

STUDY OF AIR STABILITY INDEX THRESHOLD VALUES IN CUMULONIMBUS AND THUNDERSTORM CLOUDS AT HASANUDDIN METEOROLOGICAL STATION

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Abstract

The purpose of this study was to analyze the characteristics of the current air stability index threshold value for Cumulonimbus (CB) and Thunderstorm (TS) cloud events and to analyze the performance of the current air stability index threshold value for CB and TS cloud events with previous research at Hasanuddin Meteorological Station. The analysis of the characteristics of the air stability index threshold value in this study used Showalter Index (SI), K Index (KI), Total - Totals (TT) and Convective Available Potential Energy (CAPE) data for the 2013-2022 period with the Sturges method to determine the class interval obtained from the total frequency of events and then divided the class with the largest number of events in the resulting value range. Furthermore, the performance analysis of the current research air stability index threshold value used 2023 data with the 2x2 contingency table verification test method. The results of the analysis show that the characteristics of the air stability index threshold value in this study in this case the SI, KI, TT and CAPE indices for CB and TS events during 2013 to 2022 at Hasanuddin Meteorological Station have changed or shifted to the manual or previous research. Changes or shifts in current research occur more, especially in the lower threshold value in the new range or threshold value with consecutive values, namely $\geq (-5)$, $\geq (13)$, $\geq (32)$, $\geq (1)$. This indicates that the frequency of CB and TS cloud occurrences at the research location against the indices used, namely SI, KI, TT and CAPE, still has quite an influence, especially on the lower threshold value or initial potential when CB and TS clouds form. Then related to the performance analysis of the air stability index threshold value, this study was generally not significant when tested using a verification test in the following year (2023). However, if reviewed further regarding performance based on the time of occurrence, it is known that the new threshold value produced in the current study is quite consistent with previous research where the sensitivity of the index in predicting short-term weather conditions during the day is better than at night.

Keywords: Threshold Value, Air Stability Index, SI, KI, TT, CAPE, Cumulonimbus and Thunderstorm

Introduction

Indonesia is a country with a very complex atmospheric dynamics because there are several factors that influence it, including: solar activity, ENSO (El-Nino and Southern Oscillation), DMI (Dipole Mode Index), MJO (Madden-Julian Oscillation), Monsoon Winds and other local factors that interact with each other (Fatmasari & Ariandi, 2014).

In general, the results of the interaction of several factors cause the potential for bad weather. According to (Hidayat, 2015), bad weather is an abnormal, unusual weather event that can result in loss of life and property. One of the bad weather conditions that often occurs is heavy rain and thunder storm.

Heavy rain occurs due to high rainfall factors originating from convective clouds such as Cumulonimbus clouds (Hidayah, QA, Bimaprawira, AK, Yulitamora, NR, Nugraheni, IR, Deranadyan, 2019). While thunderstorms are a mechanism for releasing electrical charges originating from convective clouds which are characterized by lightning and thunder (Meilani, Wahid A., 2014). Based on the definitions of several researchers, it is generally stated that heavy rain and thunderstorms are one form of events produced by convective clouds such as Cumulonimbus.

This very complex atmospheric dynamic condition is a challenge especially for forecasters in making weather forecasts. According to (Zakir, Khotimah, & Sulistya, 2010) to predict the weather requires parameters on a local scale or data analysis based on a single station by utilizing data from upper air observations.

One of the uses of the results of processing upper air observation data is use of the Air Stability Index. This is because the index is able to represent the vertical conditions of the atmosphere that occur in a certain time span and radius of the region (Veefkind et al., 2012). Currently, the value that is often used as the threshold for the Air Stability Index in the theory in the book *The Use of The Skew T, Log P diagram in Analysis and Forecasting* cannot be fully used as a basic value (Widadi & Pratama, 2023). This is because the characteristics of each region are different, so further research is needed to determine the appropriate value in a region.

Research related to determining the threshold value of the Air Stability Index has been carried out especially in several regions of Indonesia (Putra et al., 2022). In general, research related to the upper air is more concentrated in areas or regions that carry out upper air observations. The Meteorology, Climatology and Geophysics Agency (BMKG) is one of the government agencies that conducts upper air observations using Pilot Balloons and Radiosondes which are carried out directly by the Technical Implementation Unit (UPT) in the region.

Research related to the study of the Air Stability Index threshold has been conducted by (Bangsawan, 2015) with the research location in Makassar using data from the Hasanuddin Meteorological Station to see the Showalter Index (SI) and K Index (KI) with the research results obtained respectively in the range of - 0.1 - 3.0 and 30.1 - 38.0. While the research conducted by (Hariansah, A., 2016) at the same location but using the

Convective Available Potential Energy (CAPE) Index and Total-Totals (TT) obtained values respectively in the range of ≥ 500 and ≥ 40 .

The index values obtained from previous researchers are the basis for this study to conduct further studies on the threshold values of the air stability index, especially on SI, KI, CAPE and TT in Cumulonimbus (CB) and Thunderstorm (TS) cloud events over the past 10 years (2013 to 2022) at Hasanuddin Meteorological Station. The addition of SI and KI indices in this study was carried out to determine the stable conditions or not of the middle atmosphere and how much potential there is for CB clouds to arise around the research area. While the TT and CAPE indices are each used to identify the opportunities for CB and TS clouds to occur and the amount of energy available in the air column to lift air parcels in this case in Cumulonimbus clouds.

Research Methods

This research is a type of qualitative descriptive research, namely research that is included in the type of qualitative research. The purpose of this research is to reveal facts, circumstances, phenomena, variables and conditions that occur when the research is running and present them as they are. Qualitative descriptive research interprets and narrates data related to the current situation.

The data used in this study is data sourced directly from the Hasanuddin Meteorological Station UPT office, which includes:

1. Air Stability Index data for the last 10 (ten) years (2013 - 2022) at observations at 00 UTC and 12 UTC. The data is used to obtain the SI, KI, TT and CAPE Index values. same time period, namely from 2013 - 2022. This data is used to search for Cumulonimbus (CB) and Thunderstorm (TS) cloud events.

Air Stability Index Data

The Air Stability Index data used in this study are the Showalter Index, K Index, TT Index and CAPE for the last 10 years (2013 - 2022). Currently, processing to obtain Air Stability Index data is still being carried out at the Hasanuddin Meteorological Station office because the latest application can only operate on special devices from the office that carries out Pilot Balloon and Radiosonde observation activities.

2. Surface Weather Observation Data

Synoptic data processing is done by searching for Cumulonimbus cloud events accompanied by rain, thunderstorms or not on the Me.45 and Me.48 forms. On the Me.45 form, it is done by looking at the low cloud type code (8NhClCmCh) (Table 3.1). While on the Me.48 form as an attachment to see the current weather conditions (present weather) and SPECI which shows more clearly the time of occurrence of Cumulonimbus clouds with or without thunderstorms.

Table 1 Low Cloud Type Codes in Me.45 (Table (a)) and Present Weather Codes in Me.48 (Table (b)) (Source: Manual on Codes WMO-No. 306)

Table (a)

CI	Type of low clouds
3	Cumulonimbus without anvil, accompanied/not accompanied by cumulus sc/stratus. Cumulonimbus is based on cumulus, stratocumulus or stratus
9	Cumulonimbus is based on cumulus, stratocumulus or stratus

Table (b)

w0 w	Current Weather
13	lightning visible, no thunder heard
17	thunderstorm, but no precipitation at the time of observation
29	thunderstorm (with or without precipitation)
91	slight rain at time observation (thunderstorm during the preceding hour)
92	moderate rain at time observation (thunderstorm during the preceding hour)
95	thunderstorm, slight or moderate, without hail, but with rain at time of observation
97	thunderstorm, heavy, without hail, but with rain at time of observation

In this sub- chapter , we will explain more clearly the data processing techniques in the research that will be carried out with the following framework:

1. Upper air observations are carried out using Radiosondes to measure air temperature, relative humidity and wind direction and speed at certain altitude levels.
2. Output data obtained from Radiosonde observations in code format which is then processed using the RAOB Application.
3. Collecting Air Stability Index data to be used, namely Showalter Index, K Index, Total-Totals Index and CAPE.
4. Grouping the conditions of CB and TS cloud events from the daily actual weather report (present weather) against the predetermined stability index.
5. Determine the threshold for the SI Index, K Index, TT Index and CAPE parameters for CB and TS events using the frequency distribution method based on Sturges' rules (Sugiyono, 2017).

a. Determine the Number of Classes.

$$k = 1 + 3.322 \log n \quad (1)$$

Description: k = number of classes

n = number of data

b. Determine the interval of each class

$$\text{Range (} R \text{)} = X_n - X_1 \quad (2)$$

Description: R = area of distribution (Range)

X_n = highest observed value

X_1 = lowest observed value

$$\text{Class Interval} = \frac{\text{Range (R)}}{\text{Jumlah Kelas (k)}} \quad (3)$$

6. Conduct a comparison of the new threshold with the manual and previous research on the specified weather conditions.
7. Perform verification.
8. Conduct interpretation and analysis of atmospheric dynamics.

Analysis Using Verification Method

Analysis using the verification method is needed to determine the consistency of the values obtained. The first data analysis flow is to compare the results of the threshold value with previous studies by conducting trials or applications on new thresholds of the SI index parameters, K index, TT index and CAPE index against severe weather events during 2013 to 2022. The next step is to verify using the same data in 2023 to see the performance of the resulting threshold using Table 3.2 with a 2 x 2 format to see the statistical values obtained. One of them used in this study is the accuracy value (Gustari, Hadi, Hadi, & Renggono, 2012).

Table 2 Contingency Table for Verification

		Observation	
		Yes	No
Forecast	Yes	Hits	False Alarm
	No	Misses	Correct Negatives

Accuracy is the part of the forecast that is correct overall. The accuracy value is between 0 and 1. The best forecast is when the accuracy approaches the value 1. Accuracy can be calculated using the following equation (3.4):

$$\text{Akurasi} = \frac{\text{Hits} + \text{Correct Negatives}}{\text{Total}} \quad (4)$$

Interpretation

Interpretation is done with the aim of understanding and explaining the meaning of information or data that has been collected or analyzed. In addition, Interpretation also involves the process of extracting information contained in the data, identifying patterns or trends and making conclusions that can be used to make decisions or provide deeper insights.

will later become the basis for information or data obtained to make decisions regarding the performance of the results of the study before and after as well as various things that need to be revealed in this research.

Atmospheric Dynamics Analysis

Further analysis of the characteristics of atmospheric dynamics on the resulting index values is quite important information in this study. The purpose of the atmospheric

dynamics analysis is to see how much influence the resulting index values have on the occurrence of Cumulonimbus clouds and Thunderstorms.

Results and Discussion

Research result

Results of Air Stability Index Processing

The air stability index data obtained in this study is the result of data processing from Radiosonde observations through the RAOB application and has been adjusted based on the observation time against the specified weather event conditions, namely the Cumulonimbus (CB) and Thunderstorm (TS) cloud events.

a. SI Index for Cumulonimbus Cloud (CB) Occurrence

Table 3 SI Index of CB Cloud Events

Explanation	Symbol	Results	Class	BB	BA	Freq
Amount of Data	N	1389	1	-13	-10	1
The highest score	MAX	16.06	2	-9	-6	0
Lowest value	MIN	-12.55	3	-5	-2	47
Range	R	28.61	4	-1	2	1083
Number of Classes	K	11	5	3	6	238
Class Width	P	3	6	7	10	17
			7	11	14	2
			8	15	18	1

Meanwhile, Table 4 uses 1118 SI Index data for *Thunderstorm* (TS) events, and the highest SI index value is 20.18 and the lowest value is -4.38. The highest frequency of occurrence of the SI Index for TS cloud events is known to occur in the range of values (-1 to 1) of 648 events.

B. K Index for Cumulonimbus Cloud (CB) Events

Table 5 K Index Against CB Cloud Events

Explanation	Symbol	Results	Class	BB	BA	Freq
Amount of Data	N	1389	1	-6	-2	1
The highest score	MAX	43.6	2	-1	3	0
Lowest value	MIN	-5.9	3	4	8	4
Range	R	49.5	4	9	13	9
Number of Classes	K	11.37	5	14	18	24
Class Width	P	4	6	19	23	26
			7	24	28	75
			8	29	33	386
			9	34	38	747
			10	39	43	116
			11	44	48	1

Furthermore, in Table 5, it is known that there are 1389 K index data used to identify *Cumulonimbus* Cloud (CB) events . From these data, the highest K index value is obtained at 43.6 and the lowest value is obtained at -5.9. The highest frequency of occurrence of the K index against CB cloud events is known to occur in the range of values (34 to 38) of 747 events

K Index against *Thunderstorm* (TS) Events

Table 6 K Index Against TS Events

Explanation	Symbol	Results	Class	BB	BA	Freq
Amount of Data	N	1118	1	-57	-48	1
			2	-47	-38	0
			3	-37	-28	0
The highest score	MAX	42.5	4	-27	-18	0
			5	-17	-8	0
Lowest value	MIN	-56.9	6	-7	2	1
Range	R	99.40	7	3	12	4
			8	13	22	35
Number of Classes	K	11	9	23	32	303
			10	33	42	771
Class Width	P	9	11	43	52	3

Based on Table 6 above, it can also be seen and known that the total number of incident data on the K Index used to identify *Thunderstorm* (TS) events is 1118 data. Then from the total incident data, the highest K index value is obtained, which is 42.5 and the lowest value is obtained, which is -56.9. The highest frequency of occurrence on the K Index against TS events is known to occur in the range of values (33 to 42) of 771 events.

f. TT Index for *Cumulonimbus* Cloud (CB) Events

Table 7 TT Index Against CB Cloud Events

Class	BB	BA	Freq	Explanation	Symbol	Results
1	26	31	3	Amount of Data	N	1389
2	32	37	25			
3	38	43	710			
4	44	49	642	The highest score	MAX	83.4
5	50	55	8			
6	56	61	0	Lowest value	MIN	26.46
7	62	67	0	Range	R	56.94
8	68	73	0			
9	74	79	0	Number of Classes	K	11
10	80	85	1			
				Class Width	P	5

Based on Table 6 above, it can also be seen and known that the total number of incident data on the K Index used to identify *Thunderstorm* (TS) events is 1118 data. Then from the total incident data, the highest K index value is obtained, which is 42.5 and the lowest value is obtained, which is -56.9. The highest frequency of occurrence on the K Index against TS events is known to occur in the range of values (33 to 42) of 771 events.

TT Index for *Cumulonimbus Cloud* (CB) Events

Table 7 TT Index Against CB Cloud Events

Class	BB	BA	Freq	Class	BB	BA	Freq
1	26	31	3	1	26	31	3
2	32	37	25	2	32	37	25
3	38	43	710	3	38	43	710
4	44	49	642	4	44	49	642
5	50	55	8	5	50	55	8
6	56	61	0	6	56	61	0
7	62	67	0	7	62	67	0
8	68	73	0	8	68	73	0
9	74	79	0	9	74	79	0
10	80	85	1	10	80	85	1

In Table 7, the number of TT Index data used for *Cumulonimbus* (CB) cloud events is 1389 data. The results of the analysis show the highest TT Index value of 83.4 and the lowest value obtained is 26.46. The highest frequency of occurrence of the TT Index for TS cloud events is known to occur in the range of values (38 to 43) of 710 events.

TT Index against *Thunderstorm* (TS) Events

Table 8 TT Index Against TS Incidents

Explanation	Symbol	Results
Amount of Data	N	1118
The highest score	MAX	50.3
Lowest value	MIN	-3.6
Range	R	53.90
Number of Classes	K	11
Class Width	P	5

Class	BB	BA	Freq
1	-4	1	1
2	2	7	0
3	8	13	0
4	14	19	0
5	20	25	0
6	26	31	2
7	32	37	14
8	38	43	550
9	44	49	547
10	50	55	4

Meanwhile, in Table 8, it can be seen that the number of TT Index data used for *Thunderstorm* (TS) events is 1118 data where the highest TT Index value is 50.3 and the lowest value is -3.6. The highest frequency of TT Index occurrences for TS events is known to occur in the range of values (38 to 43) of 550 events.

CAPE Index for *Cumulonimbus Cloud* (CB) Events

Table 9 CAPE Index Against CB Cloud Events

Explanation	Symbol	Results
Amount of Data	N	1389
The highest score	MAX	11829.77
Lowest value	MIN	0
Range	R	11829.77
Number of Classes	K	11
Class Width	P	1040

Class	BB	BA	Freq
1	0	1040	1143
2	1041	2081	214
3	2082	3122	28
4	3123	4163	2
5	4164	5204	0
6	5205	6245	1
7	6246	7286	0
8	7287	8327	0
9	8328	9368	0
10	9369	10409	0
11	10410	11450	0
12	11451	12491	1

Then in Table 9 the number of CAPE Index data used for *Cumulonimbus* (CB) cloud events is 1389 data. The results of the analysis show that the highest CAPE index value is 11829.77 and the lowest value obtained is 0. The highest frequency of CAPE Index occurrence for CB cloud events is known to occur in the range of values (0 to 1040) of 1143 events

CAPE Index for *Thunderstorm* Events (TS)

Table 10 CAPE Index Against TS Events

Class	BB	BA	Freq	Explanation	Symbol	Results
1	0	309	521			
2	310	619	238			
3	620	929	138	Amount of Data	N	1118
4	930	1239	83			
5	1240	1549	64	The highest score	MAX	3,419.86
6	1550	1859	33			
7	1860	2169	17	Lowest value	MIN	0
8	2170	2479	15			
9	2480	2789	5	Range	R	3,419.86
10	2790	3099	2			
11	3100	3409	1	Number of Classes	K	11
12	3410	3719	1			
				Class Width	P	309

Furthermore, in Table 10, the number of CAPE Index data used for *Thunderstorm* (TS) events is 1118 data, so the highest SI index value is 3419.86 and the lowest value is 0. The highest frequency of CAPE Index occurrence for TS events is known to occur in the range of values (0 to 309) of 521 occurrences.

The air stability index against weather conditions in CB and TS events has produced index values that represent the range of values at which the weather event in question can begin to occur. The shift in the values produced will certainly be one of the considerations that there are other external factors that can affect weather conditions, especially in the research area.

Discussion

Studies related to the threshold value of the air stability index, especially in Indonesia itself, have been conducted in several regions such as Jakarta, Surabaya, Kupang, Medan, Manado, Biak and Makassar. This was done by several researchers considering that the threshold value of the index that is currently the reference has not been fully able to represent the number of frequencies that always occur from the index value produced when processing data from Radiosonde observations because there are several external factors that are quite influential so that ongoing research is needed, especially in research related to the threshold value of the air stability index in each region, especially in Indonesia.

In this discussion, the researcher tries to conduct further research by looking at the performance of several previous studies and current research on the guidebook which is still a general reference as a measuring point for the potential for bad weather events in this case related to the formation of Cumulonimbus clouds and Thunderstorms.

The results of this study indicate that in general there are changes that occur between the guideline for threshold values in the current study and previous studies. Changes or shifts occur more in the lower threshold values and upper threshold values. This is certainly very possible because the measurement of the upper air through Radiosonde which is carried out continuously every day also produces different data depending on the atmospheric conditions at that time.

In previous research conducted by (Bangsawan, 2015), it was found that the shift in values towards the guidebook was already visible with the threshold values on the SI and KI indices, which were respectively in the range (-0.1) to (3.0) and (30.1) to (38.0). While in the guidebook, the threshold values on the SI and KI indices were known, which were respectively in the range (-3) to (-6) and (31) to (40). Then the current research was conducted to see the consistency of the threshold values produced in the previous research but by adding the latest data in the following year, namely until 2022.

The results of the study revealed that current research also tends to experience changes or shifts where the values produced in the SI and KI indices are respectively at values (-5) to (7) and (13) to (43). This also shows that the pattern of events based on the SI and KI indices for the formation of cumulonimbus clouds and thunderstorms has shifted, especially in the lower and upper threshold values.

Furthermore, the same study but using other air stability indices, namely the TT and CAPE indices conducted by (Hariansah, A., 2016) was also found to have experienced changes or shifts where the study produced threshold values for the TT and CAPE indices of ≥ 40 and ≥ 500 respectively. Meanwhile, in the current study, there was a shift again but tended to experience a shift or lower threshold value where more incidents occurred in the lower limit value range of the CAPE index, namely (≥ 1).

When compared to the manual, the threshold values for the TT and CAPE indices, especially at the lower limit where the formation of cumulonimbus clouds and thunderstorms begins, are at $TT \geq 44$ and $CAPE \geq 1000$ respectively. Thus, the shift in the lower threshold formed in the current study illustrates that the frequency of occurrence, especially for the TT and CAPE indices, does not require large energy in the formation of Cumulonimbus (CB) and Thunderstorm (TS) clouds.

The range of values produced by previous research and current research has a fairly wide class because the index value produced during processing in the RAOB application also has a fairly wide range of values, both too low and too high compared to the average index value of the manual. It should be noted that the RAOB application has quite complex settings or arrangements so that it can increase the accuracy value of an index produced by taking into account other external factors so that this study tends to look more at the justification of the initial value (lower limit) which is obtained through the air stability index which is able to represent atmospheric conditions that are predicted to cause Cumulonimbus clouds and Thunderstorms.

In addition, the comparison of the criteria or classification values of an index sourced from the manual against previous research and current research has not been known about how the manual measures an index against the intensity of events, especially

CB and TS cloud events because observations of CB or TS clouds are only done visually and reported only as far as their existence. Meanwhile, to find out whether the CB or TS is included in the weak, moderate, or strong category based on the range of values produced by previous research or current research does not yet have a strong basis so that in general it only looks at the initial value (lower limit) of the index of how many CB and TS events can be formed.

Furthermore, verification was carried out on the manual, the results of previous studies and current research to see how the performance of the four indices, namely SI, KI, TT and CAPE, was against CB and TS events using 2023 data. The verification results showed that the threshold value produced in the current study was not significant enough because the data used was still very little so as to determine the results of the performance of each index, namely SI, KI, TT and CAPE, against CB and TS events. However, if reviewed further based on the time of the incident, it is known that the best performance was produced during the incident during the day compared to at night and this is consistent with the results of previous studies which stated that the sensitivity performance of the air stability index was quite good during the day.

In physics, the formation of convective clouds during the day occurs faster due to increased heating of the earth's surface by solar radiation. In general, a combination of other physical influences ranging from surface heating, convection, atmospheric instability, and local factors such as surface type and air humidity are needed, making the formation of convective clouds occur faster during the day and all are interrelated. This process usually produces cumulus clouds that can develop further into cumulonimbus clouds where if atmospheric conditions are favorable, they can cause thunderstorms.

Conclusion

Based on the results and discussions that have been described, it can be concluded that:

1. The characteristics of the Air Stability Index threshold value in the current study in terms of the SI, KI, TT and CAPE indices against cumulonimbus (CB) and thunderstorm (TS) events during 2013 to 2022 (10 years) at the Hasanuddin Meteorological Station have experienced changes or shifts to the manual or previous studies. Changes or shifts occur more, especially in the lower threshold value in the new range or threshold value with consecutive values, namely $\geq (-5)$, $\geq (13)$, $\geq (32)$, $\geq (1)$. This indicates that the frequency of CB and TS cloud occurrences at the research location against the indices used, namely SI, KI, TT and CAPE, still has quite an influence, especially on the lower threshold value or the initial value when CB and TS events begin.
2. The performance of the current research Air Stability Index threshold value is generally not significant when tested using a verification test in the following year (2023). However, if reviewed further regarding the performance based on the time of the incident, it is known that the new threshold value produced in the current study is quite consistent with previous studies where the sensitivity of the index during the day is better at predicting short-term weather conditions than at night.

The sensitivity of the air stability index during the day is better than at night due to more intense surface heating, sharper vertical temperature gradients, increased humidity, and stronger convective activity. All these factors create more dynamic and unstable conditions in the atmosphere, which are more easily detected by the air stability index.

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