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Identifying the causes of adolescent malnutrition in Nuwara-Eliya District, Sri Lanka

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Malnutrition, a persistent illness, significantly reduces fat, muscle and bone levels, harming internal organs. The economic crisis in Sri Lanka has led to widespread malnutrition among children, including adolescents experiencing growth spurts. This study identifies factors influencing malnutrition in grade 10 pupils in the Nuwara-Eliya District, with the highest rates of malnutrition and also a multicultural area with many estate sector residents. Using a cross-sectional, quantitative approach, the data was collected from 379 respondents via a Likert scale questionnaire. Structural Equation Model (SEM) analysis was conducted using Smart PLS 4.0. Key findings indicate that environmental factors, such as access to clean water and sanitation, significantly influence adolescent malnutrition. A comprehensive strategy incorporating education, healthcare, and environmental improvements is essential for this. Ongoing observation, community engagement, and cooperative tactics are crucial for sustainable solutions. Addressing environmental issues and promoting a holistic approach to health education and infrastructure improvements are vital to combat adolescent malnutrition in vulnerable populations.

Keywords Adolescents, Environmental factors, Lifestyle, Malnutrition, Nutritional knowledge

Sri Lanka, a developing nation, is currently facing a multitude of challenges that impede its progress. The convergence of adverse events stemming from the coronavirus (COVID-19) pandemic and the subsequent political instability have plunged the country into an economic crisis. It has pushed more and more people into poverty and poverty levels have surged. This crisis has deeply impacted vital sectors such as fuel, healthcare, food, electricity, and exports, including textiles and garments, severely affecting the nation's socio-economic fabric and exerting pressures on food inflation. As a result, a staggering 4.9 million (Mn) individuals in Sri Lanka are grappling with food insecurity, leading to a pressing necessity for immediate and substantial humanitarian aid in the form of food assistance[1–3]. Tightening fiscal constraints, poor governance resulting in loss of government revenue, and waning dollar reserves saw health care services focusing on essentials and welfare programs being slashed.

The economic crisis has resulted in relentless challenges for families, with dire consequences for their children's well-being. The persistent 94% year-on-year food inflation rate, as reported by the Central Bank of Sri Lanka, reflects the average increase in prices of a basket of essential food items[4]. This significant inflation rate has induced malnutrition, particularly affecting teenagers transitioning from childhood to adulthood. Factors such as marketing, convenience, and peer pressure are pivotal in influencing dietary habits, leading to imbalanced eating patterns. Urban adolescents aged 11 to 19 exhibit a relatively high prevalence of overweight at 7.6%, which is lower than the global average of 20% for children and adolescents aged 5–19 years. This highlights the complex nature of malnutrition in Sri Lanka[5–7].

Malnutrition is a serious concern as it directly impacts growth and development across all age groups. However, it is particularly critical for teenagers due to their significant physical, emotional, and cognitive changes during this period. This age group matters more to make independent dietary choices, which can significantly impact their nutritional status. Addressing malnutrition in teenagers is essential to ensure their healthy development and future well-being.

Given the urgent need to address malnutrition, this research focuses on identifying risk factors and understanding the socio-economic and environmental conditions contributing to malnutrition. Effective interventions and policies can then be developed to improve the nutritional status and well-being of teenagers. Addressing malnutrition will not only improve health and academic outcomes but also empower students to adopt healthier lifestyles, mitigating the impact on their growth and development.

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This research offers unique contributions compared to existing studies, providing theoretical significance in three key ways. Firstly, it aims to enhance our understanding of the factors influencing malnutrition among 15-year-old adolescents in the Nuwara-Eliya District, where malnutrition is particularly prevalent for various reasons. Identifying the most influential factors is crucial to address this issue effectively. While some studies on malnutrition exist in areas like Jaffna, research specifically focusing on this age group has been limited. Previous literature often considered malnutrition in conjunction with other factors like income, gender, and ethnicity, hence considering the overall effect. However, this study addresses the empirical gap by concentrating on the age group of 15 years, which will be valuable for government bodies to develop targeted interventions to prevent malnutrition in this vulnerable population.

Secondly, given the current scenario of food scarcity in many regions in Sri Lanka, having a better understanding of the impact of these factors becomes even more critical. By identifying such factors influencing malnutrition, appropriate precautions can be taken to mitigate malnutrition not only in Nuwara-Eliya District but also in other areas facing food shortages, particularly among 15-year-old adolescents. Considering the above, this research is vital in guiding preventive measures to combat malnutrition within the age group considered for the study and contributing to overall public health efforts.

Literature review and hypothesis development

Malnutrition

The World Health Organization (WHO) describes malnutrition as a problem related to the body's ability to effectively use the nutrients consumed, which can arise either due to a shortage or a surplus of essential nutrition or a lack of balance between them. The impact of malnutrition is twofold, which include overnutrition and undernutrition[8]. Moreover, research based on Indonesian school children found that malnutrition is a serious health condition that arises in human bodies due to lack of healthy food, poor nutrition and imbalanced diet patterns[9]. According to[10], malnutrition is caused by inadequate or excessive consumption of necessary nutrients. Malnutrition is less prevalent in developed nations due to improved access to and the availability of facilities for good food and nutrition[11,12].

School children are the main age category with a higher risk of developing malnutrition because of the growth spurt age[13]. This period involves significant physical growth, sensory development, and social and emotional development[14]. Adolescents, in particular, require higher levels of energy, protein, minerals, and vitamins due to rapid growth, sexual maturity, and menstruation[15,16]. Stunting, a critical issue in this age group, significantly influences children's physical health, cognitive development, and motor abilities, leading to learning problems[17,18]. Anthropometric measurements indicate severe stunting, with 19% underweight and 14% wasting[19].

[20] reveals Sri Lanka ranks second in South Asia suffering from severe malnutrition. The coronavirus (COVID-19) pandemic exacerbated the economic crisis, leading to fuel and gas shortages, medicine scarcities, and skyrocketing prices of essential goods[6]. The World Food Programme (WFP) reported that 37% of Sri Lankan households suffer from massive food insecurity[21]. The economic crisis has increased poverty, resulting in poor energy intake and mental health conditions among children and adolescents[22].

Many school children skip their breakfast and consume fewer organic foods and vegetables, contributing to malnutrition[23]. The Sri Lankan population suffers from Protein Energy Malnutrition (PEM) and micronutrient deficiencies[24]. Even before the COVID-19 pandemic, 70% of the Sri Lankans were stunted[21]. According to a recent UNICEF report, 5.7 Mn people, including 2.3 Mn children, desperately need food assistance[25]. Physical activities can improve student lifestyle and nutritional status, with the WHO recommending at least 60 min of physical activity per day[26,27]. Environmental factors such as sanitation, hygiene, and water supply also directly impact student malnutrition[28,29]. However, a similar study on this topic in the Sri Lankan context by Rathnayake et al.[30] primarily focused on the economic determinants of malnutrition among school children in the Nuwara-Eliya district. The said study expands accordingly by incorporating a broader range of environmental factors. Specifically, the above-explained research investigates the impact of access to clean water and sanitation on adolescent malnutrition, which has not been extensively covered in previous studies. Additionally, it employs Structural Equation Modeling (SEM) using Smart PLS 4.0, providing a robust analytical framework to understand the complex relationships between various factors influencing malnutrition. This methodological approach offers deeper insights than the logistic regression used in Rathnayake's study.

Student lifestyle

The[31] describes lifestyle as "a set of behaviors and habits adopted by individuals that can reduce the likelihood of developing serious illnesses or dying prematurely". A study based in the Philippines revealed that the healthy lifestyle status among high school and college students is generally low[32]. According to Sri Lankan studies, students' lives are impacted by requirements, motives, and variables such as families, cultures, and social classes[33]. In recent years, Sri Lanka has been undergoing a considerable lifestyle change through rapid urbanization[34]. Factors like age, gender, rural or urban background, financial constraints, marital status, and residence type as socio-demographic have been some critical factors in deciding student lifestyle[35]. A narrative review of university students' eating behaviors highlights the impact of economic conditions, academic stress, and a lack of nutritional information on dietary habits, which are also relevant to high school students[36].

Many underprivileged children in Sri Lanka may experience nutritional deficiencies due to their limited access to meals[37,38]. Malnourished children typically have lower levels of physical activity because their bodies attempt to compensate for the lack of calories by lowering their energy use[39,40]. Limited availability of safe green spaces and public areas, such as playgrounds, parks, and sports fields, can immediately affect the lifestyles of children and adolescents. This can result in decreased physical activity, increased screen time, and television watching, ultimately leading to sedentary behaviour, negatively affecting the health and well-being of students[41].

While cultural habits also influence screen time and television watching, the lack of green spaces exacerbates these behaviours by reducing opportunities for physical activity.

Malnutrition in school-aged children can impair cognitive and motor development, resulting in poor school attendance, lower learning ability, and lower levels of educational achievement[42]. Studies conducted in Ethiopia highlight various decisions and events that define a student's lifestyle during their academic years, emphasizing the importance of a balanced lifestyle for academic success. Research on breakfast consumption and school-related outcomes underscores the importance of breakfast for academic performance and overall health[43].

Children from poor socio-economic backgrounds often have limited access to health services, contributing to imbalanced eating behaviors[44]. Healthcare access refers to a person's ability to access facilities to detect, treat, and manage diseases, illnesses, and other health-related problems[45]. To ensure that healthcare services are beneficial, these must be both reasonably priced and easily accessible to everyone[46,47]. The lack of healthcare professionals, challenges navigating a convoluted healthcare system, language barriers, and transportation issues contribute to poor healthcare access[48]. These factors underscore the importance of access to healthcare for individuals.

Urban students are more likely to consume fast food and poor-quality food, which directly leads to nutritional issues[49]. Several behavioural aspects impact the student's lifestyle, such as well-being, healthy practices, and adequate physical activities, which can contribute to adolescent malnutrition. Students must prioritize healthy habits and practices that enhance general health and well-being, such as frequent exercise, adequate sleep, and good stress management skills. A systematic review of lifestyle behaviours and diet quality in higher education students stresses the need for interventions to promote healthy eating habits[50].

Therefore, the existing studies provide valuable insights into the various factors influencing student lifestyle and its impact on nutrition and health. They highlight the importance of physical activity, access to healthcare, and the socio-economic determinants of lifestyle. For example, the study in the Philippines offers a broad overview of lifestyle factors among students, while Sri Lankan studies provide context-specific insights. However, many studies focus on specific regions or factors, lacking a comprehensive approach that considers the interplay of various determinants. Therefore, we postulate the following hypothesis for the current study.

H1 There is a significant impact of student lifestyle on malnutrition.

Nutritional knowledge and practices

School children's dietary patterns, actions, and practices can vary significantly, especially during adolescence (ages 10 to 19)[51,52]. During this transition period, many adolescents focus on quality dietary patterns and dietary guideline recommendations[53]. Past research indicates that nutritional knowledge and practices significantly impact malnutrition in developing countries, affecting not only adolescents but also other population groups such as children and women[54].

Nutritional knowledge involves understanding the principles and connections between nutrition, health, and well-being. A lack of substantial knowledge of nutrition can lead to improper dietary habits[55]. Studies have shown that a lack of nutrition knowledge and unhealthy practices can directly impact malnutrition[56]. To create a healthy community, it is vital to have an adequate understanding of nutritional knowledge and practices among adolescents[57]. For instance, a cross-sectional study in Bangladesh found that a lack of educational facilities prevents adolescents in low-income communities from adequately learning about nutrition to make informed health decisions[58,59]. A better understanding of nutrition is crucial for adolescents' physical and mental well-being[60,61].

Recent research supports these findings. A comprehensive food literacy intervention, which included practical activities and digital tools, significantly improved adolescents' nutrition knowledge and dietary habits in Italy[62]. Additionally, a systematic review stressed the need for robust tools to measure food and nutrition literacy, underscoring the importance of these skills in promoting healthy dietary practices[62,63].

Eating patterns and practices is the other branch leading to adolescent malnutrition. School children often consume more fast food rather than maintaining a balanced diet, increasing their exposure to health issues such as malnutrition and non-communicable diseases[64]. Nutritional knowledge and practices help identify various sectors regarding health, education, and nutrition, providing a thorough assessment of a person's beliefs and behaviours[65]. In Yemen, evidence spotlighted the importance of nutrition education in promoting good eating patterns through a nutritional questionnaire. It found that Yemen's school curriculum does not include health education as a primary subject, although it is covered in other areas of the study[66].

A recent health education intervention further supports the importance of nutrition education. This intervention effectively increased nutritional knowledge and attitudes among school-going adolescents, promoting healthier eating habits[67]. Observational studies also confirm the positive association between nutrition knowledge and dietary behaviour, underscoring the need for effective nutrition education programs[68].

Existing studies provide valuable insights into the impact of nutritional knowledge and practices on malnutrition. These highlight the importance of education and awareness in improving dietary habits and overall health. For example, the study in Bangladesh underscores the role of educational facilities in enhancing nutritional knowledge among adolescents. However, many studies focus on specific regions or factors, lacking a comprehensive approach that considers the interplay of various determinants. The Yemen-based study, for instance, does not address the broader socio-economic factors influencing nutritional practices. Therefore, the present study creates the following hypotheses to fill the existing gaps in the literature.

H2 There is a significant impact of nutritional knowledge on malnutrtion.

H3 There is a significant impact of nutritional practices on malnutrition.

Environmental factors

Environmental factors encompass various categories such as physical, chemical, biological, behavioural, or socio-economic. Multiple environmental factors can cooperate/work together to harm human health in many cases[69]. Evidence indicates that factors like childhood hunger, access to unsanitary toilets and clean water, and exposure to indoor air pollution are linked to malnutrition[70,71]. These practices cause different infections that influence stunting[47].

In the Sri Lankan context, insufficient and inadequate food intake, poor care practices, and diseases are the primary causes of undernutrition, and these are indirectly or directly associated with inadequate access to Water, Sanitation, and Hygiene (WASH) conditions[72]. The WHO statistics warn that approximately 39-61% of the global burden of malnutrition is attributed to inadequate WASH conditions. These deficiencies can result in the consumption of faecal pathogens, leading to diarrheal diseases, intestinal worms, and environmental enteric dysfunction[73].

Inadequate WASH facilities in schools increase children's vulnerability to diarrhoea, dehydration, and malnutrition, leading to absenteeism, impaired education, and severe dehydration. Investing in school WASH facilities can ameliorate health issues, enhance education, and foster children's well-being[74]. Furthermore, regarding areas with a lack of adequate WASH factors/conditions, there exists a correlation between high helminth infection rates and undernutrition. The multifaceted impact of WASH includes diverted resources and limited access to services, which contribute to undernutrition. Enhancing WASH facilities can help tackle undernutrition and related health problems effectively[75]. Moreover, a lack of hygiene education among children has been linked to stunting, as the lack of knowledge and motivation to practice healthy behaviors, like handwashing, can lead to infectious diseases affecting children's health[76].

Recent studies have highlighted the critical role of WASH conditions in addressing malnutrition. For instance[77], proved that around 2.39 billion (Bn) people suffer from the global prevalence of diarrhoea, which caused 1,655,944 deaths in 2016. Among those deaths[78], approximately 60% were due to inadequate WASH conditions. The majority of these deaths occurred in South Asia and sub-Saharan Africa, accounting for almost 90% of the total, as reported by[79]. In areas with inadequate access to water and sanitation, poor WASH conditions are linked to high diarrhoea-related death rates. The health implications of malnutrition cause school absenteeism and dropout risk[80]. Effective hygiene education, particularly soap-free handwashing, can lower diarrhoea prevalence by up to 47%[81], emphasizing the significance of promoting handwashing in households, schools, and communities.

Apart from water and hygiene factors, sanitation is one of the main environmental factors that affect malnutrition in children[82]. Inadequate sanitation endangers children's health, causing diseases and malnutrition, as well as impeding growth, education, and future possibilities[83]. Despite significant advances, disadvantaged and rural regions continue to lack basic sanitation, limiting growth and long-term development, particularly for girls' education[84].

Climate change is another critical environmental factor impacting malnutrition. Additionally, recent studies have shown that climate change exacerbates food insecurity and malnutrition by affecting household food security, dietary diversity, nutrient quality, and access to maternal and child health. The COVID-19 pandemic has further worsened these conditions, stressing the need for integrated approaches to address the underlying causes of malnutrition. Existing studies provide comprehensive insights into the impact of environmental factors on malnutrition while underscoring the importance of WASH conditions and sanitation in preventing malnutrition and related health issues. For example, the study on global diarrhoea prevalence underscores the critical role of WASH conditions in reducing malnutrition. However, a need also remains for more recent data to reflect current conditions, especially considering the impacts of environmental factors on malnutrition and postulate the below hypothesis for the current study.

H4 There is a significant impact of environmental factors on malnutrition.

Previous studies have shown that student lifestyle, nutritional awareness, and environmental variables all have a major influence on malnutrition. However, these aspects have not been examined together, requiring indepth studies. This study aims to investigate their interaction and impact on malnutrition among 15-year-old schoolchildren in Sri Lanka. Adolescents around the age of 15 are undergoing significant physical, emotional, and cognitive changes, making them particularly vulnerable to malnutrition effects. Additionally, at this age, they begin to make more independent dietary choices, which can significantly impact their nutritional status.

The economic crisis exacerbated by the COVID-19 pandemic has worsened malnutrition, with Sri Lanka's Global Hunger Index score reflecting this severity[85]. Malnutrition in teenagers is a serious concern as it directly impacts their growth and development. Factors such as rising food prices, job losses, and the termination of school meal programs have fueled this issue[86–89].

Adolescents at this age are particularly vulnerable to malnutrition due to significant physical, emotional, and cognitive changes, and their increasing independence in dietary choices[90–92]. Adolescents between the ages of 10 and 19 are in a crucial stage of physical development, making them particularly vulnerable to malnutrition[93]. Sri Lanka ranks among the top 10 nations with the highest rate of malnourished children, and mothers' lack of nutrition awareness aggravates the problem in certain situations[23,94]. Poverty significantly contributes to undernutrition in developing nations like Sri Lanka, where economic hardships have caused a drop in gross domestic product (GDP) and a rise in poverty rates[95,96]. Nuwara Eliya District in the Central Province has the highest rate of stunting among households unable to afford nutritious food, further stressing the severity of malnutrition in certain regions[97].

Data and methodology

This study used cross-sectional population-based survey data, and data analysis was conducted from Smart PLS. This investigation employs a quantitative research strategy to accomplish goals where ethical approval was obtained by the SLIIT Ethics Review Committee (SLIIT/ERC/SBS2023/BUSINESSMANAGMENT /02), and all methods were carried out in accordance with the ethical guidelines of SLIIT and the Declaration of Helsinki.

The target population for the study consisted of 12,764 tenth-grade students from schools in the Nuwara-Eliya District, Sri Lanka, from which the sample was drawn. Using a systematic sampling approach, six schools were selected from the said district to ensure geographical and socio-economic diversity. Schools with 15-year-old students in grade 10 were listed alphabetically, and selections were made at regular intervals across the list. Within each selected school, 15-year-old students were randomly invited to participate. This approach allowed us to achieve a representative sample without additional stratification, as the selection across multiple schools in different areas captured a broad demographic profile of the district's adolescent population. Anonymity was maintained throughout data analysis to protect participants' privacy.

The selected sampling method was considered appropriate because it provides a geographically and socio-economically representative sample of adolescents across different regions within the Nuwara-Eliya District. By systematically selecting schools and students, this approach ensured coverage of a diverse range of backgrounds, which was essential for the validity and generalizability of the study findings.

The sample size was calculated based on the formula for estimating proportions, considering an expected malnutrition prevalence rate among adolescents in similar socio-economic settings. Using a 95% confidence level and a 5% margin of error, the required sample size was determined to be 379 students. To ensure sufficient participation, this was adjusted for a 10% non-response rate, resulting in an initial target of 420 students. This adjustment ensured that the final sample size met the study's requirements, despite non-responses.

The participants in this study were 15-year-old male and female students, reflecting the targeted age group of tenth-grade students, from the Nuwara-Eliya District in Sri Lanka. The sample consisted of 51.2% males and 48.8% females. In terms of ethnicity, the study group was predominantly Tamil, representing 57.6% of the participants, followed by Sinhalese at 39.6%, Moors at 2.5%, and a small proportion of other ethnicities, accounting for 0.2%. This demographic composition reflects the diversity of the Nuwara-Eliya District and provides a comprehensive representation of the socio-demographic background of the study group.The study was carried out in chosen six schools from a total of 23 in the Maskeliya Ministry of Health (MOH) region to evaluate malnutrition using systematic sampling. Using the factor analysis, the impact of identified factors has been determined using Structural Equation Modeling (SEM) analysis.

The questionnaire employed in this study comprised 36 items and was designed based on a thorough conceptualization and operationalization of nine variables central to the research objectives. The items were derived from a comprehensive literature review[97–108] to ensure their relevance and alignment with established research in the field. To ensure the validity and relevance of the questionnaire items for the study context, the questionnaire underwent a review process by an expert panel comprising senior academics with expertise in educational research and adolescent behavior. The panel reviewed the questionnaire for clarity, alignment with the research objectives, and cultural relevance. Feedback was incorporated through iterative discussions to refine the questionnaire items. Additionally, the questionnaire was pre-tested with a pilot sample of 30 students to confirm reliability and comprehension before full-scale deployment. Based on the pilot test and subsequent factor analysis, 7 questions from the attitude dimension were omitted due to low extraction values, thus failing to meet statistical thresholds for inclusion. The final questionnaire consisted of 29 questions. The study's conceptual framework (as shown in Fig. 1) served as the foundation for designing the questionnaire, ensuring that its goals were closely aligned with the research objectives.

To determine the reliability of an instrument, it must produce consistent results each time it is tested. In this study, the researchers had to assess the reliability of the questionnaire they used by administering it multiple times to ensure consistency of results. To ensure the reliability and the validity of this study, the Cronbach alpha value, Kaiser Meyer Olkin (KMO) and Bartlett test have been carried out using the data collected for the factor analysis.

This study goal will be accomplished via factor loading by employing a factor analysis technique to find the factors and then analyze the relationship of those factors with malnutrition of adolescents aged 15 years. A statistical technique called factor analysis uses the correlation patterns between the variables that are seen to identify a more manageable group of latent variables or factors. Indicators are the observable variables in factor analysis that provide information about the underlying component. The goal of a factor analysis is to determine how much of the variance in the indicators is explained by each factor. The theory states that the latent components account for the common characteristics of particular observable variables[109]. Additionally, the researchers are in charge of labeling the factors been found, which may cause disagreements regarding the analysis' findings among analysts. This study uses Smart PLS version 4 to analyze data using factor analysis and identify the impact.

The informed consent from 15-year-old adolescents participants was obtained verbally. Given the practical and cultural context, obtaining individual written consent posed logistical challenges, such as varying literacy levels among parents and access constraints. In that case, we ensured ethical standards and feasible participation by obtaining written consent from the schools and parental representatives while securing verbal assent from the participants. Other than that, researchers received the written consent from several parents who posses with adequate literacy skills. This approach enabled us to maintain ethical rigor while accommodating the specific needs of the study population. Participants were also offered the opportunity to withdraw at any time. The data was acquired anonymously, and no privileges were provided to any participant in exchange for their involvement in this research, hence, it is free from bias. Additionally, all participants, researchers, and respondents declared no

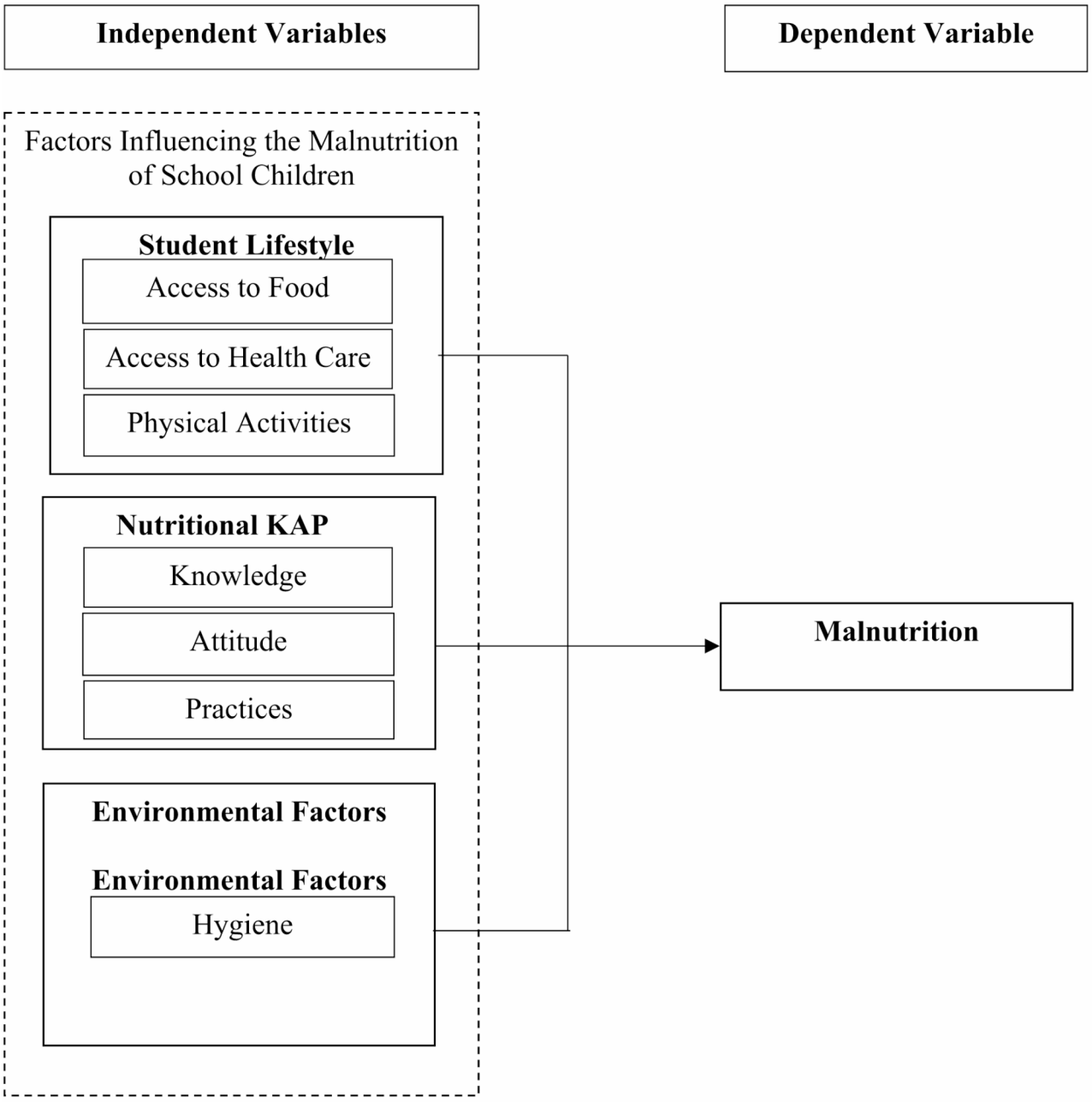

Fig. 1. Conceptual framework. Source: Authors' illustrations.

conflict of interest connected to the current study. The relevant schools were coordinated through the Provincial Ministry of Health and the Provincial Ministry of Education.

Results

Measurement model results

The adequacy of the created model was examined and reported in this study by assessing the reliability, convergent validity and discriminant validity along with the chosen criteria of Cronbach's alpha value, Average Variance Extracted (AVE) statistics and.HTMT Ratio to ensure the appropriateness of the measurement model.

Reliability statistics

The internal consistency of the variables in the model was assessed using Cronbach's Alpha, a widely accepted measure of reliability. Cronbach's Alpha values measure how closely related a set of items are as a group, with a threshold of 0.7 or above indicating that the scale is reliable for the study[110]. A higher Cronbach's Alpha value suggests that the items within a variable are measuring the same underlying concept with consistency.

Variables	Cronbach's alpha value
Student lifestyle	0.929
Access to food	0.903
Healthcare	0.932
Physical activities	0.863
Nutritional knowledge	0.843
Nutritional practices	0.833
Environmental factors	0.918
Malnutrition	1.000

Table 1. Cronbach's alpha value for variables. Source: Authors' compilation based on Smart PLS output.

Variables	Composite reliability
Student lifestyle	0.939
Access to food	0.928
Healthcare	0.948
Physical activities	0.902
Nutritional knowledge	0.888
Nutritional practices	0.882
Environmental factors	0.938
Malnutrition	1.000

Table 2. Composite reliability for study variables. Source: Authors' compilation based on Smart PLS output.

Variables	Average variance extracted
Student lifestyle	0.509
Access to food	0.721
Healthcare	0.786
Physical activities	0.650
Nutritional knowledge	0.616
Nutritional practices	0.599
Environmental factors	0.752
Malnutrition	1.000

Table 3. AVE values. Source: Authors' compilation based on Smart PLS output.

As shown in Table 1, all variables demonstrate acceptable reliability, with Cronbach's Alpha values exceeding 0.7. Specifically, the variable "Student Lifestyle" yielded a value of 0.929, indicating strong internal consistency. Other variables such as "Access to Food" (0.903), "Healthcare" (0.932), and "Environmental Factors" (0.918) also reflect high reliability, while "Nutritional Knowledge" and "Nutritional Practices" showed values of 0.843 and 0.833, respectively, affirming their reliability for the study. The dependent variable, "Malnutrition," has a Cronbach's Alpha value of 1.000, further confirming its consistency.

Composite Reliability (CR) values were also assessed to provide a more accurate measure of the true reliability of the constructs. While Cronbach's Alpha measures internal consistency, CR provides a clearer picture by considering the overall correlation of the multiple items (factors). A CR value of 0.7 or above indicates that the variables are reliable and accurately measure the constructs they are intended to[111].

All variables exceeded the threshold of 0.7, confirming the reliability of the constructs in the model (Table 2). This confirms that the variables have the internal consistency and reliability to proceed with further analysis. In this context, these values indicate that the measurement model is robust and reliable for examining the factors contributing to the adolescent malnutrition issue in the current study.

Average variance extracted (AVE) statistics

Convergent validity assesses the extent to which indicators of a construct converge to measure the same concept. It is established using the AVE score, which reflects the variance captured by the construct's indicators. To be satisfactory, an AVE score should exceed the threshold of 0.50, indicating that over 50% of the variance is captured by the construct rather than error.

As shown in Table 3, the AVE scores for all constructs exceed the minimum threshold of 0.50, confirming the convergent validity of the measurement model. The highest AVE value is observed for "Environmental Factors"

Variable	HTMT							
	FA	HC	PA	SL	H/EF	KNOW	PR	MAL
Access to food	–							
Healthcare	0.779	–						
Physical activities	0.567	0.470	–					
Student Lifestyle	0.969	0.927	0.842	–				
Environmental factors	0.220	0.181	0.512	0.349	–			
Knowledge	0.139	0.313	0.267	0.283	0.153	–		
Practices	0.093	0.062	0.143	0.115	0.143	0.192	–	
Malnutrition	0.360	0.304	0.390	0.411	0.560	0.297	0.259	–

Table 4. HTMT ratio of latent variables. Source: Authors' compilation based on Smart PLS output.

	Access to food	Healthcare	Environmental factors	Knowledge	Malnutrition	Physical activities	Practices	Student lifestyle
Access to food	0.849							
Healthcare	0.714	0.887						
Environmental factors	0.200	0.168	0.867					
Knowledge	0.124	0.280	0.137	0.785				
Malnutrition	0.342	0.293	0.538	0.276	1.000			
Physical activities	0.499	0.425	0.450	0.230	0.359	0.806		
Practices	0.074	0.044	0.125	0.160	0.238	0.122	0.774	
Student lifestyle	0.899	0.881	0.302	0.249	0.389	0.717	0.089	0.714

Table 5. Fornell-Laker criterion values of latent variables. Source: Authors' compilation based on Smart PLS output.

(0.752), indicating a strong convergence among its indicators. Other constructs, such as "Healthcare" (0.786) and "Access to Food" (0.721), also demonstrate strong convergence. The results indicate that the model has an adequate level of convergent validity for further analysis.

The high AVE values indicate that the measurement model effectively captures the variance for each construct, supporting the robustness of the data used in the analysis.

Discriminant validity

Discriminant validity assesses whether the constructs measured are distinct from each other[112]. The present study employs the Heterotrait-Monotrait (HTMT) ratio, a modern approach to evaluate discriminant validity. An HTMT value below 0.85 is generally considered acceptable indicating that constructs are adequately distinct.

As shown in Table 4, all HTMT values for the constructs are below the threshold of 0.85, except for the higher-order constructs (HOCs) of "Student Lifestyle" and "Environmental Factors," which exceed this limit. This is expected as higher-order constructs combine related lower-order constructs, leading to higher correlations. Overall, discriminant validity is established, as these exceptions align with the model's design.

The Fornell-Larcker criterion helps ensure discriminant validity by confirming that a construct shares more variance with its indicators than with other constructs. For this to hold, the square root of the AVE (shown as diagonal values) should be greater than the correlations with other constructs.

As shown in Table 5, the Fornell-Larcker criterion is met for all variables. The diagonal values, representing the square root of AVE, are higher than the correlations between constructs, confirming that each construct is sufficiently distinct from others.

The measurement model's adequacy, including factor loadings and reliability, is illustrated in Fig. 2.

Structural model results

The structural model represents the relationships between latent constructs and their impact on the outcome variable of malnutrition. SmartPLS 4 was utilized to analyze the direct effects of student lifestyle, nutritional knowledge, practices, and environmental factors on malnutrition. Hypotheses were tested through bootstrapping, calculating key values such as beta, t-statistics, and p-values.

Before testing the hypotheses, it is essential to consider the overall model quality through R^2 and VIF (Variance Inflation Factor). Table 6 below illustrates the R^2 for malnutrition was 0.389, indicating that the model explains 38.9% of the variance in malnutrition. Additionally, VIF values were below 3, confirming that multicollinearity was not a concern, thereby establishing the validity of the structural model.

Hypothesis testing

The results presented in Table 7 show that all hypotheses are accepted.

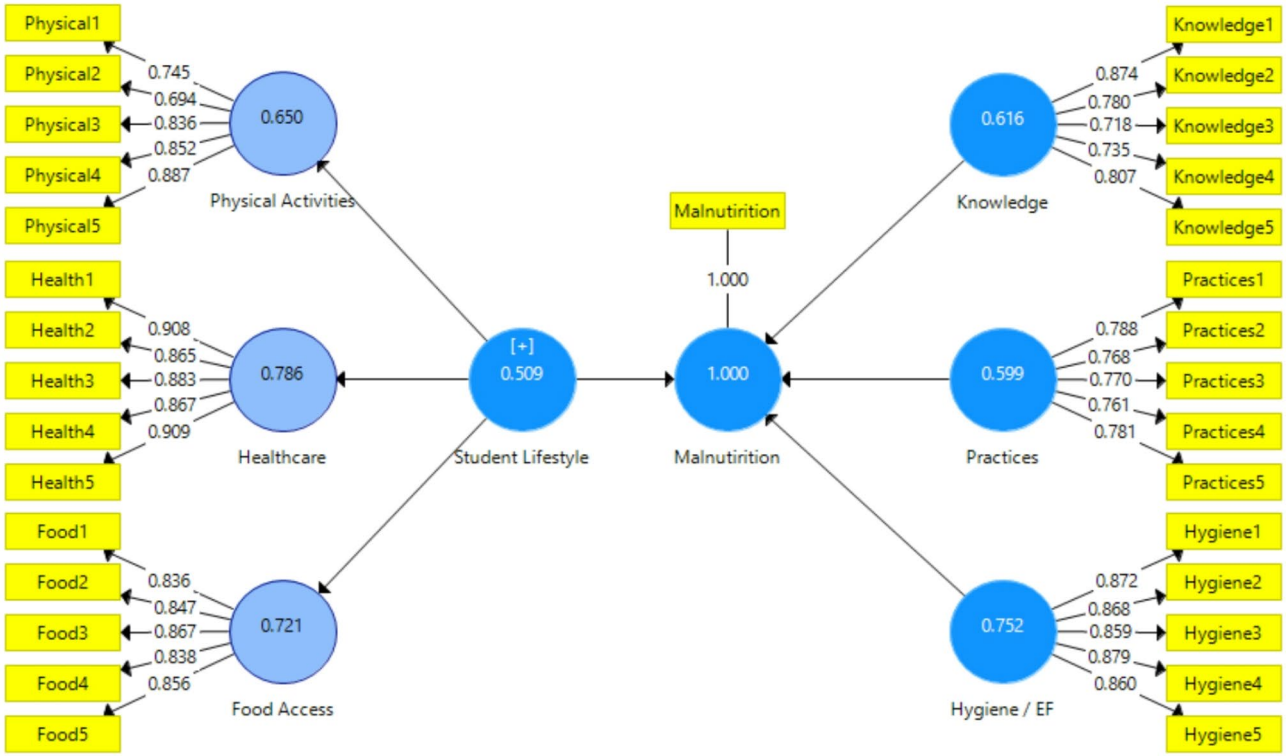

Fig. 2. Measurement model. Source: Generated by the authors from Smart PLS

Outcome variable	R^2	VIF	GOF
Malnutrition	0.389	1.158	0.624

Table 6. Quality measures of structural model. Source: Authors' compilation based on Smart PLS output.

Path	Beta values	T	*P*	F^2	Status
Student lifestyle → Malnutrition	0.209	2.840	0.005	0.062	H1: Supported
Knowledge → Malnutrition	0.142	2.322	0.020	0.030	H2a: Supported
Practices → Malnutrition	0.141	3.588	0.000	0.032	H2b: Supported
Environmental factors → Malnutrition	0.437	6.520	0.000	0.281	H3: Supported

Table 7. Path coefficient values. Source: Authors' compilation based on Smart PLS output.

The first hypothesis (H1) states that student lifestyle significantly impacts malnutrition. This is supported by the data, with a positive and significant path coefficient ($\beta = 0.209$, $p = 0.005$). It indicates that poor student lifestyle behaviors, such as limited access to healthcare and low physical activity, are strongly associated with higher rates of malnutrition, leading to the acceptance of H1.

The second hypothesis (H2a and H2b) denotes that nutritional knowledge and practices significantly impact malnutrition. The data show that both nutritional knowledge ($\beta = 0.142$, $p = 0.020$) and nutritional practices ($\beta = 0.141$, $p < 0.001$) have significant positive effects on malnutrition. Adolescents with insufficient nutritional knowledge and unhealthy practices are more prone to malnutrition, thus supporting and accepting both H2a and H2b.

The third hypothesis (H3) suggests that environmental factors significantly impact malnutrition. This is confirmed by the data, with environmental factors showing the strongest influence on malnutrition ($\beta = 0.437$, $p < 0.001$). The substantial effect of poor WASH conditions on malnutrition leads accept H3.

Accordingly, all three hypotheses—H1, H2a, H2b, and H3—are accepted, indicating that student lifestyle, nutritional knowledge and practices, and environmental factors are significant predictors of malnutrition, with environmental factors being the most influential.

Figure 3 illustrates the structural model with tested hypotheses and the relationships between variables.

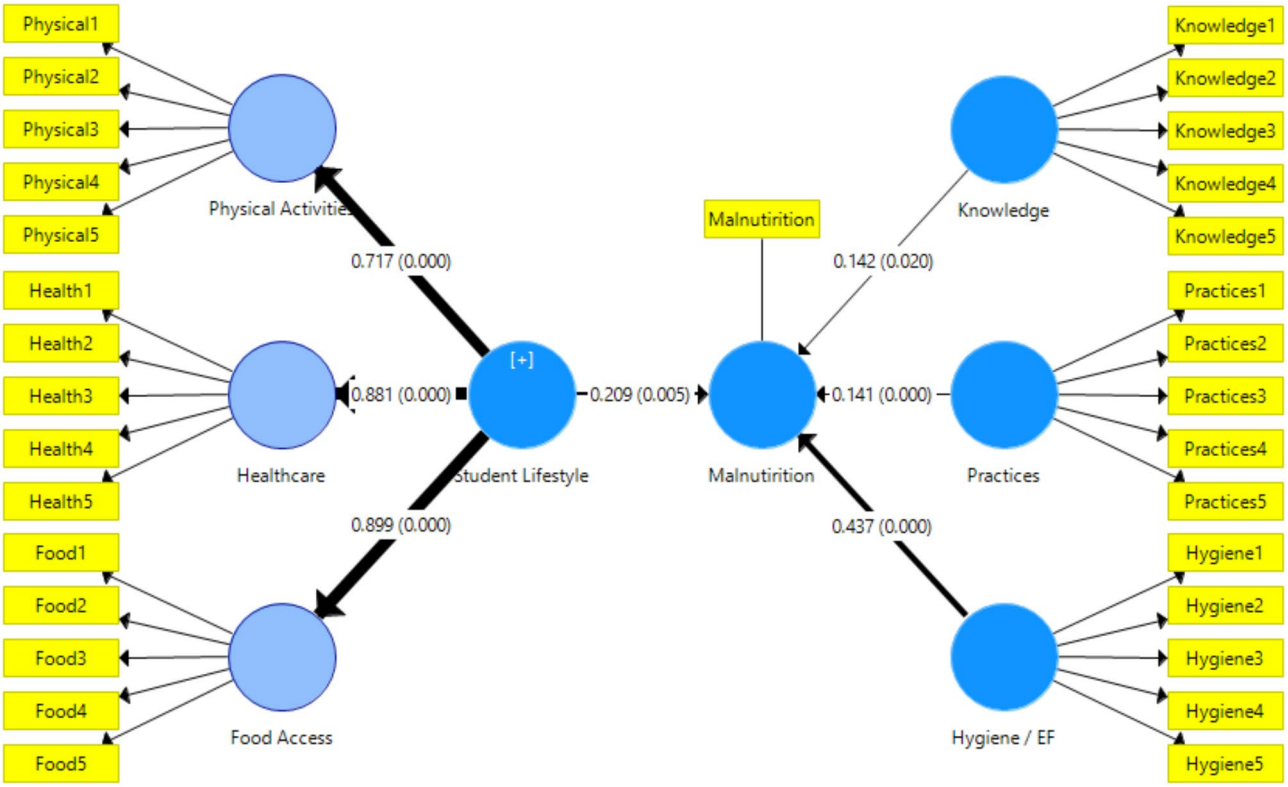

Fig. 3. Structural Model generated from SmartPLS. Source: Authors generated from Smart PLS.

Discussion

This study focuses on the malnutrition of adolescents in the Nuwara-Eliya District, a significant concern in Sri Lanka's socio-economic and public health landscape. The findings revealed that student lifestyle, nutritional knowledge, and environmental factors significantly influence malnutrition. These insights are consistent with past research, yet provide a refined understanding by considering the specific socio-economic and the geographical context of Nuwara-Eliya.

First, the significant impact of student lifestyle on malnutrition aligns with previous studies, such as those conducted in Serbia and Ethiopia, which emphasized the role of physical activity on adolescent health outcomes[42,113]. Similar to global findings, the current study reaffirms that adolescents with limited access to healthcare and food resources are more prone to malnutrition, particularly in low-income regions like Sri Lanka, where economic crises exacerbate these issues[32,114]. These results call for interventions aimed at improving access to both food and healthcare and encouraging physical activity as part of daily student routines.

Nutritional knowledge and practices were also found to significantly affect malnutrition, echoing findings from research in South India and Yemen that highlighted the importance of nutrition education in shaping adolescents' eating behaviors[115,116]. Similar to earlier studies, this research supports the idea that poor knowledge of nutrition and unhealthy dietary practices contribute to malnutrition[56,60]. As adolescents in Sri Lanka are increasingly influenced by fast food culture and peer pressures, targeted nutritional education programs are essential to mitigate the risk of poor dietary choices and their long-term health implications.

Finally, environmental factors, including access to WASH conditions had the most substantial influence on malnutrition. This finding is consistent with the global literature, which perceives inadequate WASH conditions as a key driver of malnutrition in children, particularly in developing countries[70,72]. Studies from Ethiopia and other regions cite that poor WASH conditions propel higher incidences of malnutrition through the spread of diseases and infections[29,70]. The strong association found in the present study between WASH factors and malnutrition highlights the importance of improving environmental conditions to combat malnutrition effectively.

In this perspective, this study contributes to the existing body of knowledge by demonstrating that while lifestyle and nutritional practices are important, environmental factors are the most critical role in adolescent malnutrition in the Nuwara-Eliya region. This integrated approach offers a comprehensive understanding and also contributes to fill the lacuna, as much of the previous research focused on the individual effect of variables/factors, but not the combined/overall effect. By addressing both individual behaviors and systemic environmental issues, the current research provides a foundation for future interventions to reduce malnutrition in Sri Lanka and similar regions globally.

Strengths and limitations

This study offers valuable insights into the malnutrition of adolescents in Sri Lanka, particularly in the Nuwara-Eliya District, a region with a highly diverse socio-economic and ethnic profile. One of the key strengths of this research is its focus on a specific and vulnerable age group—15-year-old students. By concentrating on this developmental stage, the study captures key influencial factors of malnutrition during a critical phase during children's physical and cognitive growth. The relatively large sample size of 379 participants, drawn from a diverse socio-demographic background, further strengthens the findings by allowing a more generalizable conclusion about the population in the selected region. Moreover, using advanced statistical techniques such as SEM provided a strong and comprehensive analysis, which facilitated identification of key factors contributing to malnutrition, including student lifestyle, nutritional knowledge, and environmental influences.

However, the study is not without limitations. One challenge was the reliance on self-reported data from adolescents, which inherently carries the risk of bias, particularly regarding sensitive lifestyles and health-related behaviors. Participants may have under-reported or over-reported their actual food habits, healthcare access, or physical activities due to social desirability or recall bias. Additionally, as a cross-sectional study, the research only captures a snapshot of the malnutrition factors at a single point in time. This limitation restricts the ability to determine causalities/causal relationships between the identified factors and the malnutrition issue. Future studies could address this by employing a longitudinal design, tracking changes over time for a deep dive into the evolution of these factors.

Another notable limitation is the regional scope of the study. While the findings provide valuable insights for the Nuwara-Eliya District, these may not be fully generalizable to other regions in Sri Lanka with different socio-economic conditions and environmental challenges. Regions with higher income levels, better access to healthcare, or more diverse food systems probably experience varying outcomes in terms of malnutrition. Therefore, the external validity of the results is relatively limited.

Despite these limitations, the study's findings offer significant value for developing evidence-based strategies to combat malnutrition. The results highlight lifestyle, nutritional practices, and environmental factors play a critical role in adolescent health. These insights can provide a foundation for policymakers, educators, and health professionals to craft targeted interventions to combat malnutrition in vulnerable populations. By addressing individual behaviors and broader systemic issues, such as access to clean water and healthcare, this research offers actionable guidance for managing and mitigating malnutrition in Sri Lanka.

Managerial implications

The research's conclusions provide a persuasive road map for dealing with the urgent problem of teenage malnutrition in Sri Lanka's Nuwara-Eliya District. First, it becomes clear that putting environmental issues first is crucial to successful intervention plans. Policymakers and groups may provide the groundwork for improved adolescent health outcomes by funding initiatives that improve access to clean water, sanitary environments, and general living circumstances. These advancements immediately influence nutrition and create the foundation for better living. To make sustained growth, a comprehensive strategy that includes both environmental improvements and focused educational initiatives is essential.

Second, the study underscores the importance of spreading nutritional information and behaviors, particularly among teenagers, parents, and caregivers. Key actors /stakeholders like schools, community organizations, and healthcare institutions can deploy educational programs to inculcate and improve knowledge of healthy nutrition and promote healthier eating habits. Breaking the vicious cycle of malnutrition depends on the extent people are equipped with the information and abilities to make wise food decisions. To ensure the success and long-term impact of these initiatives, collaboration among stakeholders from multiple sectors, frequent monitoring and evaluation, and community involvement are essential components. The research results also provide a reasonablee basis for developing evidence-based policies, increasing public awareness, and enhancing the abilities of educators and healthcare professionals. In Sri Lanka's Nuwara-Eliya District, this all-encompassing strategy has the potential to drastically lower the prevalence of teenage malnutrition and enhance the general well-being of the population.

Conclusion

This study critically stresses the pressing issue of adolescent malnutrition in Sri Lanka's Nuwara-Eliya District, revealing the complex interplay between lifestyle, nutritional knowledge, and environmental factors. The findings clearly demonstrate that environmental factors, such as insufficient access to WASH conditions, have the most substantial influence on malnutrition. Following this, student lifestyle, including healthcare access, food, and physical activity, plays a significant role. Contrary to popular belief, nutritional knowledge and practices, though vital, were found to have a somewhat lower impact on malnutrition. These rankings highlight the varying degrees of influence exerted by each factor, emphasizing the need to prioritize environmental improvements alongside lifestyle interventions to effectively combat adolescent malnutrition.

These insights showcase the urgent need for comprehensive, multi-dimensional interventions that not only address individual behaviors but also tackle broader systemic issues. Enhancing healthcare access, promoting nutrition education, and investing in improved water and sanitation infrastructure are essential steps toward reducing malnutrition in vulnerable populations. By implementing targeted, evidence-based strategies, policymakers and health professionals have much potential to make a lasting impact on adolescent health outcomes.

Importantly, this study advances existing knowledge by providing a more integrated perspective on the factors influencing malnutrition. While previous research has often examined these elements in isolation, the current study demonstrates a holistic approach to effectively comprehend and address the worrying issue of malnutrition. The findings emphasize that developing strategies to combat malnutrition at its root level is only

possible through a comprehensive approach, addressing the interconnected nature of lifestyle, environmental, and nutritional factors. In doing so, this research not only deepens the understanding of malnutrition in developing regions like Sri Lanka but also offers a blueprint for creating well-rounded interventions that can be adapted globally. By recognizing the complexity of malnutrition, sustainable solutions can be brought closer to transforming adolescent health and well-being, in Sri Lanka and beyond.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Received: 16 June 2024; Accepted: 24 March 2025
Published online: 06 May 2025

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Acknowledgements

We would like to express our deepest and sincere gratitude to Ms. Gayendri Karunarathna for proof reading our research article and providing necessary guidance for language editing. We particularly need to thank all participants of the questionnaire surveys for devoting their valuable time to make this research successful.

Author contributions

Conceptualization:.SN, SA, NW, TL, RW, NR Data curation:.SN, SA, NW, TL Formal analysis: SN, SA, NW, TL, NR, VR .Funding acquisition: Not applicable Investigation: RW, NR, VR, SN, SA Methodology: SN, SA, NW, TL, RW, NR Resources: SN, SA, NW, TL. Software: SN, SA, NW, TL. Supervision: RW, NR, VR Validation: SN, SA, NW, TL Visualization: SN, SA Writing – original draft: .Writing – review & editing: All authors have read and approved the manuscript.Sunethya Nandajeewa {SN}Sandunika Aluthwatta {SA}Ranitha Weerarathna {RW} Nilmini Rathnayake {NR}Vageesha Rajapakse {VR}Nadhee Wijesinghe {NW}Thirasha Liyanaarachchi {TL}.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

This investigation employs a quantitative research strategy to accomplish goals where ethical approval was obtained by the SLIIT Ethics Review Committee(SLIIT/ERC/SBS2023/BUSINESSMANAGMENT /02), and all methods were carried out in accordance with the ethical guidelines of SLIIT and the Declaration of Helsinki.

Consent to participate

The informed consent from 15-year-old adolescents participants was obtained verbally. Given the practical and cultural context, obtaining individual written consent posed logistical challenges, such as varying literacy levels among parents and access constraints.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-95827-9.

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