

Meteorological Indices Approach for Prediction of Thunderstorm Probability at Two Coastal Sites in Egypt

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Abstract

Siting of hazardous facilities such as Nuclear power plants requires the investigation of the meteorological and climatologically of the site region to derive extreme values of the meteorological variables to be considered in the design for safety purposes. Not only normally occurring meteorological conditions but also extremely rare events are considered. The present work is devoted to predict the likelihood of the Thunderstorm which is one of the rare events of concern for plant safety. Four atmospheric stability indices such as K-indices, the Showalter-indices, total totals-indices and the SWEAT-indices have been used for that. These function of meteorological parameters such as temperature, wind speed, wind direction and dew point at levels of pressure at 500, 700 and 850 hpa to predict the thunderstorm probability. Two Egyptian coastal sites have been chosen for the investigation, one on the Mediterranean Sea and the other on Red Sea; El Sallum and Sharm El Sheikh. The results show that the probability of thunderstorm occurred within the months January and February during 1989-2003, where the maximum value of SI, K, TT and SWEAT indices at January & February months equals 29.31 & 28.20, 18.4 & 20.3 & 48.1 & 49 and 238.01 & 350.6 for Sallum city respectively, and equals 26.05 & 24.53, 24.6 & 23.9, 50.6 & 51.5 and 253.4 & 265.4 for Sharm El Sheikh city respectively, and this agrees with the pattern reviewed based on world geographic and climatic condition.

Keywords

Showalter Indices, TT Indices, K-Indices, SWEAT Indices, Radiosond, Temperature and Dew Point

1. Introduction

Siting of hazardous facilities such as Nuclear Power Plants requires the investigation of the meteorological and

climatological characteristics of the site region to derive extreme values of the meteorological variables to be considered in the design for safety purposes. Meteorological aspects of external hazards to be considered include extreme values of meteorological parameters as well as rarely occurring hazardous meteorological phenomena [1] [2]. The important meteorological characteristics of concern include wind, precipitation, snow, temperature, storm surges [3] [4] and rare meteorological phenomena such as lightning, tornadoes, tropical cyclones.

Lightning is a visible electrical discharge most commonly produced in thunderstorms. Lightning transients exhibit extremely high voltages, currents and current rise rates. Lightning is a significant cause of interruptions or damage in almost every electrical or electronic system that is exposed to thunderstorms, [5]. Damage is usually categorized as either direct or induced (indirect). The extreme electric field created under certain circumstances produces point discharges and can cause breakdown (a conductive path) in all but the most robust of insulators. Once a path has been established for the return stroke, currents of tens to hundreds of kiloamperes flow. It should be noted that lightning is an unpredictable transient phenomenon with characteristics that vary widely from flash to flash and whose measurement is difficult. The hazard assessment for lightning should result in an estimated annual frequency of exceedance for lightning strike for the planned nuclear power plant.

The present study devoted to predict the probability occurring thunderstorms across the North and East coasts of Egypt. Four atmospheric stability indexes are measured for that. These indexes are: K-index, the Showalter, total totals and the SWEAT [6]. These indexes combine important meteorological parameters of concern to thunderstorms production, to determine its relative probability. Two Egyptian coastal cities have been chosen for the investigation, one on the Northern Mediterranean Sea and the other on Red Sea; El Sallum and Sharm El Sheikh, respectively.

2. Location and climate of the Study Area

The investigated area comprises two coastal cities in Egypt; Sham El Sheikh and El Sallum. Sharm El Sheikh city is situated on the coastal strip along the Red Sea, which includes the smaller coastal towns of Dahab and Nuweiba as well as the mountainous interior, Saint Catherine's Monastery and Mount Sinai. Nowadays it is a major touristic hotspot and resort city in Egypt [7]. And Sallum city is on the other hand situated on the Egyptian Mediterranean northwest Coast, along the border with Libya [8], as shown in **Figure 1**.

Table 1 and **Table 2** [9] [10], show indicate mean values of the major meteoric conditions of several stations including that are concerned in the studied two cities; Sham El Sheikh and El Sallum.

3. Methodology

The atmospheric stability and the thunderstorm vulnerability have been examined in two coastal cities in Egypt; El Sallum at the northwest coast and Shrm El Sheikh at the Red Sea Four meteorological indexes; Showalter Index (SI) [11] (Total Totals Index (TT), K-index, and Severe Weather SWEAT, have been calculated and functioned for that purpose. Radio soundings [12] are used to obtain vertical profiles of thermodynamic (pressure,

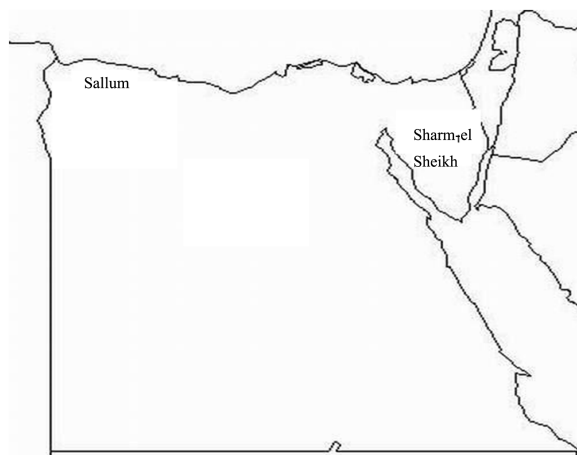


Figure 1. Map of the study area.

Table 1. Mean monthly and annual wind speed (m/s) and its direction (at a height 10 m).

Station	Month												Annual Mean	Wind Direction
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.		
<i>Sallum</i>	5.4	4.8	5.2	4.3	3.6	4.1	4.7	4.2	3.4	3.6	4.2	5.2	4.4	330NW
<i>Sidi Barrani</i>	5.6	5.7	5.9	5.7	4.7	4.6	5.2	4.5	4.0	4.2	4.6	5.6	5.0	330NW
<i>Mersa Matruh</i>	6.1	6.1	6.3	5.7	4.9	5.2	5.2	4.7	4.4	4.3	4.8	5.9	5.3	330NW
<i>El Dabaa</i>	5.5	5.8	6.1	5.8	5.1	6.0	6.0	5.7	5.0	4.2	4.5	5.5	5.4	330NW
<i>Dekheila</i>	4.5	4.6	4.9	4.8	4.3	4.5	4.6	4.5	4.2	3.7	3.8	4.1	4.4	360N
<i>Alexandria</i>	4.4	4.4	4.6	4.3	4.0	4.0	4.4	4.0	3.7	3.1	3.4	4.1	4.0	330 NW
<i>Balteam</i>	3.6	3.5	4.2	4.0	3.5	3.7	3.9	3.6	2.8	2.3	2.6	3.3	3.4	330 NW
<i>Damietta</i>	2.8	3.1	3.7	3.6	3.1	3.1	2.8	2.5	2.3	2.5	2.5	2.9	2.9	330 NW
<i>Port Said</i>	4.8	5.2	5.8	5.4	4.8	4.6	4.3	3.8	3.8	4.1	4.3	4.3	4.6	360N
<i>El Arish</i>	2.5	2.9	3.0	2.5	2.4	2.4	2.3	2.1	2.2	2.0	2.1	2.4	2.4	330 NW

Table 2. Summary of the mean annual climatic data for the Selected Weather Stations in Egypt.

Weather Station	Mean Annual Values				
	T (°C)	S (km/h)	SH (%)	CP (mm)	RH (%)
Damietta	21.84	13.56	88.76	220	66.81
Alexandria	21.8	17.22	88.78	232	64.69
Port Said	21.66	13.83	89.19	154	65.53
Marsa Matruh	21.27	18.15	89.12	119.4	63.09
Ismailia	22.2	8.97	87.91	37.5	54.31
Mansura	22.45	6.77	81.29	101.6	62.19
Tanta	21.88	8.38	84.99	95.3	59.39
Banha	23.07	8.27	87.15	73.7	54.83
Cairo	23.48	10.3	89.97	69.9	48.41
Siwa	22.16	13.3	92.3	10.2	39.99
Beni Suef	23.35	10.23	93.13	29.2	41.71
Sharm El Sheikh	25.16	13.37	95.63	60.3	45.16
Safaga	24.35	13.84	95.67	45.7	45.74
Qena	23.1	8.41	95.67	34.9	33.11
Luxor	23.42	7.74	95.69	33	33.19
Aswan	24.4	8.59	96.09	9.5	27.98

Where: T: mean annual air Temperature (°C) S: mean annual wind speed (km/h) SH: mean annual sun shine (%) CP: mean annual cumulative precipitation (mm) RH: mean annual relative humidity (%).

temperature and humidity) and dynamic (horizontal winds) variables, which have been collected from National Ocean Atmospheric Administration (NOAA) [13] for 10 years from 1989-2003 for Sallum and Sharm Sheikh. These are used for the analysis of the four indices that are described as follow:

Showalter Indices (SI) [11] (This is an indices used to determine the stability of the lower half of the troposphere. An air parcel is lifted from an initial position at 850 mb where localized low level influences are greatly

reduced. It is lifted dry adiabatically to its LCL and then pseudo-adiabatically to 500 mb. The environmental temperature is then subtracted from the parcel temperature to obtain the value of the Showalter index. The risk of severe weather activity is defined as follows: The index is the difference between lifted parcel temperature (T_{lift}) and the environmental temperature (T_{env}) at 500 mb:

$$SI = T_{\text{env}} - T_{\text{lift}} \quad (1)$$

When SI is negative, that is, the lifted temperature is warmer than the environment, the parcel is unstable.

Total Totals Indices (TT)

The Total Totals indices is a simple index derived from the temperature lapse rate between 850 mb and 500 mb and moisture content at 850 mb and moisture content at 500 mb. It is defined as follows [14] [15]:

$$TT = T_{850} + Td_{850} - 2T_{500} \quad (2)$$

where T_{850} and Td_{850} are the temperature and dew point temperature respectively at the 850 hPa level, T_{500} is the temperature at the 500 hPa level.

3.1. K-Indices

From Wikipedia, the free encyclopedia, K-Indices in meteorology is a measure of the thunderstorm potential based on vertical temperature lapse rate, moisture content of the lower atmosphere, and the vertical extent of the moist layer. The index is derived arithmetically: The K indices is similar to Total Totals index except that it takes into account moist air at 700 mb contributing to air mass thunderstorm development. The K index is defined as follows [14] [16]:

$$K = T_{850} - T_{500} + Td_{850} - (T_{700} - Td_{700}) \quad (3)$$

where T_{700} & Td_{700} are the temperature and the dew point temperature respectively at the 700 hPa level, T_{500} is the temperature at the 500 hPa level.

3.2. SWEAT (Severe Weather Threat Indices) Indices

This is an United States Air Force indices that takes into account thermal instability, low level moisture content, vertical wind shear and horizontal wind speeds. The risk of severe weather activity is defined as follows [15] [17]:

$$SWEAT = 12Td_{850} + 20(TT - 49) + 2f_{850} + f_{500} + 125(\sin[d_{500} - d_{850}] + 0.2) \quad (4)$$

where f_{850} is the wind speed at 850 hPa in knots, f_{500} is the wind speed at 500 hPa in knots, d_{850} is the wind direction at 850 hPa, d_{500} is the wind direction at 500 hPa

4. Results and Discussion

The average values of the four indices chosen to infer the probability of occurrence of thunderstorm in El Sallum and Sharm El Sheikh cities at January and February for the years, 1989-2003 are indicated in **Table 3** and **Table 4**. The indicated values of El Sallum city vary in the range from 17.8 to 23.40 and 16.19 to 20.3 & -22.34 to -3.22 and -20.52 to -2.54 & 20.15 to 31.5 and 20.53 to 33.06 and 79.54 to 113.02 & 77.05 to 113.02 for SI & K & TT and SWEAT indices respectively. On the other hand, Sharm El Sheikh city shows values varying in the range from 16.5 to 19.53 and 15.62 to 18.51 & -14.57 to -1.77 and -15.88 to 2.65 & 28.42 to 35.27 and 27.53 to 36.79 and 81.28 to 112.65 & 79.98 to 125.89 respectively.

The columnar diagrams, **Figures 2-7** illustrate the variability and comparability of the indicated values. The range of variation is narrower in ElSallum than Sharm ElSheikh indicating a more homogeneous and stable meteoric condition.

The following categories of SI, TT, K and SW describe the probability of thunderstorms hazard and the risk associated with it [17]

SI values > 3 No significant activity

SI values 1 < SI < 3 Showers possible with other source of lift

SI values -3 < SI < -2 Thunderstorms more probable (possibly strong)

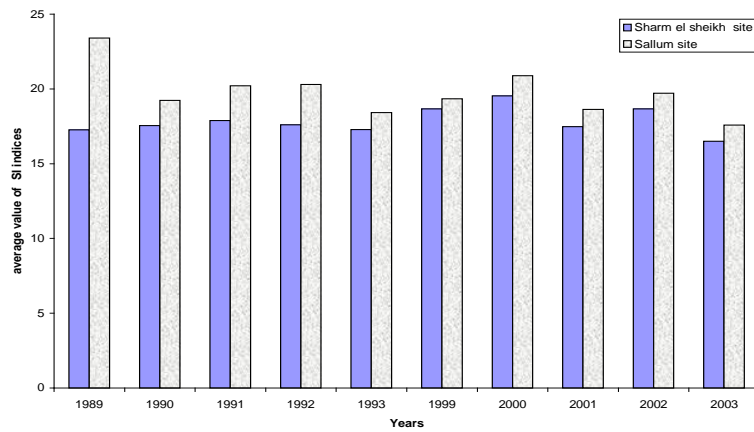


Figure 2. Average value of SI indices at January month.

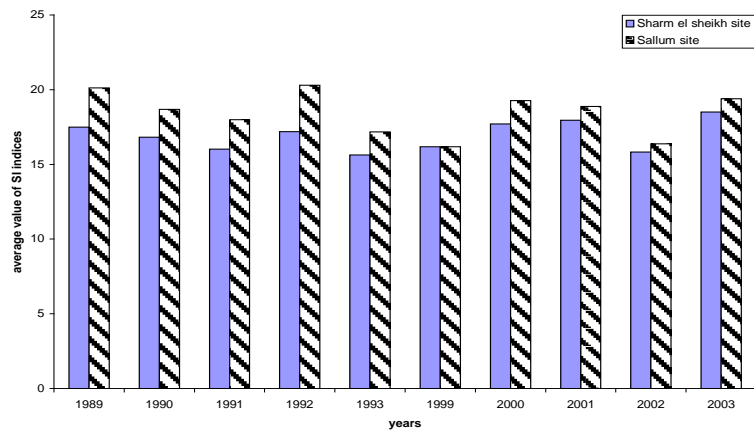


Figure 3. Average value of SI indices at February month.

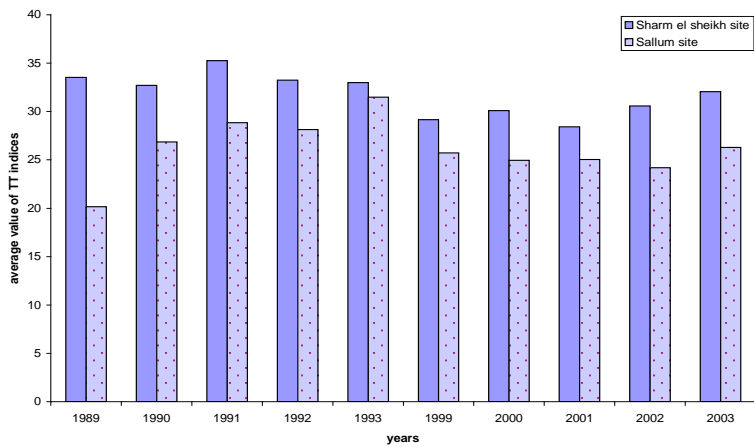


Figure 4. Average value of TT indices at January month.

SI values $-2 < SI < 1$ Thunderstorms possible (generally weak)
 SI values $-6 < SI < -4$ Strong or severe thunderstorms possible
 SI values $SI < -6$ Any thunderstorms likely to be strong or severe
 TT values 44 - 45 Isolated moderate thunderstorms
 TT values 46 - 47 Scattered moderate/few heavy thunderstorms

Table 3. Average value for different indicis at different year for Sallum city.

	SI INDICS		K INDICS		TT INDICS		SWEAT INDICS	
	January	February	January	February	January	February	January	February
1989	23.40	20.11	-22.34	-17.57	20.15	24.96	99.85	90.12
1990	19.24	18.68	-8.35	-6.16	26.87	33.06	94.87	77.05
1991	20.21	17.99	-7.81	-8.55	28.85	28.64	84.41	96.12
1992	20.30	20.30	-12.70	-12.70	28.13	28.13	113.02	113.02
1993	18.42	17.18	-3.22	-2.54	31.50	32.65	79.54	104.39
1999	19.34	16.19	-12.01	-13.30	25.73	23.79	85.53	98.52
2000	20.89	19.27	-15.18	-17.15	24.95	27.07	101.56	108.14
2001	18.63	18.88	-20.31	-20.51	25.05	24.19	86.49	112.57
2002	19.71	16.37	-18.81	-14.03	24.20	27.07	81.80	90.34
2003	17.58	19.39	-15.56	-18.81	26.29	20.53	102.94	95.94

Table 4. Average value for different indicis at different year for Sharm El Sheikh city.

	SI INDICS		K INDICS		TT INDICS		SWEAT INDICS	
	January	February	January	February	January	February	January	February
1989	17.27	17.49	-4.24	-9.84	33.54	30.45	98.19	92.14
1990	17.54	16.82	-4.21	0.17	32.71	36.79	97.80	115.33
1991	17.89	16.03	-1.77	-2.10	35.27	34.93	112.65	99.59
1992	17.60	17.19	-5.06	-2.59	33.25	36.47	94.05	125.89
1993	17.27	15.62	-2.11	2.65	32.98	36.64	96.23	106.66
1999	18.67	16.18	-9.75	-10.39	29.17	27.92	107.81	96.54
2000	19.53	17.72	-7.37	-12.89	30.10	31.60	81.28	83.03
2001	17.48	17.96	-13.27	-11.75	28.42	29.06	84.58	90.09
2002	18.67	15.83	-14.57	-15.88	30.58	31.76	85.73	82.75
2003	16.50	18.51	-8.57	-11.97	32.05	27.53	90.44	79.98

TT values 48 - 49 Scattered moderate/few heavy/isolated severe thunderstorms

TT values 50 - 51 Scattered heavy/few severe thunderstorms and isolated tornadoes

TT values 52 - 55 Scattered to numerous heavy/few to scattered severe thunderstorm/few tornadoes

TT values > 55 Numerous heavy/scattered severe thunderstorms and scattered tornadoes

K value Less than 15 = 0% Probability of Thunderstorm

K value 15 to 20 = 20% Probability of Thunderstorm

K value 21 to 25 = 20 to 40% Probability of Thunderstorm

K value 26 to 30 = 40 to 60% Probability of Thunderstorm

K value 31 to 35 = 60 to 80% Probability of Thunderstorm

K value 36 to 40 = 80 to 90% Probability of Thunderstorm

K value Above 40 = near 100% Probability of Thunderstorm

SW values < 300 No severe storms expected

SW values > 300 values and SW values < 400 Possible severe thunderstorms

SW values > 400 Severe thunderstorms likely and possible tornadoes

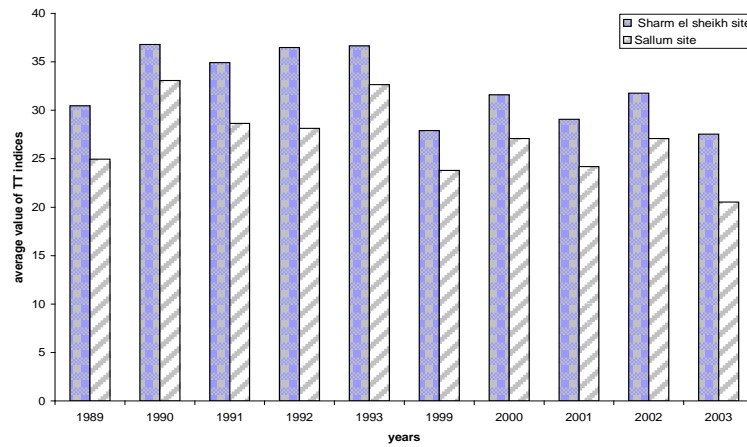


Figure 5. Average value of TT indices at February month.

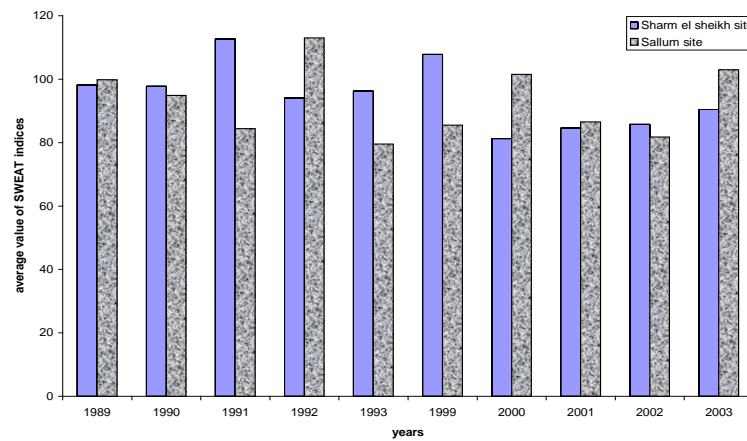


Figure 6. Average value of SWEAT indices at January month.

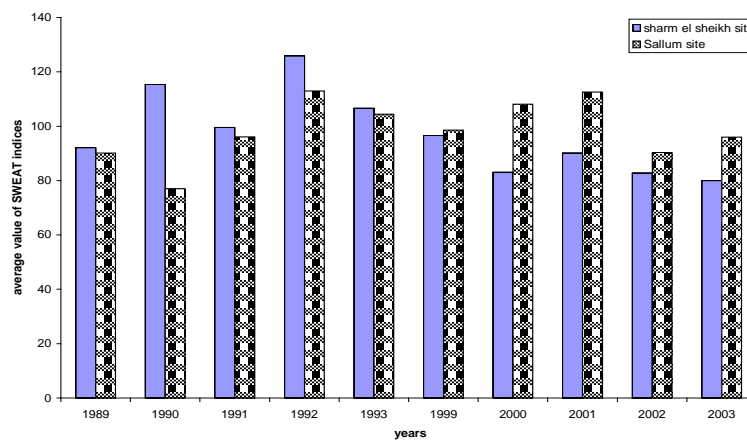


Figure 7. Average value of SWEAT indices at February month.

Comparing the values calculated for the four indexes with the indicated categories a considerable comparability exists. The probability of thunderstorm occurrence in the two examined cities, El Sallum and Sharm El Sheikh is low to moderate (in the range of 20%). Sharm El Sheikh is little more vulnerable than El Sallum to thunderstorm but still categorized with it. This results are highly compatible with the indicated geographical distribution of thunderstorm in the world, Figure 8, this could validate the use of the four indexes for referring the

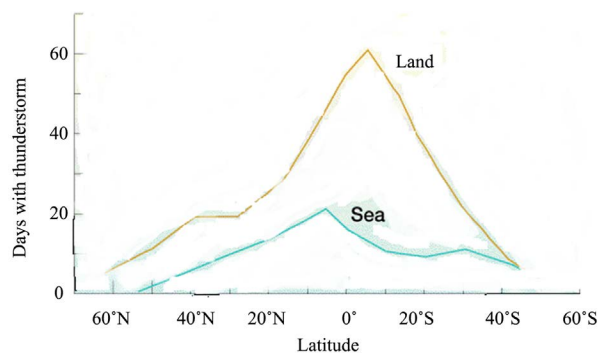


Figure 8. Days with thunderstorm vs latitude.

thunderstorm potentiality for a given locality.

5. Conclusion

The current investigation has been conducted to satisfy one of the required information for safe siting of hazardous facilities such as Nuclear Power Plants. The thunderstorm probability of occurrence has been determined for two El Sallum and Sharm El Sheikh cities in the Egyptian coasts. The four meteoric stability indexes employed for the study proved that likelihood of thunderstorm occurrence is low to moderate (in the range of 20%). An agreement exists with reviewed work on world distribution of thunderstorm reflecting the usability of these indexes as predictors in most cases.

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