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Assessing High School Students' Conceptual Knowledge, Adaptation, and Mitigation of Climate Change in Aceh, Indonesia

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Abstract: The phenomenon of climate change has been observed in Aceh, Indonesia. However, no study has specifically examined high school students' conceptual knowledge, adaptation strategies, and mitigation measures related to climate change in the region. This study aims to assess students' conceptual knowledge, adaptation strategies, and mitigation efforts related to climate change in Aceh, while investigating how these factors are influenced by gender, grade level, geographical landscape, and implementation of green school programs (*Adiwivata*). A sample of 410 students was taken from a total population of 137,283. Data were collected using online questionnaires distributed by teachers and analyzed using descriptive statistics, PCA, and ANOVA. The results of the study show that students' knowledge, adaptation, and mitigation of climate change in Aceh are generally inadequate. This is because the current framework and implementation of climate change education have not effectively achieved the goals of increasing knowledge, adaptation, and mitigation of climate change at the secondary school level. Gender was found to affect Knowledge I, while grade level influenced Mitigation III. The geographic landscape impacts Mitigation I and II. Green school programs have been shown to have a positive effect on Knowledge I, Adaptation I, and all components of climate change mitigation. These results show the need for expanded efforts to improve climate change knowledge, adaptation, and mitigation among high school students in Aceh, through education policies that encourage teachers to implement learning about climate change in a continuous, detailed, and innovative manner.

Keywords: Climate change; Concept knowledge; Adaptation; Mitigation; High school students

1 Introduction

Aceh Province in Indonesia became internationally renowned in disaster management discourse after the 2004 Indian Ocean tsunami. Aceh is located at the western tip of the island of Sumatra, with geological characteristics having a combination of lowlands and mountains [1]. Aceh is surrounded by the sea in its western, northern, and eastern parts. Some of these beaches are beaches with more vulnerable sloping morphologies. The majority of cities in Aceh are located on the slopes of the coast. In addition, the interior of the land is a mountainous area. This area is known for the sources of agricultural products, one of which is rice, which reaches 20 million tons per year [2], and other agricultural products. In addition to its advantages, these characteristics make Aceh vulnerable to natural disasters. Several disaster events have been recorded, namely drought [3], flood [4, 5], flash flood [6], and landslide [7].

According to the Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG), projections show an increase in the annual average air temperature in Aceh Province. The recorded temperature anomalies reveal a consistent warming trend, with values ranging from 0.3℃ to 0.7℃ above the climatological average. This is projected to rise to 1.2℃ by 2045 [8]. Higher than projections, other studies predict an even greater increase, with projected temperature rises of up to 2.04℃ and up to 5℃ by 2100 under two different climate scenarios [9]. This

issue is consistent with the Intergovernmental Panel on Climate Change (IPCC), which states that the global average temperature has reached 1.09℃ and is projected to rise to 1.5℃ [10]. Different vulnerabilities and threats can occur based on Aceh's projected temperature rise scenario.

Previous studies have also identified significant changes in rainfall patterns across the Aceh region, contributing to increased vulnerability to hydrological extremes such as rainfall flooding, prolonged droughts, and the danger of mass wasting [11]. Farmers tend to be aware of changes in rainfall patterns and rising temperatures as these phenomena have resulted in decreased yields and increased pest attacks [12]. Shifting rainfall patterns have had a devastating impact on agricultural productivity in Aceh [13], with farmers expressing concern over the increasing irregularity of rainfall events. In addition, climatic factors have played a role in the sea level rise observed in the coastal waters of Aceh [14]. Over a six-year period, regional sea levels increased by about 0.06 mm, linked to intensive rainfall in coastal zones, rising sea surface temperatures, and related impacts such as tidal flooding and coastal erosion [15]. The climate change indicators observed in Aceh are strongly associated with the increasing likelihood of adverse impacts in the future.

One of the best solutions to deal with the impact of climate change in Aceh is to empower the capacity of the young generation through climate education. Future generations need to be prepared to adapt and mitigate the impact of current and future climate change risks [16]. Climate education can encourage the development of professional, reflective, and critical thinking skills to address climate-related issues [17, 18]. Students can play an active role in disaster risk management, particularly in preparedness and response activities related to climate-induced hazards [19]. Young people are a logical target for climate change education, as they are the ones most directly affected and face the negative consequences of climate change in the future [20].

Students' capacity to act on climate can also depend on their multidimensional, conceptual, adaptive, and mitigation knowledge. Empowering knowledge not only conceptual, but also adaptation knowledge, and mitigation for climate change can influence the achievement of climate control targets [21]. Higher levels of knowledge about climate change are related to increased awareness of the impacts of climate change, which is an important driver of concern about climate change [22]. This concern is believed to lead to attitudes, subjective norms, and perceived behavioral control, which is an indicator of the theory of planned behaviour (TPB) as a strong predictor of intentions and actions [23]. Cognition underlies the ability of individuals to regulate their behavior, to feel vulnerability, and to engage in pro-environmental behavior [24].

Adaptation means human adaptation to natural systems and taking advantage of beneficial opportunities, in response to actual or expected climate stimuli or their impacts, while mitigation is an action to stabilize and reduce greenhouse gas (GHG) levels in the atmosphere [20, 25]. Adaptation increases resilience, while mitigation minimizes anthropogenic forces that exacerbate climate change [26]. Conceptual knowledge of climate change leads to concern about the impacts of climate change, which drives climate change adaptation [22, 27]. Moreover. There is a relationship between specific knowledge about climate change and perceptions of mitigation [28].

Several studies have been conducted on this topic in Aceh. One study examined the increase in ecoliteracy among students involved in the green school program (*Adiwivata*) in Aceh. It recommends improving environmental literacy and fully implementing the four components of a green school program rather than implementing them in a fragmented manner [20]. In addition, research has also been conducted on the role of STEM education in building student climate resilience in Aceh, suggesting the integration of ESTEM (Environmental Sciences, Technology, Engineering, and Mathematics) learning [29]. A study also explored the perception of environmental Sustainability among high school students in Banda Aceh City who participated in the green school program. The study recommends the development of environmental sustainability education in schools as part of the wider education system [30].

There has been no specific research on conceptual knowledge, knowledge of adaptation strategies, and knowledge of mitigation measures of high school students in Aceh. This includes discussing how climate change knowledge is influenced by factors such as gender, grade level, geographic landscape, and the impact of implementing green school programs (*Adiwivata*) compared to schools that do not implement the program. In fact, the analysis of knowledge about climate change is the initial capital to formulate various educational policies and innovations that are right on target.

Gender is studied to complement the issue of disparities in knowledge, attitudes, and behaviors about climate change among students [31–33], especially in Aceh, where Islamic Sharia is applied. Grade levels determine significant variations in knowledge levels about climate change [34–36]. Geographic landscapes play a crucial role in shaping local knowledge about climate change [37–39]. The implementation of the green school program is studied to expand the scope of students' climate change knowledge study, not only conceptual, but also knowledge of adaptation actions, and student mitigation influenced by the type of education obtained. In contrast to studies on aspects of disaster knowledge, perception of environmental Sustainability, environmentally friendly attitudes, and literacy development [30, 40–42].

Therefore, this study aims to assess conceptual knowledge, adaptation strategies, and mitigation actions related to climate change among high school students in Aceh. It also seeks to identify the influence of gender, grade

level, geographic landscape, and participation in green school programs on students' climate change knowledge, adaptation, and mitigation. This assessment needs to be carried out to build an innovative implementation framework in improving student knowledge in Aceh about climate change, including considering psychological factors and environmental sustainability programs that affect it.

2 Method

This study uses a quantitative approach to determine the level of knowledge, conceptualization, adaptation, and mitigation of climate change among high school students in Aceh, as well as to identify the influence of gender, class, landscape, and green school programs on these three components of climate change. The study used a cross-sectional design to estimate the prevalence of outcomes of interest in specific populations [43]. The research population is all high school students in Aceh Province, totaling 137,283 (based on Basic Education Data from the Minister of Education 2023/2024. The sample of research subjects was 410 students obtained from 15 high schools in Aceh Province. The sociodemographic characteristics of the sample students and the location of the school can be seen in Table 1 and Figure 1, respectively.

Data is collected through an online questionnaire managed through Google Forms. This research utilizes the communication network established with teachers to distribute questionnaires and coordinate student participation during regular school hours. Students complete the questionnaire in about twenty minutes. The variety of educational and learning activities between schools resulted in a data collection period that lasted for one month.

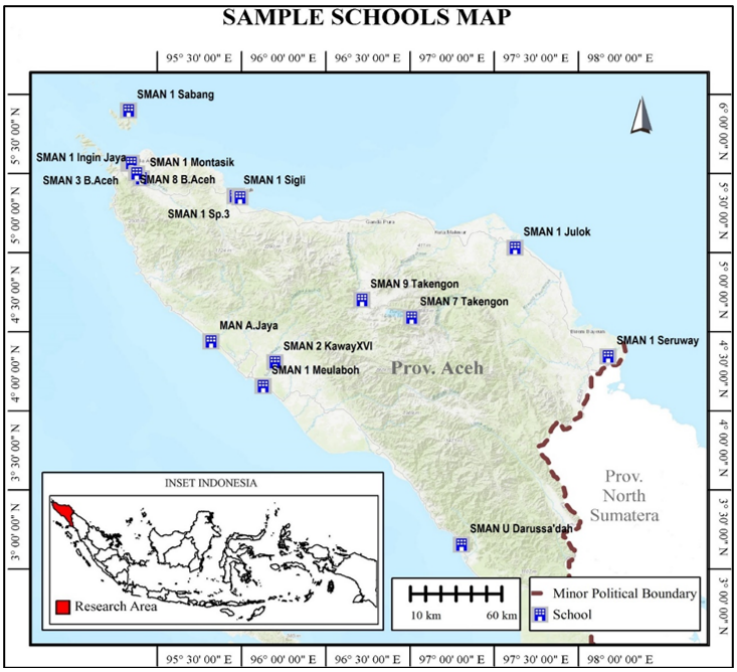

Figure 1. Location of the school studied
Source: Modified world topographic map

Table 1. Sociodemographic characteristics of student respondents

Factor	Characteristics	Students (n = 410)
Gender	Woman	260
	Man	150
Degree	X	241
	XI	106
	XII	63
Geographical landscape	Shore	248
	Lowland	103
	Mountains	59
Green School Program (*Adiwivata*)	*Adiwivata*	109
	Non-Adiwivata	301

The questionnaire consists of twenty-two statement items, including eleven items on climate change knowledge, five on adaptation, and ten on climate change mitigation. The statement is adapted directly from the items in the report table on conceptual knowledge, adaptation, and climate change mitigation [20]. 22 of the 30 statement items were taken by removing items that were not relevant to local conditions, then translated into Indonesian.

In the climate change knowledge section, students are asked about the causes of climate change. In the adaptation section, they respond to things regarding the actions that must be taken to adapt to climate change. In the mitigation section, students are asked about the appropriate response to mitigate the impacts of climate change. Responses were measured using a five-point Likert scale: Strongly Disagree = 1, Disagree = 2, Undecided = 3, Agree = 4, and Strongly Agree = 5. Students who answer "Agree" or "Strongly Agree" for each item (% agree) are considered to have answered correctly. Students are informed that each participation is guaranteed confidentiality and that the answers are for research purposes only and without consequences. Students are free to participate or decline. Any statements in research related to climate change do not contain harmful information and do not affect the personality of the students.

Table 2. PCA outcomes for conceptual knowledge, adaptation, climate change mitigation

Factor	CK Component Loading		M	SD
	I	II		
Item 1	0.79	-	3.16	1.20
Item 2	0.80	-	3.23	1.12
Item 3	-	0.60	3.66	0.87
Item 4	0.51	-	3.18	1.03
Item 5	-	0.50	3.33	0.99
Item 6	0.74	-	3.32	1.12
Item 7	0.75	-	3.10	1.32
Item 8	-	0.75	3.21	1.07
Item 9	0.50	-	3.16	1.04
Item 10	0.65	-	3.32	1.05
Item 11	0.65	-	3.48	1.14
Eigen Value	**4.63**	**1.30**		
Total variance explained (%)	**42.09**	**11.78**		
Total variance factor loading (%)		**53.87**		
KMO Value		**0.89**		

Factor	AK Component Loading		M	SD
	I	II		
Item 1	0.74	-	3.67	0.91
Item 2	0.79	-	3.80	0.88
Item 3	0.78	-	3.74	0.99
Item 4	-	0.69	3.72	0.89
Item 5	-	0.89	3.45	0.85
Item 6				
Item 7				
Item 8				
Item 9				
Item 10				
Item 11				
Eigen Value	**2.22**	**1.03**		
Total variance explained (%)	**44.33**	**20.6**		
Total variance factor loading (%)		**64.93**		
KMO Value		**0.73**		

Factor	MK Component Loading			M	SD
	I	II	III		
Item 1	-	0.76	-	3.46	1.06
Item 2	-	0.65	-	3.74	1.11
Item 3	0.49	-	-	3.65	1.07
Item 4	0.75	-	-	3.88	0.89
Item 5	-	-	0.77	2.81	1.03
Item 6	0.57	-	-	3.69	0.94
Item 7			0.72	3.23	0.90
Item 8	0.61	-	-	3.48	0.90
Item 9	0.77	-	-	3.75	0.89
Item 10	-	0.45	-	3.40	0.96
Item 11					
Eigen Value	2.22	1.50	1.33		
Total variance explained (%)	**22.22**	**15.00**	**13.26**		
Total variance factor loading (%)			**50.48**		
KMO Value			**0.75**		

The questionnaire was analyzed for validity and reliability. Validity was assessed using the Pearson correlation test. Each item that measures conceptual knowledge, adaptation, and mitigation is considered valid if it shows a

significant correlation ($p < 0.05$) between the individual item score and the total score. All items were found to be valid, with significant Pearson correlation values as follows: conceptual knowledge ($p < 0.010$, r = 0.706), adaptation ($p < 0.253$, r = 0.654), and mitigation ($p < 0.390$, r = 0.592). Reliability tested using Cronbach's alpha, with a threshold of $\alpha > 0.5$, indicates acceptable reliability. The questionnaire showed good reliability in all components: conceptual knowledge ($\alpha = 0.836$), adaptation ($\alpha = 0.582$), and mitigation ($\alpha = 0.682$). Therefore, all parts of the questionnaire used in this study were determined to be valid and reliable.

This study analyzed the characteristics of the dataset using descriptive statistics. The percentage of students who voted "Agree" or "Strongly Agree" (% agreed) for each item was used as an indicator of their level of conceptual knowledge, adaptation, and mitigation related to climate change. To overcome the limitations associated with Likert scale data analysis, Principal Component Analysis (PCA) is used to condense questionnaire items into core components, which are treated as new variables [44]. Although there are other relevant analyses such as Exploratory Factor Analysis (EFA) that have the same function in reducing dimensionality and simplifying data, PCA analysis is preferred because it is able to reduce the number of variables while maintaining the most variance in creating new variables (core components) that capture the most important information from the original data [45] rather than simply identifying the latent factors underlying the correlation between observed variables with focusing on joint variance [46].

Analyses with PCA have qualified with a measure of Kaiser-Meyer-Olkin sampling adequacy (KMO) exceeding 0.5 (Table 2). In social science research, PCA typically accounts for 50% to 60% of the total variance [47]. The resulting core components (PCAs) are used as data variables representing students' climate change knowledge, adaptation, and mitigation, which is suitable for comparative analysis without the need for assumption testing. However, an Analysis of Variance (ANOVA) was conducted to examine the influence of gender, grade level, geographical landscape, and the implementation of the Green School Program (*Adiwivata*) on these main component variables. All data analysis was conducted using IBM SPSS Statistics Version 25.

3 Result and Discussion

3.1 Concept of Student Knowledge About Climate Change

As shown in Figure 2, the average percentage of students who agree or strongly agree (% Agree) with a statement of conceptual knowledge of climate change is 52.53%. Fewer students agreed with statements regarding the specific causes of climate change, such as the existence of the Earth's ozone hole (42.93%), the contribution of domestic products to greenhouse gas (GHG) emissions (45.61%), the presence of excessive GHGs in the atmosphere (47.80%), and thermal radiation (IR) traps in the Earth's atmosphere (49.76%). In contrast, a larger percentage of students agreed with statements about the use of fossil fuels such as oil and coal (69.02%) and the impact of emissions from factories and car engines on the increase in atmospheric temperature (61.95%). Less than 50% of students demonstrate a correct understanding of the concept of climate change, particularly as it relates to the existence of the Earth's ozone hole, the role of domestic products in producing greenhouse gases (GHGs), how GHGs contribute to climate change in the atmosphere, and how heat radiation (IR) is trapped in the Earth's atmosphere, contributing to the increase in climate change.

The study's findings are consistent with recent research highlighting high school students' inadequate understanding of the basic concepts driving climate change [48–50]. Many students have misconceptions about climate change, mainly due to inadequate conceptual understanding [48]. Most students show misunderstandings, which reflect a limited and superficial understanding of the causes and impacts of climate change [49]. The majority of students have limited and superficial conceptual knowledge regarding the drivers and impacts of climate change [49].

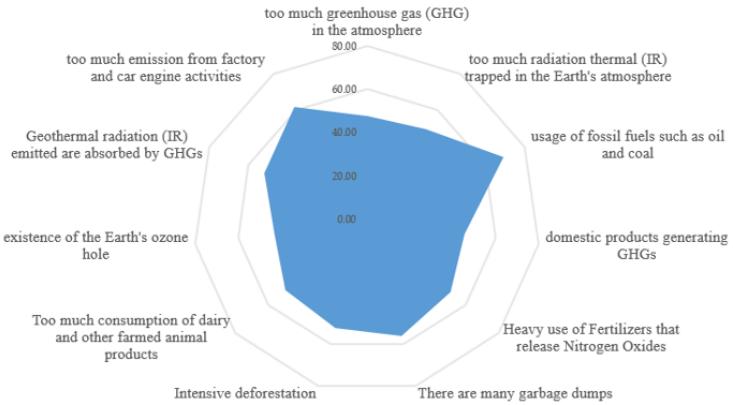

Figure 2. Students' conceptual knowledge of climate change aspects

This gap in conceptual knowledge can be caused by the formulation of educational standards that do not directly invite teachers to teach students about climate change consistently. In the high school education curriculum standards published by the Education Standards, Curriculum and Assessment Agency of Indonesia (BSKAP), in geography subjects in Indonesia, the relevant themes required are "Climate Dynamics and Their Effects on Life" and "Disaster Management". These two themes do not demand an obligation to learn about climate change. Based on the material presented in the compulsory textbook [51, 52], climate change and its impacts in the form of hydrometeorological disasters have only become highlighted and are not explicitly discussed. Teachers are free to choose to teach this theme or not to talk about it. Teaching materials and limited time allocation prevent teachers from discussing the theme of climate change specifically. These shortcomings in curriculum and content prevent the content of climate education from developing students' conceptual knowledge comprehensively [50].

The theme of climate change, which is a hot issue today, should be a learning outcome related to sustainability [30]. Improving students' understanding of climate change through comprehensive education is essential to make students care and form attitudes to engage in reducing climate vulnerability [53]. Disaster-related knowledge, which includes climate change and related hazards, drives students' preparedness for disaster response [54].

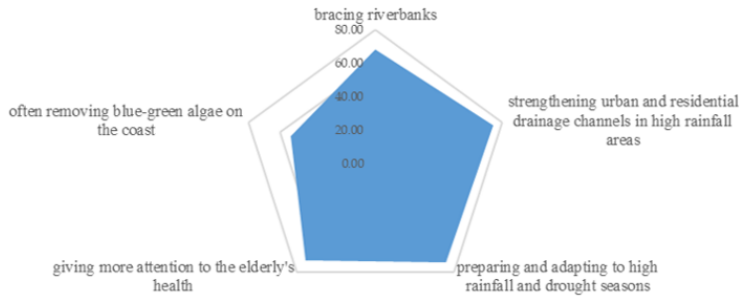

Figure 3. Students' knowledge of climate change adaptation

The knowledge of climate change among students in Aceh needs to be improved in mastering the concept of the atmosphere. Research reveals that students show an inadequate understanding of the process of atmospheric radiation balance and its relationship to climate change phenomena [20]. The students are only realizing that human activities are driving climate change, while anthropogenic economic activities are indeed causing deforestation and forest degradation associated with climate change [55]. Students understand that it is primarily associated with carbon emissions in the atmosphere; however, they remain lacking in understanding of fundamental natural processes, such as the dynamics of ultraviolet radiation and the role of non-CO_2 greenhouse gases in the atmospheric system [48]. Students primarily associate climate change with human activities; They continue to show confusion in distinguishing between climatological patterns and meteorological events [56].

3.2 Their Adaptation Knowledge of Climate Change

The total average score of climate change adaptation knowledge reached 67.85%. Based on Figure 3, the percentage of students who agree with the idea of often removing blue-green algae on shallow shores is 53.17%. In contrast, students responded most in agreement with these items: strengthening urban and residential drainage channels in areas with high rainfall (74.39%), preparing for and adapting to high rainfall and dry seasons (72.44%), paying more attention to the health of the elderly (70.98%), and strengthening riverbanks (68.29%).

These results indicate that students' understanding of climate change adaptation in Aceh needs to be improved. As many as 67.85% of students correctly recognize and believe, while another 32.15% do not understand climate change adaptation actions correctly. There are activities that lack students' adaptive understanding (Figure 3), such as climate change adaptation, which regularly cleans up green-blue algae on the coast (53.17%). Students in Aceh are not familiar with this adaptation measure, although phenomena such as changes in the color of seawater and river estuaries, as well as the sudden death of a number of fish, have occurred in Acehnese waters. Limited understanding of this topic can be due to the lack of discussion in the learning applied by the teacher. Teachers play less of a central role in determining the implementation of detailed climate learning, as a guide in the educational process, followed by their understanding to encourage effective learning [57].

Blue-green algae pose a significant threat to water quality, ecosystem stability, and public health through the production of toxins and large biomass from algal blooms [58]. Meanwhile, the population of blue-green algae is increasing due to warming temperatures and pollution of nitrogen and sulfur substances on the water surface from agricultural activities. Some varieties of blue-green algae bacteria contain toxins that cause skin irritation, indigestion, and nerve problems [59].

About 70% of students are well aware of adaptation practices, such as strengthening urban drainage systems and

areas with high rainfall, preparing to adapt to high rainfall and long dry seasons, and strengthening river banks from erosion as a climate change adaptation measure. In particular, students identified the need to adapt to improving health care for vulnerable groups, such as the elderly, who could be affected by diseases due to climate change. Parents and children are the most vulnerable groups, with less physical strength and self-rescue skills [60].

The advantage of students in Aceh to experience adaptation actions is different from the fact that students lack understanding of climate change adaptation related to increased rainfall due to climate change [20, 25]. This difference can be attributed to the increasing frequency of floods in recent years in Aceh. Students in these regions are regularly exposed to hands-on experience and mediated information about recurring flood phenomena, which increases their awareness of environmental disasters through experiential and representative learning channels. The occurrence of flood disasters in Aceh is empirically related to annual rainfall patterns related to climate change [11]. In addition, students' preferences regarding social and temporal dilemmas can influence behavioral decision-making and self-engagement in climate change; This dilemma preference influences adaptation motivation and climate mitigation intentions [61].

Students' adaptation plans to climate change are shaped by their social experiences and circumstances. Social and cultural factors also play an important role in shaping students' beliefs about climate change [25]. The life experiences of the elderly can significantly influence adaptation strategies. The Acehnese people, who belong to the Malay ethnic group, have substantial adaptive knowledge about climate change phenomena, especially floods [62]. Education rooted in indigenous knowledge has made a significant contribution to their adaptive capacity [63].

3.3 Student Knowledge to Mitigate Climate Change

The third aspect concerns the knowledge of climate change mitigation of students in Aceh (Figure 4). The average percentage of students who correctly identify climate change mitigation actions is only 60.15%. The lowest deal rate was observed on items related to reduced consumption of animal dairy products (26.83%) and purchase of fewer goods (43.9%). In contrast, the highest agreement rate was recorded for actions such as eating locally produced food (77.32%), choosing road trips and short trips (73.66%), preferring vegetarian diets (69.51%), as well as walking or cycling for short trips and avoiding food waste, both with a 68.78% agreement rate.

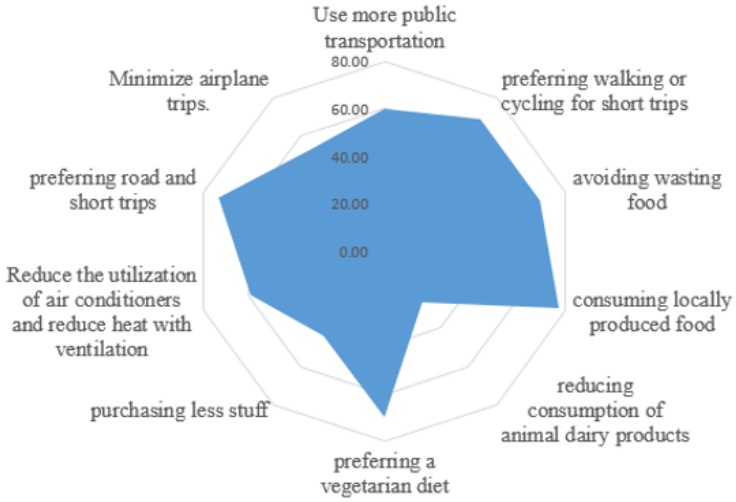

Figure 4. Description of student climate change mitigation knowledge

The results show limited understanding of climate change mitigation actions among students, with only 60.15% correctly identifying appropriate mitigation practices, while 39.85% fail to do so. Insufficient understanding was observed regarding the reduction of consumption of animal dairy products, with only 26.83% of students agreeing with this mitigation strategy. According to the IPCC, reducing meat and dairy consumption from farms can significantly reduce greenhouse gas emissions [10]. These findings are in line with previous research, which showed that less than 40% of students consider avoiding animal dairy products to be an important approach to climate change mitigation [20].

Knowledge about the climate change impacts of cow's milk products is limited due to the lack of habits of students in Aceh consuming cow's milk to meet their daily nutrition needs. Students in Aceh have nutritional problems due to poor eating habits, limited nutritional knowledge, and low socio-economic status [64]. Although the limited consumption of cow's milk products makes their answers ambiguous, and benefits climate change mitigation, an improved understanding of students and their parents about the fulfillment of balanced nutrition in students remains

necessary. The Government of Indonesia is trying to improve the fulfillment of nutrition for students through a national program.

The students in Aceh also showed limited support for climate change mitigation measures that involve purchasing fewer goods (43.9%), which contributes to waste efficiency and volume reduction. This shows a weak understanding of climate change mitigation measures. Students in Aceh, like the majority in Indonesia, show a limited understanding of the use of biodegradable substances, especially plastics, in relation to alternative materials [65]. Students' conceptual understanding has not developed enough to inform their adaptive choices about waste management. Ironically, those with greater knowledge of waste problems are often less actively participating in plastic waste management efforts directly [66]. Relevant to the findings in Pakistan, young people often lack education in sustainable food management and show limited concern about the consequences of waste [67]. Waste reduction intentions are influenced by environmental knowledge and awareness of the consequences [68].

Mitigation knowledge empowerment cannot be done only through knowledge transfer (teacher-centered) as implemented by the majority of teachers in Indonesia, including in Aceh [69]. The current learning is less innovative in supporting education about climate. The development of innovations is needed in learning, such as integrating the stages of the Climate Village Program in formal learning of geography subjects, because there is a relevance between the theme of the program and the subject curriculum. This, of course, requires support from teachers and principals. Proklim aims to increase the capacity of the community in climate change adaptation and mitigation [21], while the geography subject provides integration opportunities through the curriculum in accordance with documents from BSKAP. Existing climate education should encourage students to gain knowledge and awareness of the impacts of climate change. Through such education, students should be empowered to adopt mitigation measures by changing consumption habits and lifestyles, reducing waste, and respecting sustainability principles [56].

Regarding climate change mitigation, the majority of students (53.17%) agreed to reduce air travel. Despite their young age and limited direct exposure to flight prices, high school students are aware of the environmental impact. Media exposure has made them aware of the contribution of aviation to greenhouse gas emissions. Students do not consider the switch from airplanes to road travel to be a significant reduction in climate change [20]. These findings contradict previous research suggesting age and education have no impact on intentions to reduce flight, with young people still expressing a strong desire to explore the world [70].

The students mostly acknowledged and agreed that mitigation practices, such as eating locally produced food, choosing road and short trips, and preferring a vegetarian diet, are effective in combating climate change. More than 70% of students agree with this mitigation practice. Another study also stated that the students wanted to buy local products as a mitigation measure [25]. Students push for mobility policies that emphasize Sustainability and energy savings in a simple effort to reduce CO_2 emissions as a climate change mitigation initiative [56].

3.4 How Green School Gender, Class, Landscape, and Learning Affect Their Conceptual Knowledge, Adaptation, and Climate Change Mitigation

Based on the results of the PCA analysis (Table 2), two main components were extracted from 11 items of conceptual knowledge on climate change: Knowledge I (eigenvalue 4.63) and Knowledge II (eigenvalue 1.30), which together explain 53.87% of the total variance. Eight items have a strong correlation with Knowledge I, while three items strongly correlate with Knowledge II. Adaptation knowledge produces two main components: adaptation I (eigenvalue 2.22) and adaptation II (eigenvalue 1.03). The total variance of the load of the main components accounts for 64.93%. Adaptation I is highly correlated with three items, while Adaptation II is highly correlated with two items. The results of the PCA from climate change mitigation knowledge data produce three main components: Mitigation I (eigenvalue 2.22), Mitigation II (eigenvalue 1.5), and Mitigation III (eigenvalue 1.33). The variance in the total calculated factor load accommodated was only 50.48%. Mitigation I has a correlation with five items. Mitigation II had a significant correlation with three items. Mitigation III was predominantly correlated with two items. The results of the PCA produce seven key variables for comparative analysis.

Table 3. ANOVA results from conceptual knowledge, adaptation, mitigation

Factor	CK I	CK II	AK I	AK II	MK I	MK II	MK III
Gender	0.01*	0.26	0.34	0.32	0.49	0.11	0.86
Grade	0.18	0.78	0.61	0.12	0.31	0.33	0.01*
Landscape	0.06	0.42	0.26	0.09	0.01*	0.00**	0.57
Adiwiyata	0.00**	0.13	0.01*	0.09	0.01*	0.00**	0.02*

note: * = Sig $<$ 0.05, ** = sig $<$ 0.001

ANOVA results (Table 3) show that gender affects Knowledge I, $p < 0.001$. Gender does not affect other components. Based on the results of the ANOVA, this study identifies that gender has only a significant effect on one component of conceptual knowledge of climate change (Knowledge I), with no significant impact on the other

component of knowledge. These findings offer a valuable contribution to gender-focused studies in the context of climate change knowledge. Knowledge I accounts for 42.09% of the knowledge aspect. This knowledge is defined as a student's understanding of common scientific concepts that contribute to climate change, including excessive greenhouse gases (GHGs), thermal radiation (IR) trapped in the Earth's atmosphere, domestic products that are producing GHGs, the prevalence of landfills, intensive deforestation, the presence of the Earth's ozone hole, geothermal radiation absorbed by GHGs, and emissions from factory and car engine activities that increase atmospheric temperatures.

In Aceh Province, the implementation of Islamic sharia goes hand in hand with efforts to encourage gender equality in education, thereby creating opportunities for both genders. The local regulation, Qanun Number 6 of 2009, emphasizes women's empowerment and aims to ensure equal access to education, thereby addressing the historical inequities faced by women in the region [71]. The gender effects in this study are in line with previous research that highlighted gender differences in environmental knowledge and attitudes [20].

Female students generally exhibit more positive attitudes and psychological factors regarding environmental issues [72], consistent with the findings of this study, which revealed that female students demonstrate greater environmental concern compared to their male counterparts [73]. Equitable access to education for girls has been proposed as a means to enhance climate change literacy and understanding [74]. These results contrast with findings from the Czech Republic, where male students displayed higher levels of comprehension regarding complex topics such as the causes, consequences, and underlying principles of the greenhouse effect [75]. Individual perceptions of the material and psychological consequences of decarbonization also appear to be influenced by gender [76].

The ANOVA results (Table 3) further indicate that grade level only significantly affects Mitigation III ($p < 0.013$), and does not influence other components. Grade level may be interpreted as a proxy for age and learning experience. Mitigation III accounts for 13.26% of all mitigation aspects (Table 2). This component addresses complex mitigation actions that are rarely known by students, particularly those related to reducing the consumption of dairy products (from cows and other animals) and minimizing consumer purchases. Students' learning experiences play a role in their understanding of Mitigation III. Grade X students demonstrated lower average scores in Mitigation III compared to higher-grade students. As previously noted, most senior high school students in Aceh exhibit limited understanding of such concepts.

In line with these findings, other studies have shown that age statistically influences mitigation knowledge, with older students demonstrating better understanding of climate change mitigation [20]. Secondary school students tend to comprehend climate change and mitigation issues more effectively than their younger peers [75]. Older students also provide more frequent justifications for mitigation-related questions compared to those in lower grades [25]. However, certain aspects of climate change mitigation, such as practices promoting reduced air travel, remain unaffected by students' grade level [70].

Geographic landscape factors affected Mitigation I (based on Kruskal-Wallis results), $p < 0.003$, and Mitigation II, $p < 0.000$. There is no influence of the geographical landscape on the other key components (Table 3). Geographic landscapes, as a form of human-environmental interaction, influence anthropogenic characteristics. According to the PCA results, geographic landscapes account for 37% of the variation in students' climate change mitigation actions. Mitigation I focuses on actions aimed at improving efficiency to reduce the impact of climate change, while Mitigation II includes mitigation actions in the aspects of mobility and transportation that reduce the impact of climate change.

In climate change education, place-based approaches that highlight local and observable impacts are more effective because they link human behavior to climate change [77]. Climate change mitigation measures should take into account their respective climatic and geographical characteristics [78]. Environmental sensitivity and risk perception that are synonymous with geographical conditions influence the development of effective mitigation plans [79]. Activities and settlements in coastal areas show increased capabilities in climate change mitigation [63]. Geographic literacy and spatial thinking developed through formal secondary education determine thinking and skills in developing survival strategies [80].

The implementation of green school programs has the most significant impact on the core components of students' climate change knowledge, adaptation, and mitigation (Table 3). The green school program affects the Knowledge I component, $p < 0.000$. The realization of this program also affects the components of Adaptation I, $p < 0.005$. Green school programs have been shown to significantly affect all components of climate change mitigation, Mitigation I (based on the results of the Mann-Whitney U test results), $p < 0.011$, Mitigation II, $p < 0.000$, and affect Mitigation III, $p < 0.022$.

These results recognize that the implementation of the green school program (*Adiwivata*) has a significant impact on students' knowledge, adaptation, and climate change mitigation. Green school programs specifically affect Knowledge I, which accounts for 42.09% of students' climate change knowledge. These results emphasize previous studies that stated that students with green school programs have better knowledge and concern for global environmental issues, including climate change [30]. Students' knowledge of climate change can be enhanced

through green school programs that emphasize ecological literacy [40, 73]. In addition, students in green schools show higher levels of environmental and climate change knowledge compared to those in schools without such programs [41, 42].

The realization of the green school program also affects Adaptation I, which involves adaptation actions related to controlling the impact of floods and droughts. Adaptation I represents 44.33% of the climate change mitigation aspect. Green school programs seek to integrate all climate change and environmental management activities, including adaptation practices in education [81]. Implementing the program for students has provided mitigation experience through flood and drought impact control activities by accelerating water infiltration wells to absorb into the soil and bio-pores and building rainwater collection tanks [40].

In addition, green school programs have a positive effect on all components of climate change mitigation. The characteristics of each component have been discussed before. In schools with green school programs, students are actively encouraged to participate in climate change mitigation initiatives such as tree planting, waste management, and environmental conservation campaigns [82]. These programs foster a sense of responsibility among students to maintain, stabilize, and protect the environment, while promoting the efficient management and use of resources such as electricity and water [40].

4 Conclusion

This study concludes that students in Aceh generally lack adequate knowledge on the conceptual, adaptation, and mitigation of climate change. The findings show that only 52.53% of students demonstrate knowledge of the basic concepts of climate change. Most students show a limited understanding of fundamental issues. The adaptation aspect resulted in slightly better results, with 67.85% of students recognizing common adaptation strategies. However, their knowledge is not yet adequate in more detailed themes. In addition, only 60.13% of students demonstrated knowledge of climate change mitigation. This is because the current climate change education framework has not effectively achieved the goals of conceptual knowledge improvement, adaptation, and mitigation at the secondary school level. The formulation of existing education standards does not invite teachers to continue to teach students about climate change. Teachers play less of a central role in determining the implementation of climate learning in more detailed themes. The learning that is currently being implemented is less innovative in supporting education about the climate.

These findings also conclude that gender significantly affects students' climate change knowledge in Aceh (Knowledge I). Gender plays a role in shaping students' understanding of cause-and-effect relationships, positive attitudes, and psychological responses to climate change. Grade level affects student mitigation (Mitigation III). Age also has a statistical influence on climate change mitigation, with older students typically having a broader and more focused learning experience, better understanding and engagement in mitigation actions, with longer, more focused learning experiences influencing mitigation actions and understanding. The geographic landscape in which students attend school influences climate change mitigation actions (Mitigations I and II). Climate and geographic characteristics that indicate observable local impacts have proven to be more effective in determining environmental sensitivity and perceptions of climate change risks and mitigation plans.

This study recommends educational policies that encourage teachers to implement learning about climate change in a continuous, detailed, and innovative manner. This includes asking for the support of school principals and regional education policy makers, especially in Aceh, to seek the integration of climate change adaptation and mitigation empowerment programs such as the Climate Village Program (Proklim) and the expansion of the implementation of the green school program (*Adiwivata*) in formal subjects in schools. Of course, these improvement efforts also need to consider gender, grade level, and school landscape factors as local context. Future research is suggested to evaluate the current climate education curriculum and explore innovative approaches in learning to strengthen climate change knowledge, adaptation, and mitigation to address climate change challenges in Aceh.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Nomenclature

PCA	Analysis of the Main Components
CK	Conceptual knowledge
KMO	Kaiser-Meyer-Olkin sampling adequacy
AK	Adaptation knowledge
MK	Mitigation knowledge
C	Temperature scale in centigrades
Sig	Statistical significance
n	Sample size
p	Probability value of data observation

Greek symbols

α	Alpha Cronbach
I	First Component Loading
II	Second Component Loading
III	Third Component Loading