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# Spatiotemporal Characteristics of Compound Dry Hot Stress Events in Trabzon Province

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**Abstract.** The frequency and severity of meteorological extremes have increased under climate change conditions. In particular, compound dry hot events caused by the simultaneous occurrence of low precipitation, high temperature, and low relative humidity create significant pressure on hydroclimatic systems. In this study, the spatiotemporal characteristics of compound dry hot stress events were investigated using meteorological stations in Trabzon Province. Monthly precipitation, temperature, and relative humidity data covering the 2012-2025 period were utilized. Compound stress months were identified based on precipitation values below the 25th percentile, temperature values above the 75th percentile, and relative humidity values below the 25th percentile. For the identified compound events, duration, severity, intensity, and peak stress parameters were calculated. In addition, a 90th percentile based rare event frequency analysis was performed to evaluate rare compound event behavior. The SPI-1 benchmark comparison showed that 103 months were jointly detected by both approaches, whereas 46 months were identified only by the compound stress framework. The results indicated that although Trabzon exhibits humid climate characteristics, significant spatial differences exist among the stations in terms of compound stress behavior. Marked differences were observed among the stations in terms of event frequency, duration, severity, and intensity. Higher elevation stations generally exhibited greater compound stress severity and persistence. Rare compound event analysis revealed episodic stress behavior with high severity values at several stations. The findings demonstrate that compound meteorological stress structures may develop even in humid regions and exhibit considerable spatial variability.
**Keywords:** Compound dry hot events; Meteorological stress; Spatial analysis; SPI; Trabzon.

## 1 Introduction

Drought is a natural disaster and climate-related phenomenon that can be observed in any region of the world, and the increasing prevalence of both extreme drought and extreme wet conditions in recent years has further heightened the importance of research in this field [1]. In addition, the simultaneous occurrence of drought and high temperature conditions leads to the formation of compound dry-hot events. Such events can have more severe consequences than the effects of a single drought or heatwave and can challenge the adaptability of natural systems [2,3].

The coverage, quality, and record length characteristics of the data sets used in drought studies directly affect the level of uncertainty in drought index predictions [4,5]. Missing or insufficient data can introduce uncertainty in the representation of drought conditions. Preferences for the dry indicator, threshold, and variable combinations used in compound event analyses can also

create differences in the determined event frequency, severity, and spatial pattern [3]. Therefore, the evaluation of atmospheric dryness indicators along with precipitation deficit and high temperature contributes to a more comprehensive definition of compound stress conditions [8].

In the literature, compound dry-hot events have been evaluated using different temporal scales and variable combinations. Bevacqua et al. [2] have demonstrated the decisive effect of mean precipitation trends on the occurrence of future compound hot-dry events using large ensembles of climate models. Hosseinzadehtalaei et al. [3] have shown that the use of different dry indicators has caused significant changes in the projected event probability and uncertainty results. Wang et al. [6] combined daily SZI and STI values using Copula to develop a daily-scale compound dry-hot index and evaluated the method's applicability across seven different climate regions. Yin et al. [7] examined the vegetation vulnerability under compound heat and drought stress using the Vine Copula approach based on SPI and STI. Zhao et al. [8] have demonstrated the importance of the atmospheric dryness component in compound hazard assessment by evaluating high temperature, low relative humidity, and high wind conditions together.

The aim of this study is to determine the spatial and temporal characteristics of compound dry-hot stress events in the province of Trabzon, which has a humid climate and distinct topographic variability, and to compare the obtained results with SPI-1 based drought conditions. In this context, monthly precipitation, temperature, and relative humidity data for the period 2012-2025 from 17 meteorological stations were used. For compound conditions, it was based on the precipitation value being below the 25th percentile and the temperature value being above the 75th percentile [11]. This bivariate definition has been extended by adding the condition that the relative humidity value is below the 25th percentile to represent the effect of atmospheric dryness [8]. The identified events have been examined using duration, severity, intensity, and peak stress metrics. Additionally, rare event characteristics have been evaluated and elevation dependency analysis has been applied. The original contribution of the study is its expansion of the literature framework based on precipitation deficit and high temperature by incorporating low relative humidity, evaluating compound stress conditions through three meteorological variables, and comparing the obtained results with the SPI-1 benchmark.

## 2 Materials and Methods

### 2.1 Study Area and Meteorological Dataset

Trabzon is located on the coast of Turkey's Eastern Black Sea Basin, between the latitudes 40°30′-41°30′ north and the longitudes 38°30′-40°30′ east, and has an area of 4,664 km². The province is characterized by mild climate conditions, where summers are not excessively hot and winters are not excessively cold [9]. A total of 17 meteorological stations located throughout Trabzon were included in the study. The data coverage information for the station codes, observation periods, and the precipitation, temperature, and relative humidity data necessary for compound analysis, calculated from records where these data are present in the same month, is presented in Table 1. Station elevation information was obtained from the Turkish State Meteorological Service together with the station metadata.

**Table 1.** Characteristics and data coverage of the meteorological stations used in the study

| Station | Station code | Elevation m | Observation period | Data coverage % |
|---|---|---|---|---|
| Trabzon Bölge | 17037 | 25 | 2012-2025 | 85.7 |
| Trabzon Havalimanı | 17038 | 39 | 2012-2025 | 99.4 |
| Çaykara/Uzungöl | 17569 | 1114 | 2012-2025 | 100 |
| Akçaabat | 17626 | 3 | 2012-2025 | 100 |
| Maçka/Altındere Sümela | 17714 | 1030 | 2012-2025 | 100 |
| Of/Fidanlık | 17775 | 6 | 2012-2025 | 92.9 |
| Düzköy | 18229 | 622 | 2012-2025 | 91.7 |
| Tonya/Kalınçam | 18230 | 1100 | 2012-2025 | 94 |
| Beşikdüzü | 18231 | 374 | 2012-2025 | 91.7 |
| Hayrat/Pazarönü | 18232 | 395 | 2012-2025 | 92.9 |
| Arsin | 18233 | 169 | 2012-2025 | 92.9 |
| Dernekpazarı | 18570 | 721 | 2012-2025 | 84.5 |
| Köprübaşı/Beşköy | 18571 | 975 | 2012-2025 | 84.5 |
| Maçka/Örnekalan Köyü | 18572 | 955 | 2012-2025 | 83.9 |
| Çarşıbaşı/Yoroz | 18573 | 370 | 2012-2025 | 83.3 |
| Sürmene/Deniz Bilimleri Enstitüsü | 18574 | 5 | 2012-2025 | 85.1 |
| Vakfıkebir/Hamzalı Köyü | 18575 | 845 | 2012-2025 | 82.7 |

## 2.2 Compound Dry Hot Stress Event Identification and Analysis Framework

Compound dry-hot events are generally defined by the occurrence of dry and hot conditions simultaneously or in close periods [10, 12]. In the identification of these events, percentile-based thresholds that take into account regional climate characteristics are also commonly used alongside absolute thresholds [10]. In a study conducted on a monthly scale, the simultaneous occurrence of precipitation values below the 25th percentile and temperature values above the 75th percentile was considered a compound dry-warm event [11].

Based on this literature framework, in the present study, it was deemed necessary for a month to be classified as a compound dry-hot stress month if the precipitation value is below the 25th percentile, the temperature value is above the 75th percentile, and the relative humidity value is below the 25th percentile simultaneously. Threshold values were calculated separately for each meteorological station and calendar month to account for local and seasonal climate variability effects. Because the percentile thresholds were estimated separately for each calendar month, each threshold was based on approximately 10–14 observations per station depending on data availability. Therefore, some uncertainty may arise from the limited sample size used for monthly percentile estimation. By adding the condition of low relative humidity to the analysis, the traditional precipitation-temperature based bivariate definition was expanded, and the effect of atmospheric dryness was also intended to be represented within the compound stress structure [8]. Months with missing records for any variable were excluded from the evaluation.

In the literature, compound dry-hot events are generally evaluated based on different characteristics such as frequency, severity, duration, and magnitude [10]. In this study, consecutive compound stress months have been grouped as a single compound event. Duration shows the number of consecutive compound months that continue throughout an event. Severity

represents the cumulative stress level during the event, intensity represents the average stress level within the event, and peak stress represents the highest stress level reached throughout the event. These characteristics were used not to create a new index but to compare and summarize the structure of the identified events on a station basis.

For each compound month, the normalized monthly stress score was calculated using the dry, hot, and atmospheric dryness components. The dry component was calculated as the difference between the 25th percentile precipitation threshold and the observed precipitation, normalized by the precipitation interquartile range. Hot component was calculated by dividing the excess of the observed temperature value over the 75th percentile threshold by the temperature interquartile range value. The atmospheric dryness component, on the other hand, is obtained by dividing the difference between the 25th percentile relative humidity threshold and the observed relative humidity by the relative humidity interquartile range value. These three components have been defined to produce a positive stress contribution only in the months when compound conditions occur. The monthly stress score has been calculated as the sum of the three component values. Event severity shows the total of monthly stress score values over consecutive compound months. Event intensity has been calculated as the ratio of the event severity value to the duration value. Peak stress, on the other hand, refers to the highest monthly stress score value obtained during the event.

Station-based event frequency is calculated by expressing the ratio of the number of compound months to the number of valid months for the same station as a percentage. The persistence ratio has been evaluated as the ratio of the number of compound events with a duration value of two months or longer to the total number of compound events. These metrics were used to examine the associations between station elevation and compound stress characteristics.

To compare the results obtained with the compound approach with an independent drought indicator that operates solely on precipitation deficit, SPI-1 was calculated using monthly precipitation data. SPI is based on representing precipitation values with a probability distribution and converting the obtained probability values into a standard normal distribution form [13]. Months with an SPI-1 value of -1 or lower are classified as drought months. The comparison of the compound method and SPI-1 was conducted over the common months where valid data was available for both analyses. The months identified by both methods were defined as overlap months, the months identified only by the compound approach as compound only months, and the months identified only by SPI-1 as SPI only months. The agreement rate has been used to show the overall consistency of the months classified in the same way by both approaches.

WMO recommends at least a 30-year continuous monthly precipitation record for reliable SPI estimation [13]. Due to the current study covering the period from 2012 to 2025, the SPI-1 results have been evaluated not as a long-term drought climatology indicator but as an exploratory benchmark providing a comparison with the compound approach. The SPI-1 comparison was recalculated using the same valid station-month records included in the final compound event analysis.

To determine the upper tail stress conditions among compound events, events where at least one of the severity, intensity, or peak stress metrics exceeds its global 90th percentile threshold value have been classified as rare compound events. This threshold has been used not to produce a long-term return period, but to distinguish the structure of upper tail compound stress events within the current observation period. For each station, rare event count, maximum rare severity, dominant season, and empirical recurrence characteristics within the observation period have been evaluated.

To examine the relationships between topographic variability and compound stress behavior, station elevation was compared with event frequency, event count, total severity, mean intensity, persistence ratio, and rare event count. Pearson correlation was used for linear

association and Spearman rank correlation for monotonic association. The obtained correlations only indicate the level of association between the variables and have not been interpreted as a causal relationship.

## 3 Results and Discussion

### 3.1 General Characteristics of Compound Dry Hot Stress Events

The distribution of compound dry hot stress conditions across Trabzon has been evaluated based on station-based occurrence and event characteristics. In the examined period of 2012–2025, a total of 149 compound months were identified for 17 meteorological stations. When consecutive compound months are considered under a single event, a total of 141 compound events have been obtained. The values of valid months, compound months, event count, maximum duration, total severity, and mean intensity on a station basis are provided in Table 2.

**Table 2.** Station based summary of compound dry hot stress characteristics

| Station | Valid months | Compound months | Event count | Max duration | Total severity | Mean intensity |
|---|---|---|---|---|---|---|
| Köprübaşı Beşköy | 142 | 17 | 15 | 2 | 34.539 | 2.066 |
| Vakfıkebir Hamzalı Köyü | 139 | 12 | 11 | 2 | 22.176 | 1.883 |
| Maçka Örnekalan Köyü | 141 | 12 | 11 | 2 | 27.955 | 2.274 |
| Dernekpazarı | 142 | 11 | 8 | 4 | 23.493 | 1.797 |
| Hayrat Pazarönü | 156 | 12 | 12 | 1 | 21.311 | 1.776 |
| Çaykara Uzungöl | 168 | 12 | 11 | 2 | 16.251 | 1.353 |
| Maçka Altındere Sümela | 168 | 11 | 11 | 1 | 15.85 | 1.441 |
| Sürmene Deniz Bilimleri Enstitüsü | 143 | 8 | 8 | 1 | 15.042 | 1.88 |
| Beşikdüzü | 154 | 8 | 8 | 1 | 12.084 | 1.51 |
| Trabzon Havalimanı | 167 | 7 | 7 | 1 | 8.322 | 1.189 |
| Akçaabat | 168 | 7 | 7 | 1 | 5.665 | 0.809 |
| Düzköy | 154 | 6 | 6 | 1 | 11.613 | 1.935 |
| Of Fidanlık | 156 | 6 | 6 | 1 | 9.993 | 1.665 |
| Arsin | 156 | 6 | 6 | 1 | 10.698 | 1.783 |
| Çarşıbaşı/Yaroz | 140 | 5 | 5 | 1 | 8.606 | 1.721 |
| Tonya Kalınçam | 158 | 5 | 5 | 1 | 11.756 | 2.351 |
| Trabzon Bölge | 144 | 4 | 4 | 1 | 4.586 | 1.146 |

The results in Table 2 reveal that the compound stress behavior exhibits significant spatial variability throughout Trabzon. Köprübaşı Beşköy has become the station with the highest occurrence value, with 17 compound months and 15 compound events. The same station ranked first in cumulative stress with a total severity of 34.539. In contrast, the Trabzon Bölge has shown the lowest occurrence value with only four compound months and four events.

It is observed that the station ranking varies according to the used stress metric value. The highest mean intensity value was determined to be 2.351 for the Tonya Kalınçam station, while Maçka Örnekalan Köyü with 2.274 and Köprübaşı Beşköy with 2.066 stood out. In terms of maximum duration, Dernekpazarı stands out with a four-month event compared to the other stations. This result shows that the frequency, duration, severity, and intensity values do not

represent the same compound stress characteristic. In the evaluation of compound dry hot events, considering different event characteristics values together is therefore important [10].

### 3.2 Severe Compound Event Characteristics

To highlight the most significant stress periods within compound events, they have been ranked according to their severity values. The ten events with the highest severity values are presented in Table 3. This assessment allows for the observation of the difference between cumulative stress resulting from long-duration events and short-duration events that produce high intensity and peak stress.

**Table 3.** Top severe compound dry hot stress events

| Rank | Station | Start | End | Duration | Severity | Intensity | Peak stress |
|---|---|---|---|---|---|---|---|
| 1 | Dernekpazarı | 2014-03 | 2014-06 | 4 | 12.157 | 3.039 | 9.061 |
| 2 | Köprübaşı Beşköy | 2014-03 | 2014-03 | 1 | 9.911 | 9.911 | 9.911 |
| 3 | Vakfıkebir Hamzalı Köyü | 2014-03 | 2014-03 | 1 | 7.842 | 7.842 | 7.842 |
| 4 | Maçka Örnekalan Köyü | 2020-09 | 2020-10 | 2 | 5.872 | 2.936 | 5.312 |
| 5 | Hayrat Pazarönü | 2012-11 | 2012-11 | 1 | 5.583 | 5.583 | 5.583 |
| 6 | Arsin | 2012-11 | 2012-11 | 1 | 5.172 | 5.172 | 5.172 |
| 7 | Maçka Örnekalan Köyü | 2014-02 | 2014-02 | 1 | 5.084 | 5.084 | 5.084 |
| 8 | Tonya Kalınçam | 2012-11 | 2012-11 | 1 | 4.887 | 4.887 | 4.887 |
| 9 | Köprübaşı Beşköy | 2020-09 | 2020-10 | 2 | 3.956 | 1.978 | 2.722 |
| 10 | Maçka Örnekalan Köyü | 2023-10 | 2023-10 | 1 | 3.724 | 3.724 | 3.724 |

The highest event severity during the examined period was determined for the Dernekpazarı station between March 2014 and June 2014. This four-month event reached values of 12.157 severity, 3.039 intensity, and 9.061 peak stress. The single monthly event determined for the Köprübaşı Beşköy station in March 2014 produced a severity of 9.911 and the same value of intensity with peak stress. When these two results are evaluated together, it is observed that the cumulative severity value is dependent not only on the peak stress level but also on the event duration characteristic.

In the March 2014 period, the simultaneous occurrence of high severity values at the Dernekpazarı, Köprübaşı Beşköy, and Vakfıkebir Hamzalı Köyü stations is noteworthy. Similarly, severe compound events were identified at the Maçka Örnekalan Village and Köprübaşı Beşköy stations during the September and October 2020 period. The structure observed during the same periods at different stations may indicate the influence of larger-scale meteorological conditions. However, since atmospheric circulation or synoptic pattern analysis was not conducted in the study, this situation has not been evaluated as a causal relationship.

Among the single-month events, the Köprübaşı Beşköy, Vakfıkebir Hamzalı Köyü, Hayrat Pazarönü, Arsin, and Tonya Kalınçam stations stood out with high intensity values. In contrast, the long duration of the Dernekpazarı event value has been decisive in producing high severity.

Therefore, in the evaluation of severe compound stress, it is more balanced to examine not only the maximum or mean values but also the duration, severity, intensity, and peak stress characteristics together [10].

### 3.3 Comparison with SPI Based Drought Conditions

The relationship between the stress months determined by the compound framework and the SPI-1 drought conditions based solely on the precipitation variable has been evaluated comparatively. The purpose of this comparison is to reveal the extent to which the two approaches identify the same stress condition together and in which periods they differ. In this context, only common station-month records with valid precipitation, temperature, and relative humidity data for both analyses were considered. The overlap, compound only, SPI only, and overall agreement values for the compound framework and SPI-1 results are presented in Table 4.

**Table 4.** Simplified comparison between compound method and SPI-1

| Metric | Value | Interpretation |
|---|---|---|
| Common station month records | 2596 | Months with valid data for both approaches |
| Compound months | 149 | Low precipitation, high temperature and low relative humidity occurred together |
| SPI-1 drought months | 442 | Precipitation based drought months |
| Overlap months | 103 | Both approaches detected stress |
| Compound only months | 46 | Compound stress detected without SPI-1 drought classification |
| SPI only months | 339 | Precipitation deficit without simultaneous compound atmospheric stress |
| Overall agreement % | 85.2 | General monthly agreement level |

As a result of the SPI-1 benchmark analysis, 442 drought months were identified within the common station month records, while the compound framework defined 149 compound months. Both approaches showed a common stress condition for 103 months. Accordingly, approximately 69.1% of the compound months overlap with the SPI-1 drought classification, while 46 months, or about 30.9%, are identified solely by the compound framework.

In 339 out of the 442 months classified as drought by SPI-1, compound conditions did not occur simultaneously. This result stems from the fundamental conceptual difference between the two approaches. While SPI-1 determines drought conditions solely based on precipitation anomaly, the compound framework is based on the simultaneous occurrence of low precipitation, high temperature, and low relative humidity conditions in the same month. Therefore, compound only months should not be interpreted as drought events missed by SPI-1. Similarly, SPI only months are not events missed by the compound framework either. Two methods evaluate different hydroclimatic stress structures.

Overall agreement has been calculated as 85.2%. However, this value should not be considered as a standalone method agreement indicator since it includes both event and non-event classification values together. The joint evaluation of overlap, compound only, and SPI only results is more explanatory. Additionally, SPI-1 has been calculated using precipitation records only from the period 2012–2025. Since the longer observation period condition recommended by the WMO was not met, the SPI-1 results were used not as an indicator of long-term drought climatology but solely for exploratory benchmarking purposes [13].

### 3.4 Rare Compound Event Characteristics

In order to evaluate the upper tail stress structure among compound events, rare event characteristics have been examined. Severity, intensity, or peak stress metrics values exceeding the global 90th percentile threshold value were classified as rare compound events. A total of 17 rare compound events were identified during the observation period, and these events were observed at nine different stations. The station-based rare event count, maximum rare severity, and dominant season are provided in Table 5.

**Table 5.** Rare compound event characteristics during the 2012-2025 observation period

| Station | Rare events | Max rare severity | Dominant rare season |
|---|---|---|---|
| Köprübaşı Beşköy | 4 | 9.911 | Autumn |
| Dernekpazarı | 2 | 12.157 | Spring |
| Maçka Örnekalan Köyü | 3 | 5.872 | Autumn |
| Vakfıkebir Hamzalı Köyü | 1 | 7.842 | Spring |
| Tonya Kalınçam | 2 | 4.887 | Autumn |
| Hayrat Pazarönü | 1 | 5.583 | Autumn |
| Arsin | 1 | 5.172 | Autumn |
| Sürmene Deniz Bilimleri Enstitüsü | 2 | 3.642 | Spring |
| Of Fidanlık | 1 | 3.035 | Autumn |

In terms of rare event frequency, Köprübaşı Beşköy ranks first with four events, while Maçka Örnekalan Village ranks second with three events. Two rare events have been identified for the Dernekpazarı, Tonya Kalınçam, and Sürmene Marine Sciences Institute stations. In contrast, one rare event was observed for the Vakfıkebir Hamzalı Köyü, Hayrat Pazarönü, Arsin, and Of Fidanlık stations. In terms of maximum rare severity, Dernekpazarı reached the highest value with 12.157. Although Köprübaşı Beşköy produced more rare events, the maximum rare severity value was determined to be 9.911. This difference shows that the rare event frequency and rare event magnitude values do not represent the same risk characteristic.

When evaluating the seasonal distribution, Autumn was determined to be the dominant season in six out of the nine station values, while Spring was the dominant season in three. The fact that the rare compound stress structure is not limited to Summer can be explained by the relative threshold approach used. Since threshold values are calculated separately for each calendar month, the definition of a month as hot or dry is based on the local distribution characteristics of that month rather than the absolute climate value. Therefore, conditions of high temperature, low precipitation, and low relative humidity according to seasonal norms can also create compound stress during the Spring or Autumn periods.

### 3.5 Elevation Dependency of Compound Stress Metrics

To evaluate the relationship between Trabzon's distinct topographic variability and compound stress characteristics, associations between station elevation and frequency, event count, total severity, mean intensity, persistence ratio, and rare event count were examined. Linear relationships were evaluated using Pearson correlation, while monotonic relationships were assessed using Spearman rank correlation. The obtained correlation coefficients and significance levels are presented in Table 6.

**Table 6.** Relationship between elevation and compound stress metrics

| Metric | Pearson (r) | Pearson (p) | Spearman (rho) | Spearman (p) | Interpretation |
|---|---|---|---|---|---|
| Frequency (%) | 0.570 | 0.017 | 0.452 | 0.068 | positive linear association with $p<0.05$ |
| Event count | 0.551 | 0.022 | 0.462 | 0.062 | positive linear association with $p<0.05$ |
| Total severity | 0.629 | 0.007 | 0.681 | 0.003 | positive association with $p<0.05$ |
| Mean intensity | 0.521 | 0.032 | 0.458 | 0.064 | positive linear association with $p<0.05$ |
| Persistence ratio | 0.604 | 0.010 | 0.562 | 0.019 | positive association with $p<0.05$ |
| Rare events | 0.366 | 0.148 | 0.239 | 0.355 | positive but not significant |

Given the exploratory nature of the elevation analysis and the limited number of stations, p values were interpreted without adjustment for multiple comparisons and should therefore be considered exploratory. Positive correlation coefficients were obtained between elevation and all compound stress metrics examined in Table 6. Pearson correlation indicated positive associations with $p<0.05$ for frequency, event count, total severity, mean intensity, and persistence ratio. The strongest linear relationship was observed for total severity with $r=0.629$ and $p=0.007$, followed by persistence ratio with $r=0.604$ and $p=0.010$. Frequency, event count, and mean intensity also showed moderate positive linear associations with elevation.

Spearman rank correlation produced a similar but more selective pattern. Total severity showed the strongest monotonic association with elevation with $rho=0.681$ and $p=0.003$. Persistence ratio was also positively associated with elevation with $rho=0.562$ and $p=0.019$. In contrast, the Spearman relationships for frequency, event count, and mean intensity did not reach the $p<0.05$ level. These differences indicate that some elevation relationships are more evident in their linear structure than in their rank-based pattern.

Rare event count showed positive but statistically non-significant relationships with elevation in both correlation approaches. Overall, the results suggest that higher elevation stations tended to exhibit greater cumulative severity, persistence, and, to some extent, higher compound event occurrence and intensity. Nevertheless, elevation should not be interpreted as an independent causal factor because distance to coast, slope, aspect, local exposure, and atmospheric circulation were not controlled in the present analysis.

## 4 Conclusion

In this study, compound dry hot stress events were examined for 17 meteorological stations in Trabzon province using precipitation, temperature, and relative humidity data from the period 2012–2025. Compound conditions were defined as the simultaneous occurrence of precipitation values below the 25th percentile, temperature values above the 75th percentile, and relative humidity values below the 25th percentile. A total of 149 compound months and 141 compound events were identified during the examined period. Station-based results have shown that the compound stress characteristics are not homogeneous throughout Trabzon. While Köprübaşı Beşköy stands out in terms of occurrence and total severity, Dernekpazarı has drawn attention with the individual event that has the longest duration and the highest severity value. The highest mean intensity was determined for the Tonya Kalınçam station.

As a result of the benchmark comparison with SPI-1, 103 months were jointly identified by both approaches, while 46 months were defined only by the compound framework. This

difference indicates that the compound approach and the SPI-1 method represent different stress structures. The compound framework takes into account the simultaneous effects of high temperature and low relative humidity conditions alongside the precipitation deficit. However, due to the calculation of SPI-1 results over a 14-year observation period, these results have been evaluated not for the purpose of long-term drought climatology but solely as a comparative benchmark.

A total of 17 rare compound events have been identified within the scope of the rare event analysis. Rare events were predominantly observed during the Autumn and Spring periods, with the highest rare event frequency recorded at the Köprübaşı Beşköy station. Elevation analysis showed positive associations between station elevation and several compound stress characteristics. The most consistent relationships were obtained for total severity and persistence ratio, which showed positive associations with $p<0.05$ in both Pearson and Spearman analyses. Frequency, event count, and mean intensity also showed positive linear associations with elevation, whereas rare event count was not statistically significant. These findings indicate that elevation may contribute to the spatial differentiation of compound stress behavior, although it should not be interpreted as an independent causal mechanism.

The obtained results show that the characteristics of a humid climate do not completely eliminate the formation of compound meteorological stress. The joint evaluation of precipitation, temperature, and atmospheric dryness conditions provides complementary information to the classical precipitation-based drought assessment approach. However, the relatively short observation period and the limited sample size available for calendar-month percentile estimation, together with station-based spatial representation and unexamined atmospheric circulation effects, constitute the main limitations of the study. Studies conducted using longer meteorological records and more detailed spatial data can contribute to a more comprehensive evaluation of the long-term and spatial structure of compound stress behavior characteristics.

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