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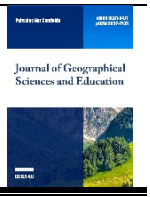

[Research Article]

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Empowering Youth for a Sustainable Future: Climate Change Awareness and Education in Higher Secondary Schools of Kerala, India

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Abstract

Climate change education is crucial for sustainable development and informed environmental decision-making, particularly in highly climate-sensitive contexts such as Kerala, India. Formalizing education to strengthen student awareness is important. Nonetheless, experiential and data-driven approaches are not yet adequately integrated into school systems. This study aims to evaluate the effectiveness of climate change education programs in enhancing awareness, understanding, and engagement among higher secondary school students in Kerala. The study used a random sampling method mixed with methodologies from all 14 districts. Between December 2023 and May 2024, data were collected from 240 government schools with weather stations, using a structured questionnaire that elicited responses from 1,514 students, and were supported by multivariate analysis. The findings identified three key dimensions: perceived climate change impacts and disaster experience, climate change awareness and education, and the influence of weather station data on student engagement. The perception levels among students with direct experience of the disaster were significantly higher than those of students with no exposure. The three components accounted for 31.48%, 21.89%, and 18.59% variance, respectively. Noticing changes in the weather (0.99), knowledge of the climate (0.96), and climate education (0.95) exhibited high factor loadings. Classroom use of weather station data was more effective in engaging students and helping them understand than informal use. The study concludes that incorporating localized climate data into the curriculum enhances students' climate literacy. The need for improved monitoring infrastructure and technology-based education to support more effective climate education and sustainable youth participation is emphasized.

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Abstrak

Pendidikan perubahan iklim sangat penting untuk pembangunan berkelanjutan dan pengambilan keputusan lingkungan yang terinformasi, khususnya dalam konteks yang sangat sensitif terhadap iklim seperti Kerala di India. Memformalkan pendidikan untuk memperkuat kesadaran siswa sangat penting. Namun demikian, pendekatan berbasis pengalaman dan data belum terintegrasi secara memadai ke dalam sistem sekolah. Studi ini bertujuan untuk

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mengevaluasi efektivitas program pendidikan perubahan iklim dalam meningkatkan kesadaran, pemahaman, dan keterlibatan di kalangan siswa sekolah menengah atas di Kerala. Studi ini menggunakan metode pengambilan sampel acak yang dicampur dengan metodologi dari semua 14 distrik. Antara Desember 2023 dan Mei 2024, data dikumpulkan dari 240 sekolah pemerintah dengan stasiun cuaca, dengan kuesioner terstruktur yang menerima tanggapan dari 1.514 siswa yang didukung oleh analisis multivariat. Temuan mengidentifikasi tiga dimensi utama: dampak perubahan iklim yang dirasakan dan pengalaman bencana, kesadaran dan pendidikan perubahan iklim, dan pengaruh data stasiun cuaca terhadap keterlibatan siswa. Tingkat persepsi pada siswa yang memiliki pengalaman langsung tentang bencana secara signifikan lebih tinggi daripada mereka yang tidak memiliki paparan sama sekali. Ketiga komponen tersebut masing-masing menyumbang 31,48%, 21,89%, dan 18,59% varians. Pengamatan perubahan cuaca (0,99), pengetahuan tentang iklim (0,96), dan pendidikan iklim (0,95) menunjukkan faktor muatan yang tinggi. Penggunaan data stasiun cuaca di kelas lebih efektif dalam melibatkan siswa dan membantu mereka memahami daripada penggunaan informal. Studi ini menyimpulkan bahwa penyertaan data iklim lokal dalam kurikulum meningkatkan literasi iklim siswa. Kebutuhan akan infrastruktur pemantauan yang lebih baik dan pendidikan berbasis teknologi untuk pendidikan iklim yang lebih efektif dan partisipasi pemuda yang berkelanjutan ditekankan.

INTRODUCTION

Climate change is a pressing global issue that necessitates immediate attention and action, particularly in the context of education. Climate change education (CCE) plays a crucial role in addressing the global crisis and promoting sustainable development. Education can empower individuals and communities to make informed decisions and take practical actions toward climate-resilient development, especially in regions such as East Africa, where economies heavily rely on climate-dependent activities (Apollo & Mbah, 2021). However, the effectiveness of CCE depends on various factors, including framing, audience characteristics, and teaching approaches. Interestingly, research has shown that global warming and climate change can elicit different responses, with global warming being more emotive and polarizing (Benjamin et al., 2017). This framing effect is particularly strong among political Independents and those disengaged from climate change issues, highlighting the importance of tailoring communication strategies to different audiences. Additionally, climate justice education, which considers the unequal impacts of climate change across racial, socioeconomic, geographic, and intergenerational lines, can be impactful in motivating climate actions and activism (Borgerding et al., 2024). In conclusion, effective CCE requires a multifaceted approach that accounts for the complexities of the issue and the diverse needs of learners. This includes addressing misconceptions, such as the common confusion between global warming and ozone depletion (Cordero et al., 2008) and incorporating action-oriented learning to enhance student understanding (Karpudewan et al., 2015). By focusing on collective interest and emphasizing the interconnectedness of environmental issues (Lubell et al., 2007), education can foster a sense of responsibility and motivate individuals to act against climate change. Ultimately, CCE is not only about imparting knowledge but also about cultivating environmental values and attitudes that will shape a sustainable future (Imran et al., 2024).

Educating young people about climate change is crucial for fostering informed and responsible future citizens who can contribute to sustainable development. Education plays a vital role in addressing climate change and promoting sustainable development by equipping young people with the knowledge, skills, and attitudes necessary to become informed and responsible citizens. Green education raises awareness about environmental issues, encourages positive behavior changes, and empowers individuals to act (Aggarwal, 2023). This approach is crucial for preparing the next generation to become proactive adults in

promoting environmental sustainability across industries and communities (Senka et al., 2024). The importance of educating young people about climate change is recognized in international frameworks. The United Nations Framework Convention on Climate Change, through Article 6, calls on governments to implement educational and training programs on climate change (Narksompong & Limjirakan, 2015). However, there are challenges in implementing these policies effectively. For instance, in Thailand, national policies insufficiently address the education and engagement of youth on climate change issues (Narksompong & Limjirakan, 2015). To address these challenges, education for sustainable development and CCE should be integrated into various learning contexts. This requires interdisciplinary and holistic methods that consider diverse learning styles, backgrounds, and circumstances (Mochizuki & Bryan, 2015; Veckalne & Tambovceva, 2022). Universities play a crucial role in shaping societal ideals and preparing future decision-makers (Rosak-Szyrocka et al., 2022). By fostering critical thinking, social engagement, and innovative problem-solving skills, education can empower young people to actively participate in addressing climate change and promoting sustainable development (Mochizuki & Bryan, 2015; Veckalne & Tambovceva, 2022). Additionally, providing opportunities for active engagement can help young people cope with their feelings about climate change and build a sense of efficacy (Sanson et al., 2019).

The use of digital tools in environmental education has shown positive impacts on students' concern for sustainability (Hajj-Hassan et al., 2024). Additionally, research has explored climate education practices and future outlooks among 16-18-year-old secondary school students in England, revealing mixed emotions about the future and a strong positive correlation between hope and action competence (Finnegan, 2023). Interestingly, there are some contradictions in the findings across different regions. While Finnegan (2023) focused on students in the United Kingdom, Eze (2020) examined students in Nigeria and found significant gender differences in climate change awareness and willingness to adopt pro-environmental behavior, with male students showing higher levels of both. This highlights the importance of considering regional and cultural contexts when studying CCE. In conclusion, while there is substantial research on CCE, the focus on higher secondary education in specific regions remains limited. The studies reviewed primarily cover general secondary education or broader age ranges. Future research could benefit from more targeted investigations of climate change awareness and education strategies for higher secondary students in diverse geographical contexts, considering factors such as digital tools, emotional responses, and sociocultural influences (Hestness et al., 2019).

Kerala's climate risk profile is further substantiated by the composite vulnerability index, which classifies all 14 districts into high, medium, and low-vulnerability categories. The assessment reveals that most districts (nine out of fourteen) fall into the high-vulnerability category, including Wayanad, Kozhikode, Kasaragod, Palakkad, Alappuzha, Idukki, Kannur, Malappuram, and Kollam, with Wayanad identified as the most vulnerable district in the state. Two districts, Kottayam and Thiruvananthapuram, are categorized as moderately vulnerable, while Pathanamthitta, Ernakulam, and Thrissur are considered to have relatively low vulnerability, with Pathanamthitta being the least vulnerable. This spatial distribution of vulnerability highlights Kerala's widespread exposure to climate-related risks and reinforces the urgency of integrating localized climate understanding into education. The predominance of highly vulnerable districts underscores the need for region-specific, data-driven climate education approaches that can effectively connect students' lived experiences with scientific knowledge (Directorate of Environment and Climate Change, 2023). Despite the recognized importance of climate education, there is a lack of comprehensive research on its implementation and effectiveness in Kerala's higher secondary schools.

Climate knowledge is incorporated into the school curriculum in Kerala, particularly through subjects such as Geography, Biology, and Environmental Studies. However, this inclusion is largely theoretical, with limited emphasis on practical or experiential learning. Students are often introduced to concepts such as climate change, global warming, and environmental conservation, but opportunities to connect these ideas with real-world observations and local environmental data

remain minimal. As a result, there is a gap between conceptual understanding and practical application, highlighting the need for more hands-on, data-driven approaches to strengthen climate literacy and meaningful student engagement.

Climate change education has been recognized as crucial for developing environmentally informed and active citizens (Cutter-Mackenzie & Smith, 2003). However, implementation in schools has been problematic and has limited success, with barriers to effective implementation not fully understood (Cutter-Mackenzie & Smith, 2003). This suggests that Kerala may face similar challenges in implementing comprehensive climate education programs. Studies have shown that knowledge is a key initial driver for climate action, especially among young people (Kolenatý et al., 2022). Sufficient climate change knowledge positively influences climate change concern, self-efficacy, and willingness to act (Kolenatý et al., 2022). This highlights the importance of developing robust climate education programs in Kerala's higher secondary schools to foster climate literacy and action. Research has revealed gaps in teachers' knowledge of environmental education, with many functioning at levels of ecological illiteracy or nominal ecological literacy (Cutter-Mackenzie & Smith, 2003). This suggests that teacher training and professional development in CCE should be a priority for Kerala's education system. To address these challenges, interdisciplinary approaches have shown promise. For example, integrating CCE into social studies and language arts frameworks has demonstrated high levels of climate literacy and student engagement (Siegner & Stapert, 2020). Kerala could consider similar interdisciplinary approaches in its higher secondary curriculum. In conclusion, while there is a lack of specific research on climate education in Kerala's higher secondary schools, the available literature suggests that developing context-specific strategies, addressing teacher knowledge gaps, and implementing interdisciplinary approaches could be effective in enhancing climate education in the region. This study seeks to address this gap by examining the current state of CCE in Kerala's higher secondary schools and its impact on students' awareness.

Climate change education in higher education institutions is recognized as crucial for addressing scientific, environmental, social, and political challenges (Jeong et al., 2021). Studies have shown that interventions such as flipped Classroom approaches can increase preservice teachers' awareness of climate change, making them more willing to engage in climate change teaching (Jeong et al., 2021). Experiential CCE has been found to be effective in improving students' knowledge and increasing motivation to care for the environment. A study of secondary school Biology lessons showed statistically significant differences in knowledge and motivation after implementing experiential-based activities (Karpudewan & Mohd Ali Khan, 2017). However, educators face challenges in balancing awareness-raising with potential eco-anxiety among students. Some educators prioritize improving nature connection over raising awareness of environmental problems, emphasizing hope and pro-environmental behaviors to avoid eliciting eco-anxiety (Edwards et al., 2023). While there is no specific data on Kerala's higher secondary schools, research suggests that effective CCE can raise awareness and motivate students to act. However, effectiveness depends on the teaching approaches used and the balance struck between raising awareness and managing potential eco-anxiety. Further research specific to Kerala's context would be necessary to assess the effectiveness of their current CCE programs.

The purpose of this study is to evaluate the effectiveness of CCE programs in enhancing awareness, understanding, and proactive engagement among higher secondary school students in Kerala. It seeks to assess the integration of climate change topics within the school curriculum, examine the role of real-time weather station data in improving climate literacy, and identify gaps and challenges in existing educational approaches. By analyzing student perceptions, personal disaster experiences, and the impact of a structured Classroom. The study aims to provide insights to strengthen CCE and promote sustainable development through informed youth participation.

METHOD

Study Area

Kerala, ensconced in the south-western part of peninsular India, stretches along the West coast for 560 km. Physiographically,

Kerala State is demarcated into three distinct natural zones: the Highland, the Midland, and the Lowland, each delineating parallel belts across the state's expanse, varying in width from 15 to 120 km. Kerala State sprawls across the south-western coast of India, spanning from 8°18'N to 12°48'N and 74°52'E to 77°22' E (Figure 1). Encompassing an area of 38,863 km^2 (Jayarajan, 2014). Kerala is ranked first among the major States in India in human development index at the four time points of 1981, 1991, 2001, and 2011. Geographic variation in population dimensions such as age, gender, culture, and economic status, in association with the spatial pattern of the study area's environmental setting, provides the foundation for the analysis and planning of health services (Jayarajan, 2014).

Geographical understanding is essential in addressing student misconceptions and enhancing comprehension of climate change within a geographic framework. As today's youth are poised to become decision-makers and societal influencers at a time when substantial mitigation efforts are required, their engagement in climate change mitigation is of utmost importance. Acknowledging the complexity of CCE, researchers use a mixed-methods approach that integrates qualitative and quantitative methods.

Climate change is perhaps one of the most important global challenges with dangerous repercussions for the environment and society. Extreme weather events, including floods, landslides, and erratic rainfall, are increasingly common. This makes CCE crucially important. Schools, which greatly influence children's minds, can be spaces where climate change awareness, resilience, and catastrophe learning are taught. In this respect, a deeper understanding of CCE and how students are taught about and perceive it will help create future citizens who are informed, proactive, and action oriented. The strengths of students' capacity to respond effectively to ongoing and

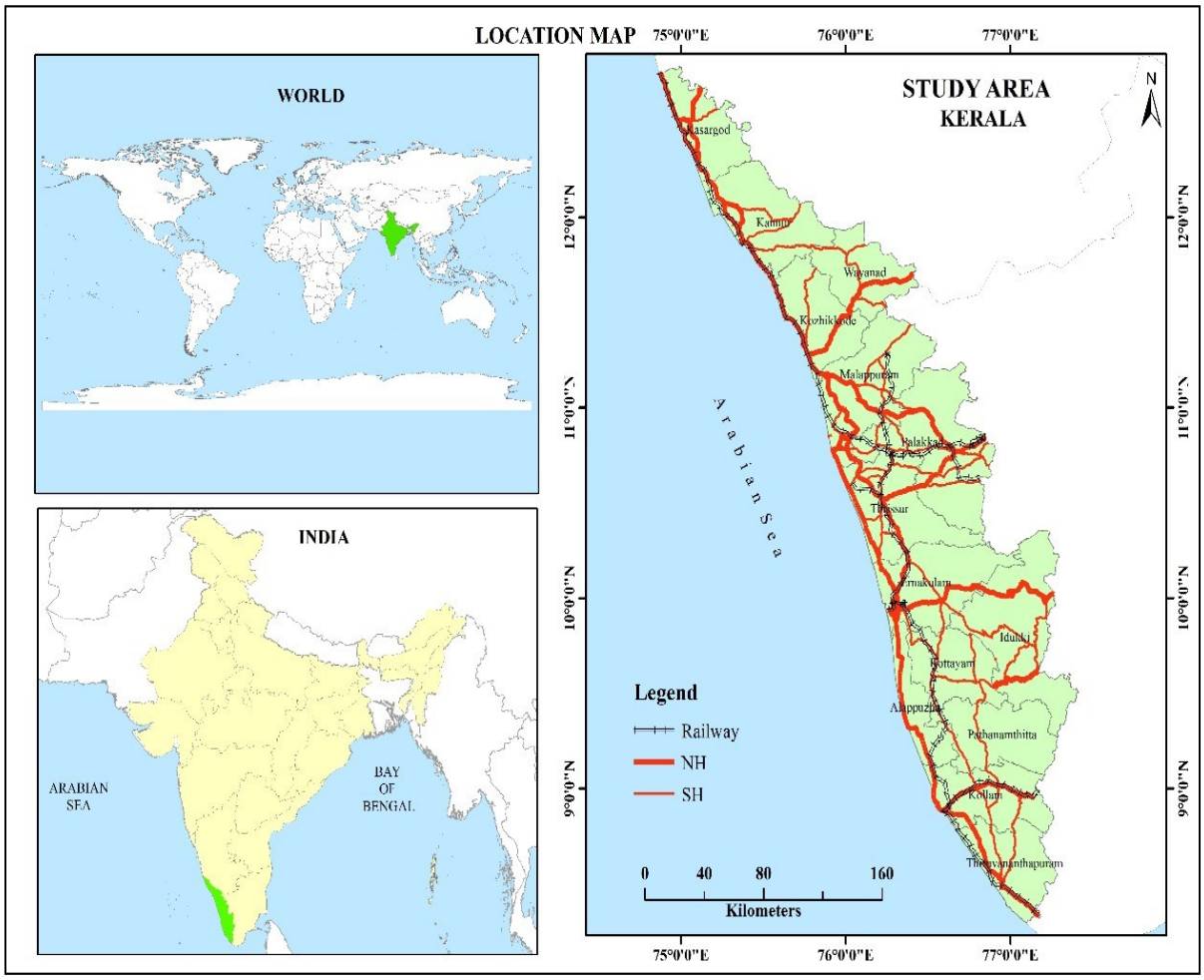

Figure 1. Study Area of Kerala

future environmental challenges. Moreover, it encourages the development of sustainable behaviors that can be sustained across generations.

Research Design

A mixed-method research design was adopted in this study to assess the effectiveness of CCE among higher secondary school students in Kerala (Figure 2). This approach combines both quantitative and qualitative techniques to obtain a comprehensive understanding of students' knowledge, perceptions, and engagement with climate change issues. The methods allow for triangulation of findings, thereby improving the robustness of the results.

Figure 2. Students Collecting Weather Data from School Weather Station

Sampling Techniques

All 14 districts of the state were covered using a random sampling technique to ensure representativeness across diverse geographical and socio-environmental contexts. The inclusion of all districts allows the study to capture spatial heterogeneity in climate change awareness and education practices.

Data were collected from 240 government schools equipped with weather stations, which were specifically selected to facilitate the integration of real-time environmental data into the teaching-learning process (Figure 3). This selection criterion strengthens the study's relevance in examining how experiential and data-driven learning influences climate literacy.

Data Collection

A structured questionnaire was administered to students from December 2023 to May 2024, resulting in a total of 1,514 responses. The questionnaire was designed to capture students' perceptions, experiences, and educational exposure related to climate change across multiple subject areas.

In addition to the survey data, curriculum documents were systematically analyzed to understand the extent to which climate change topics are formally incorporated into the education system. Classroom practices were also evaluated to examine how these topics are delivered in real teaching contexts.

Variables and Measurement

The variables included in the questionnaire were grouped into six main areas: awareness of climate change; personal experience in climate-related events; coping strategies; awareness and understanding of mitigation measures; awareness and use of weather station data; and integration of climate change topics in the school curriculum.

This categorization allows for a structured examination of different dimensions of climate literacy, ranging from cognitive understanding to behavioral responses. It also enables the identification of key domains that contribute to students' engagement with climate change issues.

Data Analysis

The underlying patterns and relationships in the quantitative data were explored using multivariate statistical analysis. Factor analysis was conducted using Principal Component Analysis with Varimax Rotation and Kaiser Normalization to identify the dominant factors influencing students' beliefs and engagement regarding climate change.

Through this approach, the central drivers of climate literacy were identified, while the systematically coded dataset enabled both descriptive and inferential statistical analysis. These techniques provide a rigorous basis for understanding complex relationships among variables.

Geospatial Analysis Integration

Spatial analysis in ArcGIS 10.4 was conducted to identify regional differences and problem areas related to climate education and sustainable planning. This analysis helps to reveal geographical disparities in access to climate education and learning resources. By integrating geospatial analytics with student perception data, the study provides a deeper understanding of how local exposure to climate risks influences educational outcomes. This combined analytical framework highlights the importance of contextual and place-based learning approaches in promoting climate literacy, particularly in regions with varying environmental vulnerabilities.

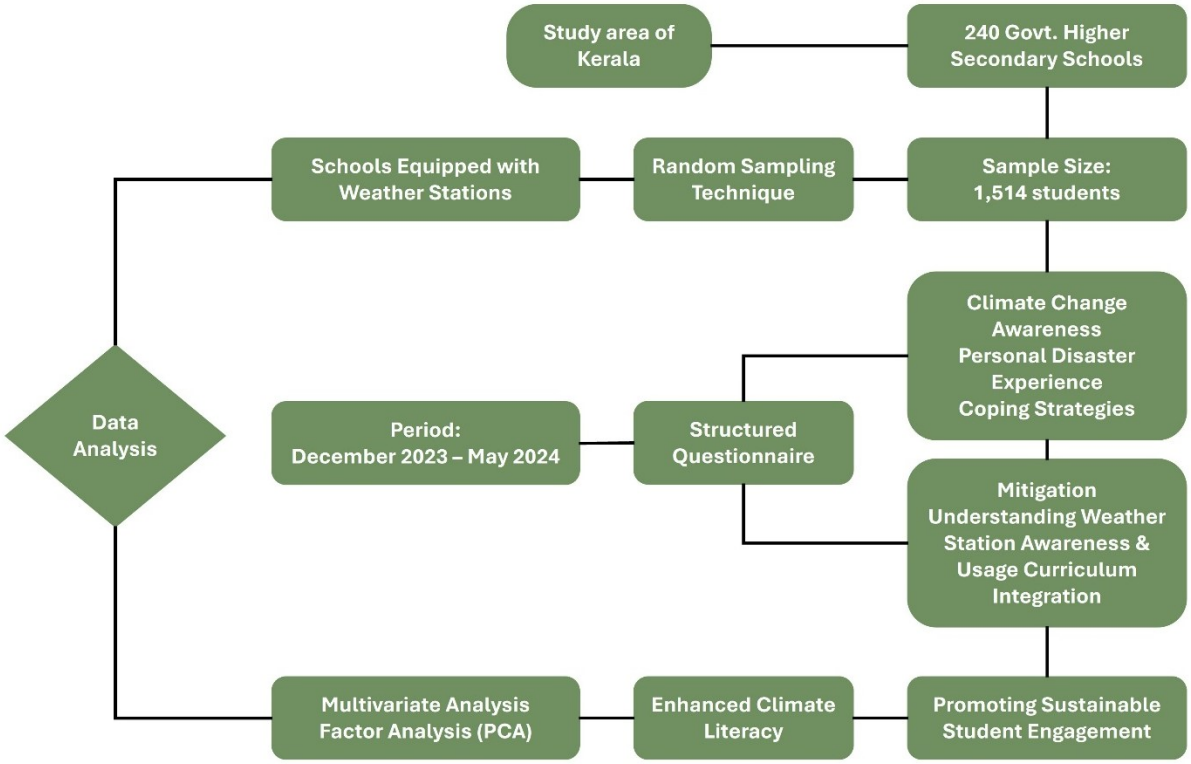

Figure 3. Methodological Framework

RESULT AND DISCUSSION

Perceived Climate Change Impact and Disaster Experience

The Total Variance Explained table presents the results of a factor analysis, showing how much variance in the dataset is explained by each component. The first five components have eigenvalues greater than 1, indicating they account for a significant portion of the variance, while the remaining components contribute minimally. The first component explains 31.48% of the variance, the second adds 21.89%, and the third contributes 18.59%, cumulatively explaining 71.96% of the variance. The fourth and fifth components further increase the cumulative variance explained to 91.41%, suggesting that these five factors capture most of the meaningful patterns in the data. After rotation, the variance distribution shifts slightly, with the first component explaining 30.64%, and the second to fifth components collectively accounting for 91.41% of the variance. The remaining components contribute negligible variance, reinforcing that only five key factors are needed to represent the dataset effectively (Table 1).

Table 1. Total Variance Explained

Component	Initial Eigen Values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.93	31.48	31.47	6.93	31.48	31.48	6.74	30.64	30.64
2	4.82	21.89	53.36	4.82	21.89	53.37	4.33	19.67	50.31
3	4.09	18.59	71.95	4.09	18.59	71.96	3.77	17.11	67.42
4	2.92	13.25	85.21	2.92	13.25	85.21	3.53	16.04	83.46
5	1.36	6.19	91.40	1.36	6.19	91.41	1.75	7.95	91.41
6	1.00	4.53	95.93						
7	0.45	2.04	97.96						
8	0.19	0.88	98.84						
9	0.17	0.75	99.60						
10	0.05	0.24	99.84						
11	0.03	0.12	99.96						
12	0.01	0.04	99.99						
13	0.01	0.00	100						

Table 2. Perceived Climate Change Impact and Disaster Experience

Sl no	Variables	Eigen Value
1	Have you personally noticed any changes in weather patterns in your region due to climate change?	0.99
2	Not experienced the direct impact of climate change	0.99
3	Experienced natural disasters in life	0.97
4	No idea about the data from the weather station should be integrated into your school curriculum	0.64
5	Never experienced natural disasters	-0.97
6	The family experienced the direct impact of climate change	-0.99
7	Not personally noticed that your region experienced any kind of changes in the weather pattern due to climate change?	-0.99

The factor loadings indicate a primary dimension associated with perceived climate change impact and disaster experience (Table 2; Figure 4a). High positive loadings for variables such as personally noticing changes in weather patterns (0.99), experiencing natural disasters (0.97), and not experiencing the direct impact of climate change (0.99) indicate strong correlations with awareness and direct exposure to climate-related events. Conversely, negative loadings for never experiencing natural disasters (-0.97), family experiencing the direct impact of climate change (-0.99), and not personally noticing weather changes (-0.99) suggest an inverse relationship, wherein individuals who have not encountered disasters or direct impacts perceive climate change differently. Furthermore, the moderate loading for uncertainty about integrating weather data into school curricula (0.64) underscores gaps in climate education. This dimension encapsulates perceived climate change impact and disaster awareness, reflecting variations in personal experience, perception, and educational awareness regarding climate change and natural disasters.

Climate Change Awareness and Education

The factor loadings presented indicate a robust association with climate change awareness and education (Table 3; Figure 4b). High positive values for variables such as knowledge about climate change (0.96), belief in the current or future impact of climate change

(0.96), and the importance of climate education (0.96) suggest that this dimension encapsulates individuals' awareness, perceived impact, and the necessity for climate education. Notably, the variable indicating a lack of awareness of climate change (0.96) also exhibits a high loading, suggesting that this factor encompasses both awareness and unawareness across individuals. The negative loading for the variable indicates that weather station data does not influence personal actions (-0.60), suggesting that individuals who are aware of climate change are more likely to be influenced by data and act. This dimension can be aptly labelled climate change awareness and education.

Table 3. Climate Change Awareness and Education

Sl no	Variables	Eigen Value
1	Knowledge about climate change	0.96
2	Climate change is affecting you, or is going to affect you	0.96
3	Climate education is important in the present context	0.96
4	Not heard of climate change	0.96
5	Did the weather station data not influence any personal actions or behaviors related to the environment or climate change?	-0.60

Awareness and Perception of Climate Change

The respondents demonstrate a notably high level of awareness and understanding of climate change, with a substantial proportion (0.91) having heard of and possessing knowledge about the issue, indicating a robust foundational comprehension (Table 4; Figure 4c). Furthermore, the same proportion (0.96) acknowledges that climate change is currently impacting them or is likely to do so in the future, reflecting a significant degree of personal concern and perceived vulnerability. However, the belief in the feasibility of mitigating climate change is comparatively lower (0.71), suggesting a disparity between awareness and confidence in actionable solutions. This observation underscores the necessity of integrating awareness with empowerment strategies to enhance proactive engagement in climate change mitigation efforts.

Table 4. Awareness and Perception of Climate Change

Sl no	Variables	Eigen Value
1	Not heard of climate change	0.96
2	Knowledge about climate change	0.96
3	Climate change is affecting you or is going to affect you	0.96
4	Something can be done to tackle climate change	0.71

Influence of Weather Station Data Communication on Student Engagement

The way weather station data is presented to students plays a crucial role in shaping their environmental awareness and actions (Table 5; Figure 4d). The Classroom discussions demonstrate a positive correlation (0.64) with student engagement, indicating that structured discussions can effectively enhance understanding and awareness. Conversely, uncertainty about how this data affects personal actions or behaviors related to climate change is negatively correlated (-0.74), suggesting that a lack of clarity or conviction may lead to disengagement. Furthermore, when weather station data is communicated via digital platforms or in informal settings, the correlation is even more negative (-0.93), suggesting that these methods may be less effective than Classroom discussions.

Table 5. Influence of Weather Station Data Communication on Student Engagement

Sl no	Variables	Eigen Value
1	The weather station data is communicated to students in your school through Classroom discussion	0.64
2	Not sure about the data, did not influence any personal actions or behaviors related to the environment or climate change?	-0.74
3	The weather station data is communicated to students in your school through other modes	-0.93

Integration of Weather Station Data in School Curriculum

The integration of weather station data into the school curriculum exhibits a strong positive correlation (0.77), indicating substantial support or uncertainty regarding its necessity in formal education (Table 6; Figure 4e). The provision of education on climate change and its impacts also demonstrates a positive correlation (0.64), suggesting that structured instruction on climate-related topics enhances students' awareness and understanding. Conversely, the communication of weather station data through Classroom discussions shows a negative correlation (-0.53), implying that while such discussions may be informative, they may be less effective at fostering engagement or comprehension than direct curriculum integration. This underscores the need for a structured approach to incorporating real-time weather data into formal education to enhance climate education.

Table 6. Integration of Weather Station Data in School Curriculum

Sl no	Variables	Eigen Value
1	Not sure about the data from the weather station should be integrated into your school curriculum	0.77
2	Received education at school about climate change and its effects	0.64
3	The weather station data is communicated to students in your school through Classroom discussion	-0.53

Composite Index

The composite index values across districts exhibit significant variation (Table 7; Figure 4f). Ernakulam demonstrates the highest composite index (5.05), indicating robust positive performance across multiple indicators, followed by Wayanad (2.83), Alappuzha (1.50), Kannur (1.42), and Malappuram (0.86), suggesting relatively superior outcomes in these regions. Kollam (0.10) and Thrissur (0.01) display near-neutral performance. In contrast, Palakkad (-4.01) and Thiruvananthapuram (-2.3) present the lowest composite index scores, indicating substantial challenges. Idukki (-1.60) and Kasargod (-1.42) also exhibit negative performances, albeit less severe. Pathanamthitta (-0.03) and Kottayam (-0.01) have composite scores close to zero, reflecting a balance of positive and negative factors (Table 7). Overall, the data underscores pronounced regional disparities, with certain districts performing significantly better across indicators than others.

Table 7. Composite Index

District	Factor I	Factor II	Factor III	Factor IV	Factor V	Composite Index
Thiruvananthapuram	-0.27	0.45	-2.16	0.60	-0.65	-2.30
Kollam	0.79	0.49	-0.12	-0.14	-0.91	0.10
Kottayam	-0.02	0.45	0.16	0.38	-0.98	0.01
Panthanamthitta	-2.09	0.72	0.64	0.66	-0.03	-0.03
Alappuzha	-0.19	0.51	0.96	0.21	0.03	1.50
Idukki	0.78	-2.36	0.66	-0.64	-0.04	-1.60
Ernakulam	0.31	0.63	0.19	1.46	2.47	5.05
Thrissur	-0.19	-1.63	0.61	1.54	-0.32	0.01
Palakkad	-0.96	-1.21	-2.14	-0.83	0.98	-4.01
Malappuram	1.40	0.76	-0.17	-0.75	-0.38	0.86
Kozhikode	0.53	-0.19	0.21	0.95	-1.08	0.42
Wayanad	1.52	0.61	0.06	-0.62	1.26	2.83
Kannur	-0.40	0.69	-0.10	-0.86	-0.75	1.42
Kasargod	-1.22	0.08	1.20	-1.96	0.42	-1.42

Note: Factor I = Perceived Climate Change Impact and Disaster Experience; Factor II = Climate Change Awareness and Education; Factor III = Awareness and Perception of Climate Change; Factor IV = Influence of Weather Station Data Communication on Student Engagement; and Factor V = Integration of Weather Station Data in School Curriculum.

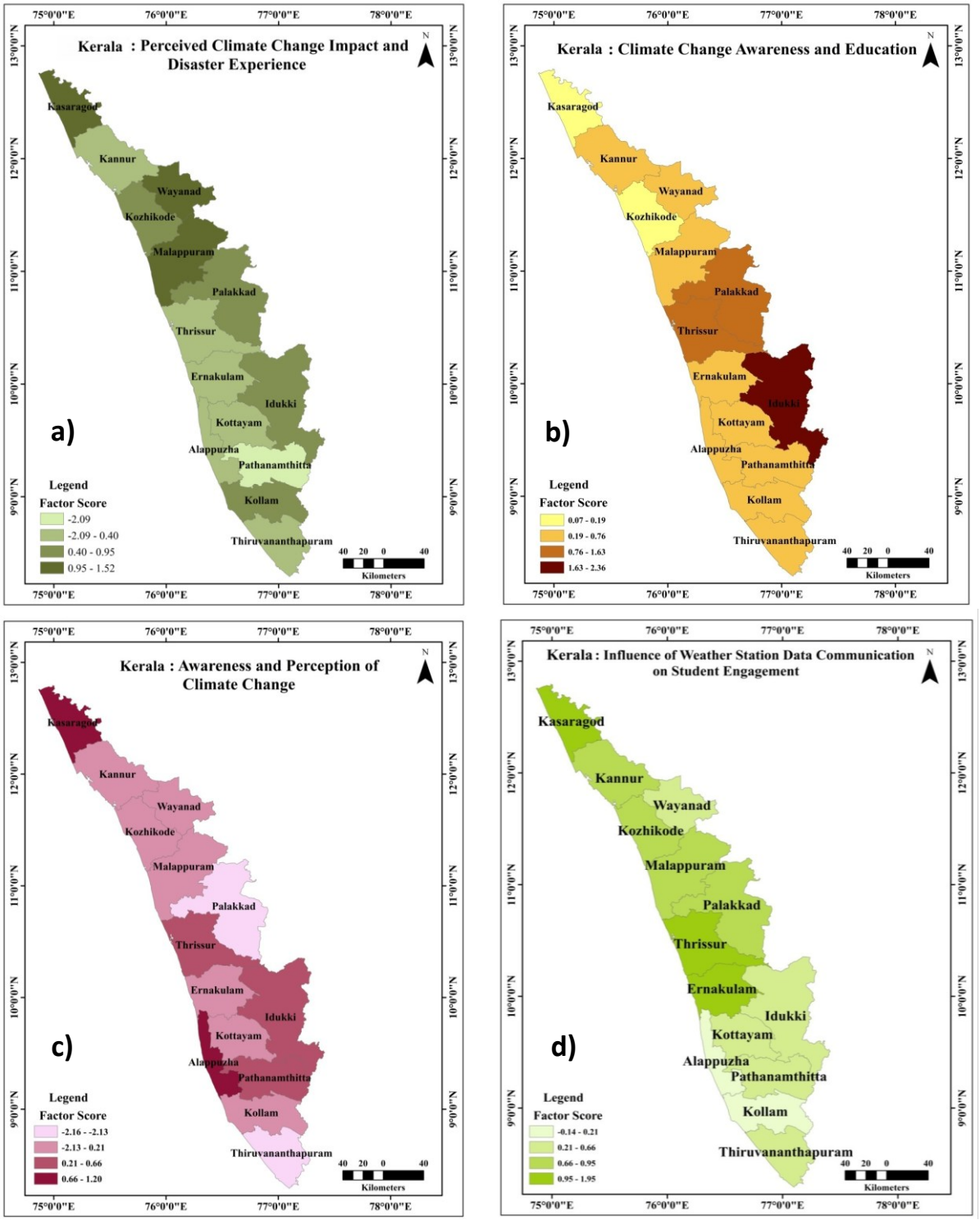

Figure 4. a) Perceived Climate Change Impact and Disaster Experience; b) Climate Change Awareness and Education; c) Awareness and Perception of Climate Change; d) Influence of Weather Station Data Communication on Student Engagement; e) Integration of Weather Station Data in School Curriculum; and f) Composite Index of Climate Change Awareness and Education

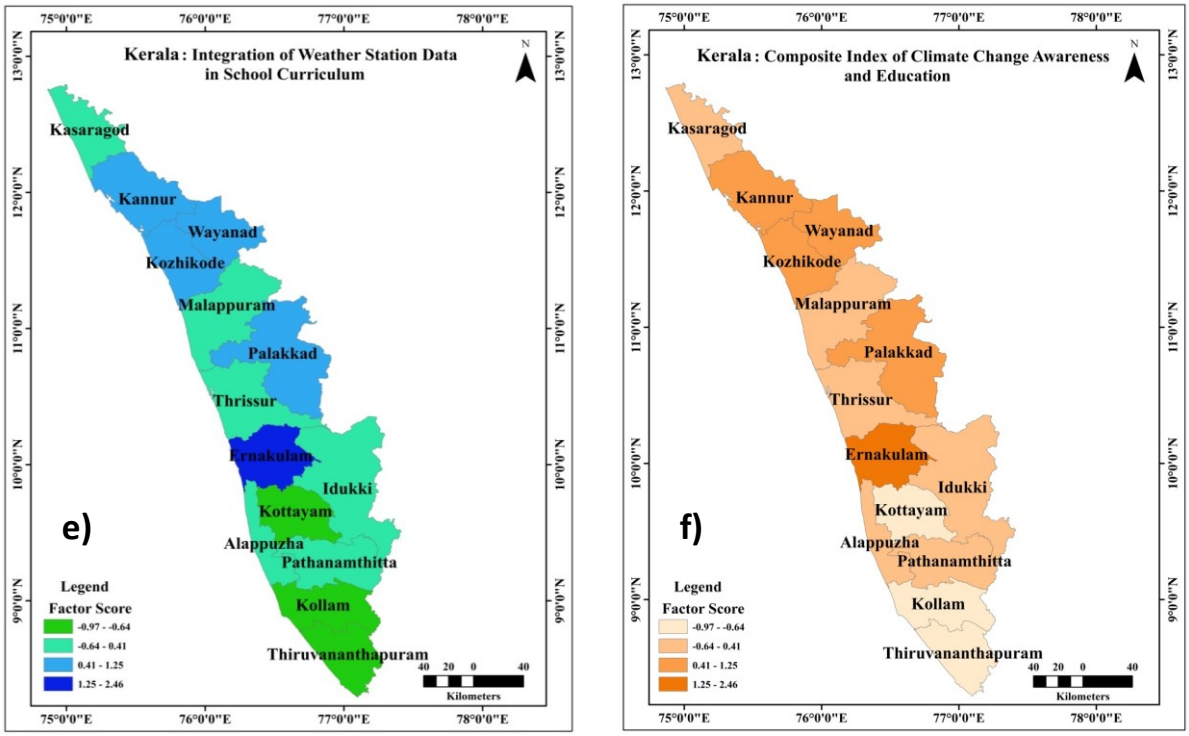

Figure 4. Continued

Perceptions of climate change and disaster experiences strongly influence individual perceptions. High positive factor loadings reveal that personal encounters with changing weather patterns and disasters deepen climate change awareness. Conversely, those without such experiences show inverse perceptions. Moderate loadings regarding climate education highlight significant gaps, emphasizing the role of disaster awareness and direct experience. Research indicates that personal experiences with extreme weather events and climate change impacts significantly influence individuals' perceptions and attitudes towards climate change (Reser et al., 2014; Ogunbode et al., 2017; Diakakis et al., 2021). These direct encounters often lead to increased climate change awareness, heightened risk perceptions, and greater acceptance of its realities (Reser et al., 2014; Ettinger et al., 2024). Interestingly, the relationship between weather experiences and climate change attitudes is not always straightforward. Factors such as political affiliation, values, and pre-existing beliefs can moderate how individuals interpret and integrate these experiences into their climate change attitudes (Ogunbode et al., 2017; Howe, 2018). For instance, the link between flood experience and preparedness to reduce energy use was observed among left-leaning voters but not right-leaning voters in the United Kingdom (Ogunbode et al., 2017). In conclusion, while personal experiences with climate change impacts and disasters generally deepen climate change awareness, their interpretation is influenced by various psychological and sociocultural factors (Reser et al., 2014; Van der Linden, 2015; Howe, 2018). This highlights the complex nature of perceptions of climate change and emphasizes the need for targeted communication strategies that account for individual differences in values, beliefs, and experiences when addressing it (Corner et al., 2014; Bain et al., 2016; Antronico et al., 2020; Venghaus et al., 2022).

Climate awareness and education reflect a broad spectrum of understanding. High factors show strong awareness of climate change impacts and the need for education. However, the inclusion of "not heard of climate change" suggests varying levels of awareness. Negative loading for ignoring weather data highlights informed individuals' proactive responses. Awareness and perception of climate change are generally high among respondents, with many recognizing its potential impact on their lives. However, confidence in their ability to mitigate climate change remains relatively low, revealing a gap between awareness and empowerment. This highlights the need for strategies that foster

proactive climate action. Climate change awareness and education among students span a broad spectrum, with varying levels of understanding and perception. Studies have shown that most respondents are aware of climate change and its potential impacts on human health (Toan et al., 2014). In Vietnam, for instance, 79.3% of non-slum and 70.1% of slum area residents had heard about climate change and its impact on human health (Toan et al., 2014). Interestingly, there are contradictions in the level of awareness and understanding across different populations. While some studies indicate high awareness, others reveal limited knowledge about specific aspects of climate change. For example, in China, although 91.4% of participants agreed that the earth was experiencing climate change, only 22% had heard of carbon capture, utilization, and storage technology, with a mere 3.6% having a good understanding of it (Li et al., 2017). Additionally, student teachers were found to hold misconceptions about the mechanisms of climate change, often confusing the greenhouse effect with ozone depletion (Papadimitriou, 2004). In conclusion, while general awareness of climate change is relatively high, there is a need for more comprehensive education to address misconceptions and improve understanding of specific climate-related issues. The varying levels of awareness and understanding highlight the importance of tailored educational approaches and communication strategies to effectively engage different populations in climate change mitigation and adaptation efforts (Cook & Overpeck, 2019; Newsome et al., 2023).

The influence of weather station data communication on student engagement is significant. Structured Classroom discussions using this data enhance environmental awareness and active participation. In contrast, informal or unstructured communication correlates with lower engagement levels. This highlights the greater effectiveness of interactive, guided discussions over passive or less organized approaches. The statement provided is not directly supported by the given context. In general, student engagement is crucial for successful learning outcomes and academic development (Wang & Ji, 2021). Various strategies can be employed to enhance student engagement, such as interactive activities, technology use, and collaborative tasks (Ullah & Anwar, 2020). While weather station data is not explicitly mentioned, the use of real-world projects and structured discussions has been shown to be beneficial for student content engagement (Martin & Bolliger, 2018). It's worth noting that Rivera et al. (2023) discuss a cost-effective local weather station that provides efficient in situ measurements of various environmental parameters. Although this paper doesn't directly address student engagement, it highlights the potential for using such data in educational settings. The open-source nature of this weather station could potentially be leveraged to create engaging learning experiences, aligning with the findings from other papers that emphasize the importance of technology use and real-world applications in promoting student engagement (Montgomery et al., 2015; Ullah & Anwar, 2020). In conclusion, while the specific claim about the influence of weather station data communication on student engagement is not directly supported by the given context, the literature suggests that incorporating real-world data and technology into structured Classroom discussions could enhance environmental awareness and active participation. However, further research is needed to establish a direct link between weather station data communication and student engagement in environmental education.

There is strong support for integrating weather station data into the school curriculum to enhance climate education. Structured use of real-time data significantly improves student awareness and understanding. In contrast, informal discussions without proper curricular backing are less effective, underscoring the need for systematic, formalized curriculum development around climate data. Several studies highlight the importance of climate literacy and the need for innovative approaches in climate education. The Heat-Cool Initiative, for instance, successfully implemented a playful learning tool using infrared cameras to explore urban heat issues, resulting in increased climate change literacy among primary and secondary school students (Kumar et al., 2023). This approach demonstrates the potential of technology-enhanced science, technology, engineering, and mathematics education programs in improving learning outcomes related to climate change. However, there are challenges in directly integrating weather

station data into school curricula. Ganesan et al. (2024) note that while commercially available automated weather stations offer cost-effective solutions for meteorological data collection, limited local deployment and reliance on expensive options hinder comprehensive monitoring efforts. Additionally, Gao et al. (2018) point out that weather station data may not directly measure some important climate factors, such as solar radiation, which are crucial for a comprehensive understanding of climate change. In conclusion, while there is support for enhancing climate education in schools, the direct integration of weather station data into curricula is not strongly emphasized in the provided papers. Instead, the focus appears to be on developing innovative, technology-enhanced approaches to climate education that can improve students' understanding of climate change and its impacts. Future research could explore ways to effectively incorporate weather station data into these educational programs to further enhance climate literacy.

Building upon the findings, future initiatives should prioritize the widespread installation of weather stations in all higher secondary schools throughout Kerala to enhance climate literacy. The development of innovative curricula that integrate technology and systematically incorporate real-time climate data will be essential. Additionally, strengthening teacher training programs, promoting student-led climate action initiatives, and conducting longitudinal studies to evaluate the long-term impacts of climate education can further empower youth. Collaborations among educational institutions, government agencies, and local communities will be crucial in cultivating a resilient generation capable of making informed, sustainable decisions in response to climate change.

CONCLUSION

Climate change education in Kerala has been successful in creating a general awareness among higher secondary students. However, a gap between their knowledge and understanding becomes apparent, and their inaction becomes evident. The students' perceptions of climate-related phenomena are largely shaped by their own experiences with climate-induced disasters, which means these must be linked to education. The identification of key dimensions through multivariate analysis further confirms that awareness, experiential learning, and access to localized climate data are critical in shaping climate literacy.

More importantly, using weather station data in class can increase student engagement and improve learning outcomes. This shows that the curriculum could more effectively link the theory behind climate change to students' lived experiences by including real-time local data. However, the limited reach of weather stations and the call for extensive climate monitoring systems indicate a need for targeted policy and infrastructure support. In conclusion, the study reveals the need for climate education to be more experiential, data-driven, and tech-enabled. When climate data is integrated into the curriculum and access to localized climate data is improved through innovative, interactive strategies, climate literacy can be strengthened. Through these efforts, students are enabled and empowered to become active agents of sustainability, energy, and climate change action and rebuilding.

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