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# THUNDERSTORM PREDICTION THROUGH STABILITY INDICES FOR LAHORE, PESHAWAR AND KARACHI, PAKISTAN

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An attempt is made here to develop a methodology to comprehend the forecast of thunderstorms through two important stability indices viz. George K Index and Total Totals Index for Lahore Peshawar and Karachi stations. The study is based on the analysis of 374 events during ten years (1996-2005). The findings infer mean values of K-Index as 35 and 25 for summer and winter, respectively, while threshold value of TT-Index comes out as 40 for the both seasons. The case study of July 30, 2006 is also incorporated for Karachi. The hypothesis and the most fitting ranges of different stability indices suggested in this research have yet to be testified and confirmed before the same can be used as one of the forecasting tools. This study will probably help the operational to make use of various stability indices and is expected to improve the weather forecast as this will be in addition to the convectional forecasting techniques now being used in Pakistan.

**Keywords**: Stability indices, Total Totals Index, K-Index, Thunderstorm, Pakistan

## 1. Introduction

Thunderstorm is one of the most typical weather phenomena as it is hazardous to the aviation industry in addition to colossal losses of life and property [1]. The associated static stability refers to the tendency of the atmosphere to either resist or enhance small-scale vertical displacements which is due to buoyancy forces arising from temperature differences between the ambient air and the displaced parcel. Although most commonly considered in relation to convection, stability influences virtually all weather phenomena, and its assessment is an integral part of operational forecasting [2]. However, conducting a thorough stability analyses over a broad area require consideration of thermal profiles at many locations, and at different time steps through the forecast period, which is often impractical due to time constraints.

To assist forecasters in this process, a number of indices have been developed that represent stability as a simple numerical field, they rely primarily on temperature difference between two or more levels in the troposphere to assess the potential for convection, based on asset of empirical threshold values [3]. The simplest indices consider only the ambient temperature and dew point (e.g., total totals, George's K-index), while more complex indices take into account other effects such as parcel lift; lifted index, or wind shear. Vertically integrated measures of instability such as the convective available potential energy (CAPE) provide a more detailed physical representation of the state of the atmosphere and are commonly used as stability indices [4].

Detailed analyses of model soundings are carried out for the areas of interest and may include the assessment of convective cloud-top temperatures, CAPE, convective temperature, etc. Combined with observational data, and an assessment of synoptic and meso-scale forcing, these analyses form the basis of forecasts of convective weather [5]. In contrast, stability indices provide limited information about the state of the atmosphere at any particular location, but offer a concise, broad-scale, representation of stability [6]. They allow forecasters to easily follow trends in stability and relate these to tropospheric dynamics, and to quickly identify those areas requiring a more detailed stability assessment.

This implies a broad role for stability indices in the operational environment. They assist forecasters in visualizing the state of the atmosphere on the synoptic scale, as well as providing a rough initial assessment of the potential for convection. Historically, the development of indices has been directed mainly at forecasting thunderstorms and, with few exceptions, they are designed to assess the potential for deep, surface-based, convection.

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Within the broad role suggested above, indices may be applied to situations that differ markedly from that for which they were designed. However, there are limits to the applicability of conventional indices, since they are so narrowly focused on the problem of deep convection.

Although some areas of Pakistan are often hit by severe thunderstorms alongwith the associated weather phenomena [1] but no remarkable research, regarding the forecast of thunderstorms, has yet been conducted in the country. So far, the practice to forecast the thunderstorms in Pakistan is to consider the synoptic situation and the local Rawinsonde data analyzed on Tephigram with reference to positive and negative areas. An account of the convective temperature is also taken into consideration. However, still no effort has been made to utilize various types of the stability indices and the other affiliated parameters.

The objective of this study is to investigate the effectiveness of various stability indices used for the forecast of thunderstorms in the northern areas of Pakistan and to develop a stability index to suit the local conditions.

## 2. Data and Methodology

Independent set of 122, 131 and 121 events regards Lahore, Peshawar and Karachi were taken into account during January 1996 to December 2005 for Karachi and Lahore while January 1994 to December 2005 for Peshawar. The data is extracted from the archives of Pakistan Meteorological Department.

An investigation, into the factors responsible for the occurrence of thunderstorm, has revealed that the "instability of atmosphere" is the basic requirement for a small convective cloud, like Cumulus (Cu) to develop into a large convective cloud, like Cumulonimbus (Cb). Besides this, enough moisture, specifically saying "perceptible water" should also be present in the upper atmosphere to allow the clouds to form, initially, and then to develop into clouds of more vigorous nature, To have an idea about the moisture contents and the stability of the atmosphere, rawinsonde data is analyzed.

In order to develop a local stability index, for the forecast of thunderstorm, the rawinsonde data for 374 events over mentioned cities were taken into account. The steps taken for the analyses of data were as follows

The events chosen were divided into three categories viz.

- Category 1 : No low clouds observed upto 1200 UTC.
- Category 2 : Partly cloudy to cloudy weather, including trace of Cb cloud but no thunder observed up to 1200 UTC.
- Category 3 : Thunderstorm with or without rain/showers.

The non-thunderstorm days were so chosen that the day was a day earlier or later than the actual thunderstorm day. Another aspect, of the selected thunderstorm days, is that the data should be available at least upto 500hpa level, because nearly all the stability indices depend on the dry bulb and dew point temperatures upto that level. Further, to assess the performance of TT and K-index for the thunderstorm prediction, False Alarm Ratio (FAR) calculated by using the graph of verified dataset.

*Total Totals Index (TT-Index)*

It is the index of atmospheric instability composed of two indices: the cross total and the vertical total.

$$\mathrm{TT} = \text{cross total} + \text{vertical total}$$

The cross total is a measure of how buoyant the air parcel is due to less dense, moist air in the lower levels. It is defined as the difference between the 850 mb dew point temperature and the 500 mb temperature. The vertical total is a measure of how buoyant the air parcel is due to warm air at lower levels. It is defined as the difference between the 850 mb temperature and the 500 mb temperature. The sum of the cross and vertical totals is the total totals index.

$$\mathrm{TT} = (\mathrm{Td}_{850} - \mathrm{T}_{500}) + (\mathrm{T}_{850} - \mathrm{T}_{500})$$

Hence, the three main factors in obtaining high total totals index values are the following: a high 850mb temperature, a high 850 mb dew point temperature, and a low 500 mb temperature. Finally it may comes out as

$$\mathrm{TT} = \mathrm{T}_{850} + \mathrm{Td}_{850} - 2\mathrm{T}_{500}$$

where TT is in °C, with $Td_{850}$ is the 850 mb dew point temperature (°C) and $T_{500}$ are the 850 and 500mb temperatures, respectively. In the typical application of $TT$ to warm season air masses generally, the values less than 44 indicate a stable stratification with respect to deep convection, while values of 50 or greater indicate a high likelihood of thunderstorms.

*George's K index (K-Index)*

In the vicinity of the upper trough, the instability normally extends above the height of the 500 mb surface and is readily apparent in the TT field. Behind the trough, an upper-level inversion typically develops in response to upper-tropospheric subsidence or warm air advection, gradually building down to lower altitude with increasing distance behind the trough. When the inversion falls below the height of the 500 mb surface the TT-index will drop markedly, regardless of how unstable the atmosphere is at lower levels. This leads to a situation where significant convective weather may occur with TT well below 45. For the purpose of this, the K- index values are more susceptible for the forecasting of weather in addition of TT-index.

The K-index has proved useful in indicating the probability of thunderstorms. It represents the thunderstorm potential as a function of vertical temperature lapse rate at 850 mb temperature and 500 mb temperature, low-level moisture content at 850 mb dew point, and the depth of the moist layer at 700mb dew point. The formula to find out the value of K-index is as

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

where K is the K-index (°C), $T_{850}$ is the temperature at the 850 mb level, $T_{500}$ is the temperature at the 500 mb level, $Td_{850}$ is the dew point temperature (°C) at the 850 mb level, $T_{700}$ is the temperature (°C) at the 700 mb level, and $Td_{700}$ is the dew point temperature (°C) at the 700 mb level. Typically, it its value greater than 25 then there is 50% probability of thunderstorm.

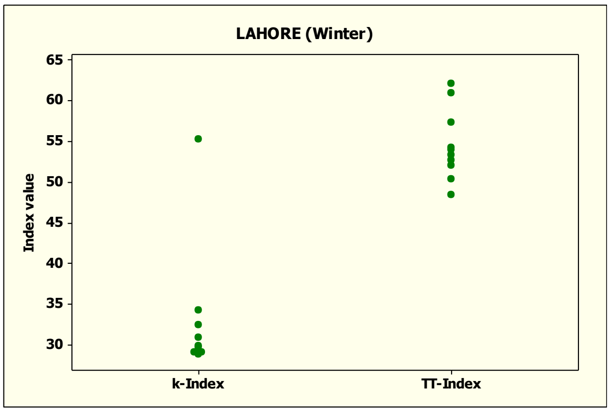
## 3. Results and Discussion

### 3.1. Lahore

Taking into account the fact that thunderstorms occur in Lahore during summer (due to monsoon) and winter (due to westerlies, both seasons are analyzed separately and threshold values of both seasons are estimated. Thunderstorm frequency in summer (82) is found almost twice in comparison to winter (40). Based on weather assessment, 50+30 stable and 32+10 unstable events are found in the training dataset.

The best threshold for unstable events in summer and winter comes out as TT = 45 & K = 38 and TT = 45 & K = 29, respectively (Fig.1). The accuracy scores obtained from the verification data set are presented in graph with 2% FAR. All scores are statistically significant, indicating that TT and K-Index are able to effectively resolve unstable events in forecasting. Comparing the scores for TT and K-Index achieved by the graph, it is observed that both are different from actual values. The values of these indices for the Lahore station are summarized in Table 1.

The mentioned thresholds for Lahore may be applied as a forecasting and operational tool in resolving the unstable events. Moreover, application of these thresholds to situations that lie outside of the limits of our analysis, such as embedded convection, may lead to a high rate of FARs. Despite these concerns, the indices itself remains a valid representation of static stability under any circumstance and can be used to follow trends in stability and to highlight areas with the potential for significant convection.



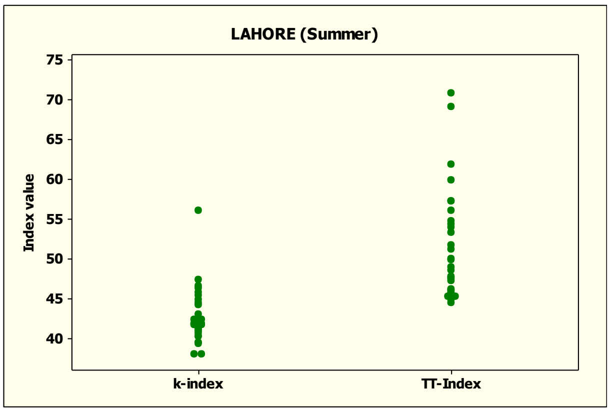




Figure 1. Thunderstorm stability index analyses for Lahore in both seasons.

K-Index for both seasons show that average value of winter's K-Index is well below than summer's value such that the probability of their fusion is extremely less. TT-Index for both seasons

Table 1. Estimated values of stability Indices for the Likely/Unlikely chances of thunderstorms.

| | TS likely (winter) | | TS unlikely (winter) | | TS likely (summer) | | TS unlikely (summer) | |
|---|---|---|---|---|---|---|---|---|
| Station | TT index | K index | TT index | K index | TT index | K index | TT index | K index |
| Lahore | >45 | >29 | <45 | <29 | >45 | >38 | <45 | <38 |
| Peshawar | >40 | >25 | <40 | <25 | >40 | >35 | <40 | <35 |
| Karachi | - | - | - | - | >40 | >35 | <40 | <35 |

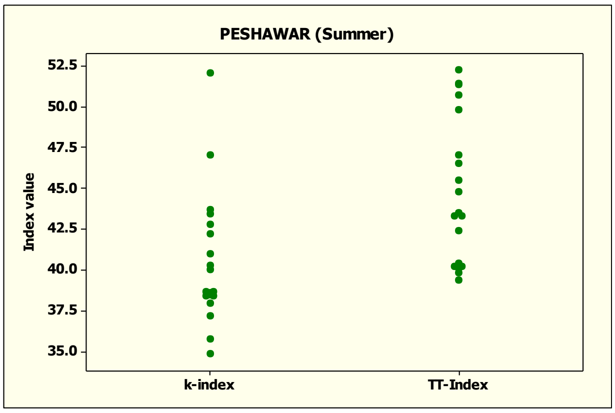
shows that average value of winter's TT-Index is markedly above than summer such that the probability of their fusion is considerably less. Only occasionally it happens. Collectively it is explored that TT-Index has greater value for winter but lesser value for summer and vice versa for K-Index.

### *3.2. Peshawar*

Peshawar also endures thunderstorms during summer and winter months. An independent set of 131 events was developed, i.e. 81 during summer and 44 during winter. Based on our weather assessment, the training data set consists of 62+33 stable events and 19+17 unstable events.

The estimated best threshold for unstable events (for summer) was found to be TT = 40 and K- index = 35 and (for winter) TT = 40 and K-Index = 25 (Fig. 2). The accuracy scores obtained from the verification data set are presented in graph with 8% FAR. All scores are statistically significant, indicating that TT and K-Index are able to effectively resolve unstable events in forecasting. Comparing the scores for TT and K-Index achieved by the graph, we find they are different from actual values. The values of these indices for Peshawar are summarized in Table 1.

All values of both indices are smaller than Lahore. The value of TT-Index remains unchanged with changing season, while K-index's values for summer is greater than winter months. Further K-Index during summer is more spread than the winter's one. It is noticeable that the values of both indices merged during summer season while completely separate identity in winter.



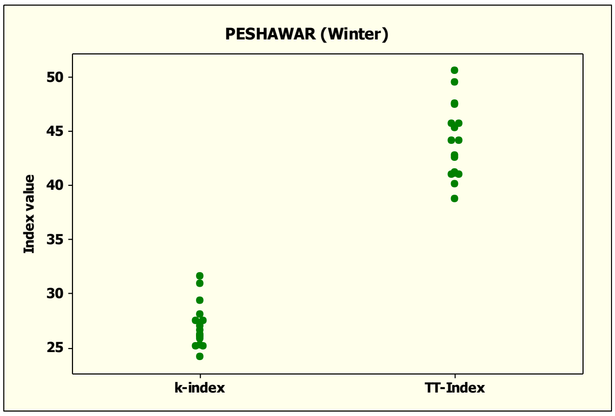




Figure 2. Thunderstorm stability analyses for Peshawar in both seasons.

### *3.3. Karachi*

Thunderstorms are likely to be expected in June and July sometimes accompanied with strong squalls [7]. As their frequency is negligible during winter season, hence an independent set of 112 events was developed only for summer season. All 0000 UTC soundings for these time periods were considered. For each event, the actual weather was assessed as either stable or unstable based on a representative set of surface observations taken. Unstable events were identified using the following criteria: Scattered or frequent Cb reports in manned observations with supporting evidence from satellite imagery; or heavy showers reported at any station; or hail or lightning reported at any observatory of Karachi. Based on weather assessment, the training data set consists of 90 stable events and 22 unstable events.

In Karachi almost all thunderstorm activity occurs in June, July and August (i.e. partially summer with rainy month August). As this period does not clearly represent any season (but partial mixture) so data was analyzed to calculate indexes values collectively for the period.

For unstable events, TT-Index = 40 and K-Index = 35 for summer season only. The accuracy scores obtained from the verification data set are presented in graph with 2% FAR with all statistically significant scores. Comparison of scores for both indices with the help of graph shows that they are slightly different from actual values.

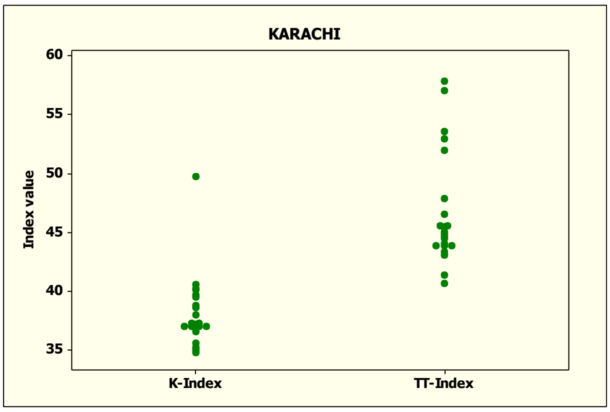



Figure 3. Thunderstorm analyses for Karachi.

### *3.4. Test Case Study*

Following sounding message was reported on July 30, 2006 at 0000 UTC

TTAA 80001 41780 99995 28055 27006 00522 ///// ///// 92700 25077 28505 85407 24861 03015 70084 14057 02017 50582 03559 02028 40755 12757 02019 30970 24546 06521 25100 34556 10523 20251 48157 09528 15434 65161 09025 10673 757// 08551 88999 77999=

During the period 29-30 July, 2006, a monsoon trough migrated westward over Sindh, causes to bring warm and moist air over the eastern Sindh and coastal areas as well. By 1200 UTC 29$^{th}$ July, the weather at Karachi was cloudy with rain at one and odd places.

The sounding taken at Karachi during this period illustrates the trend of instability in the upper air. The 0000 UTC 30$^{th}$ July sounding shows that the upper air is conditionally unstable from 850 hpa to 500 hpa (note that, this depth of conditionally instability in the 0000 UTC sounding is alarming), with TT-Index = 45.6 and K-Index = 35.1. These values clearly meet the criteria sets in this study for the thunderstorm prediction i.e. TT = 40 and K-Index = 35

During afternoon of 30$^{th}$ July, the satellite imagery and surface observations indicate that significant Towering Cumulus (TCu) and Cb convection occurred over Sindh and Coastal areas, which coincides reasonably well with the model criteria for the forecasting of thunderstorm.

## 4. Conclusion

Operational forecasters are routinely required to assess large scale information from observing networks often under tight time constraints. Stability indices have proven valuable in simplifying this process and are a staple component of the surface observation, surface charts and upper air charts used a met observatories and elsewhere. However, since the indices presently available to forecasters are designed principally to assess deep instability, it is unlikely that the stability index concept is being used to its full potential.

This issue is addressed in present presentation by two indices capable of resolving instability that is capped between 850 and 500 mb. The principal application of the TT and K-index outlined here are forecasting surface-based convective events, using TT = 40 and K-index = 35 as the threshold (during summer) and TT = 40 and K index = 25 as the threshold (during winter) are the best fit value for the studied areas of Pakistan.

The development of a local stability index will help the weather forecasters in the improvement of their forecasts of thunderstorms and allied weather phenomena for their areas of interest. The improved weather forecast will not only help for the safety of civil and military aviation but it will also help the industrialists, the architects and the agriculturist in the form of advance weather warnings for hailstorms, heavy rains and showers etc. In this manner it will also contribute indirectly, to a large extent, to the betterment of the economy of our country. It will not be out of place to mention that like other research works this study will also contribute towards the enhancement of forecasting science and its applications in the country.

### Acknowledgement

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