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Geotechnical Properties Evaluation Utilizing Geological, Geomorphological and Shallow Geophysical Surveys of Wadi Habib Entrance Site, Eastern Desert, Egypt.

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Research Article

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Abstract

An integrated approach is carried out in a proposed engineering site at Wadi Habib, Egypt. The study aimed to characterize the geological, geotechnical and hydrogeological environment evaluate their suitability for civil engineering constructions. The present study reveals that the area is mainly covered by the Eocene carbonate rocks uncomfortably overlain, in some areas, by the Oligocene gravels. The Pliocene mudstone and the Pleistocene/recent fine clastic deposits are recorded in the subdued ground. The surface and subsurface fractures around Wadi Habib area are mainly represented by high angle normal faults trending NNW- SSE, NW-SE, WNW-ESE and ENE-WSW. The morphometric analysis reveals that Wadi Habib is generally of seventh order, sinuous course, elongated, untainous and hilly, course topographic texture and high resistance and low permeable floor. A total of 32 seismic refraction profiles were conducted in two directions N 35° W and N 55° E. Three geoseismic layers of different lithological, compressional and shear velocities and elastic properties are achieved. The geotechnical parameters involving kinetic elastic moduli, soil material competence parameters and the bearing capacity are estimated and hence indicated the characteristics of the foundation materials for civil engineering constructions in the investigated site. Also, 30 VES'es are implemented and interpreted to test the geological and hydrogeological conditions. Subsurface geoelectrical layers are delineated and verified. The proposed site is characterized by a relatively low to moderate seismicity. The geotechnical parameters of geoseismic layers and the hydrogeological probable troublesome (cavities, fractures, faults) for building structure and soil suitability for foundation purposes are concluded

Introduction And Motivation

The entrance of Wadi Habib is a proposed engineering site since it locates near to the Assiut-Hurghada desert road between latitudes 27° 00' to 27° 30' N and longitudes 31° 20' to 32° 00' (Fig. 1). Adequate geotechnical investigations are needed to establish competency of the foundation medium for the installation of structures under all static and seismic loading conditions. Site investigations are conducted to discover the characteristics of the soil at the location to determine their ability to support structures emplaced on them. Geophysical techniques are being increasingly used at stages of new settlement sites evaluation to assess the geological hazards and site characterization (Imai, 1975; Gregory, 1976; Sjogren et al., 1979; Dutta, 1985; Abdel Rahman, 1991; Abdel Rahman et al., 1994, El-Behiry et al., 1994 and others). The geophysical methods apply a non-destructive testing which can reduce cost and time of a project. Shear and compressional wave velocities (Vs & Vp) are direct indicators of the ground strength (stiffness) and therefore are commonly used to derive load-bearing capacity. The ground resistivity interpreted from VES survey is related to various parameters such as mineral composition, porosity, clay content and degree of water saturation.

The objectives of this study are: (i) analysis of surface structures and interpretation of drainage net of Wadi Habib to determine the morphometric properties of this basin and their effect to the flash flood hazards and groundwater replenishment, (ii) determining depths and thicknesses of the subsurface geoseismic layers to the bedrock and construction of a subsurface models of P & S-wave velocities as estimated from shallow seismic refraction technique, (iii) calculating the dynamic geotechnical properties of foundation layer, (iv) demonstrating the site seismicity, (v) determining depths and thicknesses of the subsurface geoelectric layers and recognition of hydrogeological situation (wet and dry zones) from VES data, and (vi) concluding soil suitability for foundation purposes and evaluate their qualification for civil engineering constructions.

Materials And Methods

To achieve the study objectives, structural, geomorphological, seismic refraction and vertical electrical sounding (VES) investigations are carried out and integrated in the proposed site aiming at imaging shallow subsurface layers, determine the geotechnical characteristics and competency of the subsoil as foundation materials and evaluate their suitability for civil engineering constructions. Set of professional software programs were used such as SEISVIEW, IPI2Win. 6, Surfer and Geosoft Oasis Montag.

Geological setting and structural analysis of Wadi Habib area

Wadi Habib drainage trunk channel runs in a general east-west direction on the limestone plateau east of Assiut town. Its entrance is a triangular flat area which is bounded from two sides (northeastern and southwestern) by the Eocene limestone plateau where it opens from its northwestern side to Wadi El-Assiuti main channel.

The exposed sedimentary sequence in the studied area is mainly represented by the Eocene carbonate rocks (Serai, Drunka and Minia formations), which is unconformably overlain, in some areas; by the Oligocene elongate mounds of gravels. Together with the Pliocene chocolate brown marlstone and mudstone deposits which are recorded only in the subdued ground in the lower reaches of the western parts of the studied area and the Pleistocene (Issawia and Qena formations) and the recent fine clastic deposits (Fig. 1).

Surface structural analysis of the studied area shows that the capping Eocene formations are essentially composed of nearly horizontal limestone beds except at the vicinity of faults, which represent the main structural features affecting the area. They are mostly of high angle normal faults with various extensions and relatively small throw amounts. Folding is represented by very dense fold system superimposed on the fault system (Gigot et al., 1986 and Bakheit, 1989). The surface faults which have been affected the study area was traced from the geological map of the Gebel El-Urf Quadrangle prepared by the Egyptian Geological survey (1983). Faults are grouped into NNW- SSE, NW – SE (Gulf of Suez – Red Sea trend), WNW – ESE and ENE – WSW categories arranged in decreasing order of abundance .The subsurface faults affecting the basement complex in the study area are delineated from the magnetic data by Bakheit (1989) showing an upward extension in the overlying sedimentary cover. However, relatively younger faults affecting the sedimentary cover are recorded (Fig. 1). The contrast between the Azimuth frequency diagram of the surface structural pattern (A and B) and that interpreted from magnetic data (C) shows that the NW tectonic trend represents the best pronounced direction among surface fractures. It is very rare among fracture trends interpreted from magnetic data.

Geomorphometrical Analysis

The quantitative interpretation of the drainage net of Wadi Habib was carried out to determine the morphometric properties of this basin and their effect to the flash flood hazards and groundwater replenishment. The analysis includes; stream order, stream numbers, stream lengths, bifurcation ratio, drainage density, drainage frequency, valley index, texture ratio and basin shape (elongation and circularity ratios).

Accordingly, the drainage net of Wadi Habib basin is well developed, integrated, dense, and controlled by fractures (faults and joints). The hydrological assessment of morphometric parameters and their consequent surface runoff variables emphasize that, huge quantities of surface runoff water would be yielded and their overland flows towards the outlets have considerably highly–peaked discharges. The basin is underlain by highly resistance and impermeable exposed rocks of rough surface and great possibility to collect surface runoff during flash flood periods. Nevertheless, Wadi Habib area can infiltrate a considerable amount of surface water, which increases the ground water potentiality (Fig.2&3).

The calculated bifurcation ratios and basin bifurcation ratio for the studied Wadi Habib basin is about 5.1403 Table (1). This indicates that Wadi Habib basin is mountainous, hilly and dangerous floods (Mucullagh, 1978). The analyzed morphometric properties of the drainage net of Wadi Habib area has been shown in Table (2). The relief ratio of Wadi Habib basin is relatively small value 0.0044) indicates that the surface of Wadi Habib basin characterized by low relief and presence of isolated hills (Inselbergs).

Seismic Refraction Survey:

A total of 32 short discontinuous doubled forward and reverse seismic profiles (120 m length with 10 m geophone spacing) were conducted in line spreads in two directions N 35° W and N 55° E to detect the geoseismic layers, thicknesses and corresponding compressional and shear velocities (Vp and Vs) using ES-1225 seismograph (EG&G GEOMETRICS), 12 volt battery set, 110/220 volt batterycharger, Geophone spread cable (240 m length), 12 Geophones, Sledge hammer (8 kg weight), Hammer switch and Striker plate (Fig. 4 A, B & C , Table 3). Three geoseismic layers of different lithological and elastic properties are achieved. The geotechnical parameters are estimated, mapped and compared to indicate the characteristics of the foundation layer for civil engineering constructions in the investigated site. (Figs 5-6, Table 4).

Geotechnical Parameters Estimation:

Computation of geotechnical parameters for subsurface material in a construction site is very important before foundation design. These parameters involving kinetic elastic moduli (e.g.shear modulus, Young's modulus and Poisson's ratio), soil material competence parameters (concentration index, material index, standard penetration testing, density-gradient and stress ratio) and the bearing capacity (ultimate and allowable) are estimated (Table 4). The estimated parameters names and symbols, equations used, references as well as the minimum, maximum and mean values for the surface layer are given in Table 4. Hence, their indications to the characteristics of the foundation layers for civil engineering constructions in the investigated site could be concluded. All the estimated seismic and geotechnical parameters of the foundation layer (the first seismic layer) in Wadi Habib site are mapped (Fig 6 a,b,c,d,e,f,g,h,i,j,k and l), compared , interpreted and discussed based on the referenced classification data (Tables 4, 5, 6, 7, 8 and 9).

Vertical Electrical Sounding (VES) Survey:

A total of 30 VES'es are also implemented, processed, inverted and interpreted to realize the geological and hydrogeological conditions. Using Terrameter SAS 300, Terrameter SAS 2000 Booster, Ni – Cd batteries, Battery charger, Stainless-steel electrodes, Wire reel for current line and potential lines. (Fig. 7, Table 10). The final interpreted results were used for the preparation of geoelectrical sections, and maps. Subsurface geoelectrical layers are delineated and verified from the correlation with bore logs. (Table 10, Figs 8-9). All estimated resistivity parameters of Foundation Layer in Wadi Habib site are mapped and compared (Figs 9 a, b, c and d).

Seismicity Of The Study Area:

Egypt is affected by moderate seismic activity compared to other countries (Badawy, 2005). Several moderate to strong earthquakes (e.g., 12 October 1992 Ms 5.9 Cairo) have been taking place in Egypt during the last decades causing considerable damage (Abou Elenean, 2007). Generally, seismic activity for the whole Egyptian territory is mainly concentrated in the surrounding plate boundaries and on some active seismic regions, like Aswan and Abu Dabbab (e.g., Sawires et al., 2016 a,b). The studied area (located in Assiut region), is characterized by low to moderate seismic activity (Abou Elenean, 2007). The region within a 400-km radius around Assiut area is affected by 11 seismic sources shown in a map (Fig.10) (Sawires et al. ,2015 and Mohamed Arfa and Fat-Helbary R.E. , 2021).

A seismic hazard evaluation with level hazard 10% probability of exceedance in 50 years in terms of 5% damped peak ground acceleration (PGA) and spectral acceleration (SA) was carried out in an area located in Assiut region using site amplification factors corresponding to various site classes based on Vs30 by Mohamed Arfa and Fat-Helbary R.E (2021). The obtained PGA and SA values are 0.065g and 0.158g, respectively, for a return period of 475 years and for rock-site conditions. Accordingly, the proposed site in Wadi Habib is characterized by a relatively low to moderate seismicity and is considered as a safe region for the construction purposes according to the world standard regulations and seismic building codes guidelines (Sawires et al., 2016, 2017 and Mohamed Arfa and Fat-Helbary R.E, 2021).

Discussion And Conclusions

The studied site in Wadi Habib area (Fig. 1) are subjected to seismic refraction, vertical resistivity sounding and density of soil determination in order to evaluate their foundation layers reliability for civil engineering constructions (buildings, roads, …etc). This includes evaluation of the soils kinetic elastic moduli, competence and ultimate and allowable bearing capacities as well as the subsurface geological and hydrogeological situations.

The predominant surface fracture trends affected the area around Wadi Habib are: N25°W, N55°E, N45°E, N35°W, N35°E and N65°E arranged in decreasing order of abundance. The faults affected the basement surface are rejuvenated upward through the relatively thin sedimentary cover. Many fractures have been developed in the sedimentary cover are not recorded on the basement surface.

The quantitative interpretation of the drainage net of Wadi Habib basin revealed that Wadi Habib is generally of seventh order, sinuous course, elongated, untainous and hilly, course topographic texture and high resistance and low permeable floor. These indicate that Wadi Habib has a high capacity of dangerous flash flooding and allowing surface water runoff.

Interpretation of the shallow seismic refraction sections exposes three geoseismic layers of different lithological and elastic properties: The first layer (dry gravels and boulders) has a seismic velocity (Vp) ranged from 796 to 1199 m/sec. It's thickness ranges from 3 to 22.55 m. The second layer (dry sand and gravels) has a Vp ranged from 1415 to 1784 m/sec. The thickness of this layer changes from 8.4 to 19.25 m. The third layer (semi consolidated sand) has Vp ranged from 1816 to 2610 m/sec. The thickness of this layer is undefined.

The lateral distribution of the calculated compressional (V_p) and shear (V_s) wave velocities of the first (surface) layer as well as the thickness are represented as contour maps (Fig. 5). The values of both V_p and V_s of the surface layer range between 355 and 613 m/sec for V_p and between 222 and 395 m/sec for V_s. These velocity ranges reveal a distinct lateral variation throughout the layer where the velocities increase generally towards (the northwestern side) of the area as compared with the other sides. It is interpreted as due to lithologic changes, water saturation or erosion effect. Thickness of the surface materials is ranged between 2.5 and 19 m. Twelve selected geoseismic cross sections trending NW-SE and NE-SW (Fig. 4c) have been constructed to show the lateral and vertical distribution of V_p and display the detailed lithologic and structural variations prevailing in the foundation zone. An example is shown in the subsurface geoseismic cross section C-C' (Fig. 5d).

Three different lithologic units were identified in these sections (Table 3, Fig. 5). The uppermost (surface) one, consisting of a loose dry sandy gravel and limestone fragments, is characterized by V_p from 796–1199 m/sec. The second unit is demarcated by V_p range 952–2041 m/sec, which is composed of dry gravel and sand showing lateral thickness variation. The third unit is represented by wet sand, silt and gravel and has V_p range 1419–2711 m/sec. The lower boundary of this water-bearing unit is not detected from the shallow seismic refraction records but could be determined from the resistivity survey that gave deeper investigation. It is indicated that the foundation zone consists of layers composed of loose dry sandy gravel and limestone fragments. The layer thickness varies from 2.5 to 19 m. The competence of the soils, as evaluated by the concentration index (C_i), material index (v), N-value, density gradient (D_i) and stress ratio (S_i) (Table 4, Fig. 6), suggest moderately to good competent soil for this layer.

The consolidation characteristics of the different rock types are diminished at the southeastern part of the area. The sites of good or even moderate competent soils are the best for constructing any building, tunnel, bridge or highway. The allowable bearing pressure (Q_{all}) of the layer indicates relatively strong enough materials in comparison with the building static load and the machine dynamic cyclic loading and perhaps the dynamic loading due to the low seismic activity of the area. Thus, the sand liquefaction and construction damages in the study area are not highly expected (Table 4, Fig. 6).

The limits of the geotechnical parameters estimated for the first seismic layer (foundation layer) in the studied area are in good matching and reveal that the materials of this layer are generally moderate competent *(in B zones)* to good competent *(in A zones)* (Fig. 11), i.e. fall within the specifications recommended (Tables 5, 6, 7, 8 and 9, Fig. 6).

On the other hand, the quantitative interpretation of the VES data reveals that there are five geoelectrical layers corresponding to different lithological facies (Table 10, Fig. 8). The surface geoelectrical layer of average thickness ranged from 1 to 70 m exhibits very high resistivity ranged between 730 to 21780 ohm.m. Lithologically, this layer is probably composed of very dry loose sand, gravels, boulders and fanglomerates which represent recent wadi deposits. The second geoelectrical layer has resistivity ranged from 210 to 670 ohm. m., thickness changed from 2 to 81 m. and found at depth ranged between 1 to 70 m from the ground surface. This layer is possibly composed of dry weathered sand and gravels. The third geoelectrical layer has resistivity values ranged between 55 to 184 ohm m., thickness varied from 6.5 to 98 m. and found at depth range from 6 to 133 m. beneath the ground surface. This layer may represent the possible wet sand layer (Fig. 9). The flow of the water through the probable wet layer takes place generally from southeast to northwest direction (Fig. 9).

The study indicated also that few to non-troublesome for construction work from subsurface geological and hydrogeological situations viewpoint might be expected in the considered area as concluded from the data of VES interpretation. The possible risks from the effect of clay swelling or ground water on the potential civil structures are rarely expected. At locations of shallow water table, the problems associated with high water saturation should be avoided. The clay layers are not occurred through foundation depths. Therefore, the hazard of clay swelling and/or sliding is limited and probably non expected. In addition, thickness of the Neogene sediments and in turn the depth to the Eocene limestone bedrock are found in the range 30–224 m. There are no indications of any bedrock serious subsurface major structures such as faults, joints or voids which can cause subsidence in the area. Consequently, the shallow underground cavities or irregularities are not expected to occur throughout the foundation layers or shortly beneath.

It is worth-mentioning that, the buildings should be designed in this area to resist the damage effects of the peak ground acceleration (PGA) of 0.065g for rock-site conditions and the proposed site is characterized by a relatively low to moderate seismicity (Mohamed Arfa and Fat-Helbary R.E, 2021).

In conclusion, the applied integrated technique has proved very useful and cost effective in mapping the subsoil for civil engineering purposes, since the results of geotechnical tests are for point measurements and can't provide lateral information on the subsurface, however the applied integrated method can give volumetric measurement and produce images of the subsurface without physically disturbing the subsoil. Also, the study highlights some elementary limitations and hazards in Wadi Habib inertance area and offers information and awareness to the planners, decision makers, engineers and geo-environmentalists, to attack the existing hazards.

List Of Used Symbols And Abbreviations

E	Young modulus	RQD	Rock Quality Designation Factor
K	Bulk modulus	V	Material Index
μ	Shear modulus	λ	λ Lame's constant (Stress/Strain)
ρ	Rock density	q_{ult}	Ultimate Bearing Capacity
σ	Poisson Ratio	q_{all}	Allowable Bearing Capacity
VES	Vertical electrical sounding	γ	the unit weight of the ground
Vp	Primary wave velocity	δ	Settlement
Vs	Shear wave velocity	N-value or SPT	Liquefaction Potentiality or Standard Penetration Test
Si	Stress Ratio	Z	Depth
Ci	Concentration Index		

Declarations

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Conflict of interest: The authors declare that they have no known competing financial interests.

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Tables

Due to technical limitations, table 1-10 is only available as a download in the Supplemental Files section.

Figures

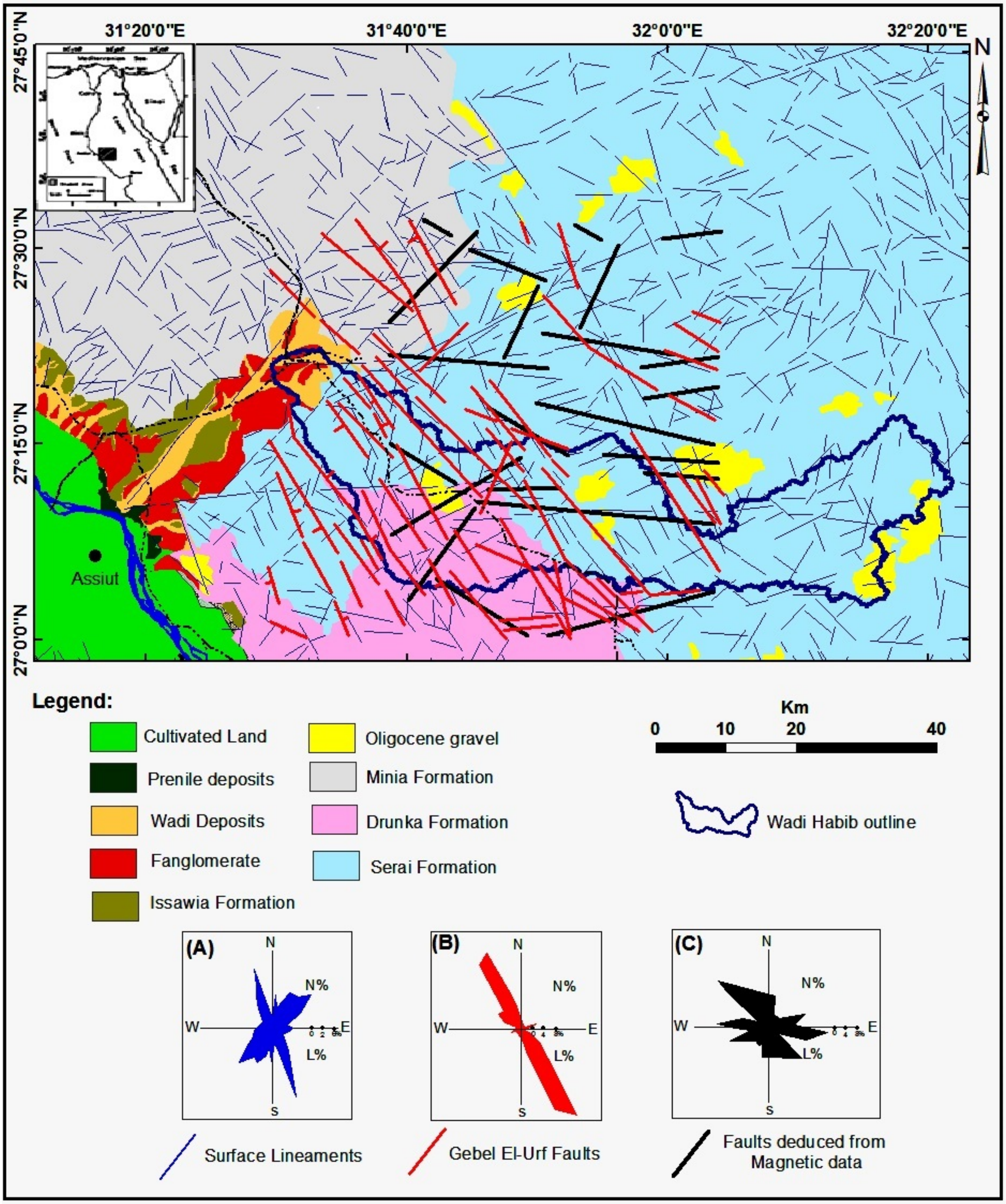


Figure 1

Geological map of Wadi Habib area showing location site, stratigraphic rock unites and Surface fractures affected the area as traced from the geological map of Egypt after E.G.P.C. and CONOCO, 1987 (A), Geblel El-Urf area (B) and faults deduced from Magnetic data (C) with their azimuth frequency diagrams.

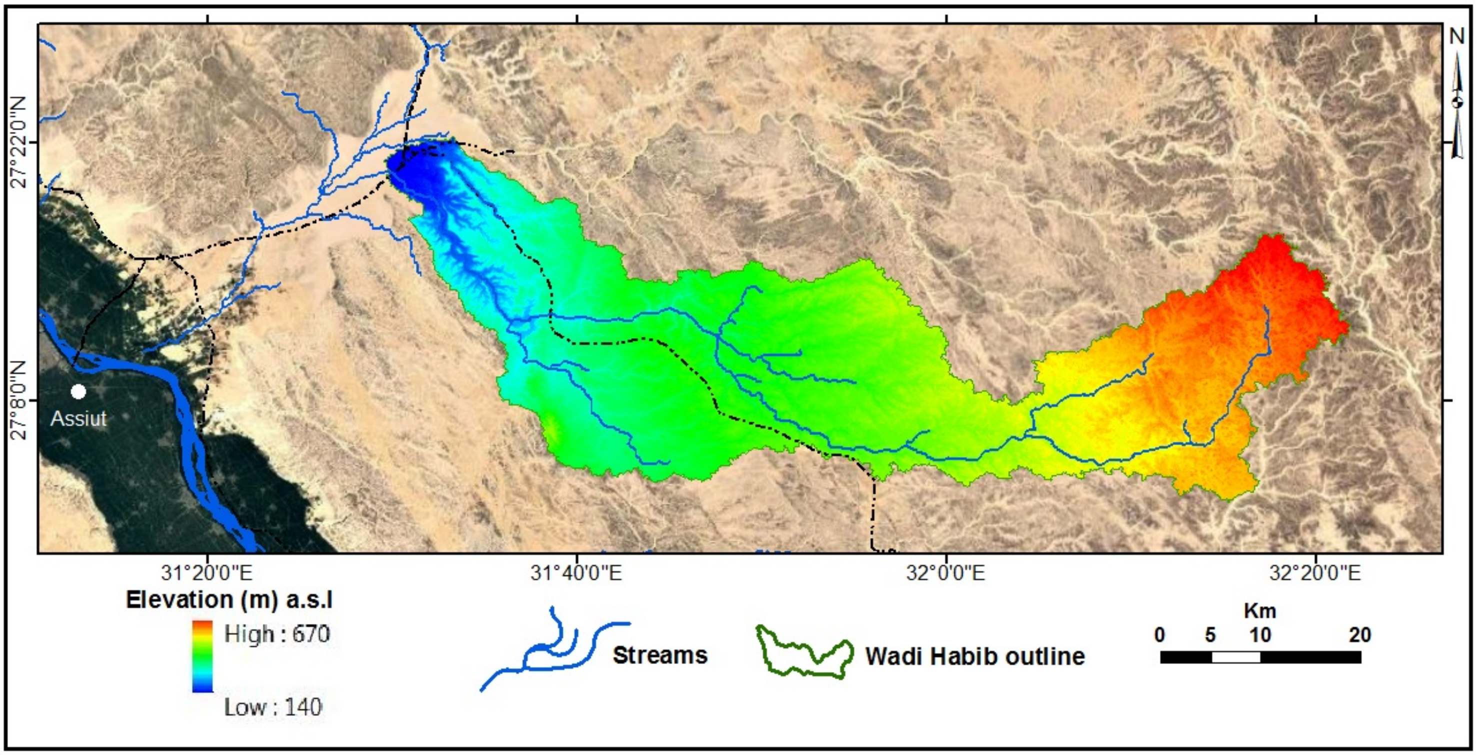


Figure 2

The topographic map of Wadi Habib (deduced from Landsat Image (L8), 2020).

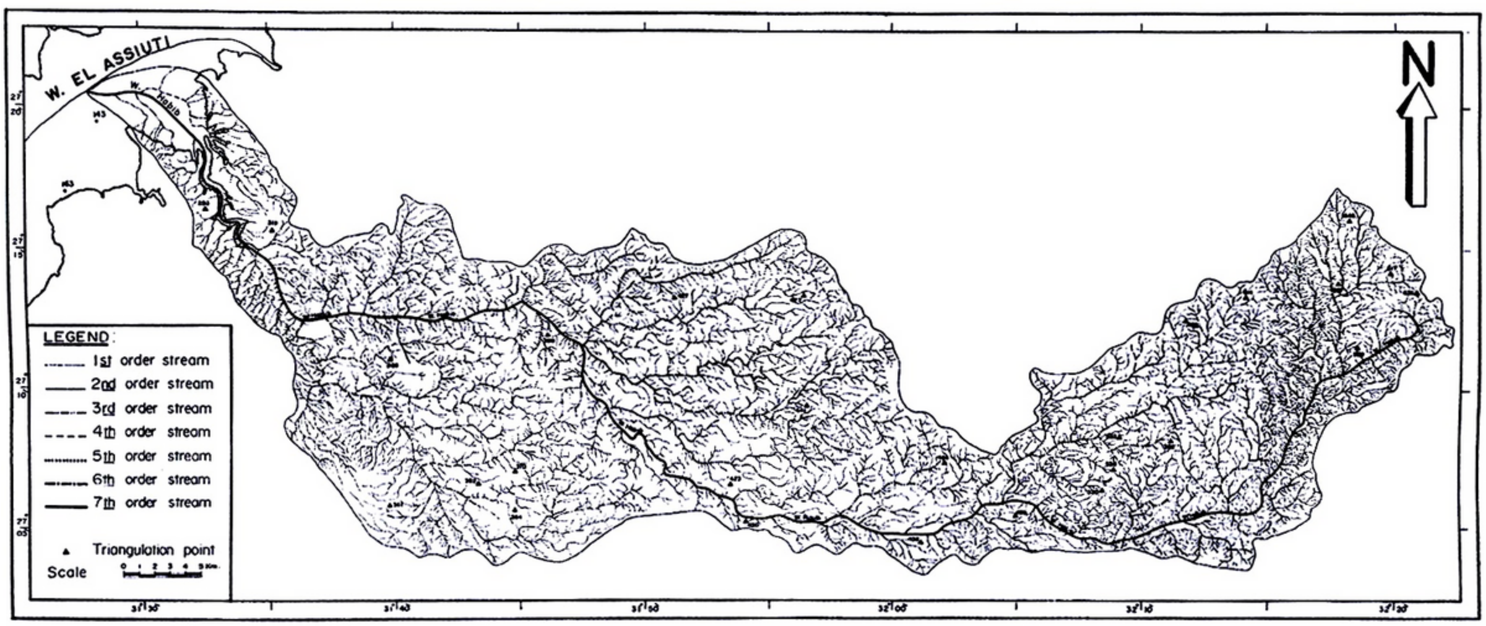


Figure 3

The drainage network of Wadi Habib (Prepared from the Topographic Map after Egyptian General Survey Authority).

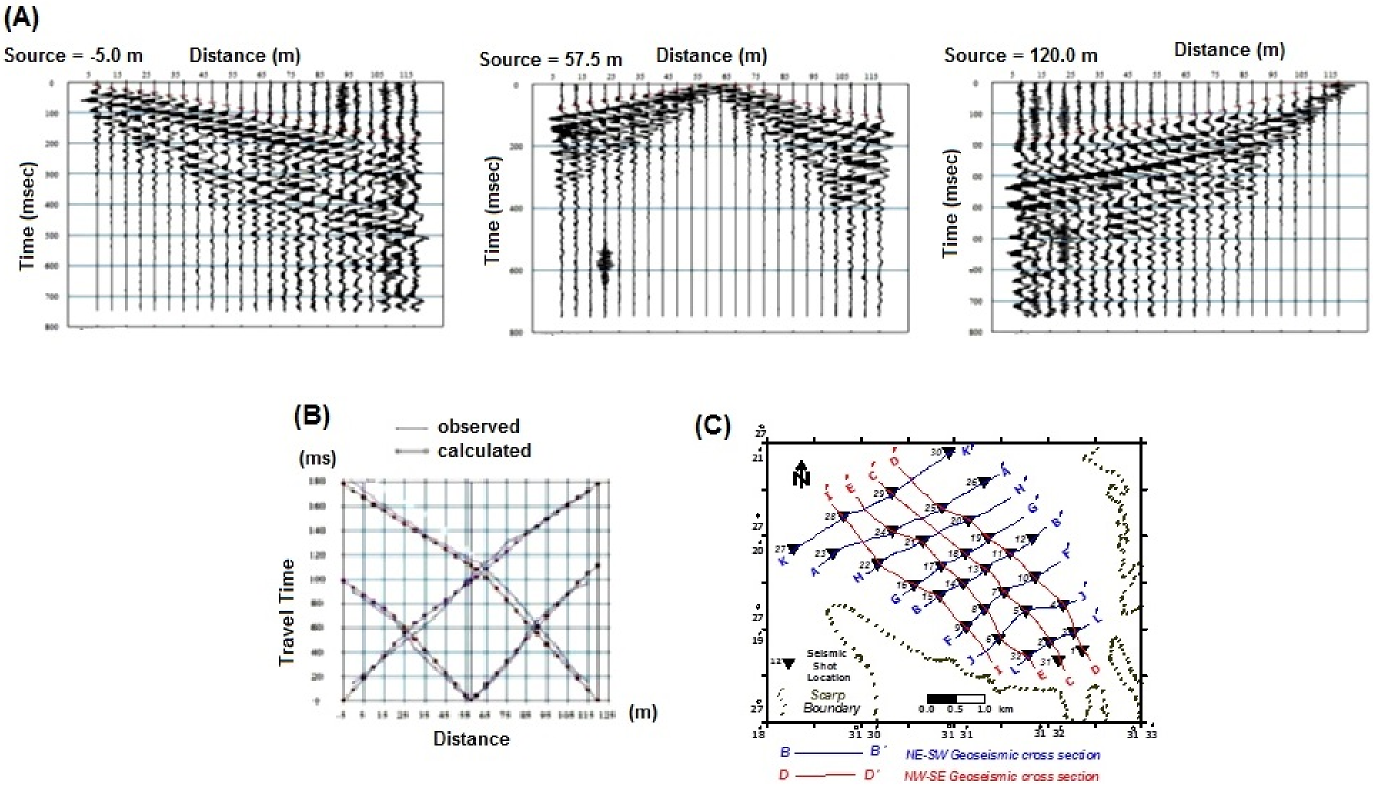


Figure 4

Example of recorded seismograms (forward, midpoint and reverse shooting) from vertical impact source at site No. 15 (A) and the corresponding constructed time-distance curve (B), as well as the location map of the constructed seismic shots and the geoseismic cross sections (C).

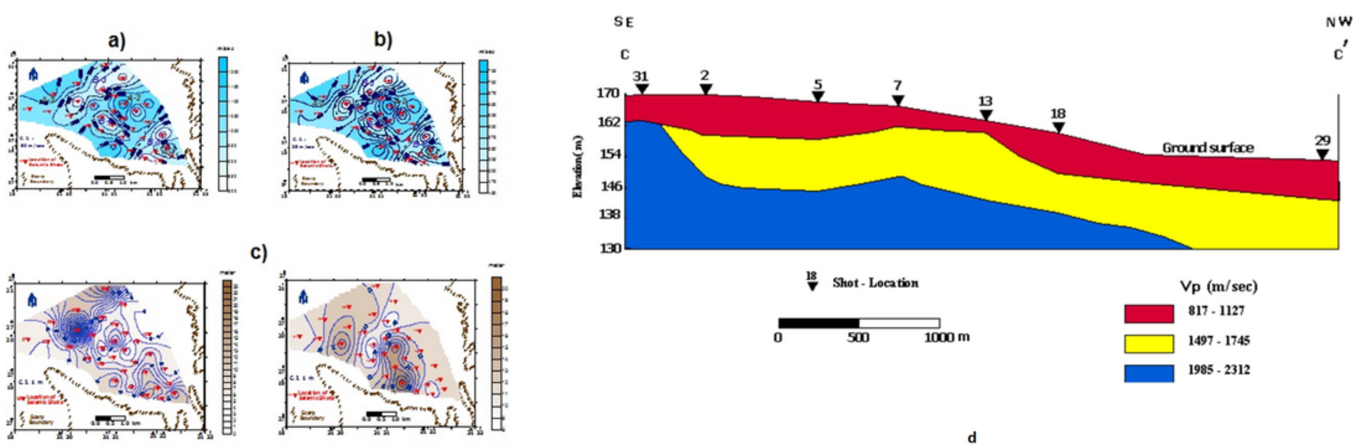


Figure 5

(a) Compressional wave velocity map, (b) Shear wave velocity map, (c) Thickness contour map for the first (left) and second (right) geoseismic layer. (d) Subsurface geoseismic cross section C-C'

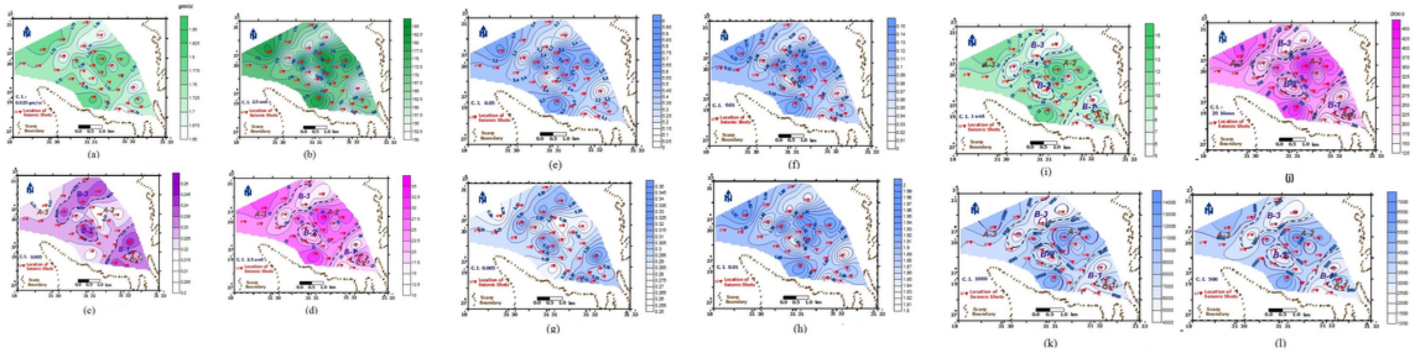
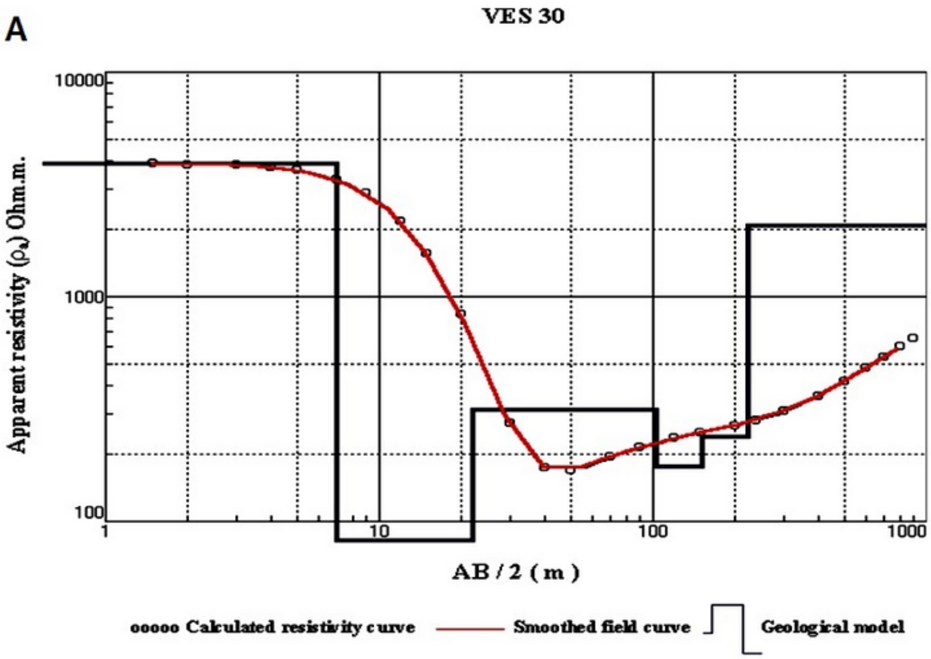


Figure 6

Estimated seismic and geotechnical parameters of foundation layer in Wadi Habib site; (a) Bulk density map, (b) RQD factor map, (c) Poisson's ratio map, (d) Kinetic Young's modulus map, (e) Concentration index map, (f) Material index map, (g) Stress ratio map, (h) Density gradient map, (i) Kinetic rigidity modulus map, (j) SPT or N-value map, (k) Ultimate bearing capacity map, (l) Allowable bearing capacity map.



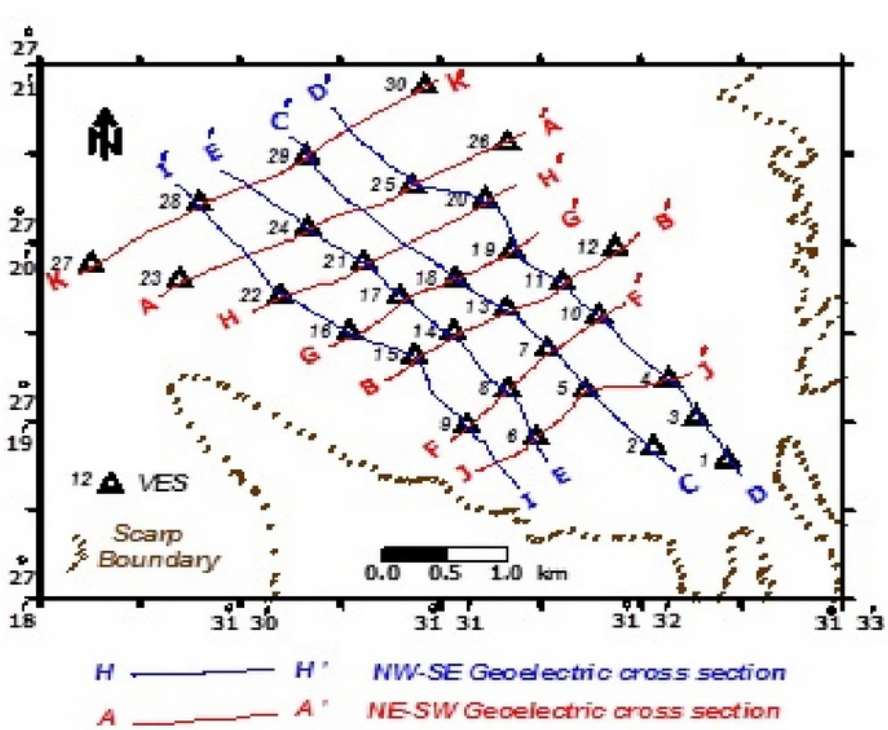


Figure 7

(a) An example of conducted vertical electrical sounding Used Schlumberger electrode arrangement at VES No. 30 showing the smoothed field curve, the interpreted model and the calculated curve using the computer software IPI2Win. 6 and (b) Location map of the constructed VESes and geoelectrical cross sections.

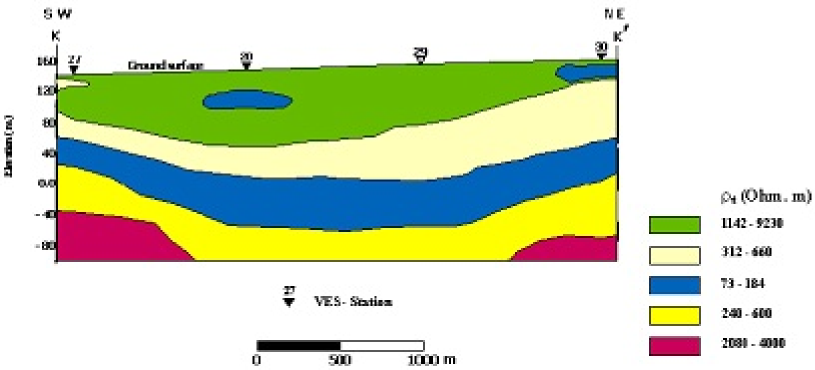


Figure 8

Subsurface geoelectrical cross-section K-K'.

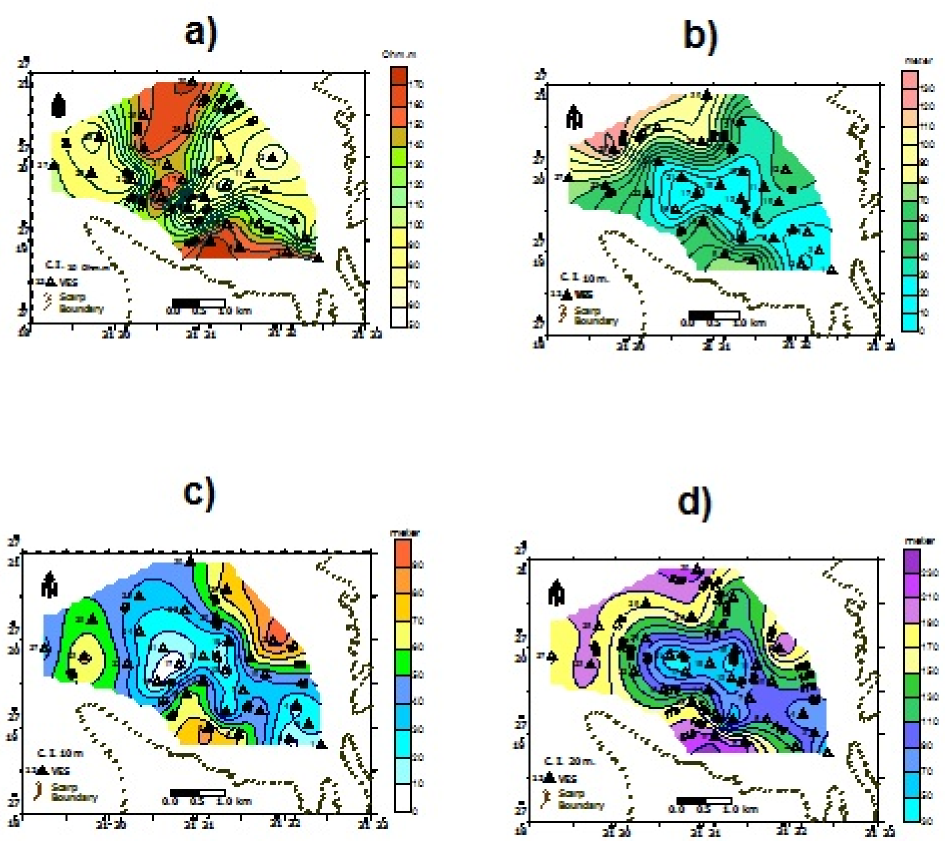


Figure 9

(a) True resistivity map of the probable wet zone , (b) Depth contour map to the probable wet zone, (c) Isopach map of the probable wet zone, (d) Depth contour map to the bed rocks.

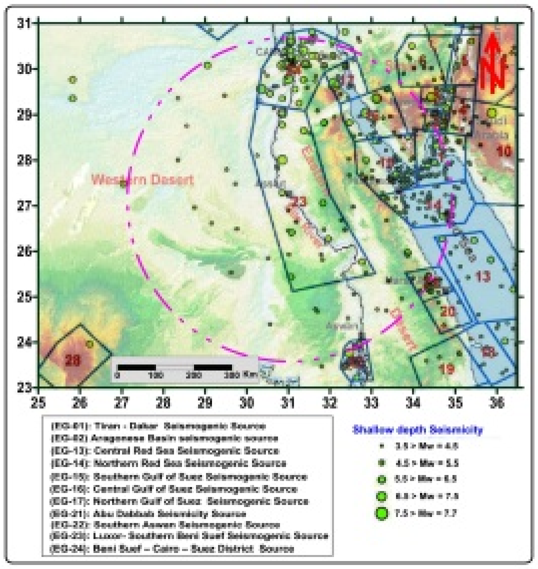


Figure 10

Shallow-depth seismicity (d ≤ 35 km) and delineated seismic sources along the Red Sea, Gulf of Suez, and the Nile River modified after Sawires et al.(2015), and Mohamed Arfa and Fat-Helbary R.E. (2021).

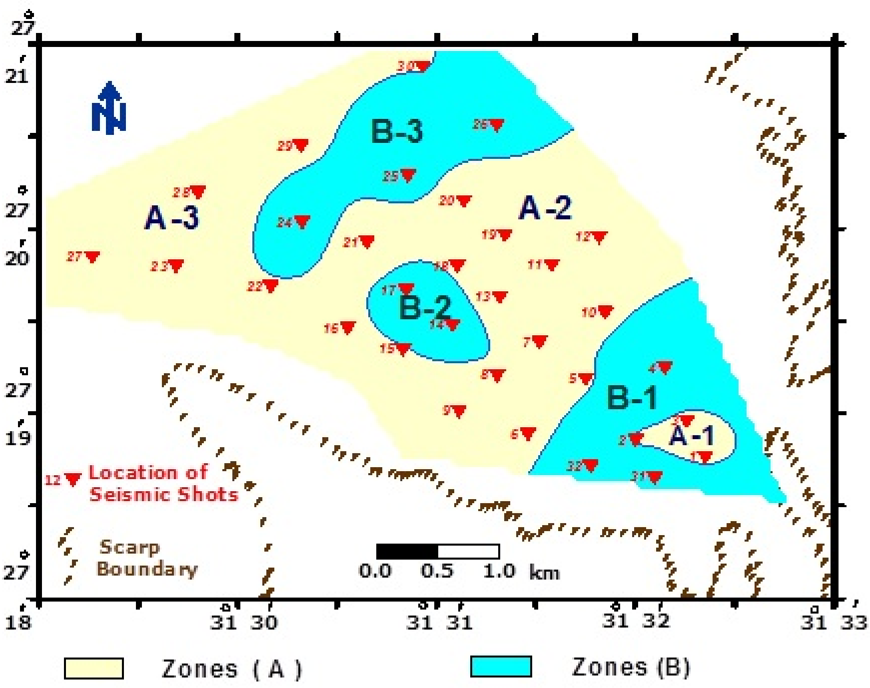


Figure 11

Classification of the material quality according to the Elastic, Competence and Bearing capacity characteristics of the surface geoseismic layer into A and B zones.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.pdf
- Table2.pdf
- Table3.pdf
- Table4.pdf
- Table5.pdf
- Table6.pdf
- Table7.pdf
- Table8.pdf
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- Table10.pdf