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Combating the Scorch: Tailored Strategies for Heat Wave Consequences Mitigation in Bangladesh Using the Best-Worst Method

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Abstract

Bangladesh's average temperature has crossed the global average by 0.2 degrees Celsius due to the El Nino Southern Oscillation (ENSO) patterns, coupled with the solar maximum period exacerbating the heat waves in summer making the challenges faced in health, infrastructure and ecosystem particularly in urban settings worse. This paper builds on this by examining relevant studies conducted in Bangladesh to analyze these concerns and look into possible remedies. The research used the Best Worst Method (BWM) to analyze which appropriate responses could be undertaken taking into consideration cost and environmental safety. Among the findings, the most beneficial strategies in mitigating the effects of heat waves included 'Heat Early Warning System' and 'Implementation of Heat Action Plan' which were indicated to have performed well in decreasing heatwave hazards. The study practical recommendations for policymakers, where it is noted that it is important to use evidence based approaches, geographical, timely warning systems and specific thresholds for countries in alleviating heat stress and protecting health. It is the basis for forming adaptive measures to prevent negative impacts of increased temperature and more frequent heat waves in Bangladesh. By adapting the prevention strategies introduced in this study, the leaders will enhance cities' capacity to cope with heat waves in a way that will be protective of public health and promote the wellbeing of the people in Bangladesh within an appropriate environment. The study also emphasizes the importance of employing evidence-based measures when developing effectiveness strategies, especially considering the rising temperatures and the threats associated with them.

Keywords: ENSO (El Nino Southern oscillation), Heat waves, Health threats, Best-Worst Method, Mitigation strategies

1. Introduction

The impact of extreme temperature events is widespread, influencing human health, ecosystems, agriculture, and economies. Between 1980 and 2017, the average number of annual heat waves in large U.S. cities has tripled, increasing from an average of two heat waves per year in the 1960s to six per year in the 2010s. The Intergovernmental Panel on Climate Change (IPCC) warns that heat wave frequency, duration, and intensity will continue to rise, especially if global warming exceeds the 1.5°C and 2°C thresholds above pre-industrial levels. Under these scenarios, heat wave days could increase by 30 times by the end of the century. Heat waves were responsible for 4 of the 10 deadliest natural disasters in 2015, with South Asian heat waves ranking third and fourth by mortality [13]. From the evidences of impacts of climate change across the world it is perceived that due to the geographical location of the country, Bangladesh have experienced different types of adverse phenomena that there has been an increasing climate extremity such as heat wave, sudden moderate cold wave, etc [1].

The IPCC also recognizes Bangladesh as one of the most vulnerable countries in the world to the negative impacts of climate change [1]. Bangladesh's location near the tropics contributes to its high temperatures. The country's flat, low-lying landscape means that there are no significant geographical features to moderate heat waves, allowing hot air masses to linger for longer periods. Climate anomalies like El Nino contribute to extreme weather, including heat waves. During an El Nino year, the warm waters of the Pacific Ocean shift weather patterns, leading to drier, hotter conditions in Bangladesh. Rossby waves, which are large-scale waves in the mid-latitude westerly winds, can create conditions favorable for heat waves. These waves can lead to the formation of high-pressure ridges over Bangladesh, blocking the flow of cooler air and allowing heat to accumulate over time.

2. Literature Review

In Bangladesh and South Asia heatwaves are becoming more frequent and intense especially in the pre-monsoon season due to the combination of solar insulation, temperature advection, moisture incursion [3]. Heatwaves are becoming more frequent and prolonged with the highest frequencies and durations in regions such as Rajshahi and Jashore [4], [5]. Cities are particularly vulnerable because of rapidly urbanizing and often-overburdened cooling infrastructures, causing temperatures to rise further in the so-called urban heat islands when other factors like clear skies, low wind speeds and dry conditions coincide [6], [4]. While attention and knowledge of the issue have been increasing, only a few statewide, locally driven comprehensive heat action plans have been fully implemented, with some notable exceptions led by Ahmedabad, Odisha or Rajasthan [4]. Uncertainty in local heatwave behavior adds to difficulties of adapting to a changing climate, and stresses the need for more precise forecasts and better tools in seasonal-to-decadal climate services [8]. In South Asia, while the social and instrumental adaptation the physiological response and public awareness again act to attenuate overall heatwave impacts this is certainly not to say that there are no vulnerability reducing strategies in production including those for Nepal [9], [7]. As seen in at least one study, heatwave trends are increasing in Bangladesh given the large-scale atmospheric conditions like subtropical highs and anticyclones accompanying sparse precipitation [12]. The literature has also emphasized a call for climate resilient solutions required to counter heatwaves, such as green infrastructure, community cooling strategies and policy mainstreaming [8], [9]. Warmth waves, specifically in interplay with food safety and health epidemiology [10] although there has inserted conspiracy vacuum along with the micro-level influences upon more model illness-prone populations such as example this tribal Santals. While multiple mitigation strategies, such as afforestation, reservoirs or green roofs, have been suggested [6], [11] their long-term efficacy is largely unknown and particularly so in cities. The review highlights the necessity of targeted and context-specific actions, and promote scaling up those that have already proved their efficacy for overcoming the threat of heatwaves in Bangladesh and other parts around the globe [4], [13].

The cited works offer valuable insights into heat wave mitigation strategies but lack sufficient contextualization for Bangladesh's socio-economic conditions and rural areas, leaving gaps in localized implementation and predictive approaches. This paper identifies a research gap in exploring long-term efficacy and sector-specific impacts of heat mitigation strategies, as well as insufficient integration of advanced technologies like predictive analytics. It also highlights the need for broader geographical analysis and enhanced grassroots community engagement for sustainable implementation.

3. Data Collection

In this research, primary data gathering was carried out with the help of consultation with experts in order to gather complete information about heat stresses and measures to protect from heat wave in Bangladeshi context. These included a climate scientist (4 years of experience), an environmental engineer (3 years of experience), a public health specialist (5 years of experience), an urban planner (3 years of experience), and a geographic information system (GIS) specialist (4 years of experience), whose combined knowledge contributed to a comprehensive understanding of mitigation strategies and local challenges related to extreme heat events. Climate scientist, environmental engineer, and public health specialist all highlighted the importance of integrating green infrastructure, such as green roofs, alongside public health strategies to mitigate heat-related illnesses, while urban planners and GIS specialists stressed the need for data-driven urban layouts and geospatial tools to optimize resilience efforts. The experts involved in the research were interviewed and asked to participate in surveys, where they were required to evaluate a number of mitigation alternatives by comparing them based on specific criteria. The alternatives are: Heat early warning system [3], [7], [8], [10]; Implementation of heat action plan [3], [4], [7], [10]; Promotion of urban environmental greening [10]; Urban planning and infrastructure [1], [2], [3], [4]; Adaptation of blue infrastructure [4], [11]; Advancement of urban green initiatives [4], [8], [9], [11]; Country based heat stress indicator and threshold [7]; Public health strategies to reduce heat related illness [11]; Use of cool surface with high solar reflectance [11]; Construction of cooling center [10]; Technological upgradation [8] and the criteria's are Cost Sustainability, Health and safety, Time to implementation and Integration with existing system. The experts analyzed the alternatives by weighing factors such as cost-effectiveness, feasibility of implementation, and alignment with existing systems, ultimately recommending solutions that offer the best balance between sustainability, health impact, and long-term resilience.

4. Methodology

Step 1: Determine the Decision Criteria

In this step, the decision-maker identifies the set of decision criteria, [14] denoted as:

$C = \{c_1, c_2, \ldots, c_n\} \ldots \ldots (i)$Where C represents the decision criteria that need to compared to reach a decision. In fig 1, this decision-making procedure for n numbers of criteria, the total number of feasible comparisons is n^2. Here, 2n-3 are reference comparisons and the rest are secondary comparisons.

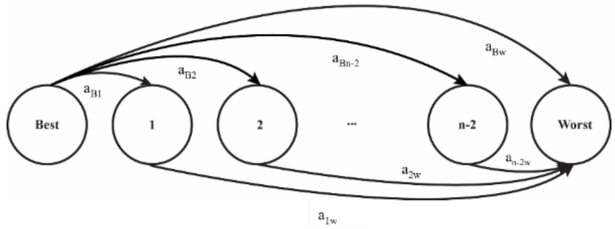

Fig 1: Reference comparisons

Secondary comparisons are challenging, less accurate and at best redundant. This section demonstrates how weights can be determined using reference comparisons.

Step 2: Mention the Best and Worst criteria

- The Best criterion B (most desirable or important).
- The Worst criterion W (least desirable or important).

Step 3: Execute the Best-to-Others Comparison

For each pair of criteria, the decision-maker evaluates and ranks them according to how much better one is than the other on a scale from 1 to 9 (with 1 representing equal importance and 9 represents drastically more important). This gives a Best-to-Others vector:

$$A_B = \{a_{B1}, a_{B2}, \ldots, a_{Bn}\} \ldots \ldots (ii)$$

Where a_{Bj} represents the preference of the best scale B over criterion c_j. Note that $a_{BB} = 1$, since B is compared to itself.

Step 4**:** Perform Others-to-Worst Comparison

The decision-maker now compares all other criteria to the worst criterion using the similar 1 to 9 scale. This outcomes in the Others-to-Worst vector:

$$A_W = \{a_{1W}, a_{2W}, \ldots, a_{nW}\} \ldots \ldots (iii)$$

Where a_{jW} denotes the preference of criterion c_j over the Worst criterion W. Again, $a_{WW} = 1$, since W is compared to itself.

Step 5**:** Determine the Optimal Weights of the Criteria

The weights $w_1, w_2, \ldots, w_n$ are calculated for a set of n criteria such that:

- The weight of Best divided by the weight of any other criterion as 1. So, it provides the condition which signifies the predilection of criterion to Worst criterion. Once again and vice versa due to.
$$\frac{w_B}{w_j} = a_{Bj} \text{ for all } j$$
- The ratio of the weights between any point of reference j and the Worst criterion should be similar to a_{jW} .This gives the formula:
$$\frac{w_j}{w_W} = a_{jW} \text{ for all } j$$

To satisfy these conditions, the maximin problem is formulated as:

$$\min_{\xi} \max_{j} \left(\left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right) \ldots \ldots (iv)$$

The optimization problem described here is such that the maximum absolute differences between this actual weight ratios and the pairwise comparison values are minimized early.

Step 6: Convert the Problem into a Linear Programming Model
After reducing the optimization problem to linear programming form:

$$\text{minimize}\xi$$

Subject to the constraints:

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi \text{ for all } j \dots\dots (v)$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi \text{ for all } j \dots\dots (vi)$$

$$\sum_{j=1}^{n} w_j = 1 \text{ (sum of all weights equals 1)}$$

$$w_j \geq 0 \text{ for all } j$$

This system of linear inequalities, subject to the constraints: Solving $w_1, w_2, \dots, w_n$ allows us to determine the optimal weights and minimized value of ξ.

Step 7: Consistency Ratio
It decides whether or not the comparisons are reliable. A comparison is totally consistent provided that

$$a_{Bj} \cdot a_{jW} = a_{BW} \dots\dots (vii)$$

for all j, where a_{BW} being the ratio between the best and worst criteria. The comparisons may not be completely consistent in that case a consistency ratio can be calculated on the basis on the ξ value. The larger the value of ξ, the less consistent the comparisons are.
Depending on the decision scale, pre-defined consistency thresholds are calculated the Consistency Index (CI) for problem is computed. The Consistency Ratio (CR) is then calculated as:

$$\text{Consistency Ratio } = \frac{\xi}{\text{Consistency Index}}$$

Here, a CR closer to zero means high consistency.

Step 8: Determine the Overall Value to Choose the Best Alternative
This is the last step in the decision-making method. In this step, criteria ranking of alternatives is done based on the opinions of experts.
Suppose we have a performance matrix P and the elements of this matrix indicate the average values of different criteria of the alternatives. The matrix P represents a framework where there are three alternatives (Alternative 1, 2, and so on) evaluated against some criteria (C_1, C_2, and so on). Each element in the matrix $a_1,\ b_1,\ c_1, d_1, e_1$ etc., represents the value or score of each alternative with respect to the corresponding criteria.
For minimum and maximum ξ, we get the minimum and maximum weights. We take the center weights between the minimum and maximum intervals.

$$W^*_{Center} = \{W^*_1, W^*_2, W^*_3, W^*_4, W^*_5\} \dots\dots (viii)$$

Then we can get the overall value of each alternative using the following function:

$$V_i = \sum_{i=1}^{n} W_i P_{ij}$$

The alternative which has the highest overall value is the best alternative and the rest of the alternatives can be prioritized based on the ranking of the overall value.

5. Calculations

Table 1 contains one expert's opinion. There are five criteria in best worst decision named sustainability, health and safety, time to implementation, integration with existing system. Five experts gave their opinions. We have multiplied criteria with opinions. There are eleven alternatives. If the criteria have different weights, adjust the calculation accordingly.

Table 1: Heat Adaptation Alternatives Evaluation

Alternatives	Criteria					Total
	Cost	Sustainability	Health and safety	Time to implementation	Integration with existing system	
Heat early warning system	1.37014	0.36844	1.62388	2.55863	0.60896	6.53006
Implementation of heat action plan	0.91343	0.27633	1.82686	3.5820	0.52196	7.12068
Promotion of urban environmental greening	0.45672	0.32239	1.21791	3.07036	0.43497	5.50235
Urban planning and infrastructure	0.60896	0.36844	1.21791	1.02345	0.43497	3.65373
Adaptation of blue infrastructure	0.45672	0.32239	1.4209	3.07036	0.69595	5.96631
Advancement of urban green initiatives	0.60896	0.36844	1.01493	2.04691	0.52196	4.56119
Country based heat stress indicator and threshold	1.06567	0.27633	1.01492	4.09321	0.69595	7.14669
Public health strategies to reduce heat related illness	0.91343	0.32239	1.4209	4.09382	0.69595	7.44648
Use of cool surface with high solar reflectance	0.76119	0.32239	1.21791	2.04691	0.43497	4.78337
Construction of colling center	0.45672	0.36844	1.62388	3.07036	0.43497	5.95437
Technological upgradation	0.91343	0.32239	1.4209	1.02345	0.17399	3.85415

By solving the min max model, we get the respective weights. For example, if sustainability has a weight of 0.3 and health & safety has a weight of 0.2, the calculation for a random alternative would be:

$$Weighted\ score = (4 * 0.3) + (5 * 0.2) + (3 * 0.1) + (2 * 0.1) = 3.1$$

Table 2: The overall value of all alternatives

Alternatives	Values
Heat early warning system	7.37960
Implementation of heat action plan	7.37099
Promotion of urban environmental greening	4.87229
Urban planning and infrastructure	4.76505
Adaptation of blue infrastructure	5.89259
Advancement of urban green initiatives	5.54507
Country based heat stress indicator and threshold	6.90690

Public health strategies to reduce heat related illness	7.01256
Use of cool surface with high solar reflectance	4.95446
Construction of cooling center	5.78002
Technological upgradation	5.24862

In table 2, the total value of all proposed alternatives was assessed to determine the most effective solution for the research objectives. The calculations have been put into practice using Excel. Each expert's thoughts are organized in a table. The results of the multiplication are then displayed in a different table. The consistency ratio has then been determined for each of the eleven options. There is also a threshold value calculation for each connected alternative. The best options among these are heat stress indicators and thresholds based on country.

6. Results & Discussion

The data presented suggests that the "heat early warning system" and the "implementation of heat action plan" have been selected as the best two options because of their "highest overall score”. The heat early warning system's ratio is 7.37961. In the event that this option cannot be carried out, the Country based implementation of heat action plan, with a ratio of 7.37099, is the second-best plan. At 4.76506, urban planning and infrastructure had the lowest average of all the alternatives. Thus, we may conclude that the heat early warning system is the best choice using the based-worst method. In this study, we evaluated different heat mitigation measures and determined which ones worked best by using the Best-Worst Method (BWM). Based on our investigation, the Heat Early Warning System was found to be the best option, indicating that it has a higher potential to reduce dangers associated with heat. The fact that the implementation of heat action plan came in second emphasizes how crucial it is to deliver precise and timely information for efficient heat management. These results highlight the need of customized heat stress indicators and early warning systems in addressing the problems caused by heatwaves and protecting public health.

7. Conclusion

The study concludes with the use of the BWM method considering critical issues on increasing heatwaves and their impacts on public health, infrastructure, and ecosystems. The research questions which are the best mitigation strategies which means Actions taken to reduce or minimize the harmful effects of a problem, in this case, heatwaves. The recommended heat wave effects mitigation strategies in Bangladesh, such as implementing heat early warning systems and heat action plans, align with approaches in other countries like India and Mediterranean regions, but with localized adaptations. Based on findings from research papers, we recommend that Bangladesh adopt systems like Ahmedabad, India’s targeted awareness campaigns and cooling centers to reduce heatwave mortality. Additionally, Bangladesh can implement comprehensive early warning systems similar to those in the U.S.,integrating [15] meteorological data with public health advisories. A global exposure dataset for long-term historical use would allow research into the future to concentrate on interventions beyond heat-related mortality. We found that 'Heat Early Warning System' and 'Implementation of a heat action plan' had the biggest associated reduction measures that performed well in the modeling of hazard from heatwave events. Other strategies, such as urban cooling initiatives, are considered moderately important for long-term resilience. Due to time constraints, sensitivity analysis could not be included, which might have strengthened the findings. The study also relied on a small number of expert opinions, which may affect the generalizability of the results. Additionally, the focus was limited to Bangladesh, and including more diverse regions and specialists could provide broader insights. These results again point toward the need for accurate spatially distributed early warning systems to effectively manage the heat and country-specific thresholds in strategies toward reductions in heat stress. More alternatives and criteria should be added in future studies to meet the evolving challenges related to climate which is one of the alarming terms. These will include a diverse set of metrics on how to evaluate heatwave impacts on various sectors of energy consumption, economic productivity, and health. The scope of analysis shall be extended to a wider geographical region and socio-economic context. The research identifies heat early warning systems as the most effective strategy, underscores the need to implement heat action plans for timely and precise management, emphasizes tailoring mitigation through country-specific heat stress thresholds, advocates for adapting urban cooling initiatives to local contexts, highlights prioritizing cost-effective community-driven solutions, and calls for strengthening urban cooling infrastructure for better resilience against heatwaves.

8. References

[1] G. M. Rashid, M. M. T. Hossain, M. A. E. Akhter, and M. A. K. Mallik, "A Study on the Heat Wave Conditions over Bangladesh During 1990 - 2019," *Journal of Engineering Science*, vol. 14, no. 2, pp. 59–67, Jan. 2024, doi: 10.3329/jes.v14i2.71227.

[2] S. Tawsif, M. S. Alam, and A. Al-Maruf, "How households adapt to heat wave for livable habitat? A case of medium-sized city in Bangladesh," *Current Research in Environmental Sustainability*, vol. 4, Jan. 2022, doi: 10.1016/j.crsust.2022.100159.

[3] H. Nissan, Á. G. Muñoz, and S. J. Mason, "Targeted model evaluations for climate services: A case study on heat waves in Bangladesh," *Clim Risk Manag*, vol. 28, Jan. 2020, doi: 10.1016/j.crm.2020.100213.

[4] A. Sharma, G. Andhikaputra, and Y. C. Wang, "Heatwaves in South Asia: Characterization, Consequences on Human Health, and Adaptation Strategies," May 01, 2022, *MDPI*. doi: 10.3390/atmos13050734.

[5] S. Das and S. C. Smith, "Awareness as an Adaptation Strategy for Reducing Mortality from Heat Waves: Evidence from a Disaster Risk Management Program in India," *Clim Chang Econ (Singap)*, vol. 3, no. 2, May 2012, doi: 10.1142/S2010007812500108.

[6] J. Qin *et al.*, "Modelling analysis of the potential impact of large reservoir on heatwave events," *Ecol Indic*, vol. 154, Oct. 2023, doi: 10.1016/j.ecolind.2023.110841.

[7] M. K. Sah and R. Chitrakar, "Strategic Framework for Implementation of Heat Wave Early Warning System," 2023.

[8] Q. Fu, Z. Zheng, M. N. I. Sarker, and Y. Lv, "Combating urban heat: Systematic review of urban resilience and adaptation strategies," *Heliyon*, vol. 10, no. 17, Sep. 2024, doi: 10.1016/j.heliyon.2024.e37001.

[9] P. Montero-Gutiérrez, J. Sánchez Ramos, Mc. C. Guerrero Delgado, T. Palomo Amores, A. Cerezo-Narváez, and S. Álvarez Domínguez, "Heat wave resilience in open Spaces: A case study of a Self-Sufficient cooling shelter," *Energy Build*, vol. 320, Oct. 2024, doi: 10.1016/j.enbuild.2024.114626.

[10] M. A. Rahman *et al.*, "Nexus between heat wave, food security and human health (HFH): Developing a framework for livelihood resilience in Bangladesh," *Environmental Challenges*, vol. 14, Jan. 2024, doi: 10.1016/j.envc.2023.100802.

[11] G. Maggiotto, A. Miani, E. Rizzo, M. D. Castellone, and P. Piscitelli, "Heat waves and adaptation strategies in a mediterranean urban context," *Environ Res*, vol. 197, Jun. 2021, doi: 10.1016/j.envres.2021.111066.

[12] S. Karmakar and M. K. Das, "ON THE HEAT WAVES IN BANGLADESH, THEIR TRENDS AND ASSOCIATED LARGE SCALE TROPOSPHERIC CONDITIONS," 2020. [Online]. Available: https://www2.kuet.ac.bd/JES/

[13] H. Nissan, K. Burkart, E. C. de Perez, M. Van Aalst, and S. Mason, "Defining and predicting heat waves in Bangladesh," *J Appl Meteorol Climatol*, vol. 56, no. 10, pp. 2653–2670, Oct. 2017, doi: 10.1175/JAMC-D-17-0035.1.

[14] J. Rezaei, "Best-worst multi-criteria decision-making method," *Omega (United Kingdom)*, vol. 53, pp. 49–57, Jun. 2015, doi: 10.1016/j.omega.2014.11.009.

[15] We built a whole-of-government strategy to fight extreme heat," Federation of American Scientists, https://fas.org/publication/strategy-extreme-heat/ (accessed Nov. 19, 2024).