Examining Public Perceptions and Concerns about the impact of heatwaves on Health outcomes Using Twitter Data.

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Abstract

Background

Heat is becoming a global public health concern. This paper presents a comprehensive Twitter data analysis (2011-2023) to gain insights into public perceptions of heatwaves and their health-related concerns.

Methods

A number (N=2,070,197) of filtered tweets were included for analysis after preprocessing. Utilizing the Extractor of Demographic Characteristics (EDC) module, we extracted demographic attributes, including user type, gender, and age, highlighting the diverse voices in the Twitter conversation. Sentiment and emotional analyses were conducted utilizing BERT models. An active learning content analysis approach was employed using the GPT-3 model to identify health outcomes and concerns related to heat waves.

Results

Our results show that joy and anger were the dominant emotions, reflecting positive and negative sentiments surrounding heat waves. Public sentiment varied, revealing concern and optimism in response to changing weather patterns.
In terms of health outcomes, the paper categorizes and analyzes a wide range of concerns during heat waves, from heat-related illnesses to mental health issues. These findings provide valuable insights into how different health concerns are distributed across gender, user type, and age categories. An overview of the measures people took to control these issues was also given.

Conclusions

This study illustrates the evolving dynamics of public emotional responses to heat waves, offering a holistic view of the various health-related concerns raised by the public during these extreme weather events. Such insights are essential for informing public health strategies and emergency responses to mitigate the adverse effects of heat waves and protect vulnerable populations.

Keywords: heat wave, Twitter, health outcomes, heat-related illnesses, climate change, healthcare

1. Introduction

Earth's climate has dramatically changed throughout history [1]. With a recorded temperature rise of about 1.8°F (1°C) from 1901 to 2020, as reported by the National Oceanic and Atmospheric Administration [2], it is predicted to be 2-4 degrees (°C) higher than pre-industrial levels by 2100 [3]. This planet-warming resulted in severe and more frequent extreme weather events (e.g., flooding, intense storms, droughts.) [4]. Some are even happening faster than scientists previously assessed and predicted [5, 6]. Based on the National Aeronautics and Space Administration reports, scientists have high confidence that global temperature will continue to rise for many decades, resulting in more intense and longer heat waves [7].

Studies have shown that this heat is becoming a public health concern and one of the "most underappreciated hazards of climate change," as stated by Philip, S.P. in Nature's editorial [8-10]. NOAA described it as one of the most deadly weather phenomena [2]. More than thirty million people died because of the occurrence of extreme weather events in the last 30 years in urban and non-urban areas [11] and increased populations' exposure to morbidity and mortality from extreme heat and related heat illnesses [12, 13]. Some regions are predicted to become uninhabitable due to the already exceeded life-threatening thresholds during heat waves [14]. Heat impacts on human health vary from direct impacts such as fatigue, headaches, malnutrition, changes in disease transmission, and death to indirect impacts such as productivity drop and violence and crime [15-19]. However, public recognition of climate change and its impact on economics and the environment is still an issue with significant societal and even political implications, which urges research on heat adaptation and awareness [20].

Heat adaptation research remains limited to developed countries, particularly metropolitan areas [21]. The limitation is mainly due to the scarcity of data directly linking heat waves to health issues. For instance, researchers have resorted to data from occupational accident reports and ambulance call-outs to overcome data shortages [22, 23]. However, people do not necessarily report to their doctors and local hospitals when they are subject to mild symptoms of issues caused by extreme heat events [24], which limits the generalizability of the findings. Few studies have also resorted to surveys to collect data on the measures people take to adapt to heat waves [25]. However, little attention has been paid to data coming from social media expressing people's concerns about heat
waves affecting their health. Twitter is one of the most frequently used social media platforms in research [26]. It was a useful tool for public health research in surveillance, event detection, and disease tracking and forecasting [27].

In this study, we aimed to explore the potential utility of large available social media data in determining the impact of heat waves on health outcomes. We collected Twitter text data to (1) explore the reactions and health issues that people admitted having as a result of heat waves, (2) investigate the measures taken by both people and organizations to overcome these impacts, and (3) investigate the differences in reactions across different types of users (based on gender, age, and account type). Our paper contributes to extending the applications of disaster-related Twitter studies to heat waves, which are severe and destructive natural hazards.

2. Data and methods

2.1. Data collection

Twitter, currently named X, is a social network with around 313 million monthly active users in 2020 [28]. To build the database for this study, we utilized the functionalities of the Twitter API v2 through a developer account. The data collected was limited to tweets written in English and posted over 13 years (January 2010 - May 2023). We used the following keywords to select Tweets that conveyed only perceptions about heat waves: 'heat wave', 'heatwave', 'sweltering heat', 'unbearable heat', 'torrid heat', 'heat warning', 'heat watch', 'heatstroke', 'heat stroke', and 'extreme temperature'. This list was built based on the keywords used in other systematic reviews capturing heat waves' impact on health [29-33]. We excluded retweets and replies [34, 35].

2.2. Data Preprocessing

Subsequently, the dataset of fetched tweets (6,647,792 tweets) underwent preprocessing, which involved the following steps: duplication removal, lowercasing, format-noise cleaning, and topic-noise cleaning. The final dataset of clean, relevant tweets consisted of 2,070,197 data instances. More information on the preprocessing is available in Appendix 01.

2.3. Extractor of Demographic Characteristics

The Extractor of Demographic Characteristic (EDC) module was utilized to extract three demographic attributes, namely user type, gender, and age, by analyzing profile images, screen names, names, and biographies [36]. User type and gender were modeled as binary classification tasks, while age was categorized into four classes: ≤18, 19-29, 30-39, and ≥40 years [36]. Fine-tuning was performed across all pipelines to ensure accurate extraction of demographic features. More details about this methodology can be found elsewhere [37, 38].

2.4. Sentiment Analysis, emotion analysis, and text classification

We utilized RoBERTa and SiEBERT to conduct sentiment analysis and the BERT model for emotion classification [39-41]. We also utilized GPT-3 for text classification to identify the main topics or health issues covered in the tweets [42]. The authors manually coded a sample of 30,000 tweets, and then the model was trained to consider the initial codes identified. The label creation was done in a qualitative, inductive way. Saturation was reached after coding 1208 tweets.
3. Results

3.1. General Statistics

Table 1 presents a breakdown of the tweets collected for a study focusing on heatwaves and their impact on people. The dataset consisted of a total of 2,070,197 tweets. Most of these tweets (76.06%) were written by individuals, while 24.04% came from corporate accounts.

Across the individuals, 70.22% of the accounts that tweeted about heatwave belonged to men, while only 29.78% belonged to females. A majority of 56.93% were over 39 years old, and 20.49% were between 19 and 39 years old. Only 13.07% of the account holders were under 19 years old.

**Table 1: Tweets Statistical Distribution**

Regarding emotions expressed in these heatwave-related tweets, joy emerged as the emotion (38.81%), closely followed by anger (33.15%). Fear was conveyed in 11.45% of the tweets, while sadness comprised around 10.55%. Love was mentioned in 5.54% of the tweets, whereas surprise was observed in about 0.53%. Moreover, when examining the sentiment of tweets regarding heatwaves, it is evident that the average sentiment score is 0.608, with a deviation of 0.4647. The data indicates that slightly over half of the tweets (53.04%) express a positive sentiment, while the remaining tweets (around 46.96%) convey a negative sentiment.

3.2. Twitter's Sentiment Polarity Perspective

Analyzing the sentiments over time in Figure 1 reveals discernible seasonal patterns, particularly during summer, where peaks in both negative and positive sentiments are evident. This observation aligns with the anticipation that heat waves are more prevalent during summer. It suggests that individuals may be more inclined to express their sentiments about heat waves when they personally experience them rather than merely commenting on distant occurrences in other locations. The fluctuations in sentiment throughout the summer months underscore the importance of considering the actual experiences individuals have with heat waves, as reflected in their willingness to engage in tweeting about these climatic events. In the years of famous heat waves, sentiment appeared consistently negative, as shown in Figure 1, with a significant dip in 2021, 2013, and 2022, suggesting potentially severe or impactful heat waves. These events coincide with three important heat events. First, the Summer 2012 North American heat wave was one of the most severe heat waves in modern North American history and resulted in many deaths as it was not well predicted, which could explain the dip in negative emotions but the low positive reactions by tweeters [43]. Second, the year 2013 is the fourth warmest year globally since records began in 1880 [44]. However, it recorded more positive tweets. This could be explained by how "less surprised" people were this year compared to the year before, considering that 2012 was already hot. Additionally, NASA rated 2022 the fifth-warmest year on record. This could explain the abundance of negative tweets for these two years [45]. However, over the years, the positive sentiment rates grew more importantly to align with the negative sentiment rates. This could indicate improved responses to heatwaves, mitigation efforts, and personal preparedness for heatwaves, highlighting the evolving dynamics of how people perceive and respond to this environmental challenge.
The recent positive sentiment on Twitter towards heatwaves appears to stem from an ironic or satirical reaction, skewing sentiment analysis results towards positivity. This irony, particularly in the context of extreme heat, highlights the nuanced public reaction captured over recent years. Analysis of sentiment during significant heatwaves across different years reveals a complex interaction between extreme weather and public sentiment. For instance, negative sentiment spikes during 2012, 2013, and 2015 heatwaves in North America and Europe correlate with these severe events. In contrast, the notably negative sentiment in 2014 reflects its status as the hottest year on record, whereas the positive sentiment in years like 2017, 2018, 2021, and 2022 suggests either better responses to heatwaves or milder weather conditions in affected regions.

3.3. Emotional Responses to Heatwaves

Analysis of the emotional sentiment data about heatwaves from September 2011 to September 2021, as shown in Figure 2, reveals intriguing insights into how people’s emotions and perceptions evolved during this decade. In September 2011, tweets exhibited mixed emotions, with sadness at 20% (“Me watching little Mexican kids nearly pass out from heatstroke cause their mom decided to make caldo on the hottest day of the year”), joy at 25% (“Even though it's hot outside I am enjoying my summer. Try to stay cool guys and drink plenty of water. I hope your heatwave ends soon”), and “Good news is, we won our flash football tournament even though it may not a good idea to play in the heat”), and fear at 18% (“I was pronounced dead for three minutes after heatstroke and now spooky things happen to me.”). This emotional diversity potentially reflects the uncertainty and emotional impact of early heatwave experiences. However, as we move forward in time, a noticeable trend emerges. By September 2015, joy had steadily increased to 35%, indicating a growing resilience or adaptation to heatwaves, sadness, and fear. However, it fluctuated and remained relatively elevated (sadness at 28% and fear at 22%). This suggests a persistent emotional impact associated with heatwaves that people were still grappling with.

Furthermore, love remained stable in tweets, consistently around 15% throughout the decade, indicating a lasting sense of community and support during these challenging times. While fluctuating between 8% and 15%, anger did not exhibit a significant upward trend, suggesting that people were not attributing blame for heat waves to a particular source or entity but rather expressing frustration at the situation (“Am tired, but I can't [curse] sleep because of this heatwave”). Interestingly, the expression of surprise was minimal throughout the years, hovering around 5%, indicating a general expectation or awareness of the occurrence of heatwaves, likely due to increasing climate change awareness and integrating weather forecasts into daily life.

The observation that a heatwave occurs annually during July and August, accompanied by a significant increase in tweets, raises interesting questions about the potential link with emotional sentiments. The data on emotions previously discussed indicates that emotions like sadness and fear remain relatively elevated throughout the years, even when not in the immediate presence of a heatwave. This could suggest a lingering emotional impact from past experiences with heatwaves.

Figure 2: Mean emotional distribution of heatwave-related tweets through time
The fact that sadness and fear remain at relatively elevated levels outside of July and August, even during years without heatwaves, suggests that people may carry forward the emotional impact of previous heatwaves. This lingering emotional response could contribute to tweets' consistent sadness and fear. This emotional phenomenon may be explained by the climate fatigue experienced by people as a result of climate change. Climate fatigue is a psychological state characterized by the weariness or emotional exhaustion of climate-related information and challenges [46].

Additionally, the increasing joy observed in September 2015 may indicate that people were experiencing relief and happiness as the heat waves of that year receded.

The stable presence of love throughout the years may indicate that during the annual heatwave periods, people come together and show support for one another, leading to a consistent level of positive emotion. Conversely, the relatively low levels of surprise may indicate that the annual occurrence of heatwaves had become an expected event, with people not expressing surprise but responding with emotions tied to their experiences and adaptations.

3.4. Classification of healthcare concerns during heatwaves.

3.4.1. Health-related issues

In the thematic analysis, a list of themes emerged that we classified into main topics. Table 2 summarizes the themes.

Table 2. Themes emerging from the text analysis.

| Figure 3: Percentage Distribution of Heatwave Health Impact Categories |
| Most people tweeting about heat waves expressed their reaction regarding a heat-related illness (e.g., heat stroke, dehydration, headache) (44.3%). The second emerging category was the methods of addressing health-related issues (30.1%). Only 11% and 7% of the tweets showed that people were suffering from organ failure or mental health issues as a result of the heat waves. Figure 4 breaks down each subcategory with the associated number of tweets. |
| Heat-related illnesses |
| Most tweets (44.3%) complained about how the heatwave negatively impacted tweeters' health, inducing heat-related issues. Mainly, as shown in Figure 4, 84.4% of them experienced or were exposed to heat strokes, while the rest experienced heat exhaustion (8.19%), dehydration (4.51%), and headaches (1.31%). Some other tweeters experienced other heat-related issues, such as heat cramps, fainting, nausea, and hay fever. |
| "I forget how bad it is every year until the first heatwave hits, and my body is like, OH GOD! It's summer, so air pressure headaches, feeling faint, and constantly getting heat exhaustion season." |
| Figure 4: A Holistic View of Health Issues, Concerns, and Measures |
**Respiratory issues, organ failure, and cardiovascular concerns**

Although only 3% of the tweets acknowledged having a cardiovascular issue due to heatwave, it is noteworthy that such chronic conditions should be looked at seriously considering their negative impact on health.

"Heart ache, perspiration... Just some of the wonderful symptoms I am experiencing today."

For instance, 79.6% of the patients had increased heart rates, 12.9% of them experienced annoying heart palpitations, and ranges between 2.29% and 2.71 of them had perspiration, hypertension, and experienced extreme cardiovascular events.

A rate of 11% of the tweets showed that tweeters experienced organ failure as a cause of heatwaves, and 1.53% of them had organ failure that included problems with the kidneys, stomach, and lungs.

Among this population, 61.9% of the tweeters experienced trouble breathing and 26.6% experienced asthma exacerbations due to heat.

"Am alarming patients like me suffering from asthma and hypertension. This heat is serious."

"Kidney failure, heatstroke cases up in hospitals amid heat wave."

**Skin and hair conditions**

Among the 1.05% of tweets that reported harmed skin or hair due to heat waves, 63.7% of the tweeters admitted having sunburns, 8.93% said suffering heat rash, and 15.5% reported that heat waves damaged their hair.

"It was a hard day today. I am sunburnt. I got a heatstroke. Back to reality."

"My hair is getting pretty greasy in this heatwave."

**Mental health and well-being**

Heat waves did not only impact tweeters' physical well-being but also their mental health (7.5%). Stress induced by this extreme weather was complained about by 41.2% of the tweeters. Heat waves also cause mood changes (5.29%), anxiety (18.5%), mental fatigue (8.51%), panic attacks (7.52%), and sleeping troubles (18.9%).

"With every tortured breath, I feel my will to live sliding inexorably away and the approach of my surely imminent death by heatstroke."

**Vulnerable populations**

Heatwave is critical for some of the vulnerable populations. For instance, 29.4% of the tweets expressed concerns about the vulnerability of older adults who cannot bear extreme weather. Older adults are more vulnerable to health risks such as dehydration and heart attacks.
"With the heatwave beginning, it's important to remember that some countries have no infrastructure for extreme heat, putting the elderly at risk."

It also impacted infants (19.8%), pregnant females (15.5%), people with immunization issues (2.14%), people with chronic diseases (6.95%), marginalized communities (13.9%), and people with preexisting heatwave-related conditions (21.3%).

"Any other autistic people find the heat just completely takes the spoons out of you?? Like I usually have a good amount of energy, and this heat wave has just burned that to a crisp-I can barely do anything."

"You need to leave this man alone. Heat impacts everyone differently. He could be on medications that make him more susceptible to heat stroke."

"Our heat wave in the last year killed homeless people, and everyone still made jokes."

3.4.2. Methods of addressing the heat-related issues

Tweets did not only enumerate health concerns resulting from heat waves, but 30.1% also talked about preventative and corrective methods to these consequences.

Adaptation and coping strategies, and personal measures

As shown in Figure 4, most tweets shared insights into adapting to heat waves and coping with extreme heat events by staying hydrated (44.9%).

"Try to stay cool, guys, and drink plenty of water. I hope your heatwave ends soon."

Some Tweets were posted to share advice based on the personal measures that helped them overcome heat wave impacts (8.85%).

"I stayed in my room to stay cool today because the house is boiling."

Public health response

Tweets also covered insights into the response of public health to the heatwaves (21.28%). Mainly, most of them covered (15.6%) different calls for action and awareness.

"CHP reminds public on precautions against heat stroke during very hot weather..."

"This doctor explains why heatwaves are worse in the UK..."

Preparedness and emergency response, and weather hazard watch

Through Twitter, information on emergency response plans was distributed to the public, covering conversations about emergency services and plans and information on cooling centers and shelters (3.26%).

"Keep your family safe this summer. Know the signs and call 911 if you or a loved one are suffering from a heat stroke."

A rate of 6.04% of the Tweets shared alerts about upcoming weather hazards and issues.
"Are you enjoying the sunshine and heat? Whilst many of us can enjoy our current heatwave, there are thousands of people who are vulnerable to these conditions. A new heat-health alert (HHA) service has been launched in England."

**Media and public discourse**

Some tweets (3.21%) portrayed experts' analysis of heatwave impacts and corrections of public misconceptions.

"We have developed resources for members to use to support patients during the heat. Find out more and download the full resource here..."

**Other measures**

Some other tweets talked about the indirect impact of heat waves on patients' well-being by covering economic loss, job productivity issues, and the geographic disparities related to shaded areas.

3.5. **Distribution of the topics across different types of users.**

Different types of users tweeted about the heat wave health issues, as shown in Table 3. Heat exhaustion (59%), headaches, heat edema, and hay fever were experienced by more male than female tweeters. Females suffered from more dehydration (71%) and heat strokes (65%). More females admitted having had difficulty breathing (87%), increased heart rates (81%), heat rash (80%), stress (80%), and sleeping issues (74%). More females tweeted about the vulnerability of infants (68%), older adults (69%), and pregnant females (93%).

Older adults were more likely to tweet about almost all health issues, showing that vulnerability increases with age.

**Table 3.** Distribution of the topics covered in the topic analysis on the different types of users.

Based on our findings, although many organizations tweeted about the impacts of heat waves on health status, most of the tweets were from personal accounts. Organizations shared mainly information about shelters and cooling centers (85%) and public health advisories (65%).

**3. Discussion**

In this study, we aimed to explore the potential utility of large available social media data in determining the impact of heat waves on health outcomes. We collected Twitter text data to (1) explore the reactions and health issues that people admitted having as a result of heat waves, (2) investigate the measures taken by both people and organizations to overcome these impacts, (3) investigate the differences in reactions across different types of users (based on gender, age, and account type). The built dataset, consisting of over 2 million tweets, offers valuable insights into various aspects of this topic.

The distribution of the tweets (76% personal accounts vs 24% corporate accounts) suggests that heat waves are growing as a subject of concern for both individuals and organizations. Moreover,
there is a significant gender disparity among individual users, with 70.22% of accounts belonging to males and only 29.78% to females. This disparity could be explored further to understand gender-specific heat wave responses and potentially inform public health campaigns to personalize mitigation strategies to the needs of the different subgroups.

The age distribution is also noteworthy, with 56.93% of the accounts belonging to individuals over 39 years old. This suggests that older individuals are more active in discussing heatwaves on Twitter, possibly due to increased vulnerability to extreme heat, which is also consistent with other literature [47].

According to the sentiment analysis, the primary emotions exhibited in heatwave-related tweets are joy (38.81%) and anger (33.15%). The frequency of joy may suggest that humor and sarcasm play an essential role in how individuals cope with high heat, particularly in recent years. This observation was substantiated during the systematic quality check of the analysis of the diverse tweets categorized under "joy," such as "Absolutely loving this scorching weather! It's not like we needed a break from mild temperatures or anything. Who needs comfortable outdoor activities anyway? Embracing the joy of being roasted alive!".

This could be related to growing awareness of climate change and the need to solve its issues. Observing seasonal sentiment patterns aligning with heat waves highlights the strong connection between weather events and public sentiment. Negative sentiment peaks in specific years correlate with severe heat waves, emphasizing the emotional impact of such events.

Conversely, positive sentiment in some years may indicate improved responses or milder conditions, reflecting the evolving dynamics of how society perceives and responds to heat waves. The overall presence of emotions tied to people's experiences with heat waves suggests that people are developing coping strategies and community support in dealing with extreme weather events.

The fluctuations in sentiment throughout the summer months underscore the importance of considering the actual experiences individuals have with heat waves, as reflected in their willingness to engage in tweeting about these climatic events. This nuanced perspective adds depth to our understanding of the interplay between personal experiences and expressing sentiments about heat waves on social media.

Understanding these perspectives shared in conversations can be pivotal in developing strategies for mitigating and responding to heat waves specifically and climate change generally. People come to social media to support one another, seek help, and share opinions and experiences [48, 49]. Our study also highlighted and classified the main health issues that may result from extreme heat waves (mental and physical health-related problems). These issues generated the negative emotions of sadness, stress, anxiety, and anger spotted in the Tweets. For example, heat-related illnesses, such as heat strokes and dehydration, were the most commonly mentioned health concerns, affecting a substantial portion of the tweeters. Many studies have shown associations between strokes and extreme heat weather [50, 51].

Additionally, mental health concerns, including stress and anxiety, were prevalent among tweeters, highlighting the psychological toll of heat waves. These findings could help identify tweet patterns
related to health vulnerabilities, which can contribute to developing early warning systems. Monitoring social media can help anticipate and respond to potential health crises during extreme heat events, allowing for timely interventions and resource allocation. Additionally, health authorities can use this information to design targeted awareness campaigns and public health interventions, distribute resources, and implement strategies to mitigate the impact of extreme heat on vulnerable populations. Understanding the specific health issues identified in this study can aid in more efficient resource allocation. Emergency services can use such information to prioritize areas and communities most at risk during extreme heat events and other extreme weather events related to climate change. Understanding the health vulnerabilities highlighted on social media can guide the incorporation of health considerations into broader climate resilience plans at the local and regional levels.

The summary of the vulnerable populations that heat waves could impact can serve as a repertory to patients and organizations aiming to issue information on preventative measures before heat waves and extreme weather events related to climate change. Consistently with previous studies, our findings suggest that social media data can be used to advance our understanding of public attention and reactions to severe weather [52]. Our results can, thus, provide a reference for developing and improving relevant public health awareness strategies and campaigns and early extreme weather and health warning systems to prevent and reduce the health risks due to extreme weather and climate change, accounting for mental and physical health safety [51]. Finally, through the difference in response across groups, we shed light on the importance of understanding disparities to help tailor the preventative and corrective public health initiatives related to heatwaves to target the specific groups needed effectively.

In summary, this study analyzes Twitter data related to heat waves and delves into the emotional and health-related aspects of the public's response to extreme heat. These findings can inform policymakers, healthcare professionals, and organizations working on climate change mitigation and adaptation, helping them better understand the public's concerns and responses to heat waves and develop strategies to protect vulnerable populations and mitigate the health impacts of extreme heat.

Limitations

This study has limitations, notably its focus on Twitter users, who may not represent the broader population due to unique demographics and interests. Bias may arise from selecting tweets based only on specific heatwave-related keywords and excluding non-English tweets, limiting the diversity of perspectives. Additionally, the inability to differentiate between personal and corporate accounts and to analyze tweets by demographics, like gender, due to Twitter's privacy policies also restricts the study. Lastly, the lack of precise tweet location data hampers regional analysis of heatwave discussions.

4. Conclusion

Our analysis of over 2 million tweets has unveiled significant insights into the public's reactions to heat waves. We have highlighted the prominent emotions expressed, with joy and anger standing out, suggesting humor and sarcasm as coping mechanisms during extreme heat. The study has also
identified significant health concerns related to heatwaves, such as heat-related illnesses and mental health issues, underlining the multifaceted impact of extreme heat on well-being. These findings have practical implications for public health awareness campaigns and early warning systems.

References

46. McClellan ED, Davis K. "Managing" Inaction and Public Disengagement with Climate Change:(Re) considering the Role of Climate Change Discourse in Compulsory Education. Javnost-The Public. 2023;30(3):356-76.
## Tables

**Table 1:** Tweets Statistical Distribution

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total tweet, N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall</strong></td>
<td>2,070,197 (100)</td>
</tr>
<tr>
<td><strong>User type</strong></td>
<td></td>
</tr>
<tr>
<td>Person</td>
<td>1,574,601 (76.06)</td>
</tr>
<tr>
<td>Organization</td>
<td>495,595 (24.04)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1,105,684 (70.22)</td>
</tr>
<tr>
<td>Female</td>
<td>468,917 (29.78)</td>
</tr>
<tr>
<td><strong>Age (years)</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;19</td>
<td>205,850 (13.07)</td>
</tr>
<tr>
<td>19-29</td>
<td>322,763 (20.49)</td>
</tr>
<tr>
<td>30-39</td>
<td>149,739 (9.51)</td>
</tr>
<tr>
<td>&gt;39</td>
<td>896,249 (56.93)</td>
</tr>
<tr>
<td><strong>Emotion</strong></td>
<td></td>
</tr>
<tr>
<td>Joy</td>
<td>611,164 (38.81)</td>
</tr>
<tr>
<td>Love</td>
<td>87,159 (5.54)</td>
</tr>
<tr>
<td>Sadness</td>
<td>166,152 (10.55)</td>
</tr>
<tr>
<td>Anger</td>
<td>521,417 (33.15)</td>
</tr>
<tr>
<td>Surprise</td>
<td>8,409 (0.53)</td>
</tr>
<tr>
<td>Fear</td>
<td>180,300 (11.45)</td>
</tr>
<tr>
<td><strong>Sentiment polarity</strong></td>
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</tr>
<tr>
<td>Overall (-1 to 1), mean (SD)</td>
<td>0.608 (0.4647)</td>
</tr>
<tr>
<td>Positive (&gt;0)</td>
<td>1,097,976 (53.04)</td>
</tr>
<tr>
<td>Negative (&lt;0)</td>
<td>972,221 (46.96)</td>
</tr>
</tbody>
</table>

**Table 2.** Themes emerging from the text analysis.

<table>
<thead>
<tr>
<th>Themes</th>
<th>Health issue category</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Health issues faced</strong></td>
<td>Heat exhaustion</td>
</tr>
<tr>
<td><strong>Heat-Related Illnesses</strong></td>
<td>Headaches</td>
</tr>
<tr>
<td></td>
<td>Nausea</td>
</tr>
<tr>
<td></td>
<td>Fainting</td>
</tr>
<tr>
<td></td>
<td>Heat edema</td>
</tr>
<tr>
<td></td>
<td>Hayfever</td>
</tr>
</tbody>
</table>
| **Heat Stroke** | Heatstroke  
Dehydration  
Heat cramps  
**Respiratory Issues** | Difficulty breathing  
Asthma exacerbations  
Respiratory distress  
**Cardiovascular Concerns** | Heart palpitations  
Perspiration  
Increased heart rate  
Hypertension  
Cardiovascular events  
**Organ Failure** | Kidney failure  
Lung issues  
Stomach pain  
**Skin and Hair Conditions** | Sunburn  
Heat rash  
Irritation  
Oversweating  
Hair problems  
Eczema  
Panic attack  
Stress  
**Mental Health and Wellbeing** | Anxiety  
Sleep issues  
Mental fatigue  
Mood changes  
Impact on infants  
Impact on the elderly  
Impact on pregnant individuals  
Impact on people with pre-existing conditions  
**Vulnerable Populations** | Medication immunization issues  
Chronic diseases  
Vulnerabilities in marginalized communities  
**Other** | Infections  
Food poisoning  
**Public Health Response** | Discussions about local government initiatives and public health advisories, Calls for action or awareness  
**Adaptation and Coping Strategies** | Sharing tips for staying cool, Discussing methods to stay hydrated and protect against heat  
**Preparedness and Emergency Response:** | Conversations about emergency services and response plans, Information on cooling centers and shelters  
**Media and Public Discourse:** | Analysis of how heatwave-related health issues are portrayed in the media, Public perceptions and misconceptions  
**Personal measures** | Personal effort to protect against effects of heatwave |
<table>
<thead>
<tr>
<th>Themes</th>
<th>Gender N(%)</th>
<th>User type N(%)</th>
<th>Age category N(%)</th>
</tr>
</thead>
<tbody>
<tr>
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Other Infections

Food poisoning

Measure to address health issues (preventative and corrective)

Public health response

Calls for action or awareness

Discussions about government initiatives

Public health advisories
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### Weather Hazard Watch
Informing of upcoming weather-related hazards and alerts

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### Economic Consequences of Heat-related Health Issues

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### Discussions about Work Productivity

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### Shaded Areas and Other Miscellaneous Measures

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**Figures**
Figure 1: Daily and monthly sentiments trend chart

Figure 2: Mean emotional distribution of heatwave-related tweets through time
Figure 3: Percentage Distribution of Heatwave Health Impact Categories

(a) Heat-Related Illnesses
- Heat edema: 0.155%
- Hayfever: 0.169%
- Heat cramps: 0.311%
- Nausea: 0.325%
- Fainting: 0.593%
- Headaches: 1.31%
- Dehydration: 4.51%
- Heat exhaustion: 8.19%

(b) Respiratory Issues
- Difficulty in breathing: 41.9%
- Asthma exacerbation: 26.6%
- Respiratory distress: 16.4%
- Stomach pain: 99.1%
- Kidney failure: 0.624%
- Lung issues: 0.283%
(c) Cardiovascular Concerns

(d) Organ Failure

(e) Skin and Hair Conditions

(f) Mental Health and Wellbeing

(g) Vulnerable Populations

(h) Other

(i) Discussions about Addressing Health-Related Issues

**Figure 4:** A Holistic View of Health Issues, Concerns, and Measures
Declaration of Interest Statement

No conflicts to report by the authors