

Domain-specific Biosafety Knowledge, Attitude and Practices among Senior Secondary Students: Hygiene, Food Safety, Infection Control and Environmental Health

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ABSTRACT Biosafety preventive health behaviours related to hygiene, water, food safety, infection control, and environmental health are crucial for public health resilience. A cross-sectional Knowledge-Attitude-Practice (KAP) survey was carried out among 840 senior secondary students in Dehradun district in India, using a validated questionnaire, to assess the domain-wise performance. Data were analysed in Python 3.13.9 using descriptive and inferential statistics. Students possessed overall moderate knowledge (14.03 ± 3.42), high attitude (54.26 ± 6.28) and favourable practice (84.18 ± 11.91). Science students, females, and urban students scored significantly better ($p < 0.001$). Correlation between knowledge-attitude was stronger than knowledge-practice across domains. Regression analyses and Random Forest model indicated that attitude consistently and strongly predicted bio-safety practices, whereas knowledge predicted only selected domains. School biosafety education should aim at risk perception, personal responsibility and sustained behaviour engagement besides knowledge to improve school students' health resilience.

INTRODUCTION

Infectious diseases in the 21st century have time and again emerged at a rapid rate, partly owing to fast urbanisation, environmental degradation, ecosystem disruption and unprecedented global connectivity. These anthropogenic changes have fundamentally altered patterns of disease transmission, and created conditions that facilitate the quick spread of biological hazards across national boundaries (Everard et al. 2020). Recent pandemics and regional epidemics have pointed out that as international mobility and trade continue to accelerate, localised outbreaks increasingly have the capacity to develop into international public health emergencies within a short span of time (Montiel et al. 2022).

Controlling biological hazards is much more than the detection of pathogenic organisms only. This has increasingly focused public health poli-

cies to start using biosafety as the basis of health and safety to mitigate exposure to biological risk and build resilience in communities. Biosafety has historically been associated with containment practices of labs. But over the past few years, the range of biosafety has greatly expanded. Today, scientists and policy makers have tried to define biosafety that involves practices and policies leading to the protection of humans, animals and ecosystems from natural phenomenon or human-mediated biological threats (Gao et al. 2025). In communities, biosafety also includes routine practices related to hygiene, food safety, infection control, and environmental health. All of these help to prevent infectious diseases and make the society ready for future health emergencies.

The COVID-19 pandemic also implemented biosafety-related behaviours in everyday life for containing the transmission. Worldwide, hand hygiene, respiratory etiquette, surface disinfection, food safety and safe waste disposal became important public health measures. Schools became pivotal locations for entrenching such behaviours. This suggests that proactive biosafety literacy

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during this formative period of life in school may be important for building a lifetime of public health preparedness.

Research in a variety of educational settings has consistently identified a substantial gap between knowledge and practice of hygiene. While approximately 78 percent of students understand the health benefits of handwashing, only half perform it consistently at critical moments such as before meals or after restroom use (Tupone et al. 2025). Similarly, 99.5 percent of middle school students in Belagavi, India, recognised that unwashed hands spread diseases. Nevertheless, operational handwashing with soap was severely restricted by institutional shortages (Sarawade et al. 2026). A persistent gap was found between knowledge and practice in school-based hygiene interventions where awareness does not always lead to behavioural compliance (Otto et al. 2022). Many students understood hand hygiene, but infrastructure problems such as the lack of soap and clean water prevented them from applying this knowledge in practice (Kuandyk et al. 2025). Longitudinal studies revealed measurable improvements in handwashing behaviour and reductions in hand contamination following structured health promotion programmes (Enkhbat et al. 2025; Ly et al. 2025). In Guatemala, knowledge of correct handwashing materials reached 100 percent post-intervention (Pieters et al. 2025). Many learners had a good knowledge of sanitation and hand hygiene but this knowledge was not always translated into practice. Common barriers to proper hygiene were the lack of infrastructural support including soap (Ngcongo and Tekere 2025).

Studies on students' knowledge of infectious diseases show significant differences in knowledge of transmission and disease prevention. Limited knowledge and persistent misconceptions have been reported for dengue, rabies, hepatitis B, diarrheal diseases and other infectious conditions (Addo et al. 2025; Srusti et al. 2022). However, certain groups such as students who have been previously exposed to health education, pet-owners and those with prior experience with disease have demonstrated higher awareness and preventive compliance. Infection-control behaviours have been successfully changed through education interventions. Role-playing activities, visual learning aids, and school-based awareness programmes that enhance knowledge and preventive practices

have been demonstrated to be helpful for students and their families (Sarmiento-Senior et al. 2022; Srusti et al. 2022). Approximately 73 percent of student respondents from Malaysian public universities possessed good knowledge about COVID-19, 58.6 percent had positive attitudes, and 54.6 percent presented good practices regarding COVID-19 prevention. No statistically significant differences were found in knowledge scores by socio-demographic data. Knowledge and practices were weak but positively correlated. At the same time, there was no relationship between knowledge and attitude (Hawary et al. 2025).

Environmental health studies have previously shown positive associations between environmental awareness, pro-environmental attitudes, and appropriate waste management behaviours among school students (Britos and Sambo 2024). Environmental responsibility has also been found to be impacted by gender and residential types, with female students often revealing higher ecological concern and more extensive waste-management practices (Thakur et al. 2023). Positive environmental attitudes do not necessarily lead to appropriate behavioural outcomes if there are no segregation systems in schools or if waste management processes nullify the efforts of students (Nisa et al. 2025). Likewise, infrastructure challenges have been recognised as formidable barriers in under-resourced educational contexts, especially in rural areas where open dumping continues to be prevalent (Ade et al. 2022).

Food safety behaviours directly influence exposure to foodborne and waterborne diseases. The present study showed that the knowledge level was insufficient, practices were moderate and acceptable, and attitude was high about foodborne diseases among these college students in western areas of China. Demographic characteristics affected knowledge, attitudes and practices (Ma et al. 2024). A study among medical students in Romania reported that although the respondents had a low level of knowledge on food safety, students reported a high level of food safety practice (Nitescu et al. 2025). Secondary school students in Iran demonstrated moderate knowledge but favourable attitudes and practices regarding food safety (Moghaddam et al. 2020). Such findings suggest that practical compliance may sometimes exceed theoretical understanding. Male students performed better on theoretical food safety assess-

ments, whereas female students demonstrated superior compliance with practical food hygiene behaviours (Wanniarachchi and Abeysundara 2022). These findings reinforce the importance of distinguishing between cognitive understanding and actual behavioural execution when evaluating public health competencies.

A recurring theme across the literature is the significant disconnect between theoretical awareness and behavioural execution. Environmental context, infrastructure, and socio-demographic variables acted as predictors of practices. Most studies have examined hygiene, infection control, environmental sanitation, or food safety as independent domains rather than investigating them within an integrated biosafety framework. Second, relatively limited evidence is available from the Indian senior secondary school population, particularly in the post-pandemic context where health resilience has become a major educational and public health priority.

The Knowledge-Attitude-Practice (KAP) framework assumes that individuals acquire knowledge about a health issue, develop attitudes based on that knowledge, and subsequently translate these attitudes into behavioural practices. It allows for the comparison between demographic groups and the identification of behavioural determinants to inform targeted educational interventions, while also being efficient for large school-based surveys. These domains imply interrelationship, and attitude is supposed to channel knowledge into behaviour (Zarei et al. 2024). This current study adopted this framework to provide an overview of the present status of students' KAP regarding biosafety preventive practices.

Objectives of the Study

This study was undertaken to:

1. Assess the levels of KAP related to biosafety domains of hygiene, food safety, infection control, and environmental health among senior secondary students.
2. Investigate demographic differences in biosafety-related KAP on gender, academic stream, and residential location.
3. Explore the relationships among knowledge, attitudes, and practices across biosafety domains.

4. Determine the relative contribution of knowledge, attitudes, and demographic characteristics in predicting biosafety practices.
5. Identify the most influential factors associated with biosafety behaviour in the post-pandemic educational context.

Hypotheses

The study tested the following hypotheses:

- H₀₁:** There is no significant difference in biosafety KAP across all biosafety domains between rural and urban students.
- H₀₂:** There is no significant difference in biosafety KAP across all biosafety domains between science and non-science students.
- H₀₃:** There is no significant difference in KAP across all biosafety domains between male and female students.
- H₀₄:** There is no significant association between biosafety knowledge and biosafety attitudes across all biosafety domains.
- H₀₅:** There is no significant association between biosafety knowledge and biosafety practices across all biosafety domains.
- H₀₆:** There is no significant association between biosafety attitudes and biosafety practices across all biosafety domains.
- H₀₇:** Knowledge does not significantly predict biosafety practices.
- H₀₈:** Attitude does not significantly predict biosafety practices.
- H₀₉:** Demographic variables (gender, academic stream, and location) do not significantly predict biosafety practices.
- H₁₀:** The determinants of biosafety practices do not differ across all biosafety domains.

MATERIAL AND METHODS

Study Design and Setting

A cross-sectional descriptive survey design (Pareek et al. 2023) was applied among senior secondary school students enrolled in Classes XI and XII in Dehradun district, Uttarakhand, India. This study intended to assess students' KAP towards daily-life biosafety and health resilience in four specific domains.

Study Population

Senior secondary students studying in Classes XI and XII in recognised CBSE schools of Dehradun district formed the population of this study. As adolescents can make independent decisions in health-related issues and actively participate in school and community life, they were selected as the study population.

Sample Size Determination

Cochran's formula for large or infinite populations was used to determine the sample size (Lachenbruch et al. 1991). As no prior estimates regarding the prevalence of biosafety awareness were available among senior secondary students in Dehradun district, the proportion was conservatively assumed to be 0.5. The minimum necessary sample size was 385 participants to achieve a 95 percent confidence level with a ± 5 percent margin of error. A total of 840 students were included to reduce the margin of error to approximately 3.38 percent at the same confidence level. The sample size provided sufficient statistical power to compare subgroups and multivariable analyses.

Sampling Procedure

A multistage sampling strategy was employed across major demographic and educational categories. In the first stage, schools were selected from five blocks of Dehradun district. Due to administrative accessibility and permission-related constraints, fifteen CBSE board schools were purposively selected. These included both private institutions and Atal Utkrisht Government Inter Colleges located in urban and rural settings. In the second stage, students were selected from Classes XI and XII using proportionate simple random sampling. The sampling framework was designed to achieve balanced representation across gender, academic stream, school type, and residential location. The final sample consisted of 840 students.

Instrumentation

A structured and pretested questionnaire (Thapa and Laskar 2024) was administered in classrooms. Eleven subject experts evaluated the face validity and content validity of the instrument. A

pilot study with 290 senior secondary students was conducted later. The content validity, construct validity and internal consistency were presented with Scale-level Content Validity Ratio (S-CVR)=0.79 and Scale-level Content Validity Ratio (S-CVI)=0.96, Kuder-Richardson Formula 20 (KR-20) = 0.6062 for knowledge, Cronbach's alpha = 0.7426 for attitude and Cronbach's alpha = 0.8060 for practice. The Biosafety and its Application in Daily Life (BADL) questionnaire had an acceptable level of reliability and it was qualitatively and quantitatively validated (Sinha et al. 2025). The instrument was divided into knowledge (23 binary items), attitude (13 Likert-scale statements), and practice (22 Likert-scale items) domains. Demographic variables consisted of class (XI/XII), gender, academic stream, school type, and region.

Conceptual Organisation of Biosafety Domains

To facilitate domain-specific analysis, questionnaire items were organised into four thematic biosafety domains, namely, the hygiene domain assessed awareness, attitudes, and practices related to personal hygiene, hand hygiene, and respiratory etiquette in everyday settings. The food safety domain evaluated knowledge and behaviours related to safe food handling, drinking water quality, contamination prevention, and foodborne disease prevention. The infection control domain examined understanding of disease transmission pathways, zoonotic diseases, vaccination, vector-borne diseases, injury-related infection prevention, and biosafety practices associated with infectious disease control. The environmental health domain focused on environmental sanitation, waste segregation, disposal of potentially hazardous materials, wastewater management, and environmentally responsible behaviours. This domain-based structure enabled examination of whether relationships among knowledge, attitudes, and practices differed across specific biosafety contexts rather than being treated as a single homogeneous construct.

Scoring Procedure

Each knowledge item was given a score of 1 for correct and 0 for incorrect answer. Total knowledge scores ranged from 0 to 23. Attitude items were scored on a five-point Likert scale from Strongly Agree = 5 to Strongly Disagree = 1. Practice

items were also scored using a five-point Likert scale from Always = 5 to Never = 1. Negatively framed statements and behaviours were reverse scored. Composite scores were subsequently generated for each KAP domain and for the overall biosafety construct.

Data Collection Procedure

Data collection was carried out during regular school hours in classroom settings. Before questionnaire administration, students were duly informed about the purpose of the study, confidentiality of responses, voluntary nature of participation, right to withdraw at any stage without penalty. Questionnaires were administered in a supervised environment, and completed forms were collected immediately after completion to minimise data loss and consultation among respondents.

Statistical Analysis

The statistical analysis, including the coding, cleaning, and analysis of the data, was done using the Python version 3.13.9 with the Pandas library, NumPy, SciPy and statsmodels. All analytical procedures were performed using reproducible scripted workflows. Descriptive statistics consisted of minimum and maximum values, frequencies, percentages, means, and standard deviations. Independent sample statistics tests were employed to compare KAP scores by gender, academic stream and residential location. Spearman rank-order correlation coefficients were calculated to explore associations among KAP within individual biosafety domains and between overall KAP composite scores. Ordinary Least Squares (OLS) regression models were employed to detect the predictors of biosafety practices, controlling for demographic variables. Random Forest regression was used to estimate relative importance of questionnaire items in predicting biosafety practices across biosafety domains. All inferential analyses were performed considering $p < 0.05$ as the significance level.

RESULTS

Description of the Participants

The sample of 840 senior secondary students was purposively balanced across major demo-

graphic categories to allow for subgroup comparisons. Equal representation was made for gender (420 boys and 420 girls) and academic stream (420 science and 420 non-science students). Residential distribution was also relatively balanced with 422 rural and 418 urban students. This demographic symmetry improved the robustness of the comparative analyses and lowered the chance of subgroup-related sampling bias.

Biosafety KAP in General

Descriptive statistics revealed large differences between the three KAP dimensions. The overall mean for knowledge score of 14.03 ± 3.42 (range: 3-23) showed a moderate level of biosafety knowledge among participants. The considerably higher attitude scores with a mean of 54.26 ± 6.28 (range: 23-65), reflected generally positive perceptions and beliefs regarding biosafety-related issues. Practice scores with a mean of 84.18 ± 11.91 (range: 47-110) suggested favourable self-reported biosafety behaviours (Table 1).

Domain-wise Distribution of KAP Scores

As shown in Table 1, the mean score of KAP in the domain of hygiene were 2.87 ± 1.12 (maximum score: 5), 12.78 ± 2.01 (maximum score: 15) and 26.50 ± 4.86 (maximum score: 35), respectively. Students showed very positive attitudes towards behaviours related to hygiene but their knowledge and practice were relatively moderate. The mean of KAP scores were 4.02 ± 1.22 , 16.21 ± 2.41 and 16.09 ± 3.21 , respectively. In this area students showed a relatively high degree of knowledge and a correspondingly high degree of practical observance and attitudes. Knowledge in the infection control domain was 5.69 ± 1.64 , attitude was 17.25 ± 2.38 and practice was 33.58 ± 5.64 . These results suggested moderate knowledge with relatively good preventive behaviours and high attitude. The domain with the lowest knowledge score was environmental health (1.44 ± 0.86). However, the scores of attitude (8.01 ± 1.73) and practice (8.01 ± 2.14) were still high, indicating environmentally responsible behaviours.

Comparison of Rural-Urban

The comparison of biosafety-related KAP of students in rural and urban areas was given in

Table 1: Descriptive statistics of KAP scores across domains

<i>Metric</i>	<i>Mean</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
<i>Overall Scores</i>				
Overall knowledge	14.03	3.42	3.0	23.0
Overall attitude	54.26	6.28	23.0	65.0
Overall practice	84.18	11.91	47.0	110.0
<i>Domain 1: Hygiene</i>				
Knowledge (max = 5)	2.87	1.12	0.0	5.0
Attitude (max = 15)	12.78	2.01	4.0	15.0
Practice (max = 35)	26.50	4.86	7.0	35.0
<i>Domain 2: Food Safety</i>				
Knowledge (max = 6)	4.02	1.22	0.0	6.0
Attitude (max = 20)	16.21	2.41	6.0	20.0
Practice (max = 20)	16.09	3.21	4.0	20.0
<i>Domain 3: Infection Control</i>				
Knowledge (max = 9)	5.69	1.64	1.0	9.0
Attitude (max = 20)	17.25	2.38	6.0	20.0
Practice (max = 45)	33.58	5.64	15.0	45.0
<i>Domain 4: Environmental Health</i>				
Knowledge (max = 3)	1.44	0.86	0.0	3.0
Attitude (max = 10)	8.01	1.73	2.0	10.0
Practice (max = 10)	8.01	2.14	2.0	10.0

Source: Authors

Table 2. The urban students had significantly higher scores in knowledge (14.32 vs. 13.75, $p=0.0157$), attitude (55.09 vs. 53.44, $p=0.0001$), and practice (85.14 vs. 83.24, $p=0.0208$) than the rural students in general. The domain-wise analysis showed that the urban students scored significantly higher in hygiene attitude (12.94 vs. 12.62, $p=0.0192$), food

safety knowledge (4.12 vs. 3.93, $p=0.0206$), food safety attitude (16.53 vs. 15.90, $p=0.0001$), infection control attitude (17.43 vs. 17.08, $p=0.0297$), infection control practice (34.01 vs. 33.15, $p=0.0264$), environmental health attitude (8.18 vs. 7.84, $p=0.0045$) and environmental health practice (8.26 vs. 7.77, $p=0.0010$). Urban-rural differences in hy-

Table 2: Urban–Rural differences across KAP domains

<i>Metric</i>	<i>Maximum score</i>	<i>Rural mean</i>	<i>Urban mean</i>	<i>p-value</i>
<i>Overall Scores</i>				
Overall knowledge	23	13.75	14.32	0.0157
Overall attitude	65	53.44	55.09	0.0001
Overall practice	110	83.24	85.14	0.0208
<i>Hygiene</i>				
Knowledge	5	2.81	2.94	0.0759
Attitude	15	12.62	12.94	0.0192
Practice	35	26.42	26.58	0.6445
<i>Food Safety</i>				
Knowledge	6	3.93	4.12	0.0206
Attitude	20	15.90	16.53	0.0001
Practice	20	15.89	16.29	0.0741
<i>Infection Control</i>				
Knowledge	9	5.63	5.75	0.2863
Attitude	20	17.08	17.43	0.0297
Practice	45	33.15	34.01	0.0264
<i>Environmental Health</i>				
Knowledge	3	1.38	1.50	0.0505
Attitude	10	7.84	8.18	0.0045
Practice	10	7.77	8.26	0.0010

Source: Authors

giene knowledge, hygiene practice, food safety practice, and infection control knowledge were not statistically significant. In general, results indicate that urban students had significantly more positive attitudes and practices related to biosafety in several domains and better knowledge in one domain than the rural students.

Academic Stream Differences

Table 3 showed that science students significantly outperformed non-science students across nearly all overall and domain-specific indicators. Overall knowledge scores (15.17 vs. 12.89, $p < 0.001$), attitude scores (55.65 vs. 52.86, $p < 0.001$), and practice scores (85.51 vs. 82.86, $p = 0.0012$) were significantly higher among science students than their non-science counterparts. Within the hygiene domain, science students demonstrated significantly higher knowledge (3.08 vs. 2.66, $p < 0.001$) and attitude (13.17 vs. 12.39, $p < 0.001$) scores. Science students scored significantly higher than non-science students across the food safety domain knowledge (4.31 vs. 3.74, $p < 0.001$), attitudes (16.51 vs. 15.91, $p = 0.0003$), and practices (16.38 vs. 15.80, $p = 0.0099$), the infection control domain knowledge (6.23 vs. 5.16, $p < 0.001$), attitudes (17.67 vs. 16.84, $p < 0.001$), and practices (34.40 vs. 32.77, $p < 0.001$), and the environmental health domain knowledge (1.54 vs. 1.34, $p = 0.0005$), attitudes (8.30 vs.

7.72, $p < 0.001$), and practices (8.24 vs. 7.79, $p = 0.0020$). Academic stream emerges as the most structurally consistent determinant across domains, though no statistically significant difference was achieved in hygiene practices.

Gender Differences

Table 4 identified patterns in gender-based comparisons. Overall, female students demonstrated significantly higher mean scores than boys in all three KAP components. Female students had higher overall knowledge scores (14.27 vs. 13.79; $p = 0.0403$), attitude scores (55.43 vs. 53.09; $p < 0.001$), and practice scores (87.34 vs. 81.03; $p < 0.001$). Female students scored significantly higher than their male counterparts in the hygiene domain knowledge (2.96 vs. 2.79; $p = 0.0223$), attitudes (13.13 vs. 12.44; $p < 0.001$), and practices (27.44 vs. 25.56; $p < 0.001$), in the food safety domain attitudes (16.54 vs. 15.89; $p = 0.0001$) and practices (16.79 vs. 15.39; $p < 0.001$), in infection control and disease prevention domain knowledge (5.83 vs. 5.55; $p = 0.0131$), attitudes (17.61 vs. 16.90; $p < 0.001$), and practices (34.54 vs. 32.63; $p < 0.001$), and in the environmental health domain attitudes (8.15 vs. 7.86; $p = 0.0149$) and practices (8.58 vs. 7.45; $p < 0.001$). Overall, all domain-specific attitude and practice scores showed statistically significant differences between male and female stu-

Table 3: Science versus non-science differences across KAP domains

<i>Metric</i>	<i>Maximum score</i>	<i>Science mean</i>	<i>Non-Science mean</i>	<i>p-value</i>
<i>Overall Scores</i>				
Knowledge	23	15.17	12.89	<0.001
Attitude	65	55.65	52.86	<0.001
Practice	110	85.51	82.86	0.0012
<i>Hygiene</i>				
Knowledge	5	3.08	2.66	<0.001
Attitude	15	13.17	12.39	<0.001
Practice	35	26.50	26.50	0.9830
<i>Food Safety</i>				
Knowledge	6	4.31	3.74	<0.001
Attitude	20	16.51	15.91	0.0003
Practice	20	16.38	15.80	0.0099
<i>Infection Control</i>				
Knowledge	9	6.23	5.16	<0.001
Attitude	20	17.67	16.84	<0.001
Practice	45	34.40	32.77	<0.001
<i>Environmental Health</i>				
Knowledge	3	1.54	1.34	0.0005
Attitude	10	8.30	7.72	<0.001
Practice	10	8.24	7.79	0.0020

Source: Authors

Table 4: Gender differences across KAP domains

<i>Metric</i>	<i>Maximum score</i>	<i>Boys mean</i>	<i>Girls mean</i>	<i>p-value</i>
<i>Overall Scores</i>				
Knowledge	23	13.79	14.27	0.0403
Attitude	65	53.09	55.43	<0.001
Practice	110	81.03	87.34	<0.001
<i>Hygiene</i>				
Knowledge	5	2.79	2.96	0.0223
Attitude	15	12.44	13.13	<0.001
Practice	35	25.56	27.44	<0.001
<i>Food Safety</i>				
Knowledge	6	3.96	4.08	0.1589
Attitude	20	15.89	16.54	0.0001
Practice	20	15.39	16.79	<0.001
<i>Infection Control</i>				
Knowledge	9	5.55	5.83	0.0131
Attitude	20	16.90	17.61	<0.001
Practice	45	32.63	34.54	<0.001
<i>Environmental Health</i>				
Knowledge	3	1.49	1.39	0.1178
Attitude	10	7.86	8.15	0.0149
Practice	10	7.45	8.58	<0.001

Source: Authors

dents except for knowledge scores in the food safety and environmental health domains.

Overall Correlational Structure

Spearman correlation analysis indicated significant positive correlations among all three KAP components (Table 5). The strongest association was between total knowledge and total attitude ($r_s = 0.439$) and between attitude and practice ($r_s = 0.400$). The relationship between knowledge and practice was comparatively weak ($r = 0.272$). These findings indicated that knowledge was more strongly related to attitudinal orientation than to behavioural implementation.

Correlations Specific to a Domain

Table 5 also revealed that there was virtually no direct link between knowledge and practice in

the hygiene domain ($r_s = 0.037$). However, there were modest positive relationships between knowledge and attitude ($r_s = 0.257$) and attitude and practice ($r_s = 0.217$). Food safety exhibited a more coherent KAP sequence. Positive correlation was found between knowledge and attitude ($r_s = 0.213$), knowledge and practice ($r_s = 0.173$) and attitude and practice ($r_s = 0.215$). The strongest knowledge-attitude association was observed in infection control ($r_s = 0.302$) across all domains. However, the corresponding knowledge-practice relationship was weaker ($r_s = 0.189$). The strongest relationship in environmental health was between attitude and practice ($r_s = 0.251$), while knowledge had only moderate associations with both attitude and practice. The correlation analysis revealed positive associations between knowledge and attitude in all biosafety domains. Knowledge and practice was positively correlated across all domains, although the strength of these associations was generally

Table 5: Spearman correlations among knowledge, attitude, and practice within domains

<i>Domain</i>	<i>Knowledge–Attitude (rs)</i>	<i>Knowledge–Practice (rs)</i>	<i>Attitude–Practice (rs)</i>
Hygiene	0.257	0.037	0.217
Food Safety	0.213	0.173	0.215
Infection Control	0.302	0.189	0.212
Environmental Health	0.203	0.176	0.251
Overall Composite Score	0.439	0.272	0.400

Source: Authors

weak. Attitude and practice scores were positively associated across all biosafety domains.

Multivariable Regression Analysis

Table 6 demonstrated four OLS regression models estimated with the dependent variables as the domain-specific practice scores. All models were statistically significant ($p < 0.001$), specifying that the included predictors together explained significant variation in biosafety behaviours. But the explanatory power was modest, with R^2 ranging from 0.068 to 0.144. Knowledge had significant prediction to practice in food safety [$\beta = 0.375$, 95% CI (0.199, 0.551), $p < 0.001$], infection control [$\beta = 0.384$, 95% CI (0.139, 0.629), $p < 0.01$], and environmental health [$\beta = 0.362$, 95% CI (0.201, 0.523), $p < 0.001$]. However, knowledge was not a significant predictor of hygiene practice [$\beta = -0.097$, 95% CI (-0.399, 0.205), $p = 0.597$]. Attitude surfaced as a significant predictor of practice in all four domains (all $p < 0.001$). The most influential attitude was hygiene [$\beta = 0.448$, 95% CI (0.277, 0.619), $p < 0.001$], followed by infection control [$\beta = 0.370$, 95% CI (0.205, 0.535), $p < 0.001$], food safety [$\beta = 0.211$, 95% CI (0.121, 0.301), $p < 0.001$] and environmental health [$\beta = 0.199$,

95% CI (0.119, 0.279), $p < 0.001$]. After controlling for knowledge and attitude, female gender remained a significant positive predictor of practice across all domains of hygiene [$\beta = 1.593$, 95% CI (0.944, 2.242), $p < 0.001$], food safety [$\beta = 1.207$, 95% CI (0.790, 1.624), $p < 0.001$], infection control [$\beta = 1.490$, 95% CI (0.751, 2.229), $p < 0.001$], and environmental health [$\beta = 1.087$, 95% CI (0.817, 1.357), $p < 0.001$]. Science-stream background was only significant in infection control ($\beta = 0.895$, 95% CI (0.123, 1.667), $p < 0.05$). After adjustment for knowledge and attitude, rural location was not independently significant. The regression analysis demonstrated that knowledge was not a significant predictor of hygiene practices but it significantly predicted practices related to food safety, infection control, and environmental health. Attitude was a significant positive predictor of biosafety practices across all four domains as regression coefficients were statistically significant. The predictive effects of demographic variables varied across the biosafety domains. Gender was a significant positive predictor for biosafety practices in all four domains, with female students reporting significantly higher practice scores than male students. In the domain of infection control and disease prevention, academ-

Table 6: Ordinary Least Squares (OLS) regression models predicting domain-specific practice scores

Predictor	Hygiene $\hat{\alpha}$ (95% CI) p -value	Food Safety $\hat{\alpha}$ (95% CI), p -value	Infection Control $\hat{\alpha}$ (95% CI), p -value	Environmental Health $\hat{\alpha}$ (95% CI), p -value
Constant	20.468 (18.396, 22.540), $p < 0.001$	10.398 (8.946, 11.850), $p < 0.001$	23.550 (20.843, 26.257), $p < 0.001$	5.089 (4.436, 5.742), $p < 0.001$
Domain Knowledge	-0.097 (-0.399, 0.205), $p = 0.597$	0.375 (0.199, 0.551), $p < 0.001$	0.384 (0.139, 0.629), $p < 0.01$	0.362 (0.201, 0.523), $p < 0.001$
Domain Attitude	0.448 (0.277, 0.619), $p < 0.001$	0.211 (0.121, 0.301), $p < 0.001$	0.370 (0.205, 0.535), $p < 0.001$	0.199 (0.119, 0.279), $p < 0.001$
Rural (Dummy)	-0.114 (-0.755, 0.527), $p = 0.728$	0.075 (-0.342, 0.492), $p = 0.701$	0.528 (-0.203, 1.259), $p = 0.566$	0.270 (-0.001, 0.540), $p = 0.512$
Science (Dummy)	0.313 (-0.968, 0.342), $p = 0.649$	0.227 (-0.198, 0.652), $p = 0.594$	0.895 (0.123, 1.667), $p < 0.05$	0.259 (-0.013, 0.531), $p = 0.541$
Female (Dummy)	1.593 (0.944, 2.242), $p < 0.001$	1.207 (0.790, 1.624), $p < 0.001$	1.490 (0.751, 2.229), $p < 0.001$	1.087 (0.817, 1.357), $p < 0.001$
<i>Model Summary</i>				
Domain	R^2	F -statistic		
Hygiene	0.068	12.10, $p < 0.001$		
Food Safety	0.108	20.18, $p < 0.001$		
Infection Control	0.096	17.74, $p < 0.001$		
Environmental Health	0.144	28.08, $p < 0.001$		

Source: Authors

ic stream was a significant predictor of practices while it was not significant in the other three domains. In none of the domains did location (rural) significantly predict biosafety practices.

Random Forest Analysis of Behavioural Drivers

Random Forest regression models were estimated separately for each practice domain to identify item-level drivers of behaviour in Table 7. The analysis of feature importance revealed a common pattern across the domains, with attitudinal variables taking the top predictive positions. Hygiene showed the strongest predictors to the beliefs about the importance of handwashing and public responsibility for hygiene. Perceptions of risks associated with preservatives, avoidance of contaminated foods, and support for water filtration were the most influential predictors in food safety. The strongest determinants were confidence in vaccination, awareness of injection safety and concern regarding vector-borne diseases in infection control. In environmental health, support for waste segregation and wastewater treatment was the most important predictor. Knowledge variables generally had lower predictive ranks than attitudinal variables across the board, though knowledge played a more visible role in environmental health. These findings were in accordance with the correlational and regression analyses that factual knowledge alone was not the main driver of biosafety practices but attitudinal orientation was. The relative importance of predictors was found to vary across biosafety domains. Attitude was the strongest predictor in several domains, but other predictors such as knowledge and demographic variables contributed differently depending on the domain.

DISCUSSION

The present study showed significant differences in biosafety KAP on demography, correlations and predictions. Urban students had slightly higher scores on KAP in selected domains. However, residential location was not an independent predictor of biosafety practices after adjustment for other variables (Table 2). Science students had higher KAP scores than non-science students, indicating greater exposure to biological and health-related concepts (Table 3). In all the domains of biosafety, female students were consistently better than the male students in attitude and practice. However, the knowledge difference between genders was domain specific (Table 4). These findings are consistent with previous studies reporting greater health consciousness and preventive compliance among female adolescents (Hawary et al. 2025; Wanniarachchi and Abeysundara 2022). This suggested that differences were mediated largely by knowledge and attitudes rather than geography per se. Knowledge, attitude and practice were positively associated with each other in all biosafety domains (Table 5). Knowledge and attitude showed the strongest relationship whereas the knowledge-practice associations were comparatively weaker, suggesting that knowledge alone was not enough to bring about behavioural change. This finding was consistent with previous studies that had reported ongoing knowledge-practice gaps in hygiene, food safety, and prevention of infectious diseases, where behavioural compliance is affected by environmental support, institutional facilities, personal motivation, and knowledge (Otto et al. 2022; Kuandyk et al. 2025; Hawary et al. 2025). Regression analysis also revealed that the determinants of biosafety practice-

Table 7: Top predictors of practice behaviour by domain based on random forest analysis

<i>Domain</i>	<i>Most important predictor</i>	<i>Second most important predictor</i>	<i>Third most important predictor</i>	<i>Dominant predictor type</i>
<i>Hygiene</i>	Handwashing is not a waste of time (0.148)	Public hygiene responsibility (0.110)	Public space hygiene attitude (0.106)	Attitude
<i>Food Safety</i>	Preservative and colour risks (0.133)	Avoid fruits bitten by animals (0.125)	Water filtration as protection (0.124)	Attitude
<i>Infection Control</i>	Confidence in vaccine effectiveness (0.111)	Needle safety awareness (0.107)	Vector precaution importance (0.086)	Attitude
<i>Environmental Health</i>	Waste segregation support (0.222)	Wastewater treatment support (0.210)	Disposal awareness (0.106)	Attitude + Knowledge

Source: Authors

es differed across domains (Table 6). Attitude was a significant predictor of all domains while knowledge was a significant predictor of practices related to food safety, infection control and environmental health but not to hygiene practices. Unlike the Nigerian boarding school study, which found that favourable attitudes did not necessarily translate into improved hygiene behaviour, this present study found attitude to be a consistent predictor of biosafety practices. This underscores the significance of infrastructural and institutional factors (Adebayo et al. 2026). Gender remained the strongest demographic predictor with academic stream only significantly predicting infection-control practices and residential location not significantly predicting any of the practices. Random Forest analysis further confirmed that biosafety behaviours are multidimensional and domain-specific, with attitude being the most influential predictor in several domains, while knowledge and demographic characteristics contributed differently depending on the behavioural context (Table 7). Another study highlighted that knowledge alone was insufficient as repeated behavioural reinforcement substantially improved hand hygiene (Levine et al. 2025). WASH intervention was found effective in promoting safe water, sanitation and hygiene practices among school students leading to improvement in knowledge, behaviour and health outcomes. This success was achieved through joint implementation supported by strong institutional support. However, continued support and resources were considered to be necessary for a sustainable future and impact (Ezenwaka et al. 2026). Taken together, these findings suggested that biosafety behaviours could not be solely explained by knowledge acquisition and underscore the importance of comprehensive educational approaches that incorporate cognitive, motivational, behavioural, and environmental components. Overall, the results generally supported the proposed hypotheses, suggesting that biosafety practices are shaped by multiple interacting cognitive, attitudinal, demographic, and contextual factors, with the relative influence varying across biosafety domains.

Knowledge scores remained comparatively lower while attitude scores were the highest followed by the practice scores (Table 1). This pattern suggested that students generally agreed with biosafety principles and reported positive preven-

tive behaviours even with moderate conceptual understanding. These findings were consistent with previous research in food safety and environmental health, which reported positive attitudes and acceptable practices despite moderate levels of knowledge (Moghaddam et al. 2020). This pattern opposed the high knowledge and low practice pattern generally observed and did not correspond to the usual assumption in the KAP model that knowledge is the main driver of behaviour. As a result, it can be assumed that many students may have adopted safe practices through repeated exposure and social reinforcement even when detailed scientific understanding remained incomplete.

The weakest association between knowledge and practices was seen in the hygiene domain where knowledge was not a significant predictor of hygiene practices but attitude was. These results were consistent with previous findings on persistent knowledge-practice gaps in school hygiene behaviour (Otto et al. 2022; Kuanddyk et al. 2025; Masthi and Pruthvi 2022). In contrast, food safety showed the most consistent progression from knowledge to attitude and then to practice, with knowledge remaining a significant predictor after controlling for demographic variables. This finding suggested that conscious risk evaluation is more important for food related decision making than routine hygiene behaviours. The Random Forest analysis further identified perceived risks related to food preservatives, contaminated fruits and water filters as important determinants of behaviour. Similarly, the infection control domain had the highest knowledge-attitude relationship, which suggested that factual knowledge influenced preventive attitudes primarily, but the behavioural implementation depends on other motivational and contextual factors. The Random Forest model identified the importance of confidence in vaccines, knowledge of unsafe injection practices, and concern about vector-borne diseases, which aligned with prior intervention studies that had shown increase in awareness of infection-control and preventive orientation (Sarmiento-Senior et al. 2022; Srusti et al. 2022). Regarding environmental health, high attitudes and practices in spite of low knowledge suggested that civic responsibility and environmental values had a great contribution to behaviour. Another study found that environmental awareness and positive attitudes are strong predictors of waste-management behaviour (Britos and

Sambo 2024). The lack of school waste segregation systems can limit behaviour expression despite the positive attitudes (Nisa et al. 2025). Contrary to the current findings, a study in Indonesia showed that positive environmental attitudes did not necessarily lead to accurate waste-sorting behaviour until the introduction of visual prompts and behavioural interventions, emphasising the role of environmental cues in maintaining responsible waste-management behaviour (Fenitra et al. 2025). Previous studies showed that although students possessed adequate knowledge of hand hygiene, they often failed to translate this knowledge into consistent practice (Otto et al. 2022; Tupone et al. 2025). Similarly, Sarawade et al. (2026) reported high awareness of disease transmission through unwashed hands but poor handwashing practices because of institutional constraints, while Kuandyk et al. (2025) and Ngcongo and Tekere (2025) identified inadequate access to soap, clean water, and sanitation facilities as major barriers to hygienic behaviour. Conversely, intervention studies have demonstrated that structured health education combined with supportive infrastructure significantly improved hygiene behaviour and handwashing practices (Enkhat et al. 2025; Ly et al. 2025; Pieters et al. 2025). Likewise, superior hygiene knowledge and attitudes among rural students without corresponding improvements in practice, reinforcing the view that knowledge alone is insufficient to change behaviour (Rajagopal et al. 2026). Collectively, these findings supported participatory and whole-school approaches that integrated behavioural reinforcement, environmental cues, social support, and institutional commitment (Ly et al. 2025; Pieters et al. 2025; Sagar et al. 2025). The apparent gap between knowledge and practice may not be solely due to infrastructural deficits, but may also be due to social desirability bias, cultural practices and structural constraints that impede behavioural implementation (Choudhury et al. 2026).

Science students consistently performed better than non-science students in most knowledge, attitude and practice measures, thus reflecting greater exposure to biological and public health concepts. However, the lack of differences in hygiene practices despite higher scientific knowledge suggested that habitual behaviours were more influenced by social norms and environmental conditions than by formal instruction alone. Gender was the most consistent demographic predictor, with female students showing better biosafety practices even after adjustment

for knowledge and attitudes, corroborating previous findings of higher health consciousness and preventive compliance in female adolescents (Thakur et al. 2023; Wanniarachchi and Abeyesundara 2022).

Convergent findings from correlation analysis, regression modelling, and Random Forest analysis show that attitudes were more influential than knowledge in predicting biosafety practices, but the relative importance of knowledge, demographic characteristics, and contextual factors varies across biosafety domains. These findings indicate that school biosafety programmes should go beyond knowledge dissemination to strengthening attitudes, behavioural reinforcement, social responsibility and supportive institutional environments to promote sustainable preventive behaviours among adolescents.

CONCLUSION

This present study assessed the post-pandemic biosafety related KAP among senior secondary school students of Dehradun district in four inter-related domains namely, hygiene, food safety, infection control and disease prevention, and environmental health. The descriptive analysis showed several important structural patterns. The attitude scores in all domains were above 80 percent of the maximum values in all domains, indicating a general acceptance of biosafety principles. A knowledge-practice gap was found in the hygiene domain, with relatively good attitudes but moderate knowledge and practice levels. The food safety showed the highest correlation between knowledge and practice, which suggested that conceptual knowledge had been successfully translated into daily habits. Next, environmental health had a relatively high level of behavioural compliance despite low knowledge scores, suggesting the influence of social norms, environmental conditioning or institutional expectations. Standard deviations were consistently larger for practice than for attitude, indicating a greater heterogeneity in actual behavioural execution than in beliefs and perceptions. Gender was generally the most consistent demographic predictor of biosafety behaviour. The results gave important insights into the structure of biosafety competence of adolescents and indicated that biosafety behaviour was an outcome of a complex interaction of knowledge, attitudes, demographic characteristics, and situational factors and not solely dependent on knowledge. Students

had not only average knowledge but also good practice. In essence, it showed that the biosafety behaviour of adolescents was mostly linked to their attitudes and values. Knowledge was still important but knowledge alone was not enough. By internalising responsibility, perceiving risk and developing positive preventive orientations, students were more likely to engage in safe behaviours. Interventions should be adapted to the domain-specificity of biosafety behaviour. For instance, hygiene promotion should target habit formation and behavioural reinforcement, while food safety and infection control interventions might get benefited from a stronger focus on conceptual instruction. The gender differences observed also pointed to the need to adopt gender responsive approaches in health education. Schools after the pandemic needed to be recognised not just as places of academic learning but as critical settings to build lifelong health resilience, risk awareness and responsible citizenship.

RECOMMENDATIONS

Longitudinal studies should be designed in future research to explore the changes of biosafety-related knowledge, attitude and practice over time and to clarify the causal pathways in the KAP model. Additional research should also be needed to understand the persistent knowledge-practice gap observed in the hygiene domain. Comparative studies in different geographical regions and educational settings would help establish the generalisability of the present findings, while intervention-based research could assess the effectiveness of integrated biosafety education programmes combining knowledge acquisition with attitude formation, behaviour reinforcement and community engagement.

LIMITATIONS

There were a number of limitations in the interpretation of the findings. As the study was cross-sectional in nature, causality could not be inferred for the relationships across KAP and the directionality of such relationships over time could not be explored. For that, the authors had to rely on the previous studies. In addition, the study used self-reported practices, which might be affected by recall bias and social desirability bias. Although the sample was large and demographically balanced, schools were selected purposively due to administrative and accessibility constraints, limit-

ing the generalisability of the findings beyond the study area. Moreover, factors that might have been bearing significance, such as parental education, socio-economic status, household sanitation conditions, media exposure, peer influences, were not directly assessed.

DISCLOSURES AND DECLARATIONS

AUTHOR CONTRIBUTION(S)

Sukla Sinha: Conceptualization; Investigation; Data Collection; Data curation; Methodology; Validation; Writing – original draft.

Dr. Geetu Gupta: Conceptualization; Supervision; Investigation; Validation; Writing – review and editing.

Dr. Himanshu Tolani: Supervision; Validation; Writing – review and editing.

Lalit Sachan: Formal analysis; Software; Validation; Writing – review and editing.

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The authors do not have any competing interests.

CONSENT FOR PUBLICATION

All authors agree to this submission/publication.

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AVAILABILITY OF DATA AND MATERIALS

Data were stored securely in password-protected files accessible only to the research team. The data are, however, available from the authors upon reasonable request.

ETHICAL CONSIDERATIONS AND CONSENT TO PARTICIPATE DECLARATION

The study involved a voluntary, non-interventional, questionnaire-based educational survey

study assessing awareness of biosafety concepts and practices in daily life in the post-pandemic era, posing minimal risk to participants. Participants were informed about the study purpose, and confidentiality, anonymity, and data de-identification were ensured. Data were stored in password-protected files accessible only to the research team, and analyses were conducted using Python (version 3.13.9) following predefined analytical protocols to ensure reproducibility and data integrity. Therefore, the institutional review committee did not recommend any ethical clearance.

CLINICAL TRIAL NUMBER

Not Applicable

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