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Interrelation among different instability indices of the troposphere over Dhaka associated with thunderstorms/nor'westers over Bangladesh during the pre-monsoon season

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सार – इस षोध पत्र में भिन्न–भिन्न अस्थायित्व सूचकांकों के सांख्यिकीय आंकड़ों को परस्पर समन्वित करने के प्रयास किए गए हैं। इस अध्ययन से पता चला है कि ओसांक सूचकांक (डी. पी. आई.), उर्ध्वाधर योग सूचकांक (वी. टी.), परिवर्तित उर्ध्वाधर योग सूचकांक (एम. वी. टी.) तथा परिवर्तित के–सूचकांक (एम. के.) को छोड़कर षोल्टर स्थायित्व सूचकांक (एस. आई.), विभिन्न अस्थायित्व सूचकांकों के साथ सामान्य से बेहतर सहसंबंध दर्षाता है। षुष्क अस्थायित्व सूचकांक (डी. आई. आई.) जिसका एस. आई. के साथ परस्पर संबंध 95 प्रतिषत तक सही है, को छोड़कर अधिकांष सहसंबंध गुणांक 99 प्रतिषत तक सही पाए गए हैं। डी. आई. आई., के–सूचकांक (के. आई.) तथा एम. वी. टी. को छोड़कर लिफ्टेड सूचकांक (एल. आई.) का विभिन्न अस्थायित्व सूचकांकों के साथ सामान्य से बेहतर सहसंबंध है। वी. टी., स्वेट सूचकांक (एस. डब्ल्यू. आई.) और एम. के. आई. जिनके लिफ्टेड सूचकांक (एल. आई.) के साथ परस्पर सहसंबंध 95 प्रतिषत तक सही हैं, को छोड़कर अधिकांष सहसंबंध गुणांक 99 प्रतिषत तक सही पाए गए हैं। अपरिवर्तित अस्थायित्व सूचकांकों के परिवर्तित अस्थायित्व सूचकांकों के साथ सहसंबंध सामान्य से अधिक प्रबल देखे गए हैं जो 99 प्रतिषत तक सही पाए गए हैं। वी. टी. और एम. वी. टी.,, एस. डब्ल्यू. आई. तथा परिवर्तित स्वेट सूचकांक (एम. एस. डब्ल्यू. आई.) और के. आई. तथा एम. के. आई. के सहसंबंध गुणांक तुलनात्मक रूप से काफी अधिक हैं। कुछेक को छोड़कर लगभग सभी मामलों में आकलित मानक त्रुटियाँ बहुत कम हैं। विभिन्न अस्थायित्व सूचकांकों का परिकलन करने के लिए संभवत प्राप्त किए गए समाश्रयण समीकरण उपयोगी सिद्ध होंगे।

ABSTRACT. Attempts have been made to correlate different instability indices among themselves statistically. The study reveals that the Showalter Stability Index (SI) has moderate to good correlations with different instability indices except Dew-point Index (DPI), Vertical Total Index (VT), Modified Vertical Total Index (MVT) and Modified K-Index (MK). Most of the correlations co-efficient are found to be significant up to 99% level of significance except Dry Instability Index (DII), which has correlation with SI up to 95% level of significance. Lifted Index (LI) has moderate to good correlation with different instability indices except DII, K-Index (KI) and MVT. Most of the correlations co-efficient are significant up to 99% level of significance except VT, SWEAT Index (SWI) and MKI, which have correlation with LI up to 95% level of significance. Unmodified instability indices have moderate to strong correlation with the corresponding modified instability indices, having 99% level of significance. The correlation co-efficient of VT and MVT, SWI and Modified SWEAT Index (MSWI), and KI and MKI are comparatively large. Standard errors of estimate are small in almost all the cases except a few. The regression equations obtained are likely to be helpful in the computation of different instability indices.

Key words – Stability Indices, Showalter Stability Index, Lifted Index, Vertical Total Index, Modified Vertical Total Index, K-Index, Modified K-Index, SWEAT Index and Modified SWEAT Index.

1. Introduction

Thunderstorms occur much more frequently in the tropics than in higher latitudes and especially in the continental areas where warm and moist air mixes with relatively dry and cold air. Bangladesh is having such an environment. Though the thunderstorm activity may continue over the country during the southwest monsoon, the severity of thunderstorms is marked only in the pre-monsoon season, when these, on a number of occasions, are accompanied by squalls (Srinivasan *et al*., 1973). The thunderstorms during the pre-monsoon are stronger than other seasons and are known as Kalbaishakhis or nor'westers in Bangladesh. These form from cumulonimbus cloud, having substantial vertical development where the tops usually reach well into the upper levels of the troposphere. However, most cumulonimbus cloud tops are restricted in height by the tropopause (Krishnamurti, 2003). Stability indices have been used by the forecasting offices to locate the area in which the severe weather is likely to occur (Faubush *et al*., 1951; Showalter, 1953; Galway, 1956; Miller, 1972). The presence of strong potential instability and mesoscale convergence are important for the formation of thunderstorms. These thunderstorms associated with squalls cause severe damage to standing crops, properties and loss of lives during the pre-monsoon season in Bangladesh. So, the study of different instability indices and their interrelations are imperative for determining the instability conditions of the troposphere favourable for the occurrence of severe thunderstorms/nor'westers. In this regard, different instability indices over Dhaka have been determined and modifications of some instability indices have already been made by many workers (Chowdhury and Karmakar, 1986; Das *et al*., 1994, Karmakar, 2005).

In this paper, attempts have been made to relate different instability indices, both unmodified and modified, among themselves statistically on the days of occurrence of thunderstorms / nor'westers.

2. Data used

Rawinsonde data of 0000 UTC on TS days during the pre-monsoon season of 1990-1995 at different isobaric heights from 1000 to 100 hPa at Dhaka have been used for this study.

3. Methodology and significance

3.1. *Methodology*

During the pre-monsoon season of 1990-1995, 108 cases of thunderstorms/nor'wester over Bangladesh have been taken into consideration for the study. Different instability indices such as Showalter Stability Index (SI), Lifted Index (LI), Dew-point Index (DPI), Dry Instability Index (DII), Cross Total Index (CT), Vertical Total Index (VT), Total Totals Index (TT), K-Index (KI), Energy Index (EI), Modified Cross Total Index (MCT), Modified Vertical Total Index (MVT), Modified Total Totals Index (MTT), Modified K-Index (MKI), Modified Energy Index (MEI) have been computed on the days of occurrence of these 108 thunderstorms/nor'westers. Linear correlations among the above instability indices have been studied and the corresponding correlation co-efficient are computed.

3.2. *Statistical significance test of the coefficient of determination*

The regression equations and the co-efficient of determination (R^2) have been obtained through scattered diagrams by taking two indices at a time. The significance test of the coefficient of determination (R^2) has been carried out by using F-Test (Makridakis, *et al.*, 1983; Alder and Roessler, 1964).

$$\mathrm{F} = \frac{R^2(n-k)}{(1-R^2)(k-1)} \tag{1}$$

where n is the number of observations (n-k) is the degree of freedom and k is the number of parameters. This coefficient of determination indicates how best the data are fitted to the regression line. If the calculated value of F is greater than the theoretical value at certain significance level (0.05 or 0.01 *i.e.*, 95% or 99% significance level) then R^2 is taken as significant at that level.

The Standard Error of Estimate (SEE) between the actual data and the estimated values has been computed with the help of the equation:

$$\mathrm{SEE} = \sqrt{\frac{(Y-Y_e)^2}{N}} \tag{2}$$

where Y is the actual value, Y_e is the computed value and N is the number of data pairs.

3.3. *Physical significance*

Existing instability indices are generally computed using the data at 850 hPa level. During the pre-monsoon season, sufficient moisture is not available at 850 hPa whereas that is available at 925 hPa in the morning on the dates of occurrence of thunderstorms/nor'westers. Since low-level moisture plays an important role in the formation of thunderstorms, the existing instability indices have been modified by taking the data at 925 hPa level.

The physical significance of this study is to identify how the different instability indices and modified instability indices are related with Showalter Stability Index (SI) and Lifted Index (LI) and to see whether the modified instability indices could be used in place of the existing indices. If SI and LI are computed properly, then the other indices can be determined. The study also gives the relation among other instability indices.

4. Results and discussion

The linear correlations among different instability indices have been studied in order to find out the interdependent empirical regression equations for different instability indices with the help of scattered diagrams. Some of the scattered diagrams are given in Figs. 1-6.

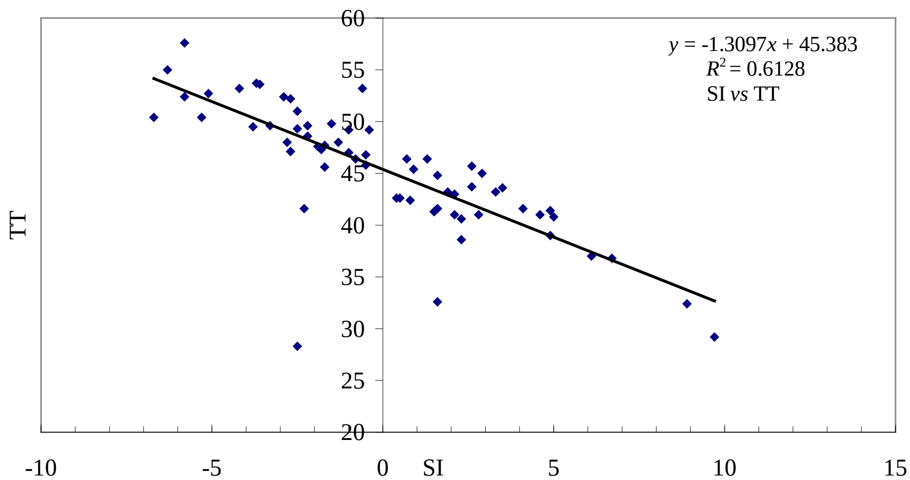

Fig. 1. Scattered diagram of SI *vs* TT over Dhaka on the dates of occurrence of nor'westers in Bangladesh during the pre-monsoon season of 1990-1995

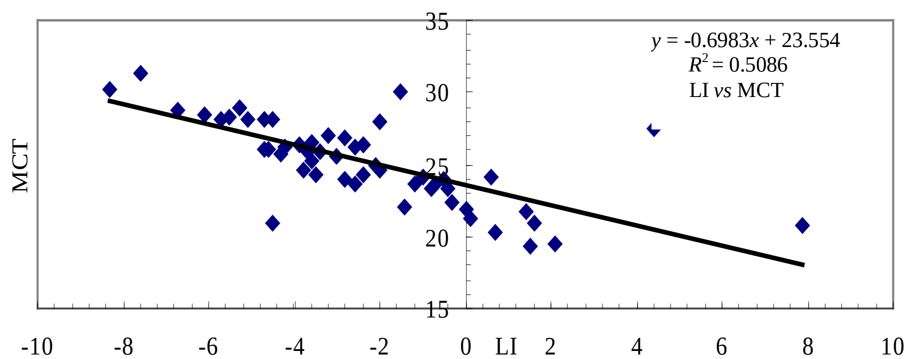

Fig. 2. Scattered diagram of LI *vs* MCT over Dhaka on the dates of occurrence of nor'westers in Bangladesh during the pre-monsoon season of 1990-1995

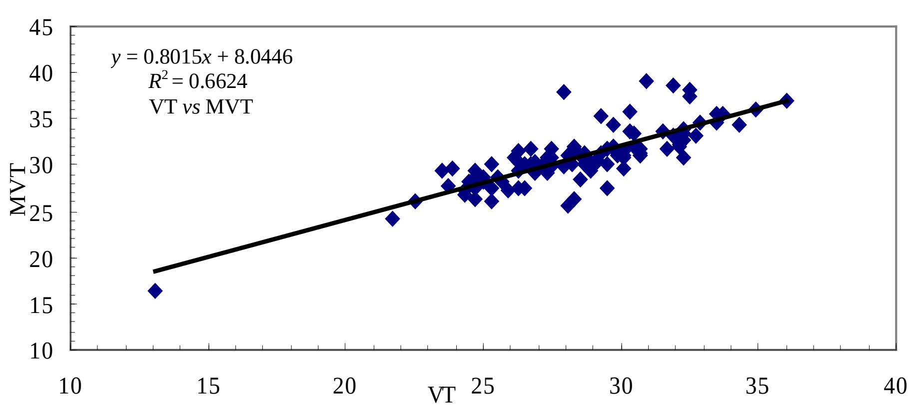

Fig. 3. Scattered diagram of VT *vs* MVT over Dhaka on the dates of occurrence of nor'westers in Bangladesh during the pre-monsoon season of 1990-1995

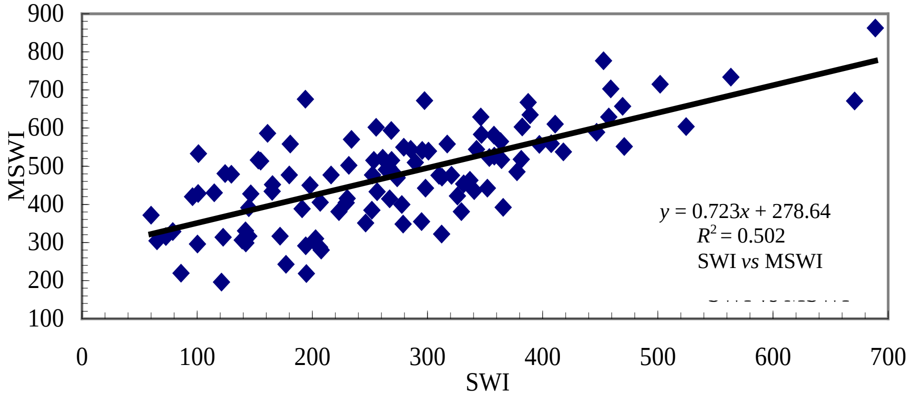

Fig. 4. Scattered diagram of SWI *vs* MSWI over Dhaka on the dates of occurrence of nor'westers in Bangladesh during the pre-monsoon season of 1990-1995

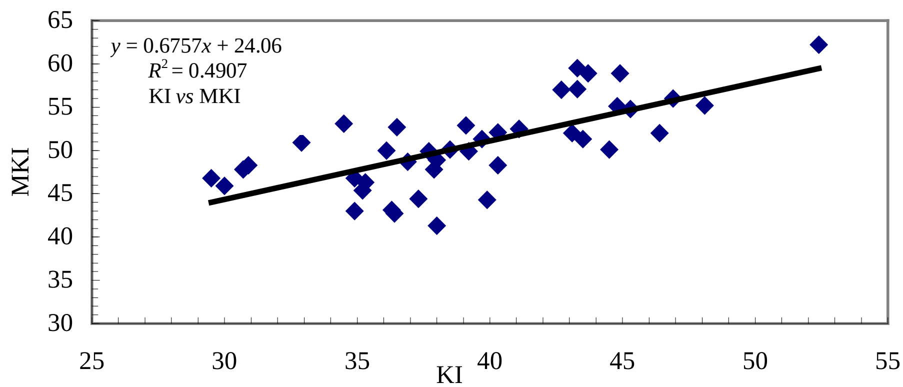

Fig. 5. Scattered diagram of KI *vs* MKI over Dhaka on the dates of occurrence of nor'westers in Bangladesh during the pre-monsoon season of 1990-1995

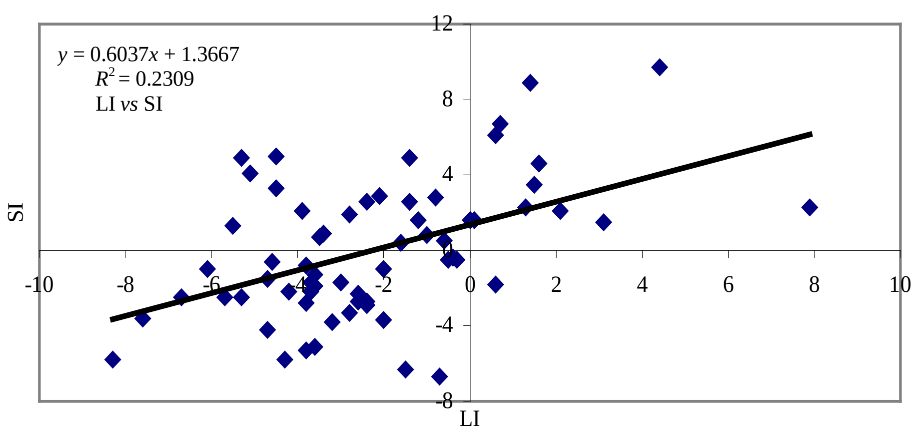

Fig. 6. Scattered diagram of LI *vs* SI over Dhaka on the dates of occurrence of nor'westers in Bangladesh during the pre-monsoon season of 1990-1995

TABLE 1

Correlation of SI with other instability indices over Dhaka on the dates of occurrence of nor'westers in Bangladesh during the pre-monsoon season of 1990-1995

Correlation between	R	R^2	n	Significance	SEE
SI and LI	0.48053	0.2309	64	99%	± 2.51338
SI and DPI	0.02611	0.0007	64	Insignificant	± 3.61443
SI and DII	0.05409	0.0029	64	95%	± 4.01215
SI and CT	-0.78356	0.614	64	99%	± 3.74455
SI and VT	0.00224	5E-06	64	Insignificant	± 3.05005
SI and TT	-0.78282	0.6128	64	99%	± 3.74827
SI and KI	-0.43299	0.2771	56	99%	± 5.10871
SI and EI	0.749034	0.5611	56	99%	± 4.11850
SI and SWI	-0.43261	0.1872	56	99%	± 120.095
SI and MCT	-0.51512	0.2654	57	99%	± 2.45615
SI and MVT	-0.07342	0.0054	57	Insignificant	± 2.74055
SI and MTT	-0.40469	0.1638	57	99%	± 3.46557
SI and MKI	0.00162	8E-05	56	Insignificant	± 5.08077
SI and MEI	0.32401	0.105	56	99%	± 6.02954
SI and MSWI	-0.39383	0.1551	57	99%	± 121.2301

n = Number of data, SEE = Standard Error of Estimate, R= Correlation co-efficient

4.1. *Correlation of Showalter Stability Index with other instability indices*

The correlations of SI with other different instability indices have been studied and the correlation co-efficient have been computed. The correlation co-efficient (R), co-efficient of determination (R^2), standard error of estimates (SEE) and level of significance of R are given in Table 1.

Table 1 shows that SI has moderate to good correlation with different instability indices except DPI, VT, MVT and MKI. Most of the correlation co-efficient are significant up to 99% level of significance except DII, which has correlation with SI up to 95% level of significance. SEEs are small in almost all the cases except the correlation of SI with SWI and MSWI.

The regression equations between SI and other instability indices are given below :

$$LI = 0.3825 \times SI - 2.252$$

$$DII = 0.0604 \times SI - 3.4631$$

$$CT = -1.3116 \times SI + 17.231$$

$$VT = 0.0019 \times SI + 28.152$$

$$TT = -1.3097 \times SI + 45.383$$

$$KI = -0.7375 \times SI + 40.089$$

$$EI = 1.2625 \times SI - 6.8538$$

TABLE 2

Correlation among unmodified and modified instability indices

Correlation between	R	R^2	n	Significance	SEE
CT and MCT	0.62670	0.3927	108	99%	± 2.78258
VT and MVT	0.81386	0.6624	108	99%	± 1.877454
TT and MTT	0.65801	0.433	108	99%	± 3.280246
SWI and MSWI	0.708553	0.502	108	99%	± 90.07745
EI and MEI	0.64573	0.2785	106	99%	± 5.06526
KI and MKI	0.77990	0.4907	105	99%	± 3.88489

n = Number of data, SEE = Standard Error of Estimate, R = Correlation co-efficient

SWI = –15.738 × SI + 281.3

MCT = –0.4032 × SI + 25.155

MVT = –0.0551 × SI + 31.109

MTT = –0.4189 × SI + 56.011

MEI = 0.599 × SI – 10.793

MKI = –0.0102 × SI + 50.844

MSWI = –14.185 × SI + 484.2

The above regression equations will be useful in the computations of different instability indices.

4.2. *Correlation between Lifted Index (LI) and other instability indices*

The correlation of LI with other different instability indices have been studied and the correlation co-efficient (R), co-efficient of determination (R^2), SEE and level of significance of R have been computed.

It is seen that LI has moderate to good correlation with different instability indices except DII, KI and MVT. Most of the correlation co-efficient are significant up to 99% level of significance except VT, SWI and MKI, which have correlations with LI up to 95% level of significance. Standard errors of estimate are small in almost all the cases except the correlation of LI with SWI and MSWI in which cases the standard errors of estimate are ± 128.2326 and ± 101.57365 respectively.

The regression equations between LI and other indices corresponding to the significant correlations are given below :

SI = 0.6037 × LI +1.3667

DPI = 0.3549 × LI – 6.249

CT = –0.709 × LI + 15.625

VT = 0.2802 × LI + 27.522

TT = 0.9892 × LI + 43.146

EI = 1.0281 × LI – 4.1618

SWI = –12.833× LI + 252.16

MCT = –0.6983 × LI + 23.554

MTT = –0.9233 × LI + 53.66

MKI = –0.4348 × LI + 49.087

MEI = 1.639 × LI – 6.858

MSWI = – 28.5268 × LI + 419.79

4.3. *Correlation among unmodified and modified instability indices*

The correlations among different unmodified and modified instability indices have been studied and the correlation co-efficient (R), co-efficient of determination (R^2), SEE and level of significance of R are given in Table 2.

It is observed that unmodified instability indices have moderate to strong correlation with the corresponding modified instability indices, having 99% level of significance. The correlation co-efficient of VT and MVT, SWI and MSWI, and KI and MKI are comparatively large. Standard errors of estimate are small except in the case of SWI and MSWI, which is ± 90.07745.

The regression equations corresponding to the significant correlations are given below :

MCT = 0.3647 × CT + 18.507

MVT = 0.8015 × VT + 8.0446

MTT = 0.4197 × TT + 36.469

MSWI = 0.723 × SWI + 278.64

MEI = 0.4923 × EI -11.62

MKI = 0.6757 × KI + 24.06

The regression equations obtained so far will be useful for the computations of different instability indices.

5. Conclusions

On the basis of the present study, the following conclusions can be drawn :

(*i*) The SI has moderate to good correlations with different instability indices except DPI, VT, MVT and MKI. Most of the correlation co-efficient are significant up to 99% level of significance except DII, which has correlation with SI up to 95% level of significance.

(*ii*) LI has moderate to good correlation with different instability indices except DII, KI and MVT. Most of the correlation co-efficient are significant up to 99% level of significance except VT, SWI and MKI, which have correlation with LI up to 95% level of significance.

(*iii*) Unmodified instability indices have moderate to strong correlation with the corresponding modified instability indices, having 99% level of significance. The correlation co-efficient of VT and MVT, SWI and MSWI, and KI and MKI are comparatively large.

(*iv*) Standard errors of estimate are small in almost all the cases except between SWI and MSWI with LI and SI and also between SWI and MSWI.

(*v*) The regression equations obtained are likely to be helpful in the computation of different instability indices from one index.

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