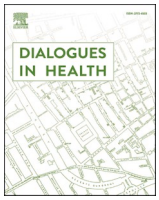
Dialogues in Health 4 (2024) 100177

Contents lists available at ScienceDirect

Dialogues in Health

journal homepage: www.elsevier.com/locate/dialog



Reducing consequences of extreme heat: The role of weather information access

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ARTICLE INFO

Keywords:
Weather information sources
Climate adaptation
Extreme heat events
Vulnerable groups
Vietnam

ABSTRACT

This study investigates the impact of weather information sources on consequences associated with extreme heat events, employing a cross-sectional survey conducted on hospitalized individuals who have experienced heat stress in Central Vietnam. Multiple information channels, including official agencies and social media, were found to significantly reduce the Cost of Illness (COI) associated with heat-related ailments. Social media, in particular, emerged as a potent tool for climate adaptation. Improving the clarity and accessibility of weather information through official channels is crucial, especially for households with varying income levels. Demographic factors such as age and gender should be considered when fine-tuning communication strategies, with special attention given to individuals with underlying medical conditions, who are particularly susceptible to extreme heat effects. These findings underscore the need to maximize the reach of weather-related information and reduce economic burdens on affected populations. This provides valuable insights for policymakers aiming to bolster climate resilience in vulnerable regions like Vietnam, emphasizing the significance of diverse information sources and tailored communication in climate change adaptation.

1. Introduction

Climate change has emerged as a global concern, as evident from the increasing impacts observed worldwide [1,2]. One important outcome of climate change is the increased frequency and severity of extreme heat events (EHEs), which pose significant challenges for vulnerable regions such as Vietnam [3,4]. It is crucial to understand how individuals and communities adapt to extreme heat as the world is confronting the consequences of global warming. This study examines a vital aspect of this issue: the influence of weather information sources on the development of adaptation strategies and their subsequent impacts on individuals, particularly in Vietnam. The Intergovernmental Panel on Climate Change (IPCC) [1] and Meehl and Tebaldi [5] highlighted the significance of this problem, emphasizing the need for further investigation.

The literature extensively discusses the phenomenon of EHEs, including the increasing frequency and severity of heatwaves worldwide, and their global impact [1,5]. Between 1998 and 2017, heatwaves led to over 166,000 deaths, with the 2003 European heatwave alone causing more than 70,000 fatalities [6]. A recent global study found a disproportionate increase in humid-heat extremes in densely populated regions, with an increasing magnitude and frequency [7]. Moreover, the existing literature has predominantly focused on analyzing individuals' choices of coping strategies during EHEs and the factors influencing these decisions. The body of research on coping strategies during EHEs underscores the multifaceted nature of individual responses and the diverse factors that shape these decisions. Studies have shown that adaptive coping strategies, such as seeking shade, hydration, and utilizing cooling centers, are crucial for managing the health risks associated with EHEs [8]. The selection of coping strategies for heat extremes is influenced by a variety of factors, including the socioeconomic and environmental characteristics of households, as well as local climate and vulnerability to heat [9]. Additionally, demographic and socioeconomic factors, along with individuals' physiological

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https://doi.org/10.1016/j.dialog.2024.100177
Received 29 January 2024; Received in revised form 1 April 2024; Accepted 11 April 2024
Available online 12 April 2024

conditions, significantly influence vulnerability to heatwaves [10,11]. However, only a limited number of studies have explored how individuals use weather information to shape their coping mechanisms. Interestingly, these studies primarily document the channels through which weather information is accessed, without delving into the subsequent health-related impacts of these choices on individuals [12]. This creates a notable gap in the literature that the current study seeks to address.

Adapting to extreme heat depends on timely and accurate weather information [12,13]. Reliable information enables proactive measures to reduce vulnerability and enhance resilience [14]. The choice of the weather information source is crucial to the success of these adaptation efforts. Previous studies have explored the role of various sources in influencing coping mechanisms in the face of extreme events [15,16]. Scientifically rigorous sources such as meteorological agencies and peer-reviewed publications are considered more trustworthy and accurate, whereas reliance on informal sources may lead to misinformation [17]. However, despite the availability of such information, studies have found that the public often lacks knowledge about their heat-health risks and the preventive actions they should take [18].

This study aims to bridge the existing gap by conducting a comprehensive analysis of the role played by weather information sources for hospitalized groups of heat-related illnesses in a cross-sectional survey within the Vietnamese context. This study contributes significantly to the existing body of knowledge by offering an improved understanding of the relationship between weather information sources in forming coping strategies and the associated economic burdens, specifically focusing on hospitalized groups experienced EHEs in Central Vietnam. In essence, the two-stage regression model used in this study offers a promising analytical approach for understanding the decision-making process regarding the access to weather information sources and their subsequent impact on economic outcomes – the economic burden associated with heat-related illnesses in our case. It enables us to go beyond mere correlations, establish causal relationships, and inform evidence-based interventions aimed at reducing the economic burden of those illnesses in changing weather. Furthermore, identifying the most impactful sources can guide targeted communication strategies and enhance the overall effectiveness of weather adaptation efforts [15,19,20]. The findings of this study are intended to guide policy decisions concerning weather resilience in Vietnam and formulate strategies and interventions that can effectively address the challenges brought about by weather changes [1,21,22]. Moreover, the insights derived from this research are expected to enhance our understanding of the role of weather information. This will contribute to global conversation regarding weather resilience and adaptation strategies, particularly in response to the escalating frequency of EHEs.

2. Data and methods

2.1. Data

The rising hospitalizations in Vietnam's Central Coast region underscore the escalating threat of heat-related illnesses amid shifting climatic conditions. Prolonged hot spells in this area significantly jeopardize public health, resulting in dehydration, exhaustion, and heat stroke owing to prolonged exposure to high temperatures. Projections indicate that rising temperatures will particularly impact central provinces, including Quang Binh, Thua Thien Hue, Binh Dinh, and Khanh Hoa. Recent years have witnessed a surge in extreme heat, with temperatures exceeding 37 °C and occasionally reaching 39 °C, 40 °C, or even higher. These severe conditions adversely affect the health, daily lives, and activities of residents of Central Vietnam.

To ensure a representative sample, we employed a stratified quota sampling method, considering variables like heat-related stress levels, geographic locations (Quang Binh, Thua Thien Hue, Binh Dinh, and Khanh Hoa), and socio-economic characteristics (gender, age, education, and income) within Central Vietnam (Fig. 1). Initially, hospital databases were accessed to identify potential participants for the study on heat-related illnesses and background diseases, focusing on specific ICD codes associated with heat-related conditions such as heat exhaustion, heat strokes, and heat cramps, as well as background diseases including heart disease, asthma, and respiratory diseases. Subsequently, participants were randomly selected from filtered hospital patient lists, and face-to-face interviews were conducted during the summer of 2022. Interview centers were set up in local hospitals across the four provinces, resulting in four interview hubs.

We interviewed 400 respondents who had experienced heat-related illnesses such as heat exhaustion, heat strokes, and heat cramps. We found significant proportions of respondents reported of having some symptoms related to heat-related illnesses (Appendix C). Eligible participants met specific criteria, including ownership of devices capable of accessing weather information (e.g. mobile phones) and having knowledge or experience related to relevant health issues. Only participants aged 18 years or older were included, and all participants provided informed consent before participating in the survey. Due to missing data on information access, we analyzed 366 valid questionnaires.

The escalating heatwaves exacerbated by weather change and effective coping strategies have become paramount for vulnerable communities in Vietnam. In the study area, we found diverse weather information sources, such as from official agencies, social media, and local authorities, which have been adopted to respond to heat-related stresses. In addition, a significant proportion of the population does not have access to these information channels, posing a barrier to effective heatwave preparedness and leaving communities exposed to preventable health risks. Official agencies such as the National Center for Hydro-meteorological Forecasting (NCHMF) and the Ministry of Health (MOH) play a critical role in providing authoritative forecasts, advisories, and educational materials. Their information carries inherent credibility and triggers large-scale interventions, such as heatwave action plans, public awareness campaigns, and resource mobilization. However, limitations, such as potentially limited local reach, bureaucratic inefficiencies, and lack of context specificity, can hinder the effectiveness of agency communication, especially for remote communities.

The rise of social media platforms, such as Facebook, Zalo, and online forums, presents a double-edged sword. While fostering rapid information sharing and community discussions, their inherent vulnerability to misinformation and malicious actors can amplify confusion and panic. However, their potential for real-time updates, peer-to-peer support, and localized coping strategies is undeniable. Fact-checking initiatives, empowering community voices, and promoting media literacy are crucial to harness the power of social media while ensuring its credibility to audiences. Finally, local authorities act as vital bridges between official pronouncements and community requirements. Their ability to translate advisories into local languages, mobilize resources such as cooling shelters and first-aid training, and facilitate two-way communication between agencies and communities is critical for effective preparedness and response. Building strong communication channels and empowering local authorities through capacity building are essential to strengthen community resilience. Further discussions on the characteristics of the weather information channels used in the study area, collected from focus group discussions, are presented in the Appendix A.

Secondary data gathered from various organizations were used to provide context to the study sites and to identify the study's target demographics. These secondary data include statistics on health-related illnesses at the provincial level, along with socio-economic data, population figures, and information on disasters and damages caused by heatwaves (e.g., heat records, frequency, and intensity).

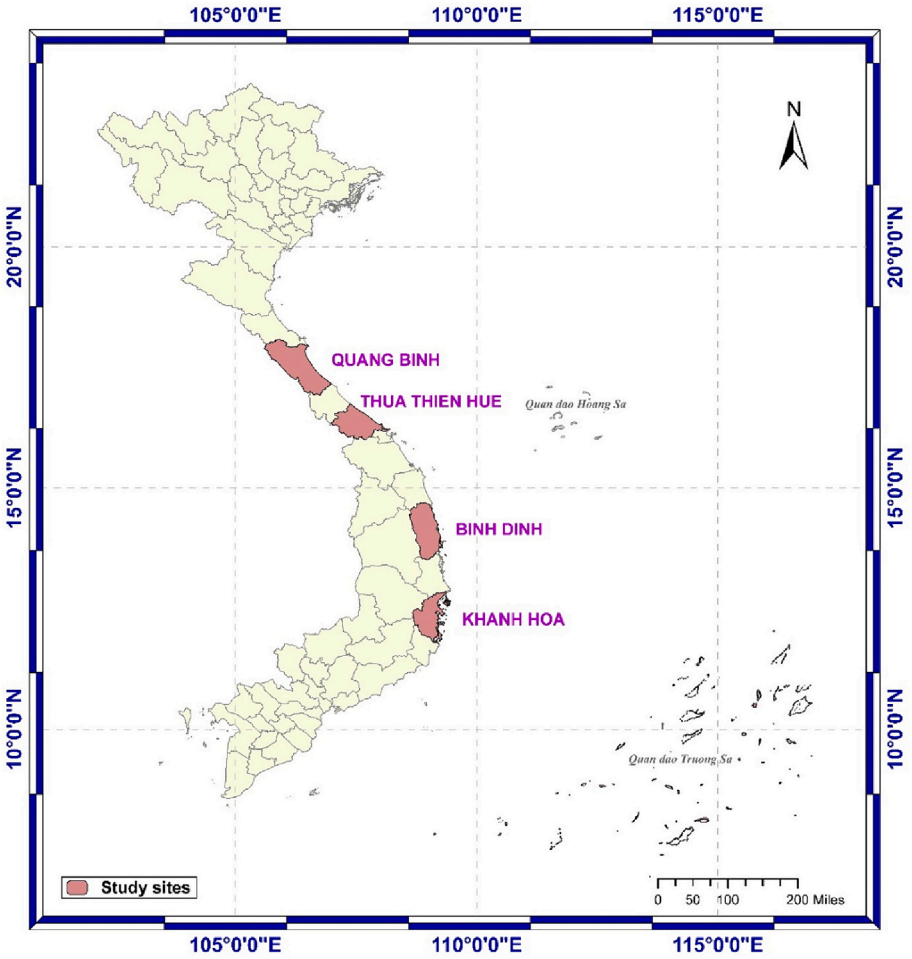

Fig. 1. The study sites in Central Vietnam.

2.2. Analytical methods

2.2.1. Nonparametric analysis

Nonparametric analysis can be used to visually illustrate the impact of weather information source access. Nonparametric tests are particularly useful when dealing with non-normally distributed data. In this study, we used Kernel Density Estimation (KDE) for non-parametric analysis. This is a way to estimate the probability density function of a random variable. In the context of access to weather information source, KDE could be used to visualize the distribution of access rates of weather information channels across different regions or groups in relation to their associated consequences measured by Cost of illness (COI). By combining KDE with statistical tests in the next step, we provide more robust analysis to understand the impact of access to weather information source. This approach enhanced the clarity and interpretability of the findings.

2.2.2. Econometric modeling

The Multinomial Endogenous Treatment Effects (METE) model represents a two-stage regression model that offers a powerful analytical framework for understanding the decision-making process regarding the choice of weather information sources and their subsequent impact on economic outcomes. The model could establish causal relationships and inform evidence-based interventions aimed at reducing the economic burden of heat-related illnesses in the study areas. This model is particularly valuable when studying contexts where treatment options are diverse and the assignment is influenced by unobservable factors [23]. The METE model incorporates a multinomial treatment structure, allowing researchers to simultaneously estimate the treatment effects across multiple categories. In the context of weather information sources, the METE model can help analyze how the selection of these sources (the treatment) affects individuals' impact of extreme heat (the outcome). Evidence-based interventions are crucial for the treatment of heat-related illnesses. For instance, if the model reveals that access to certain types of weather information significantly reduces the economic burden of heat-related illnesses, interventions could focus on improving access to these information sources. In the context of a cross-sectional survey, addressing endogeneity and potential selection biases is crucial for ensuring the validity and reliability of the study findings. Endogeneity issue refers to the potential correlation between the independent variables (such as choice of weather information sources) and the error term in the regression model, which can lead to biased estimates of the relationships of interest. Selection biases occur when the sample is not representative of the population due to non-random selection processes, leading to distorted conclusions. To address endogeneity and potential selection biases in a cross-sectional survey, several strategies can be employed, including the two-stage regression approach. By employing this approach, the first stage of the model explores factors influencing individuals' choices of weather information sources while considering endogeneity and potential selection biases. In the second stage, the treatment effects of these choices on the economic burden of heat-related illness were estimated, providing insights into the direct and indirect pathways through which weather information affects economic outcomes.

First stage: Factors influencing choices of weather information sources

The first stage involved identifying the factors influencing in-

dividuals' decisions regarding weather information sources. The first-stage equation for the choice of weather information sources can be represented as:

$$Choice_{ji} = \alpha + X_{ji}\beta + \varepsilon_i = \begin{cases} 1 \text{ if } Choice^*_{ji} > \left(Y^*_{mi}\right) \text{ with } m\#1\ldots \\ j \text{ if } Choice^*_{ji} > \left(Y^*_{mi}\right) \text{ with } m\#j \end{cases} \text{ for all } m\#j \quad (1)$$

where $Choice_{ji}$ is a categorical variable representing the chosen weather information source j (official agencies, social media, local authorities, and non-access) of respondent i; α is the intercept term; β is a vector of coefficients reflecting the impact of independent variables of interest X on the choice of weather information sources; and ε_i is the error term capturing unobservable factors affecting the choice. As utility is unobservable, the model assumes that the observed choice m reflects the choice with the highest utility for individuals. In this stage, the Inverse Mill Ratios (IMRs) were calculated using $IMR = \phi(F(X'\beta))/\Phi(F(X'\beta))$, where ϕ (probability density function) and Φ (cumulative distribution function), and were added to Stage-2 to prevent biased estimation from sample selection bias.

In the context of modeling the choice of weather information sources, it is crucial to consider a range of variables that capture individual and household characteristics, exposure to heat stress, individual health conditions, and awareness of weather predictions. A literature review indicates that these variables play a significant role in shaping how individuals and households seek weather-related information and make decisions to adapt to changing environmental conditions. Demographic factors such as age, gender, income, and education have been widely recognized as influential determinants of information-seeking behavior [24,25]. Exposure to heat stress, which is often measured through contact with heatwave events, can influence an individual's motivation to access weather information sources. Moreover, individual health conditions including chronic illnesses and allergies may lead to increased sensitivity to weather-related health risks [26]. Finally, awareness of weather predictions and the perceived accuracy of forecasts can significantly affect an individual's reliance on specific sources of weather information. Thus, we use the variables identified through an extensive literature review to construct our choice model for weather information sources.

Second stage: Treatment Effects on the Economic Burden of Heat-Related Illness conditional on the choices made by individuals

The second stage of the METE model involves estimating the treatment effects of the choice of weather information sources on the economic burden associated with heat-related illnesses. We used COI approach to measure economic impact associated with heat stress. COI refers to the economic value of resources spent or lost due to a health issue, including direct health-related expenses (direct costs), the economic impact of reduced productivity of patients (indirect costs), and the value assigned to pain and suffering (intangible costs) [27]. This stage allowed us to quantify the economic consequences of specific information choices, accounting for potential endogeneity in the treatment assignment. The second-stage equation involves estimating the outcome equation of the economic burden (Y_i) associated with the chosen weather information source as follows:

$$\begin{cases} Regime\ 1: Y_{1i} = X'_{1i}\beta_1 + \hat{IMR}_{ji}\ \lambda_1 + \varepsilon_{1i} \text{ if } Y=1\ldots\ldots \\ Regime\ j: Y_{ji} = X'_{ji}\beta_j + \hat{IMR}_{ji}\ \lambda_j + e_{ji} \text{ if } Y=j \end{cases} j = 1,2,3,4 \quad (2)$$

where Y_{ji} is the outcome variable COI in log form of the i^{th} respondent in regime j. This two-stage regression model allowed us to examine the influence of individual characteristics on the choice of weather information sources in the first stage and subsequently estimate the treatment effects of these choices on the economic burden of heat-related illness in the second stage.

To calculate the Average Treatment Effect on the Treated (ATT) using the Multinomial Endogenous Switching Regression (MESR) model, we use Eq. (3). Understanding the ATT for various weather information sources can guide policymakers in identifying the most effective strategies for disseminating information and reducing the economic impact of heat-related illnesses. It helps in pinpointing which sources of information are most beneficial, or conversely, which may be less effective or even detrimental in terms of economic burden. These insights are essential for informing targeted public health interventions and adapting to weather changes.

$$\begin{aligned} ATT &= E\left(Y_{ji}|Y = \mathrm{j}, \mathrm{X}, \widehat{IMR}\right) - E(Y_{1i}|Y = 1, \mathrm{X}, \widehat{IMR}) \\ &= X_{ji}'\left(\beta_j - \beta_1\right) + \widehat{IMR}_{\mathrm{ji}}\left(\lambda_{\mathrm{j}} - \lambda_1\right) \end{aligned} \quad (3)$$

where: $E\left(Y_{ji}|Y = j, X, \widehat{IMR}\right)$ and $E(Y_{1i}|Y = 1, X, \widehat{IMR})$ are the expected values of the economic burden for the ith individual, given that they have chosen the jth and baseline weather information sources, respectively.

3. Empirical results and discussions

3.1. Results of descriptive analysis

In the face of escalating heatwaves exacerbated by weather changes in the study area, we found diverse weather information sources, such as from official agencies, social media, and local authorities that have been used to response to heat-related stresses. Fig. 2 presents the percentages of respondents from four study sites in Vietnam - Binh Dinh, Khanh Hoa, Thua Thien Hue, and Quang Binh - who use different sources of weather information concerning heatwaves.

For official agencies, reliance on agencies such as NCHMF or MOH as a source of weather information is the second-highest across survey areas. Quang Binh has the lowest percentage at 14.4%, while Binh Dinh has the highest at 17.6%. This indicates a moderate level of trust in and utilization of information from official agencies, such as meteorological or weather forecast departments. For social media, these platforms are the least used sources of weather information in Khanh Hoa, Thua Thien Hue, and Quang Binh, with percentages ranging from 8.3% to 11.7%. Binh Dinh has a slightly higher usage at 13.6%. Moderate engagement with social media for weather information could be due to either a lack of access, preference for more traditional information sources, or concerns about the accuracy of information on these platforms. Information from local authorities was variably used, with the highest percentage in Thua Thien Hue (16.7%) and the lowest in Khanh Hoa (9.9%). This variation might reflect the differing levels of activity and communication effectiveness of the local authorities in these regions. Importantly, a significant majority of respondents in all four study sites did not access any sources of weather information about heatwaves. The percentage was the highest in Khanh Hoa (65.8%) and lowest in Binh Dinh (57.4%).

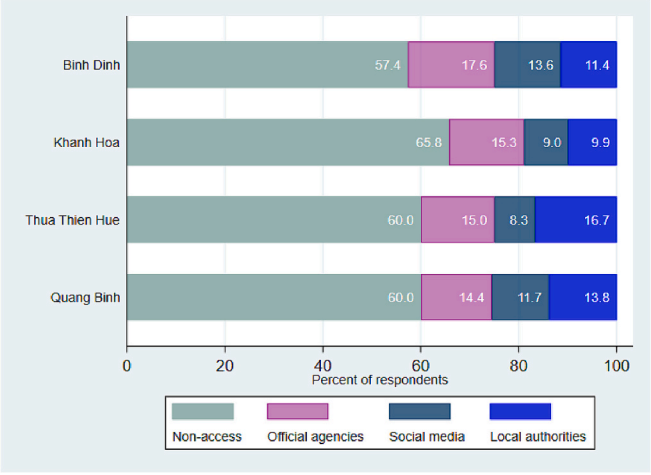

Fig. 2. Percentages of respondents access to different sources of weather information.

This suggests that a substantial proportion of the population may be underinformed about heatwave risks and preparedness, which may have serious implications for public health and safety. Further discussions related to other variables used in the study are presented in Appendix B.

3.2. Results of nonparametric analysis

Fig. 3 shows a Kernel Density Estimation (KDE) plot, which is a non-parametric technique for estimating the probability density function of the outcome variable. Here, we utilized the KDE plot to visualize the economic burden of heat-related illness (log) across different categories of weather information sources: Official agencies, social media, and local authorities, in relation to the base scenario of non-access to any of the aforementioned channels. Notably, for the channels of official agencies and local authorities, similar patterns emerged in the KDE plot, suggesting that the economic burden of heat-related illness tends to be slightly reduced for those adopting weather information from agencies or local authorities compared to non-adopters.

However, graphically, the comparison between access and non-access to social media lacks clarity and requires further rigorous analysis. Despite this, it appears that the economic burden for social media access is less variable than that for non-access, as indicated by the narrower width of the social media plot. It is crucial to emphasize that these initial observations are based on the KDE plot, and the actual values may exhibit variations. Therefore, rigorous methods are strongly recommended for validating and confirming these findings.

3.3. Results of multinomial endogenous treatment effects model

3.3.1. Factors affecting choices of weather information sources

The first-stage results of the MESR model provided a detailed examination of the determinants influencing the access to weather information to response to heat-related stresses (Table 1). Higher household income is consistently associated with an increased likelihood of adopting all forms of weather information sources. These findings are in line with economic theories that suggest that income level influences information-seeking behavior and resource allocation for health-related adaptive measures [28].

The main characteristics of respondents indicate that there is a positive and statistically significant correlation between individuals' age and their preference for official weather agencies and local authorities. This finding supports the idea that older populations tend to rely more on those two traditional sources of information. In other words, as individuals get older, they are more likely to use official agencies and local authorities as their sources for weather-related information. This observation aligns with a common trend where older individuals may have developed habits and preferences for traditional sources of information, such as official weather agencies and local authorities, while younger generations may be more inclined to use social media and digital platforms for accessing weather information [29]. Gender differences significantly affect the likelihood of using social media as a source of weather information. Being a male appears to have a higher likelihood of utilizing weather information sources from local authorities, social media or official agencies. This finding supports research indicating gender-specific preferences in information channels, particularly where social media usage is concerned [30]. Surprisingly, an inverse relationship between education level and the use of official agencies may suggest that more educated individuals prefer direct information sources, while a positive relationship with local authorities could indicate trust in community-level dissemination [31]. Larger households show a significant preference for official agencies. This could be because of the collective need for validated information to protect multiple members [32].

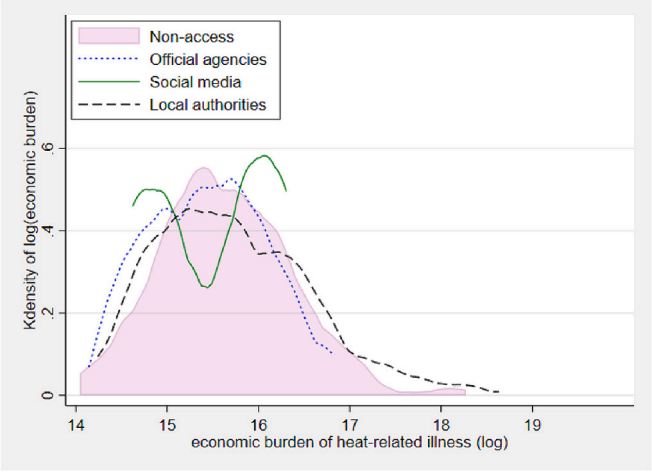

Fig. 3. Unconditional log(COI) kernel density distributions.

The presence of underlying medical conditions increases the propensity to use official agencies and local authorities, highlighting heightened awareness and the need for reliable information among vulnerable populations [33]. Awareness of weather predictions has a strong positive effect on the choice of all the information sources. This may reflect active engagement with weather issues and pursuit of detailed meteorological insights. The level of exposure to heat has a differential impact, decreasing reliance on official agencies but increasing reliance on local authorities. This could indicate a preference for localized and actionable information when directly faced with heat risk.

These results shed light on the multifaceted factors that guide the choice of weather information sources for the Vietnamese population in the context of heat-related health risks. The significant role of access to weather predictions across all sources underscores the importance of broadening the access to meteorological information services. Additionally, the varying influence of demographic factors such as age and gender on information source preference calls for tailored communication strategies. The findings from this first-stage MESR analysis emphasize the need for policy interventions that consider these determinants to enhance the effectiveness of weather information dissemination and improve public health outcomes.

3.3.2. Factors affecting COI conditional on weather information sources accessed

Table 2 outlines the second-stage Multinomial Endogenous Switching Regression (MESR) estimation results, detailing how factors influence the COI of heat-related illness based on the choice of weather information sources. The age-related variations in economic burdens align with literature suggesting that older individuals may face heightened health risks during EHEs [34]. The increased economic burden for older individuals relying on specific information sources underscores the vulnerability of this demographic group. Interventions should consider age-specific communication strategies and healthcare support to address the unique challenges faced by older populations during EHEs [34].

Gender differences observed in the economic burdens associated with different weather information sources resonate with studies highlighting the gendered nature of climate impacts [35,36]. The decrease in economic burden for females accessing information from social media and local authorities underscores the importance of recognizing gender-specific vulnerabilities and preferences in the design of climate adaptation policies [35].

The inverse relationship between education level and economic burden for those accessing weather information aligns with research emphasizing the role of education in enhancing adaptive capacity and decision-making during weather events [4,37]. Higher education may contribute to better risk perception and adaptive behaviors, highlighting the potential of educational interventions to reduce the economic

Table 1
Factors associated with the choice of weather information sources: First-stage MESR model.

Variables	Official agencies		Social media		Local authorities	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Household income	0.327***	0.029	0.402***	0.052	0.248***	0.032
Age	0.046***	0.013	−0.022**	0.009	0.012***	0.002
Gender	0.024	0.301	0.68***	0.19	0.08	0.141
Education level	−0.267**	0.125	0.003	0.141	0.369***	0.092
Household size	0.388***	0.03	0.037	0.044	−0.092	0.069
Underlying medical conditions	0.589***	0.076	0.077	0.181	0.536***	0.207
Awareness of weather predictions	1.15***	0.048	1.44***	0.262	0.593***	0.037
Level of exposure to heat	−0.702***	0.145	−0.005	0.084	0.399***	0.141
Constant	−9.20***	1.16	−10.98***	1.64	−6.09***	0.724

*Note: Estimated by STATA user-written command selmlog [42]; Base outcome is j = 0; *, **, *** significant at the 10%, 5% and 1% levels.*

Table 2
Determinants of COI by weather information sources accessed: Second-stage MESR estimation.

Variables	Non-access		Official agencies		Social media		Local authorities	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Age	−0.009	0.008	−0.004	0.019	0.063**	0.029	0.012***	0.003
Gender	0.181	0.119	0.579*	0.300	1.781*	1.021	0.185**	0.078
Education level	0.092	0.132	−0.763**	0.299	−1.913**	0.900	0.117	0.083
Household size	0.083*	0.045	−0.406*	0.213	−0.718*	0.429	−0.041	0.070
Underlying medical conditions	0.041	0.118	−0.600*	0.368	−1.554*	0.955	−0.157*	0.111
Coping strategies	−0.734***	0.154	0.886***	0.179	−0.228	0.192	0.719***	0.260
Awareness of weather predictions	−0.038	0.110	−0.137	0.347	1.140	0.944	0.124	0.128
Level of exposure to heat	0.105	0.179	−0.860	0.588	1.923**	0.769	0.140*	0.076
Constant	16.13***	0.600	17.38***	3.517	5.310	6.294	13.0***	1.293
Sigma2	1.131	1.945	58.8	75.9	205.4*	121.0	0.886	1.678
rho1	−0.113	0.589	0.488***	0.106	0.513**	0.222	−0.726*	0.434
rho2	−0.717	0.442	0.650***	0.152	0.469**	0.241	−0.336	0.460
rho3	0.726	0.614	−1.186***	0.026	−1.170***	0.107	0.715	0.791

*Note: Estimated by STATA user-written command selmlog [42]; *, **, *** significant at the 10%, 5% and 1% levels.*

burden associated with heat-related illnesses [37].

Underlying medical conditions significantly influence the economic burden of those accessing weather information, which is consistent with research highlighting the elevated health risks for individuals with pre-existing conditions during EHEs [38,39]. This underscores the importance of targeted healthcare support for vulnerable populations, particularly those that do not utilize weather information sources. The relationship between exposure to heat and the economic burden reveals nuances in the decision-making process. Individuals with higher level of exposure may be associated with a greater economic burden of heat illness. This finding resonates with literature emphasizing the importance of reducing exposure and vulnerabilities to heat stress [40,41].

The second-stage METE estimation provides valuable insights that complement and extend existing literature on climate change adaptation and vulnerability. The nuanced relationships uncovered between socio-demographic factors, weather information sources, and economic burdens contribute to the development of targeted interventions and policies aimed at enhancing resilience to EHEs.

3.3.3. Treatment effect for the impact of access to weather information on COI

This table presents the Multinomial Endogenous Switching Regression (MESR)-based unconditional average treatment effects (ATT) of accessing different weather information sources on the COI. ATT is calculated as the difference in outcomes between those who access information (j = 2,3,4) and those who do not (j = 1) (Table 3).

For all three sources of weather information (official agencies, social media, and local authorities), ATT is negative and statistically significant at the 1% level, indicating that access to these sources reduces COI. In details, it was observed that individuals who had access to weather information disseminated by official governmental agencies experienced a notable decrease of 10.2% in the COI associated with heat-related ailments. Conversely, the availability of weather-related information through social media platforms yielded a more substantial reduction in COI, amounting to 19.9%. Similarly, the provision of weather information by local authorities was linked to a noteworthy 12.8% reduction in the COI pertaining to such illnesses. These findings suggest that access to weather information sources can significantly reduce the economic burden of illness, underscoring the importance of disseminating such information to the public. This aligns with previous research emphasizing the role of information access in enhancing adaptive capacity and decision making during extreme weather events [4,37].

Table 3
MESR-based unconditional average treatment effects of access to weather information sources on COI (log).

Weather information sources	Access status to information sources			Outcome change
	Access (j = 2,3,4) (a)	Non-access (j = 1) (b)	ATT (c) = (a)-(b)	(%)
Official agencies	15.455	15.563	−0.107***	−10.2
Social media	15.485	15.707	−0.223***	−19.9
Local authorities	15.646	15.784	−0.139***	−12.8

*Note: Estimated by STATA user-written command selmlog [42]; t-test to compare means between groups; *, **, *** significant at the 10%, 5% and 1% levels; Outcome variables are in* log *form.*

However, the varying effects across different sources highlight the need for a nuanced approach to disseminating information. For instance, the larger reduction in COI associated with social media access may reflect its wider reach, immediate feedback, and increasing reliance on digital platforms for information access. This suggests that leveraging social media could be an effective strategy for climate change

adaptation. On the other hand, the relatively smaller reduction associated with official agencies might indicate barriers to accessing or understanding official weather information. This underscores the need to improve accessibility and comprehensibility of information from official sources [40]. Overall, these findings contribute to the literature on climate change adaptation and vulnerability by providing empirical evidence on the economic benefits of weather information access. They also offer valuable insights for policymakers in designing targeted interventions and policies to enhance resilience to weather events.

4. Conclusion and recommendations

This study explored a crucial aspect of this issue: the influence of weather information sources on the development of adaptation strategies and their subsequent impact on individuals, notably in the context of Vietnam. The findings from the study suggest that access to weather information from multiple sources, including official agencies, social media, and local authorities, has a significant impact on reducing the COI associated with heat-related ailments. A negative and statistically significant treatment effect at the 1% level of significance indicates this reduction. These variations underscore the importance of leveraging different information dissemination channels to enhance adaptive capacity and decision-making during extreme weather events. Particularly, the effectiveness of social media suggests its potential as a crucial tool in climate change adaptation strategies, highlighting the need for tailored approaches to maximize the reach and impact of weather-related information. These insights are invaluable for policymakers aiming to design interventions that bolster resilience to extreme weather events and reduce their economic burden on affected populations. Special attention should be given to how age and gender influence the perception and impact of EHEs, thereby fine-tuning the communication to be as effective as possible. Individuals with underlying medical conditions should be at the forefront of weather information campaigns, as they are particularly susceptible to the adverse effects of extreme heat.

To build upon these interventions, future research should focus on examining the longitudinal effects of access to weather information sources on the economic and health outcomes associated with EHEs. This study's limitations primarily revolve around its singular focus on Vietnam and the potential challenges of generalizing its findings to other regions with differing socio-cultural, economic, and geographical contexts. Additionally, while the study proposes the potential effectiveness of tailored communication strategies, it does not implement or assess specific interventions, indicating the importance of conducting pilot intervention programs for real-world evaluation. Future research could consider to investigate other factors, such as cultural influences, beliefs regarding the utilization of weather information sources, and the impact of diverse geographical locations in the choice of various weather information means to mitigate health risk associated with heat stress. Confronting the challenges posed by EHEs in the era of climate change demands a multi-pronged approach. This approach should not only enhance the dissemination and reliability of weather information but also tailor communication strategies to the specific needs of diverse demographic groups. These efforts will contribute significantly to enhancing weather and climate resilience and public health strategies in Vietnam and beyond.

Declaration of generative AI in scientific writing

No artificial intelligence was used to prepare this work.

Ethical approvals

The work received approval from the Human Research Ethics Committee of Hue College of Medicine and Pharmacy (Vietnam) and Queensland University of Technology Research Ethics Committee (Approval number: H2021/016).

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

CRediT authorship contribution statement

Nguyen Duc Kien: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nguyen H.D. My:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Dang Thi Anh Thu:** Formal analysis, Data curation, Conceptualization. **Thai Khanh Phong:** Writing – original draft, Formal analysis, Conceptualization. **Tran H.B. Chau:** Writing – review & editing. **Phung Tri Dung:** Writing – original draft, Visualization, Validation, Supervision, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Dataset is available upon reasonable request.

Acknowledgements

This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 502.99–2020.36.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dialog.2024.100177.

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