR records P1, the path of Wadi Auranah in Al-Husayniyah region:**

This radar record (Fig. 17) is an attempt to detect the effect of the electromagnetic field resulting from the high-voltage lines of 38 kV power, whose effect appears for a distance of 20 m on both sides of the towers as shown in Fig. 16 zone (C, which necessitates the prevention of activities at those distances and a safe limit when establishing residential installations and plans in these areas. Obviously, the effect of the electromagnetic field emitted from the high-voltage power lines was traced at the base of the radar records from depth ranging from 5 to 7 m depending on the applied voltage in the lines. These effect did not disguise the main fingerprint of the studied targets.

## Summary and conclusions

Ground penetrating radar technique was used to determine the subsurface geological layers and to determine their extensions and structural factors affecting them to determine their suitability for construction purposes, as well as to determine the thickness and depth of concrete bases of high-voltage towers and its suitability to the surrounding

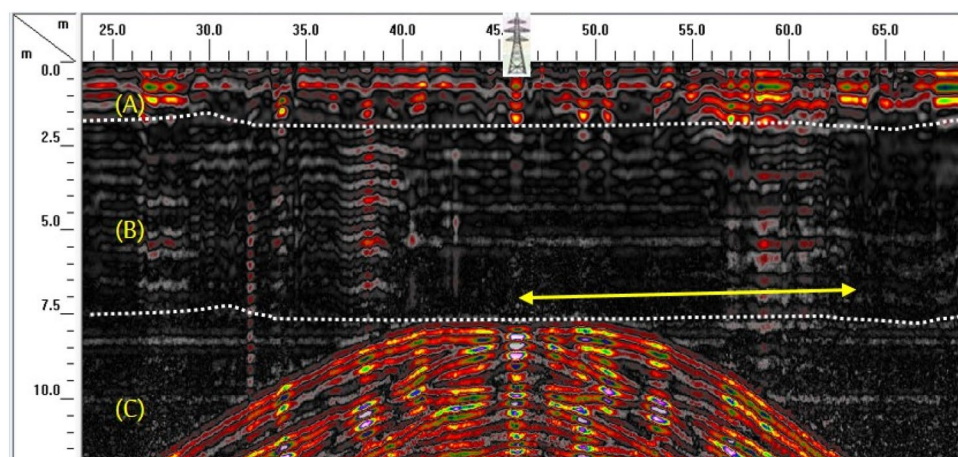
geological and hydrogeological conditions. Wherever the field investigations have been done to evaluate the protection tools means used for the basics of high-voltage towers against the risks of torrents in the vicinity of the central region. These tools varied from one site to other: Al Auqom “soil barriers, the rocky hills, the defensive collision net system and the concrete wall system.

Many of the electrical network infrastructure installations are located in areas that cross or collect torrential water, which poses a major threat to the adjacent areas and threatens the lives of individuals around them. Where the facilities varied between (1) high-voltage towers that were constructed in the main paths of the valleys without any protection tools or limited protection, (2) electrical transformers and lighting columns located within the plans and on the roads were created in the paths of torrents and (3) Not well covered power lines in areas of severe drainage of torrential water.

Inspection of the GPR records illustrated different hazardous zones, which were mainly classified on the basis of soil type and inadequate design of the base of the high-voltage towers, i.e., some areas characterized by the dominant of non-coherent saturated clay soil and the tower basis dimensions do not exceed 4 m depth and 1 m<sup>2</sup> area. This problem was overcome by making additional concrete pillars for those bases in some places and moving the other to safer places. While the digital elevation model with the main valley’s streams cutting the study area designed map clearly demonstrate some general risky areas due to the intersection of the streams valley with the high-voltage lines (Fig. 8).

The researchers suggested the following recommendations: (1) Geotechnical studies must be conducted for the areas where electrical installations are planned. (2) Providing and establishing rainwater and torrential drainage systems for newly constructed plans of concrete drainage channels and ferries below the roads, according to engineering and technical standards commensurate with the amounts of discharged rain into the basins. (3) The importance of

**Fig. 17** Part of the GPR record conducted along profile No. 1 (from H.D 25 m to 68 m) at the path of Wadi Auranah in Al-Husayniyah region



reviewing the determinants of the preparation of urban plans, taking into account their protection from the dangers of streaming torrents when studying the future urban expansion of population center and giving the low areas located below the mountain slopes the importance of establishing discharge networks for rainwater drainage and torrents.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that the current manuscript has no conflict of interest.

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