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Valuation of a Heatwave Early Warning System for Mitigating Risks Associated with Heat-Related Illness in Central Vietnam

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Abstract: Heatwaves are increasingly recognized as a severe natural hazard that pose substantial threats to human wellbeing and sustainability with physical, mental, and economic impacts. Heatwave Early Warning Systems (HEWSs) have emerged as a promising solution to mitigate these adverse impacts. This study aims to valuate a Short Message Service (SMS)-based early warning system specifically targeting heat-vulnerable populations and their determinants in central Vietnam, an area prone to heat-related illnesses. By employing the contingent valuation method, individuals' willingness to pay (WTP) for the warning system and the determinants of the WTP were assessed. The findings showed an average WTP of VND 283,110 (~USD 11) per person per year, according to the parametric estimate. The total WTP for the affected population in central Vietnam reached VND 857,283,678,000 or USD 37,273,203 per year, assuming that 50% of the heat-vulnerable population contributes to HEWSs financially. Significant determinants of WTP were identified, including bid levels, cost of heat-related illnesses, background diseases, and exposure to heat. Policymakers and health authorities can utilize these findings to develop effective adaptation strategies for preventing and mitigating heat-related illnesses, while also promoting sustainable development in central Vietnam.

Keywords: heatwave early warning systems; contingent valuation method; willingness to pay; vulnerable populations; central Vietnam

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1. Introduction

Heatwaves are widely recognized globally as a devastating natural hazard, posing significant threats to human wellbeing, encompassing physical, mental, and economic consequences [1]. Heatwaves are defined as extended periods lasting three or more consecutive days, during which average temperatures exceed the 95th percentile value of local temperatures [2]. The anticipated effects of climate change on heat stress conditions are expected to result in increased mortality rates and diminished labor productivity, particularly among vulnerable populations [3–5]. These impacts often remain unnoticed initially, because of their delayed and inconspicuous nature. In 2019, extreme heat was responsible for 356,000 of 1.69 million deaths worldwide [6]. This highlights the global impact of

heat-related illnesses on human health, and the need for the prevention and mitigation of heatwaves.

Vietnam has incurred substantial economic costs due to mortality resulting from heatwaves, reaching USD 11.72 billion (i.e., 34,271 deaths at the value of statistical life of USD 0.342 million) from 2003 to 2017 [7]. Over the past four decades, Vietnam has witnessed a notable climate shift characterized by a significant temperature increase [4,8]. Among the regions within Vietnam, the southeast, central highlands, and south-central coast areas are particularly susceptible to the impact of heatwaves [2,9]. Addressing the detrimental effects of heatwaves and developing effective adaptation strategies are indeed crucial for Vietnam's sustainable development, especially in the context of increasing ambient temperature due to climate change [4].

Among a range of strategies to mitigate the adverse impacts of heatwaves, heatwave early warning systems (HEWSs) have gained significant attention as promising tools [10,11]. In this study, HEWSs refer to an approach aimed at minimizing the health risks posed by heatwaves. HEWSs comprise several essential components: forecasting the occurrence and severity of heatwave events, predicting potential health outcomes, and triggering timely notifications to inform individuals, especially vulnerable populations, about heatwaves. Additionally, the systems involve communicating preventive measures, as well as evaluating and revising their effectiveness [1]. Such systems offer several potential benefits, including the reduction of disease burden, enhancement of community resilience, and reduction of economic consequences by providing timely alerts and targeted information [12,13]. HEWSs are widely recognized as cost-effective measures to enhance community preparedness in response to extreme heat events, particularly in developed countries where advanced infrastructure and institutional capacity support timely warnings and coordinated response efforts [14,15]. While the focus of these systems has predominantly been on developed countries, there is growing recognition of their importance in vulnerable regions, including in developing countries such as Vietnam, where the climate is associated with frequent extreme heat events.

Efforts to assess the willingness to pay (WTP) for interventions aimed at mitigating health risks have undergone significant development over time. Stated preference methods have emerged as effective tools for valuing health risk reductions and safety improvements [13]. However, there are few studies examining the effectiveness and advantages of Early Warning Systems (EWSs) in managing heat-related stress. While progress has been made in assessing community preparedness and response to heatwaves, including the efficacy of heat warning systems [15], addressing tailored HEWSs for local conditions and population vulnerability [16], and adopting integrated approaches for effective warning systems [17], there remain research gaps that warrant further investigation. Notably, there is a limited number of studies focusing on vulnerable populations, and the valuation of health risk reduction using the WTP approach for heat-related stress is understudied, particularly in developing countries like Vietnam. Using the WTP approach to assess the HEWS's value offers valuable insights, especially for protecting vulnerable populations from heat-related risks and shaping policies to mitigate these threats. Moreover, the existing EWSs in Vietnam lack provisions for heat-related risks, emphasizing the need for a dedicated HEWS to enhance preparedness for extreme heat events [18].

This study aimed to assess the economic value of an SMS-based early warning system for mitigating heat-related illnesses in Vietnam. We fill a research gap by making three significant contributions to the existing literature: First, it is the first study to assess the economic value of an SMS-based early warning system tailored to mitigating heat-related illnesses in Vietnam. Vietnam is extremely vulnerable to climate change and extreme weather, making it particularly important to evaluate measures that reduce the health risks and economic costs related to heatwaves. Second, the existing literature on the valuation of health risk reduction and prevention measures, specifically targeting vulnerable groups, is relatively limited. This study enriches the knowledge in this field by proposing an EWS specifically designed for populations susceptible to heat-related illnesses, namely

hospitalized patients experiencing heat exhaustion, heat strokes, and heat cramps. Third, this study distinguishes itself by incorporating the cost of illness approach when valuing EWS. By considering the economic costs associated with heat-related illnesses, this study offers a comprehensive understanding of the factors influencing individuals' preferences and choices concerning an EWS dedicated to heat-affected populations. As climate change continues to intensify, resulting in more frequent and severe heatwaves that pose a growing threat to human health [14], it becomes imperative to explore the potential benefits of the HEWS. Therefore, valuing HEWS deserves attention when tackling the effects of heatwaves, promoting climate change resilience and the various dimensions of sustainability.

2. Materials and Methods

2.1. Research Framework

The Contingent Valuation Method (CVM) is used in this study to evaluate the WTP for a HEWS in Central Vietnam. The stated preferences method, which includes Contingent Valuation (CV) and Discrete Choice Experiments (DCEs), has been widely used to assess the value of measures aimed at health risk reduction [12,13,19–22]. CV has proven to be a beneficial tool for examining the provision of protective measures to mitigate the impact of heatwaves [22].

The burden of diseases caused by heatwaves may often be underestimated in current practices owing to the prevalence of self-prescription and alternative healing methods. Vulnerable populations susceptible to heat-related illnesses encompass various groups, including individuals living in poverty, the elderly, hospitalized groups, those who are socially isolated or afflicted by chronic diseases, as well as children, and women [14,23]. Additionally, certain groups, such as urban residents lacking access to air conditioning and individuals who have previously experienced heatwaves, warrant heightened attention [22]. Therefore, it is advisable to investigate the WTP for EWS for particular groups, such as populations susceptible to heat-related illnesses [12].

Based on the literature reviewed above [12,14,20–22], a conceptual framework is proposed to assess the WTP (or decision to pay) for an EWS to mitigate the risk associated with heat-related illnesses (Figure 1).

By employing the "cost-of-illness" framework [24], it is possible to estimate the potential expenses linked to the mitigation of heatwave repercussions. These expenses encompass various elements, such as direct medical costs (e.g., emergency department or clinic visits, medical fees, treatment expenses, hospitalization), indirect costs (e.g., productivity loss, work-related costs), and intangible aspects [14] which were characterized by the elements on the left-hand side of the Figure 1. A conjecture arises that there exists a positive correlation between the costs associated with heat-related stress and individuals' willingness to allocate funds to EWS, aimed at reducing health risks. Furthermore, an individual's relationship with risks can be influenced by various factors, such as pre-existing medical conditions [12], personal experience with heat-related illnesses, or exposure to heat [20,22,25]. Zhang et al. [22] found that individuals who had previously experienced a heatwave expressed a WTP that was 1.73 times higher than those who had not encountered such events. Similarly, individuals with comorbidities, such as non-communicable diseases (NCDs), exhibited a WTP that was 1.55 times greater than individuals without such conditions [22]. Consequently, individuals who are more prone to or have a history of vulnerability to diseases tend to exhibit a greater WTP [20,25].

These factors can potentially affect an individual's WTP for an EWS aimed at mitigating the risks associated with heat-related illness. Additionally, the perceived risks associated with heat-related illnesses [12,13,26,27] or individual anxiety [28,29] and awareness/knowledge [25,30] may impact WTP. Several factors related to perceived risks may impact WTP. For instance, if an individual considers the risk to be unacceptable or perceives a higher level of risk [26], expresses significant concern about the issue [27], or feels uncertain about potential outcomes [28]. Himmler et al. [12] discovered that a greater perception of health risks (i.e., risk aversion) is positively associated with the WTP for an

EWS for infectious diseases. Individuals who perceive a higher level of risk than objectively exists tend to assign greater value to safety and risk reduction [13]. Similarly, individuals with higher perceived risk have reported a higher WTP [26,29]. Also, the adoption of certain coping strategies such as air conditioners [22], or fans [31] may influence the awareness of the risks associated with heatwaves and thus the WTP for preventive measures against heatwaves. Regarding socio-economic characteristics, some key covariates such as income [12,26,28–30,32,33], education [12,20,26,27,30,33,34], age [7,20,21,29,30,34–36], and gender [22,29,32,33,35] play a critical role in comprehending individuals' WTP for heat-related illnesses.

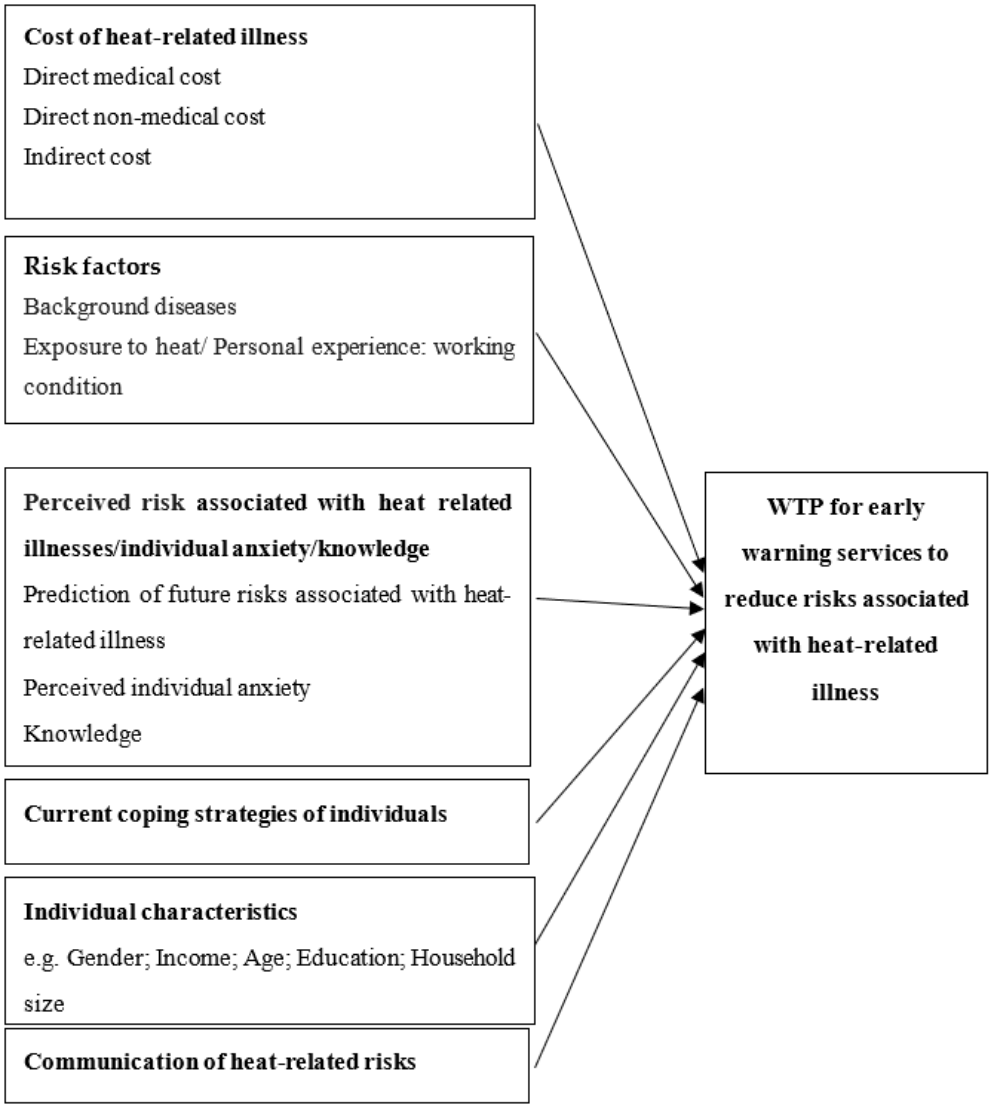

Figure 1. Conceptual framework of factors affecting the WTP for early warning services to mitigate risks associated with heat-related illness.

A reliable and accessible information channel is vital to effectively mitigate heat health risks. Key requirements for potential communication channels include availability, accessibility, convenience, credibility, relevance, and coverage [37,38]. Channels that enable tailored messages based on location, individual preferences, and specific user needs can add value to the service, thereby increasing their WTP. It was found that the dissemination of information via mobile phones can assist in timely decision making [39].

2.2. Estimation of the WTP for Heatwave Early Warning Services

We applied probit regression to estimate the participants' WTP. The dependent variable refers to the probability that participants say "yes" or "no" to a given bid level t_j. Based on the literature review, several explanatory variables, including the bid levels, perceptions, and socioeconomic characteristics of the respondents, were included in the models.

$$Pr\left(yes_j\right) = \Phi(\beta_0 + \beta_1 t_j + \beta_j X_i\Big) \quad (1)$$

based on [40]. $\Phi(\cdot)$ denotes the cumulative normal distribution. Using the estimated parameters, the mean WTP is obtained as:

$$\text{WTP} = -\left[\frac{\beta_0 + \sum \beta_j X_i}{\beta_1}\right] \quad (2)$$

based on [36]. Where β_0 and β_1 are the coefficients to be estimated. β_j refer to the coefficients of the other variables X_i with their corresponding sample mean values.

The CVM results could be validated using an equation in which the probability of answering "yes" to the WTP for the development of the HEWS to reduce health risks brought on by heat in the study area is the dependent variable. The explanatory variables include cost of illness items, bid levels, individual relationship with risk characteristics, perceived risk associated with heat-related illnesses items, current adaptation/coping strategies of individuals, individual socio-economic characteristics, and communication of heat-related risks.

WTP was estimated using Equation (2). The 95% confidence intervals were obtained adhering to the bootstrap methodology following Krinsky and Robb [41]. Data were analyzed using STATA 15.0 (Stata Corp. 2018. Stata Statistical Software: Release 15. College Station, TX, United States of America (USA): Stata Corp LP) and SPSS 26.0 (SPSS Inc., Chicago, IL, USA). An explanation of the variables used in the study is presented in Appendix A—Table A1. The final column in Table A1 shows the expected signs of the coefficients. We also used cost-of-illness (COI) approach for estimating the economic implications of diseases, encompassing both direct and indirect costs [24].

2.3. Study Area

The central Vietnam region consists of 14 provinces, covering about 28.9% of the country's total area and accounting for about 20.8% of the nation's population [42]. In this study, we selected four central provinces (Figure 2) as representatives of the climate zones found in the north and south–central Coast regions. The selection of these provinces for the assessment of measures against temperature-health risks in central Vietnam was based on key factors such as rapid urbanization, high population density, and the ongoing impacts of heat threats and climate change.

Heat-related illnesses have become a growing concern in the central region, leading to an increase in hospitalizations [43]. The prolonged hot weather in central Vietnam poses a significant risk to human health, resulting in dehydration, exhaustion, and heat stroke when exposed to high temperatures for extended periods [44]. Forecasts indicate that the central coastal provinces are among areas most severely affected by rising temperatures [45]. Recent years have witnessed a surge in high temperatures and severe, prolonged heat in many central provinces such as Quang Binh, Thua Thien Hue, Binh Dinh, and Khanh Hoa, with recorded temperatures exceeding 40 degrees Celsius [44]. These extreme heat conditions are negatively impacting people's health, daily life, and activities in central Vietnam.

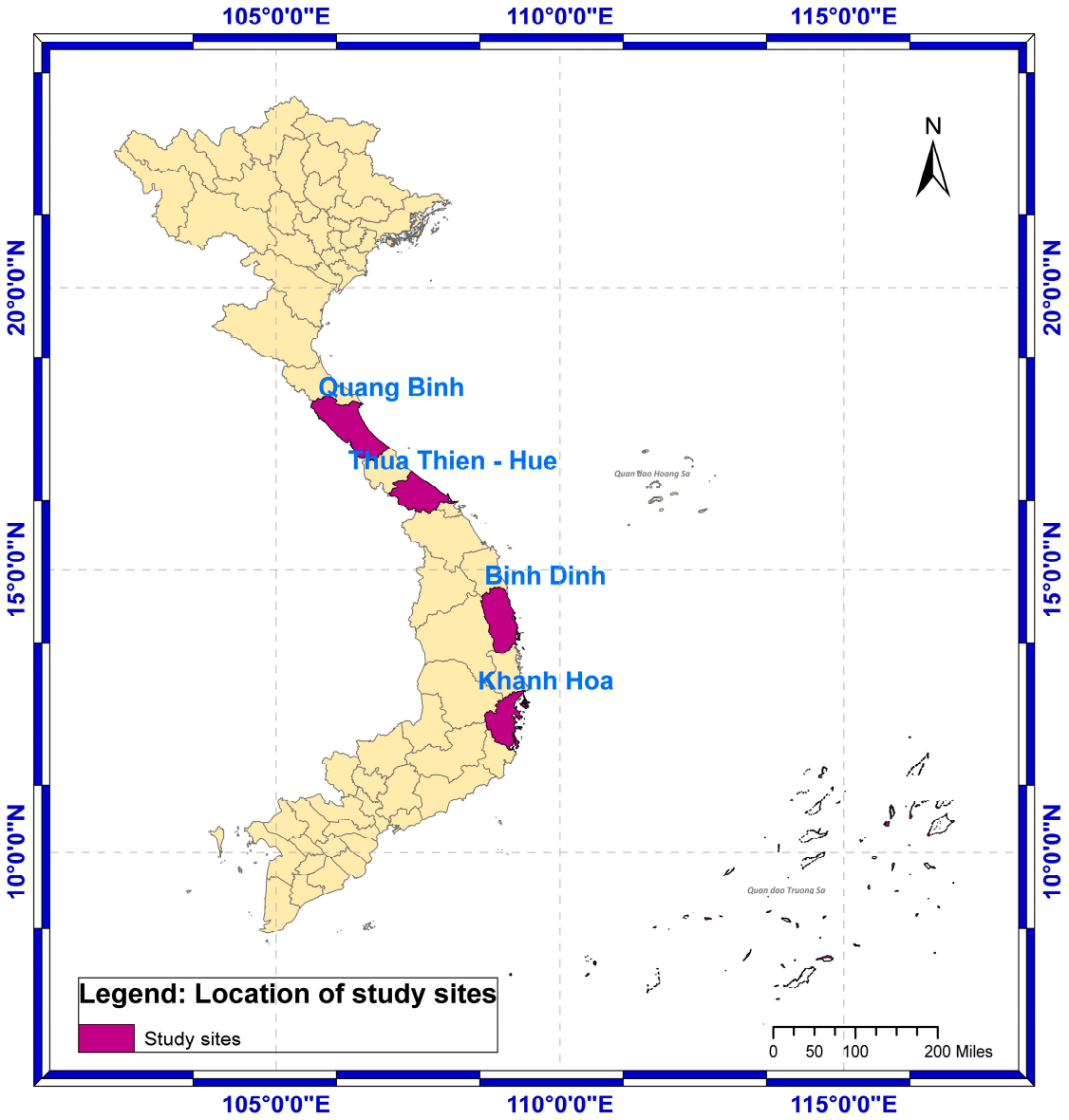

Figure 2. The study sites in north and south central Vietnam.

2.4. Data Collection

The questionnaire development involved a rigorous two-phase process. In the first phase, in order to inform questionnaire development, inputs were gathered from six semi-structured interviews conducted with local authorities and policymakers. Based on these inputs, a draft questionnaire was constructed, which was then further refined through discussions held in three focus groups, with one focus group discussion organized between experts and local authorities and two focus groups for vulnerable populations. To ensure the validity of the questionnaire, twelve cognitive interviews were conducted with participants, and six expert consultations were carried out to further assist survey design and questionnaire development. These experts included healthcare professionals specializing in heat-related illnesses, communication experts in disaster-related events, local authorities and departments responsible for disaster management, selective healthcare providers, and individuals with experience in providing health services for heat-related risks. All interviews and consultations utilized the same draft of the questionnaire to maintain consistency.

In the second phase, pilot surveys were conducted to identify any potential issues and gather feedback from participants. This valuable feedback was used to make necessary

adjustments and finalize the survey instrument, ensuring its accuracy and effectiveness. The valuation scenario was developed through focus group discussions and consultations with stakeholders. Further details on the valuation scenario applied in this study can be found in Appendix B [46–48].

To ensure the sample representativeness, a stratified quota sampling method was employed, considering the level of heat-related stress, location, socio-economic characteristics such as gender, age, education, and income of the population in the central Vietnam study regions (i.e., Quang Binh, Thua Thien Hue, Binh Dinh, and Khanh Hoa). Participants were randomly recruited from a list of patients in hospitals. Face-to-face interviews were conducted during the summer of 2022. An interview hub was established within a local hospital in each of the four provinces, resulting in four interview hubs. According to the central limit theorem, 30 observations are required for a given bid level. Given the 5 bid levels, a contingent valuation study's typical sample size falls between 300 and 500 [49]. As a result, for a CV study with 1 treatment and 5 bid levels, the target sample size was $30 \times 5 = 150$ observations [49,50]. A total of 400 respondents, who were patients affected by heat-related illnesses such as heat exhaustion, heat strokes, and heat cramps, were interviewed. Participants who met specific recruitment criteria, which included owning a mobile phone or smartphone and using mobile phone services, having knowledge or experience of the relevant health issues associated with the targeted diseases, or having family members or acquaintances who experienced such health issues, were eligible to participate in the survey. Only participants aged 18 years or older were included in the study. All participants provided informed consent before their participation in the survey.

2.5. Characteristics of the Sample

Table 1 presents an overview of the participants' demographic attributes. The sample consisted of 54.8% male participants and 45.3% female participants. The average age of participants was 65.5 years. In terms of educational attainment, the largest proportion of participants (26.0%) had primary or lower education, 25.3% secondary education, 19.5% high school education, 17.3% college education, and 12.0% university or higher education.

Table 1. Sample characteristics.

Items	%	Items	%
Gender		Household income (million VND/month)	
Male	54.8	Less than 3	9.5
Female	45.2	3 to less than 5	10.8
Age (year)	65.5 [a] (14.9) [b]	5 to less than 10	35.5
Education		10 and higher	44.2
Primary school and lower	26.0		
Secondary school	25.3		
High school	19.5		
Colleges	17.3		
University and higher	12.0		

Notes: N = 400, [a] mean, [b] Standard deviation. VND, Vietnamese Dong (approximately VND 23,000/USD 1 as of 2022).

With regard to the household's income level, the majority of the participants (80.0%) exhibited household earnings equal to or exceeding VND 5 million/month, while 10.8% of participants disclosed a household income level ranging from VND 3 million to less than 5 million/month (the exchange rate was approximately VND 23,000 VND/1 USD as of 2022). Approximately 9.5% of participants reported their household's income falling below VND 3 million/month. Generally, the income distribution among participants accurately reflects the prevailing low economic status of the population residing in the study area compared to other areas in the country.

In general, the sample characteristics indicate that the study participants predominantly consisted of elderly individuals with limited educational attainment and income

levels. These demographic attributes have potential implications for their inclination to financially support an EWS aimed at alleviating heat stress, as well as the efficacy of such interventions in mitigating the risks associated with heat-related illnesses within the study area.

3. Results

3.1. Cost of Illness

Employing the Cost of Illness approach (COI), we estimated the economic burden associated with heat-related illnesses by categorizing costs (Table 2). Notably, the primary component of the total direct cost attributed to heat-related illnesses is direct medical costs, accounting for 59.79% of the total. The average annual estimation of direct medical costs per individual is approximately VND 14 million (US$636.36).

Table 2. Annual per capita cost of illness related to heat-related illnesses.

Cost Items	1000 VND	%
Direct costs	23,801.3	79.80
- Direct costs associated with medical expenses	14,230.9	59.79
- Direct costs that are not associated with medical expenses	9570.3	40.21
Indirect costs	6025.6	20.20
Total	29,858.6	100.00

Note: VND, Vietnamese Dong (approximately VND 23,000/1 USD as of 2022).

Additionally, direct non-medical expenses encompass various items, such as daily meals for patients and caregivers, accommodation costs in case of relocation or rental for treatment requirements, travel expenses between home and hospitals (excluding emergency transport), and other miscellaneous expenses (e.g., home modifications due to illness). On average, the direct non-medical expenses associated with heat-related illnesses amount to approximately VND 9.5 million per individual per year (USD 431.81), constituting 40% of the total direct cost. Overall, the total annual direct cost of heatwave illnesses reaches VND 23.8 million per individual per year (USD 1034.7), comprising a significant portion (79.80%) of the total illness-related costs.

In addition to direct expenses, the inclusion of indirect costs is crucial when considering the financial implications of heat stress-related illnesses. Indirect costs primarily encompass opportunity costs, such as reduced or forfeited labor productivity arising from heat-induced illnesses. This pertains not only to the affected individuals themselves but also to their family members who assume caregiving responsibilities. The estimation of indirect costs attributed to heatwave illnesses amounted to approximately VND 6.0 million per individual per year (USD 260.86), constituting roughly 20% of the overall expenditure.

3.2. Participants' Perception and Experience with Heat-Related Illnesses

3.2.1. Experienced Symptoms with Heat-Related Stress

To comprehensively examine the multifaceted impacts of heatwaves on human well-being, respondents were asked to assess their personal encounters with heat-related stress using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) (see Table 3). The findings demonstrated a prevalent acknowledgment among the majority of participants regarding the psychological toll and debilitation resulting from heat-induced ailments. Moreover, common symptoms associated with heat stress, such as headaches, sleep disturbances, and heat stroke, were frequently reported by respondents. Additionally, the participants also expressed experiencing physiological manifestations, including fatigue, a sense of constraint, and impaired functioning, particularly in the face of extreme or prolonged periods of heightened temperatures.

Table 3. Experienced symptoms with heat-related illnesses (%) (n = 400).

Heat-Related Illnesses	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
Cramps due to heatstroke	2.0	24.3	26.3	44.0	3.5
Heat stroke	1.3	5.5	13.8	58.5	21.0
Heat exhaustion/fatigue due to heat	1.0	11.0	19.0	54.0	15.0
Feeling constrained/unable to do activities that I enjoy	0.8	12.0	18.8	57.8	10.8
Headache	1.0	5.8	10.8	63.0	19.5
Sleepless	0.8	6.0	12.0	61.0	20.3
Disorientation/unable to function normally/unable to concentrate on work	1.3	12.5	25.3	51.7	9.3
Mentally exhausting/draining	0.5	4.3	9.8	66.4	19.0

3.2.2. Exposure to Heat

The potential impact of heatwaves on adaptive behavior and prevention strategies can be influenced by exposure levels. To assess the diverse degrees of exposure to heatwaves, respondents were queried about the extent to which their occupations were subjected to heat. The response options ranged from 1 (no exposure) to 5 (very high exposure). Findings revealed that approximately 23.5% of the participants disclosed moderate levels and 16.8% reported high to very high levels of heat exposure in their respective jobs. Furthermore, the inclusion of heat exposure as a variable in subsequent analyses will allow for an examination of its influence on willingness to financially support an EWS aimed at mitigating heat-related risks.

3.2.3. Coping Strategies for Heatwaves

Various coping strategies could be implemented to address the challenges posed by heat-related risks (Table 4). The findings of this study revealed that a great majority of individuals employed fans as their primary means of mitigating heat discomfort. Additionally, a considerable proportion of participants reported the adoption of lightweight clothing during periods of extreme heat to facilitate evaporation and prevent overheating. Moreover, a notable percentage of respondents (>80%) opted to remain indoors or plant trees in the vicinity of their residences to alleviate the adverse effects of excessive heat. Furthermore, more than 66% of the participants affirmed that they adjusted their work schedules, preferring to commence their activities early in the morning or late in the evening to minimize exposure to heat. Additionally, over 54% of the participants utilized air conditioning as a coping mechanism, whereas approximately 52% mentioned taking multiple showers per day to alleviate heat stress. Furthermore, alternative measures, such as upgrading residential structures to enhance heat resistance and engaging in swimming activities, were reported as additional coping mechanisms to mitigate the impact of heatwaves.

Table 4. Coping strategies to tackle heatwaves (n = 400).

Coping Strategies	%Yes
1. Buy/use air conditioner	54.5
2. Buy/use fan/ceiling fan	94.5
3. Plant trees around the house	83.5
4. Stay indoors/stay out of the sun	86.8
5. Shower several times a day	52.0
6. Use thin clothes	94.3
7. Work early in the morning or late in the evening	66.3
8. Swim in pool	29.3
9. Upgrade/repair house features (e.g., thick walls, high ceilings, insulation)	36.3

Note: Sources for the items were adapted from [51,52].

3.3. WTP Estimates

The WTP according to the parametric estimates was VND 283,110 per person per year (Table 5). These figures highlight the importance and value of the HEWS in mitigating the health risks associated with heat stress. Total WTP in the study area was obtained by multiplying the mean WTP with the affected population in the study area. It is estimated that approximately 30% of the Vietnamese population is affected by heat stress [53]. The scenario analysis was conducted under different scenarios of the proportion of the affected population that would agree to support for the development of HEWS (Appendix C). The rationale for setting the scenarios is that depending on the severity, duration of the heatwave, level of preparedness to cope with the extreme heat, it is assumed that the proportion of affected population who would financially contribute to the HEWS could range from 5% to 50%. Vietnam in general and the central coast of Vietnam in particular have experienced high temperatures and severe and prolonged heatwaves in recent years, leading to significant health risks and economic consequences [9,45]. Hence, it is clear that heatwaves have a substantial impact on a significant proportion of the population particularly in the context of climate change and increased extreme weather events.

Table 5. WTP according to parametric estimates using Krinsky and Robb (95%) C.I.

Items	VND/Year/Person
Mean/median	283,110
Krinsky and Robb (95%) C.I.	
Lower bound	233,720
Upper bound	335,720

C.I.: Confidence Interval, Nb of reps: 10,000. VND, Vietnamese Dong (approximately VND 23,000/1 USD as of 2022).

Using the parametric estimates, the total WTP ranges from VND 20,137,933,000 or USD 875,562 for the study areas under the scenario of a 5% of the affected population would contribute financially to the HEWS, and VND 201,379,328,000 or USD 8,755,623 for the 50% of the affected population in the study area endorsed the measures (Appendix C, Table A2). The aggregated WTP for the affected population in the central Vietnam is VND 85,728,368,000 or USD 3,727,320 under the scenario of 5% of the affected population being willing to contribute to the development of the HEWS (Appendix C, Table A3). Alternatively, if 50% of the affected population approves the proposed service, the total contribution could reach VND 857,283,678,000 (equivalent to USD 37,273,203).

It is crucial to acknowledge that these estimates are derived from a specific sample of survey or analysis participants, and the WTP value may differ across various populations and contexts. Nonetheless, these estimates offer initial valuable insights for policymakers and other decision makers when making determinations on the implementation and allocation of funds for an EWS that aims to mitigate the risks associated with heat-related illnesses in central Vietnam.

3.4. Determinants of the WTP

Table 6 presents empirical findings concerning the determinants of individuals' WTP for an HEWS aimed at mitigating heat stress in central Vietnam. The variable bid is significant at 1%, showing that as bid levels rise, the likelihood of a "yes" response falls, which is consistent with the earlier literature [36,54]. The results indicate that the cost of illness items including the annual direct medical cost and direct non-medical cost are significant determinants of WTP for HEWS, indicating that individuals who perceive a higher direct medical and direct non-medical cost of illness attributed to heat stress are more inclined to have a higher likelihood to pay for the HEWS.

Table 6. Determinants of the WTP for the HEWS to mitigate heat stress.

	Coef.	**Robust S.E.**	**z**	***p*-Value**
Constant	−5.831	4.308	−1.35	0.176
Bid	−0.003	0.0002	−15.66	0.000
Cost of heat related illness				
Direct medical cost	0.198	0.057	3.46	0.001
Direct non-medical cost	0.241	0.102	2.36	0.018
Indirect cost	−0.103	0.180	−0.57	0.566
Individual relationship with risk				
Background diseases				
1	0.979	0.015	65.05	0.000
2	0.787	0.044	17.84	0.000
3	1.235	0.150	8.23	0.000
4 or more	1.016	0.310	3.27	0.001
Exposure to heat: working condition: base = 1				
2	0.323	0.066	4.92	0.000
3	0.640	0.082	7.79	0.000
4	0.887	0.283	3.13	0.002
5	1.213	0.818	1.48	0.138
Perceived risk associated with heat related illnesses				
Knowledge	−0.011	0.084	−1.25	0.212
Anxiety	0.088	0.323	0.27	0.787
Future risk	0.076	0.111	0.69	0.493
Coping strategies (Cop)				
Cop1	0.314	0.185	1.70	0.090
Cop2	0.469	0.192	2.45	0.014
Cop3	−0.040	0.122	−0.33	0.745
Cop4	0.392	0.210	1.87	0.062
Cop5	−0.273	0.172	−1.59	0.112
Cop6	−1.091	0.208	−5.25	0.000
Cop7	0.093	0.121	0.77	0.441
Cop8	0.250	0.025	10.08	0.000
Cop9	−0.387	0.080	−4.82	0.000
Individual characteristics				
Gender (base = Female)	−0.062	0.303	−0.21	0.837
Age	−0.004	0.006	−0.67	0.502
Income: base = 1				
2	0.434	0.303	1.44	0.151
3	0.406	0.194	2.09	0.037
4	0.814	0.116	6.99	0.000
5	0.490	0.144	3.39	0.001
Education	0.207	0.073	2.85	0.004
Household size	0.092	0.007	12.67	0.000
Communication of heat related risks				
Channel	0.069	0.032	2.14	0.032
Number of observations		368		
Log Pseudolikelihood		−153.897		
Pseudo R^2		0.3962		

S.E.: Standard Error.

Furthermore, the level of background diseases emerges as another significant determinant of WTP: individuals with one or more background diseases have a higher probability of agreeing to pay in comparison to those who have none. In addition, level of exposure to heat is a significant predictor of the WTP, as an individual who has an increased exposure

to heat stress at levels 2, 3, or 4 exhibits a higher probability of approving the payment rather than those who have least exposure.

Additionally, the results indicate that coping strategies, termed Coping 2 (buy/use fan/ceiling fan), Coping 8 (swim) are significant predictors indicating that individuals who adopted coping strategies such as using fan or swimming are likely to value the HEWS. In contrast, those who use coping strategies such as Cope 6 (use thin clothes) or Cope 9 (upgrade/repair house features such as thick walls, high ceilings, and insulation) seem to have a lower probability of approving the payment. Conversely, variables such as knowledge, perceived anxiety, gender, age, and predicted future risk of heatwaves did not exhibit significant relationships with WTP for early warning services.

In terms of socio-economic characteristics, income level emerges as another significant determinant of WTP, as individuals belonging to the third, fourth, and fifth income brackets exhibit a higher WTP than those in the base income bracket. Additionally, the size of the household matters, with a positive coefficient indicating that larger households are more likely to agree to pay for the services. Education is also significant, indicating that those with a higher level of education tend to have a higher likelihood of being willing to pay.

Finally, the information channel is a significant predictor of WTP, implying that the higher the number of channels that individuals used to access the heat information, the higher the likelihood of agreeing to pay for the HEWS. This demonstrates a substantial positive impact on anticipation of forthcoming heat stress risks, implying that individuals who acquire heat stress information through an increasing number of channels are more inclined to have a higher likelihood of paying.

4. Discussion

Findings of the study highlight individuals' WTP for an HEWS, which has significant implications for policymakers and stakeholders seeking diverse prevention strategies to effectively mitigate health risks related to heat. These results can inform the development of prevention strategies, particularly the establishment of an EWS, aimed at averting the adverse consequences of heatwaves on human health. The evaluation of the HEWS is a significant potential contributor to one or more facets of sustainability given the increasing frequency and severity of climate change-induced heatwaves, which have amplified their detrimental effects on human health [14]. Through its ability to effectively inform vulnerable populations and thereby reduce heat-related illnesses, the assessment of HEWS has the potential to enhance societal sustainability. Thus, resource allocation is optimized as public health is improved, hospital admissions are decreased, healthcare burdens are lessened, etc. Within the context of sustainability, valuing HEWS initiatives can simultaneously produce positive effects on the economy and environment at the same time. Moreover, the wise use of warning systems can result in reductions in energy demand during peak times, thereby improving resource efficiency. For example, adopting environmentally friendly practices like passive cooling techniques (e.g., natural ventilation and cooling) can reduce energy demand. Utilizing prompt notifications for proactive prevention can lessen the negative effects of heat on at-risk groups and their homes, supporting labor productivity and causing as little disruption to businesses as possible. This is particularly important in the context of developing countries. Early warnings also encourage community preparedness to combat heat-related risks, aid efforts to adapt to climate change, and support both societal and environmental sustainability.

The findings indicate that individuals with one or more background diseases have a higher likelihood of paying for HEWSs. It is apparent that individuals with underlying health conditions are more likely to be vulnerable to heightened distress during heatwaves [12]. Targeted communication such as the implementation of HEWSs as personalized alerts can enhance the reach and impact of heat warnings among at risk populations, ultimately assisting in safeguarding them from the consequences of heatwaves. In addition, climate change adaptation strategies that prioritize people with pre-existing health conditions via the adoption of HEWSs are highly recommended. Another implication is that

by utilizing warnings, community-based support systems/networks can be strengthened to reach out and provide timely support for vulnerable populations, thereby empowering their resilience during extreme heat events. Furthermore, coordinated efforts among public health authorities, community/disaster management organizations, and healthcare providers are required to ensure that early warnings are effectively disseminated and acted upon, thereby protecting vulnerable populations from heat threats.

The results showed that individuals with an increased level of exposure to heat stress have a higher probability of approving the payment. Hence, intervention policies should target and incentivize those who have high exposure to heat such as workers, outdoor labors to adopt HEWS to meaningfully help them prevent heat-related risks, thereby reducing the burden on their health and their families. In the context of Vietnam, it is predicted that a heatwave lasting for 9 consecutive days in a month results in a 13.5% increase in the mortality rate, highlighting the substantial impact of prolonged severe heat stress [7]. Climate change is projected to amplify the adverse impacts of heatwaves on human health, including increased frequency, duration, and intensity [14]. By leveraging/utilizing the early warning system, the potential damage could be minimized via enhancing the resilience of vulnerable population and strengthening the preparedness of the population to actively and effectively cope with heat-related risks to alleviate damages, particularly under climate change and extreme events [55]. Importantly, since climate change could intensify the frequency and intensity of heatwaves, improving the precision of climate early warning services is paramount to people's safety and resilience [56]. Having access to accurate weather information that is readily available, easily accessible, and user-friendly is crucial in making climate-informed decisions [38] particularly in preventing heat related illness. Nevertheless, the development of climate services, their application in decision making, and the subsequent societal benefits are still not fully coordinated, leaving certain gaps [57]. In particular, insufficient downscaled information, logistical challenges, poor communication, a lack of trust, or information not tailored to meet users' needs could collectively pose barriers to the adoption and effective utilization of climate early warning services [37]. Neglecting these barriers could diminish the progress made in delivering heat early warning information aimed at assisting individuals' preparation for and mitigation of heat-related risks, and enhancing their resilience to climate change. To foster the successful adoption of climate early warning services in mitigating heat-related risks, it is important to prioritize the mainstreaming of capacity building efforts targeting key stakeholders [37].

The cost of illness approach applied in this study enables policymakers, researchers, and medical professionals to comprehensively evaluate the various cost components associated with heat-related illnesses. This information can help identify potential opportunities for more effective prevention and treatment strategies, providing insights into improved resource allocation efficiency.

The key findings of this study may be transferable to similar climatic zones, particularly in areas with high heat exposure or regions grappling with substantial health care costs due to heat related threats. HEWSs may stand as a valuable tool for mitigating heatwave risks in such locales. Nevertheless, the effective implementation and adaptation of the HEWS to a specific region requires careful consideration of local conditions and needs. The applicability of the HEWS to other regions may rely on a variety of factors for instance local climate, topography, urban development, local vulnerabilities, available resources for setting up the system, and existing adaptive measures. To warrant the successful execution, it is required to conduct a thorough assessment of specific region's climate vulnerabilities, utilizing inputs from local experts and organizations. Strategies for adopting such a system should then be customized to tailor solutions to match particular needs and challenges of each region.

The present study had several limitations. First, it was conducted within a specific region of Vietnam, thereby limiting the generalizability of the results to other regions with distinct socioeconomic and cultural contexts. Second, the contingent valuation method employed in this study may possess certain drawbacks. Hypothetical bias, a common

bias in CVM is mitigated by carefully revising the scenario and the questionnaire with key stakeholders. Also, we used a cheap talk script to minimize hypothetical bias and generate a context/an environment that resembles an actual market. The study areas and the values provided by the HEWS were contextualized to prevent information and embedding effects. FGDs with relevant stakeholders are rigorously carried out to prevent starting point bias. Strategic bias is effectively mitigated by using a single-bounded dichotomous choice (SBDC) question [58]. The SBDC question were utilized to prevent potential bias and were used in previous CVM studies in Vietnam [36,54]. Finally, reliance on self-reported data may introduce the potential for response bias.

5. Conclusions

The study aimed to assess the willingness-to-pay for a HEWS designed to mitigate heat-related illnesses in central Vietnam and identified the factors that influenced WTP. The findings revealed that the average WTP for the warning system was estimated at VND 283,110 per person per year based on parametric estimates. Furthermore, the study identified various factors influencing WTP, including annual direct medical and non-medical costs, the level of background diseases, the degree of exposure to heat, the adoption of coping strategies, income level, household size, education, and the number of channels individuals used to access heat-related information.

The study emphasizes the importance of providing an EWS to prevent heat-related illnesses and reduce associated costs in central Vietnam. Additionally, the study's approach has relevance for other countries and regions with similar conditions facing heat-health challenges but lacking provisions for heat-related risks in their existing EWS or dedicated EWS for extreme heat events. Given that climate change has increased in terms of frequency and intensity, the investigation of the value of the HEWS has the potential to enhance human wellbeing and promote more sustainable development.

Future research should focus on evaluating the effectiveness of impact-based forecasts and understanding their role in guiding individuals' decisions to mitigate heat-related risks. Additionally, there is a need for further exploration of various factors that could impact people's WTP for an EWS designed to prevent heat-related illnesses. To strengthen the validity of our findings, it would be beneficial to incorporate alternative valuation methods like choice experiments. Moreover, it is recommended that upcoming investigations include a comparative analysis of WTP for EWS across diverse regions and countries. This approach will provide a comprehensive understanding of the variations in willingness to pay and the underlying factors that influence it.

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Abbreviations

HEWS	Heatwave Early Warning Systems
SMS	Short Message Service
WTP	Willingness To Pay
VND	Vietnamese Dong
EWS	Early Warning Systems
CVM	Contingent Valuation Method
COI	Cost Of Illness

Appendix A

Table A1. An explanation of variables used in the study.

		Description	Value	Expected Sign
1	Prob(Yes)	Probability of an individual is willing to pay for the SMS-based HEWS to mitigate health risks/illness associated with heatwaves	1 = Yes; 0 = No	
2	Bid	Bid levels (annually) (1000 VND)	5 levels	−
	Cost of illness			
3	Direct medical cost	Annual direct medical cost related heat illnesses	Continuous	+
4	Direct non-medical cost	Annual direct non-medical cost related heat illnesses	Continuous	+
5	Indirect cost	Indirect cost—Annual indirect cost related heat illnesses	Continuous	+
	Individual relationship with risk			
6	Background diseases	Number of background diseases (Heart disease, Asthma, COPD, Respiratory disease (chronic bronchitis, bronchiectasis), High blood pressure, Diabetes, Other chronic disease)	Numeric	+
7	Exposure	Exposure to heat: working condition—To what extent is your job exposed to the heat?	Completely contactless (1) Less exposure (2) Moderate exposure (3) Frequent contact (4) Very often in contact (5)	+/−
	Perceived risk associated with heat related illnesses			
8	Future risk	Prediction of future risks associated with heat related illness—In your opinion, how likely is the probability of prolonged/severe/peak heatwaves in Central Vietnam increase in the future/or in the next 10 years?	1 = likely and very likely 0 = otherwise	+
9	Anxiety	Perceived individual anxiety—How worried are you about the effects of heat stroke on yourself?	Extremely concerned/anxious (1) Concern (2) Quite Concern (3) Little Concern (4) No worries at all (5)	+
10	Knowledge	Knowledge of heat related illnesses	Numeric, Number of correct answers	+
11	Current adaptation/coping strategies of individual (Cope)			

Table A1. *Cont.*

		Description	Value	Expected Sign
	Coping strategies	Cop1. Buy/use air conditioner Cop2. Buy/use fan/ceiling fan Cop3. Plant trees around the house Cop4. Stay indoors/stay out of the sun Cop5. Shower several times a day Cop6. Use thin clothes Cop7. Work early in the morning or late in the evening Cop8. Swim Cop9. Upgrade/repair house features (e.g., thick walls, high ceilings, insulation)	1 = Yes; 0 = No	+/−
	Individual characteristics			
12	Gender	Gender of the respondents	1 = Male, 0 = Female	
13	Age	Age of the respondent in years	Continuous	+/−
14	Income	Household income level	Numeric	
15	Education	Education level of the participant	Numeric	
16	Household size	Number of persons living in the family	Persons	+/−
	Communication of heat related risks			
17	Channel	Total channels received health related warnings during the last 5 years?	Numeric, from 1 to 8 channels	+/−

Appendix B Valuation Scenario

The valuation scenario was developed through focus group discussions and consultations with stakeholders. Participants were first provided some background information regarding the current situation of heatwave in Vietnam and central Vietnam in recent years and the detrimental effects of heatwaves on human health, particularly under growing extreme weather events and climate change. Participants were then informed that among the regions across Vietnam, central Vietnam is particularly highlighted as susceptible to heatwaves and extreme events, which can have significant repercussions on human health if appropriate preventive measures are not implemented. It is also highlighted that heat-related health risks could be exacerbated due to climate change. Also, the various challenges in tackling the impacts of heat-related illness are illustrated, particularly due to the unavailability of an HEWS. Hence it is essential to develop an HEWS to mitigate health risks associated with heat stress.

Participants were then explained the key roles of the HEWS in providing timely information to act without delay and minimize the health burden of excessive heat exposure. In the context of developing or enhancing existing warning services for heat-related illnesses and problems, the implementation of an EWS ensures that individuals are well-informed about specific details concerning heat events. The utilization of an SMS-based EWS could effectively aid in preventing and reducing health issues caused by prolonged heat exposure and high temperatures. In more detail, the HEWS can provide multiple values and benefits to users. The HEWS could help to prevent or mitigate various illnesses associated with heat stress. Specifically, the EWS can help in mitigating the possible direct consequences related to health risks from heat, for instance, reducing morbidity cost of heat-related illness such as medical costs and direct non-medical expenditures [24,46,47]. Additionally, the HEWS can lessen indirect costs, such as lost productivity due to heat-related illnesses, for those affected and their family members [46]. In addition, heat stress may cause various deteriorations in the quality of life such as anger, anxiety, loss of well-being, reduced self-esteem, and antisocial behavior [46]. An EWS may help to mitigate such negative consequences by well-informed people of the plan to cope in advance. An HEWS can likewise reduce the incidence of mortality and avoid other losses of wellbeing due to heatwaves.

Next, participants were presented with the proposed HEWS as preventive measures and a coping strategy to mitigate health hazards associated with heat threats. The proposed HEWS focuses on SMS-based notifications with basic warning information. This includes temperature forecasts, peak heat times, locations with peak hot weather, potential adverse health effects, and basic prevention tips. It was emphasized to the participants that the information provided by the warning services would be sourced from trusted and reliable entities, such as reputable agencies and organizations. Participants were also presented with the proposed activities to develop an HEWS to mitigate health risks associated with excessive heat.

Respondents were then informed that the establishment of such a system incurs substantial costs, surpassing the available public investment. Therefore, raising funds becomes necessary to support the implementation of these measures. To address the funding requirement, a proposal was made to introduce a surcharge via monthly mobile phone services for individuals who wish to access the SMS mobile phone-based HEWS. In reality, nearly everyone possesses a mobile phone and utilizes phone services, rendering this payment vehicle widely acceptable and feasible. Subsequently, the provision and payment mechanisms were provided.

A cheap talk script was used to minimize hypothetical bias and encourage participants to consider their budget constraints. Cheap talk is a frequently employed technique in stated preference methods aiming at mitigating hypothetical bias [48]. This script aimed to prompt participants to carefully evaluate their WTP by simulating real-world financial constraints. Participants were then asked to state their WTP for the proposed mobile phone-based SMS HEWS. The WTP question was framed as: "Consider carefully the value/benefits of the HEWS in mitigating potential consequences of heat-related illness as outlined earlier. Assume that you will suffer from a heat-related illness in the next few days. Would you vote for the proposed early warning system for heat if it cost you <bid level> as a surcharge on your monthly phone bill?".

Five bid levels (VND 2500, 7500, 15,000, 40,000, and 75,000) (equivalent in USD: 0.11, 0.33, 0.65, 1.74, and 3.26, respectively) were used and respondents could only answer "yes" or "no".

Appendix C

Table A2. Scenarios analysis for the WTP of the affected population for the HEWS for the study area using parametric estimates.

	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Total population for the study area of 4 provinces ('000 persons)	237.10	474.21	711.31	948.42	1185.52	1422.62	1659.73	1896.83	2133.93	2371.04
Total affected population for the study area of 4 provinces ('000 persons)	71.13	142.26	213.39	284.52	355.66	426.79	497.92	569.05	640.18	711.31
WTP for the study area of 4 provinces ('000 VND)	20,137,933	40,275,866	60,413,798	80,551,731	100,689,664	120,827,597	140,965,530	161,103,462	181,241,395	201,379,328
WTP for the study area of 4 provinces (USD)	875,562	1,751,125	2,626,687	3,502,249	4,377,811	5,253,374	6,128,936	7,004,498	7,880,061	8,755,623

Note: VND, Vietnamese Dong (approximately VND 23,000/1 USD as of 2022). Population figures were obtained from General Statistics Office of Vietnam (GSO) (2023) [42]. The estimation is on 30% of the population vulnerable to heatwaves (Climate Analytics, 2019) [53].

Table A3. Scenarios analysis for the WTP of the affected population for the HEWS for the central coast of Vietnam using parametric estimates.

	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Total population for the Central Coast of Vietnam ('000 persons)	1009.36	2018.73	3028.09	4037.46	5046.82	6056.19	7065.55	8074.92	9084.28	10,093.65
Total affected population for the Central Coast of Vietnam ('000 persons)	302.81	605.62	908.43	1211.24	1514.05	1816.86	2119.67	2422.48	2725.28	3028.09
WTP for the Central Coast of Vietnam ('000 VND)	85,728,368	171,456,736	257,185,103	342,913,471	428,641,839	514,370,207	600,098,575	685,826,943	771,555,310	857,283,678
WTP for Central Coast of Vietnam (USD)	3,727,320	7,454,641	11,181,961	14,909,281	18,636,602	22,363,922	26,091,242	29,818,563	33,545,883	37,273,203

Note: VND, Vietnamese Dong (approximately VND 23,000/1 USD as of 2022). Population figures were obtained from GSO (2023) [42]. The estimation is on 30% of the population vulnerable to heatwaves (Climate Analytics, 2019) [53].

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