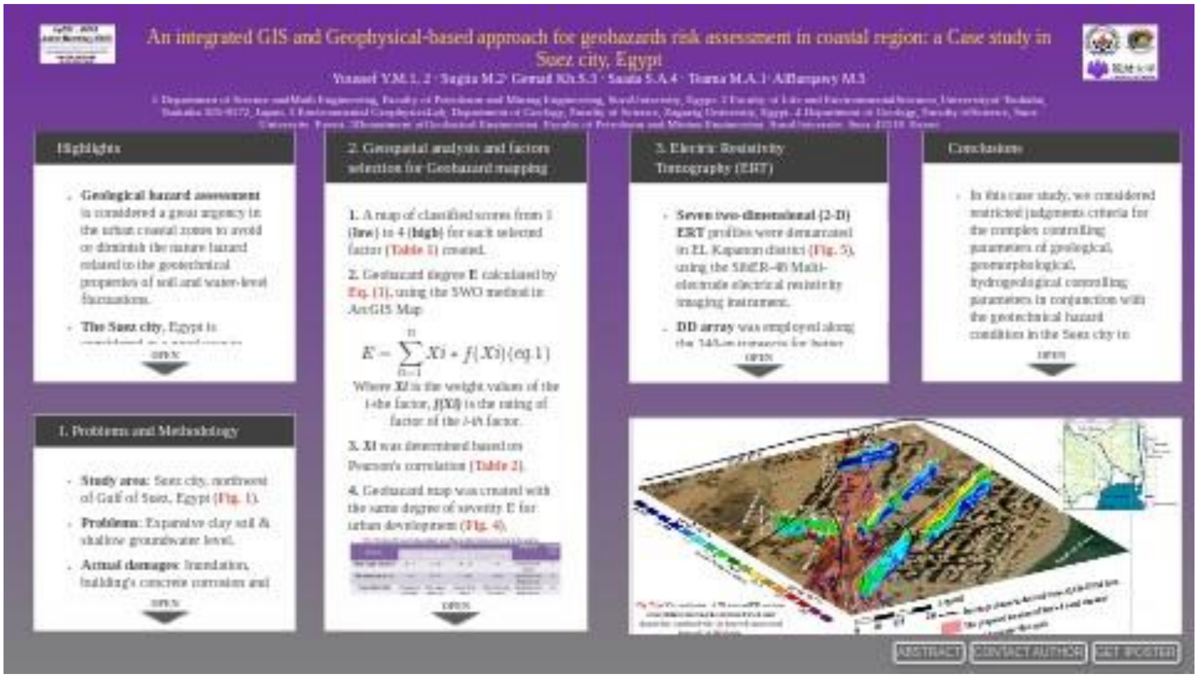
An integrated GIS and Geophysical-based approach for geohazards risk assessment in coastal region: a Case study in Suez city, Egypt



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HIGHLIGHTS

- **Geological hazard assessment** is considered a great urgency in the urban coastal zones to avoid or diminish the nature hazard related to the geotechnical properties of soil and water-level fluctuations.

- **The Suez city**, Egypt is considered as a good case to identify, characterize and map the vulnerability conditions due to the geotechnical and geological issues.

- **To achieve this goal**, a new geohazard model was established by integrating possible controlling factors for the whole city.

- **The factors** were scored and weighted according to criteria.

- It was further combined with the Simple Weighting Overlay (**SWO**) method in the Geographic Information System (**GIS**) to build a geohazard zonation map.

- **The result** identified a local severe area and was further studied to find the potential obscured cause using Electrical Resistivity Tomography (**ERT**) survey.

- **The 3D visualization** of Dipole-Dipole (**DD**) profiles shows a buried sand channel that was supposed to enhance the lateral invasion of seawater from the coastal part to the residential area.

- **This multidisciplinary approach** identified the appropriate sites for environmental interventions and/or engineering risks. It was also shown that our method is applicable in many similar areas in the world.

1. PROBLEMS AND METHODOLOGY

- **Study area**: Suez city, northwest of Gulf of Suez, Egypt (**Fig. 1**).

- **Problems**: Expansive clay soil & shallow groundwater level.

- **Actual damages**: Inundation, building's concrete corrosion and tilting. A lot of building would be demolished by the end of 2020 (**Fig. 2**).

- Very little consideration was given to evaluate these purposed in the previous studies.

- **Purpose**: Establish an extraordinary geohazard map and 2D ERT survey for a local-scale hazard area (**Fig. 3**).

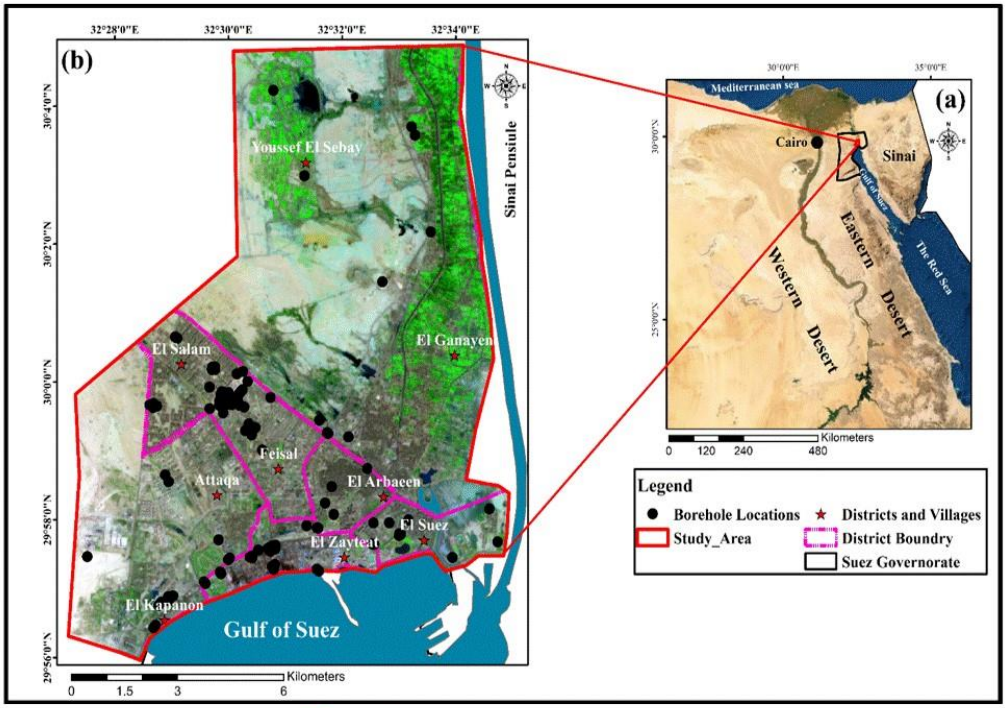

Fig. 1 Location map of the study area

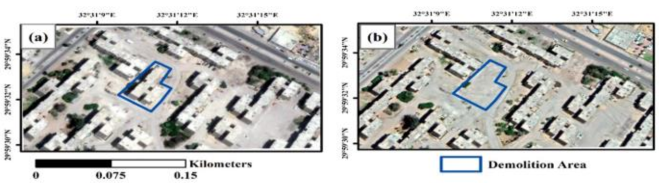

Fig. 2 Vertical view from Goggle earth map showing **(a)** Buildings exit in August 2018, **(b)** Buildings were demolished in May 2019

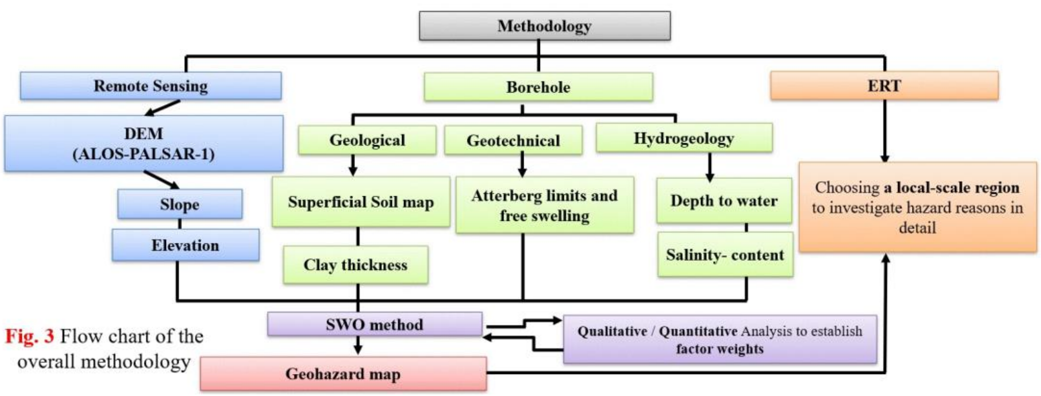

Fig. 3 Flow chart of the overall methodology

2. GEOSPATIAL ANALYSIS AND FACTORS SELECTIONFOR GEOHAZARD MAPPING

1. A map of classi ed scores from 1 (low) **low** 4 (high) **high** each selected factor (Table 1) c**Table 1**d

2. Geohazard degree E **E** alculated by Eq. (1), using the SWO method in ArcGIS Map **2** **Eq. (1)**

$$E = \sum_{n=1}^{n} Xi * f(Xi) \quad (eq.1)$$

Where Xi is the weight values of the i-the factor, f(Xi) is the rating of factor of the **i-th** factor. *Xi* *f(Xi)*

3. ***Xi*** was determined based on Pearson's correlation (**Table 2**).

4. Geohazard map was created with the same degree of severity E for urban development (**Fig. 4**).

Table 1 Factors with score rating assigned according to related reference involved in the analyses

Factors	Score				Reference	Weight (%)
	Low (1)	Marginal (2)	Severe (3)	Very – Severe (4)		
Slope angle (degree)	0 - 5	5 - 10	10 – 15	> 15	Youssef et al. (2011)	5
Elevation (m a.s.1)	> 25	25 - 3	3 – zero	< zero	Qualitative & field survey	12
Superficial Soil	Conglomerate and Gravelly Sand	Silty Sand and Fill	Sandy Silty Clay	Silty Clay and Fracture Limestone	Qualitative & field survey	12
Thickness of Silty Clay (CT)	0 – 5	5 - 10	10 – 15	15 – 25.5	Qualitatively	12
Depth to water (DW) (m)	> 5	5 – 2.5	2.5 – 2	< 2	Jones (2001)	12
Chloride (Cl^{-1}) (ppm)	< 500	500- 2000	2000-10000	> 10000	SBC (2007)	7
Sulfate (So_4) (ppm)	< 150	150- 1500	1500 – 10000	> 10000	ACI (2014)	7
Total Dissolved Salts (TDS) (ppm)	< 1000	1000 - 3000	3000 - 10000	10000 - 35000	USACE (1994); Todd (2005)	7
pH	> 6.5	6.5 – 5.5	5.5 – 4.5	< 4.5	Neville (2011)	5
Liquid Limits (LL %)	20 - 35	35 -50	50 – 70	70 - 90	IS (2002)	7
Plastic Index (PI %)	< 12	12 – 23	23 -32	> 32	IS (2002)	7
Free Swelling (S_f %)	< 50	50 – 100	100 -200	> 200	IS (2002)	7

Table 2 Pearson's correlation matrix of the geohazard model parameters

	Elevation	Slope	DW	Cl^{-1}	SO_4	TDS	pH	CT	LL	PI	S_f
Elevation	**1.00**										
Slope	-0.03	**1.00**									
DW	**0.48**	-0.13	**1.00**								
Cl^{-1}	**-0.51**	-0.02	**-0.33**	**1.00**							
SO_4	-0.12	-0.04	-0.24	**0.71**	**1.00**						
TDS	**-0.43**	-0.07	**-0.32**	**0.91**	**0.66**	**1.00**					
pH	0.26	0.02	**0.32**	-0.29	0.17	**-0.34**	**1.00**				
CT	**-0.32**	0.12	**-0.47**	**0.39**	0.29	**0.43**	**-0.33**	**1.00**			
LL	-0.23	-0.03	**-0.65**	0.11	0.19	0.18	-0.21	0.03	**1.00**		
PI	-0.01	0.02	**-0.42**	-0.02	0.02	0.11	-0.29	0.10	**0.70**	**1.00**	
S_f	-0.04	0.04	**-0.42**	0.11	0.04	**0.32**	**-0.45**	0.18	**0.40**	**0.72**	**1.00**

- Values in bold correspond for significant coefficients above **±0.31**

- Among tested factors maps, elevation (**Fig. 4** (**b**)), the depth to water level (**Fig. 4** (**h**)), soil media type (**Fig. 4** (**c**)) and clay thickness (**Fig. 4** (**d**)) appears to pose further risks under environmental dynamic circumstances.

- These entail equal high weighting values for these factors while the lowest weights were designed only for slope (**Fig. 4** (**a**)) and pH (**Fig. 4** (**l**)) maps that display less impact on-site risks (**Table 1**).

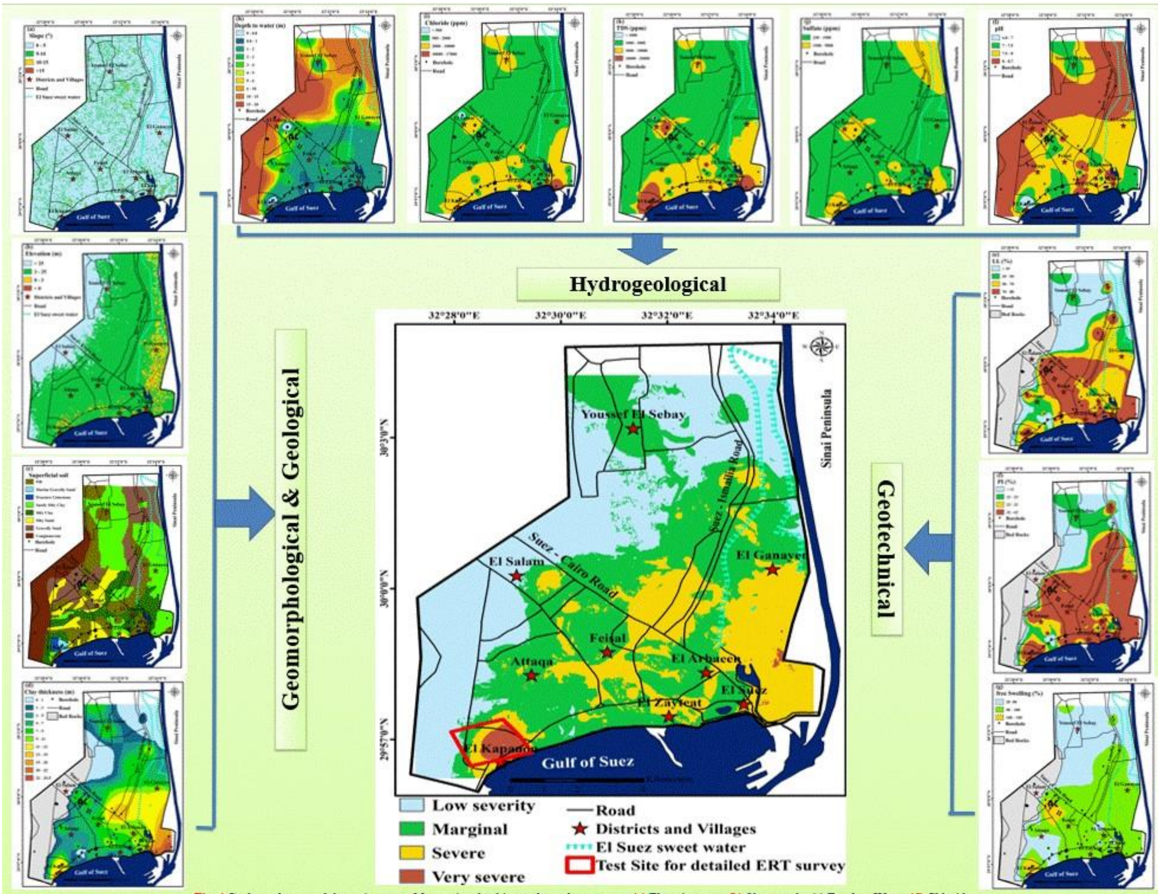

Fig. 4 Geohazard map and thematic maps of factors involved in geo-hazard assessment (a) Elevation map, (b) Slope angle, (c) Depth to Water, (d) Chloride concentration, (e) Sulfate concentration, (f) TDS concentration, (g) pH indicator, (h) Superficial soil deposit and (i) Thickness of silty clay, (j) Liquid Limit (LL) %, (k) Plastic Index (PI) % and (l) free Swelling (S_f) %.

- The very severe area was observed mainly around El Kapanon district (**Fig. 4**).

- An extensive field survey was performed to El Kapanon area, in winter of 2018 that noted significantly the existence of shallow saline groundwater moves into the sewage system.

Field visit photo show new building area flooded with groundwater

3. ELECTRIC RESISTIVITY TOMOGRAPHY (ERT)

- **Seven two-dimensional (2-D) ERT** profiles were demarcated in EL Kapanon district (**Fig. 5**), using the SibER-48 Multi-electrode electrical resistivity imaging instrument.
- **DD array** was employed along the 240-m transects for better horizontal resolution.

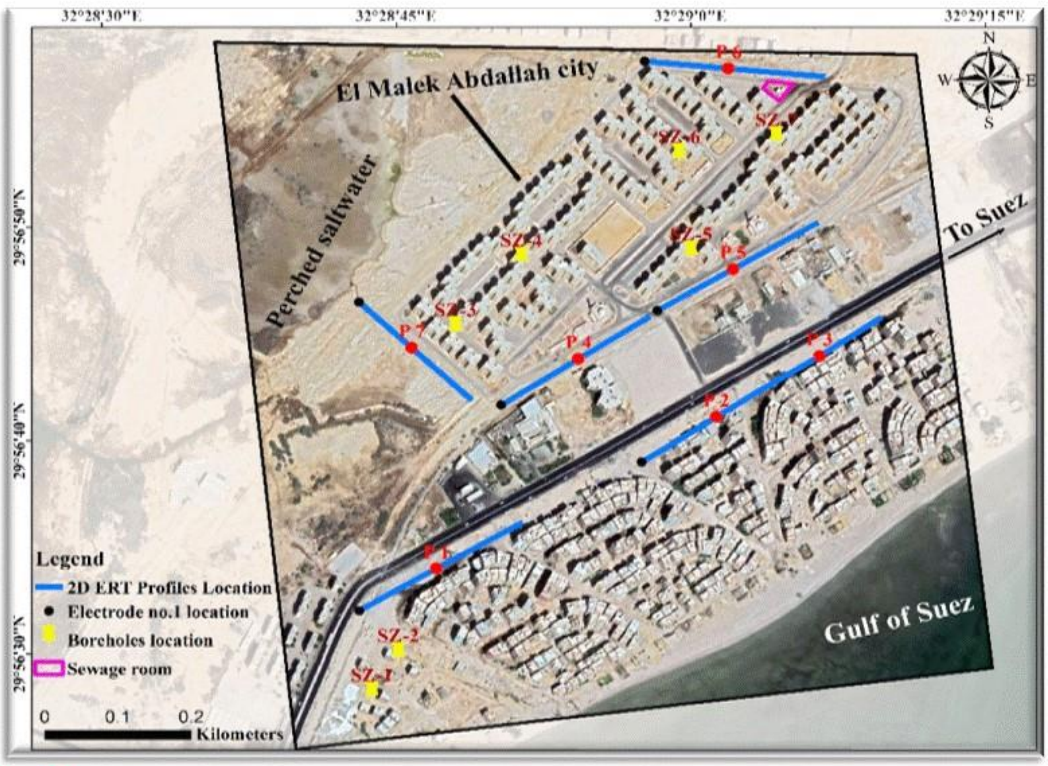

Fig. 5 Location map of the 2-D geo-electric measurements for El Kapanon area.

- **The pseudo-sections** show very low apparent resistivity values (**Fig. 6**), thus applied two steps as the following:

1. The smoothness constraint method was applied to minimize large and unrealistic variations in the output models.
2. The boreholes data used to reduce uncertainty problems during inversion steps and determine the optimum model.

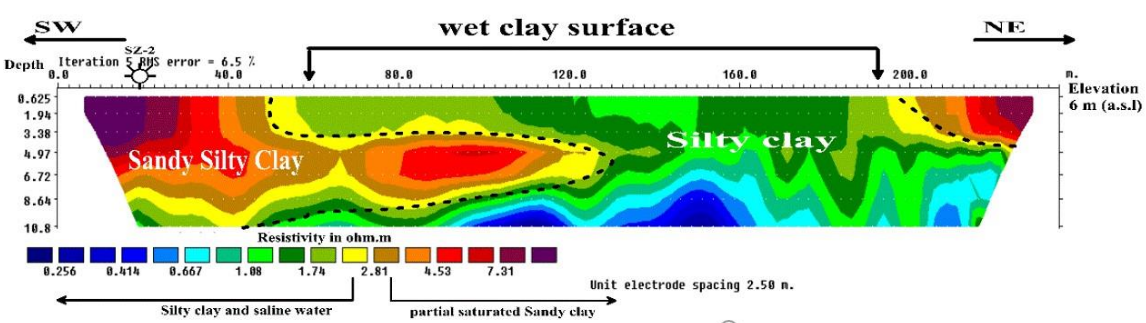

Fig. 6 Inverted DD section (P1) showing the lateral variations in the soil

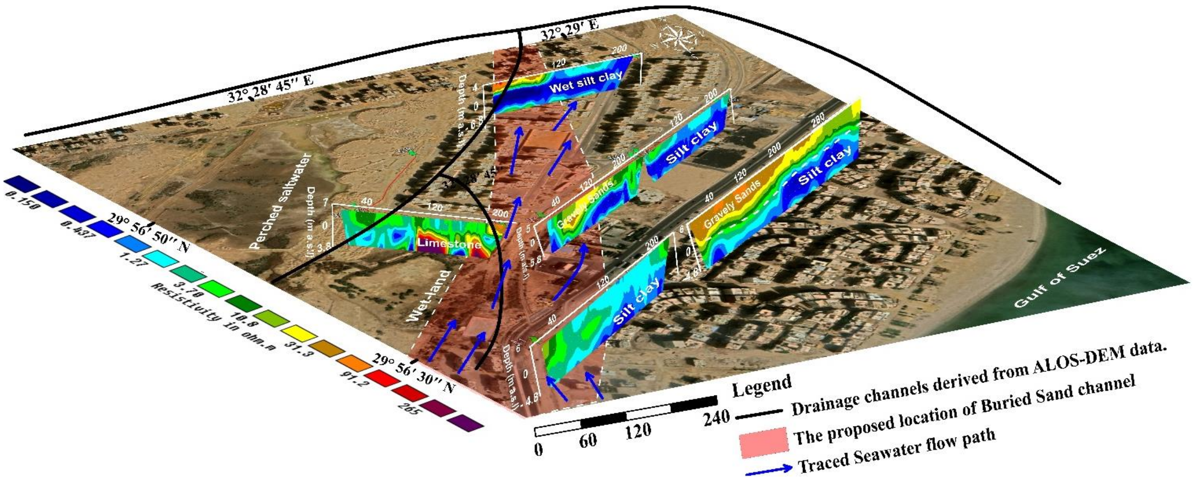

Fig. 7 shows the existence of the buried sand drainage channel passes from the western part of profile P1 through the top eastern part of profile P7 and western profile P5, going toward the western portion of profile P6.

- The accumulation of high saline water was observed near sewage room, based on a field visit, also low resistivity figures at profiles P5 and P6 and high TDS values > 25000 ppm from borehole data.

- The clay behavior underlines the topsoil is characterized by high swelling potentiality. This criterion could be reduced the vertical infiltration rate that causes rising of groundwater levels to the surface.

- Thus, if a little change on the seawater level (i.e. + 0.5 m a.s.l) takes place during the winter season, there will be a high risk of seawater passing through this channel from Gulf of Suez toward this site and that was observed during field visits.

CONCLUSIONS

- In this case study, we considered restricted judgments criteria for the complex controlling parameters of geological, geomorphological, hydrogeological controlling parameters in conjunction with the geotechnical hazard condition in the Suez city to construct a regional geohazard map.

- The applied approach illustrates the significant factors and the arithmetic weights assigned to each level of severity, and therefore they should be considered in similar studies and can be a vigorous tool for planning and management.

- The 2D ERT survey in a local-scale region detected precisely the paths of groundwater flow through buried sand channels, beside lateral and vertical litlithological variation within clay environment.

ABSTRACT

In coastal regions, more precaution for urban expansion should be considered regarding hidden geological hazard from the existence of expansive clay soil and shallow groundwater level. These conditions cause huge damage to engineering constructions that leads to losses of human lives and financial property. However, very little studies were focused on hazard assessment of swelling clay potentiality using GIS approach, because its natures as occur slowly by time. The purpose of the present work is the analysis of geological–geotechnical factors to present a geo-hazard risk assessment model for the identification of high risk-prone regions in the coastal zone using an integrated GIS statistical system and Electrical Resistivity Tomography (ERT) mapping. Suez city (the case study area) is located in the northwest of the Gulf of Suez that has a vital and attractive global location for trading and investment. The geo-hazard model was created in a GIS environment by integrating thematic maps of possible controlling factors from ALOS-DEM image and available geological and geotechnical boreholes. These factors showed a varied ranges: slope (0-35°), elevation (0-50 m), superficial soil (Conglomerate to silty clay), clay thickness (0-25 m), depth to groundwater (0-20 m), TDS (1000-35000 ppm), Cl-1 (500-17000 ppm), So4 (250-9000 ppm) and pH (6.8-8.7) and in conjunction with swelling potentiality (Liquid Limit (LL) (35-88 %), Plastic Index (PI) (12-62 %) and free Swelling (Sf) (35-150 %)). Assessment these factors causes kind of uncertainty during the evaluation procedure, thus all thematic maps were scored and weighted according to specified criteria to produce severity distributions maps. The crucial relationships between surface and subsurface factors were identified by employing geospatial qualitative and Pearson' correlation analysis. In the considered case, the clay soil is an inorganic cohesive type of high to a very high swelling degree. Among tested factors, the existence of clay soil and its thickness seem to play an important role to increase groundwater level that approach surface in several sites of Suez city, hence rising the risks of Total Dissolved Salts (TDS), Chloride (Cl-1), and augmenting swelling potential. Accordingly, the designed suitable relative weights were determined and all thematic maps were combined to produce a geo-hazard map using Simple Weighting Overlay (SWO) method. This approach illustrates the significant factors and the arithmetic weights assigned to each level of severity, and therefore they should be considered in similar studies. Geo-hazard map was produced with four degrees of severity for urban development: low, marginal, severe and very severe comprising 36.38, 40.28, 22.13 and 1.2 %, respectively, of the study area. The very severe area was observed mainly around El Kapanon district.

An extensive field survey was performed, noted significantly high saline groundwater move into the sewage system. Seven 2DERT profiles were executed in this region using Dipole-Dipole (DD) array that integrated with available boreholes to establish a clear image for subsurface layers. The topsoil identified as gravelly sand (>: 30 Ωm) extending down to - 3 m (a.s.l). A low resistivity layer (<: 4 Ωm) attribute to thick silty clay observed underlined this topsoil, the clay behaviour in this area characterized by high swelling potentiality as indicated from near boreholes SZ-3 to SZ-7. The inverted sections were used to create a 3D visualization by fitting all DD profiles. The result displays the existence of a buried channel of gravelly sand extending from the shoreline to city and underlined by thick clay soil more than 10 m that reduced the vertical infiltration rate. This suggested a lateral invasion of seawater usually occurred from a coastal part to the residential area during high tidal events in winter seasons. This continuous wetting caused the high salinity values and clay swelling measurements in this site. Therefore, government and urban planning should seriously consider treating proper action for current problematic conditions, before they become worse and affect the future development plan in this area. Overall, the results obtained in this study suggest that the GISbased hazard model combined with localized ERT survey can be a vigorous tool for planning and management, by identifying the appropriate sites for environmental interventions and/or engineering risks.