

ANALYZING FIRE SAFETY PRACTICES IN TERTIARY INSTITUTIONS OF KHULNA CITY USING GIS AND IFSS-CP FRAMEWORK

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ABSTRACT

Fire incidents in Bangladesh highlight the lack of institutional fire safety practices. They constitute a substantial barrier to the process of sustainable development. As a major urban center, Dhaka has attracted a lot of academic attention. Meanwhile, the tertiary educational institutions in the regional cities remain underexplored. The combination of the Geographic Information System (GIS)-based hazard mapping approach and the International Fire Safety Standards Common Principles (IFSS-CP) framework was used to analyze fire safety practices in the four tertiary institutions in Khulna City, including Khulna University (KU), Khulna University of Engineering & Technology (KUET), North Western University (NWU), and Northern University of Business and Technology Khulna (NUBTK). The cross-sectional survey was executed by using a random stratified sampling technique. A sample of 1,480 respondents was used to represent the students, faculty members, administrative officials, and support officials. In addition, direct field observation of the fire safety infrastructure in the institutions was conducted. According to the five IFSS-CP domains (Prevention, Detection and Communication, Occupant Protection, Containment and Extinguishment), 17 binary protocols were employed to determine the compatibility of institutional compliance, as measured by the Fire Safety Practice Index (FSPI). Inconsistency in preparedness was observed, as incidences of fire were reported at KU, NWU, and NUBTK and none at KUET. Empirical evidence shows that institutions have serious safety lapses. A summary of the respondents revealed that 65.54 % of the respondents were in the low compliance group (FSPI score 0 to 5), 24.46 % in the moderate compliance group (FSPI score 6 to 11), and 10.00 % in the high compliance group (FSPI score 12 to 17) which provided the total FSPI mean of 4.95. According to the study, more robust fire governance system, regular safety audit, capacity-building intervention, and implementation of systematic enforcement strategies are urgent in promoting institutional fire safety. The combination of GIS and IFSS-CP models shows a great potential to produce evidence-based information that can be used in decision-making. This approach can improve the sustainability and fire resilience of tertiary educational institutions in the education sector in Bangladesh.

Keywords: *Fire Safety, GIS-based Hazard Mapping, IFSS-CP Framework, Tertiary Institutions, Sustainable Infrastructure*

1. INTRODUCTION

Fire incidents have emerged as a major national problem for Bangladesh. Due to fires, people lose their life and they are injured while also losing valuable possessions. Between 2009 and 2018, Bangladesh experienced an average of 1,511 fires per year, with 5,555 of these fires taking place within Dhaka city alone (Chisty & Rahman, 2020). The study area demonstrates a high level of risk with low levels of disaster coping capacity (James et al., 2018). Nonetheless, the residents of the study area can enhance its overall resilience through proper support and intervention (Mohammed et al., 2023). Fire safety measures need to be developed to lessen the effects of fires (Abedin et al., 2022). After the Rana Plaza disaster, the 2013 Accord on Fire and Building Safety has improved garment factory standards, despite the absence of strong regulatory oversight (Biswas et al., 2018). 44 people were killed and 22 were injured due to the Bailey Road fire tragedy on 29 February 2024 emphasizing the urgency of effective safety measures. Such incidents were caused by short circuits or gas leakage and then aggravated by structural flaws, thus underscoring the dire need for reform. As a result of building fire more than 1,300 lives have been lost since 2013 (Ghaedi, 2024).

Khulna is also exposed to fire hazard threats. The lives and properties of densely populated areas of Khulna are at risk as a result of weak fire safety standards and fast construction (Ahmed et al., 2023). Combining a regulatory approach with adequate firefighting apparatus and fire safety awareness will be effective in addressing this issue (A. Ahmed & Subrina, 2020). A successful fire safety system requires ongoing collaboration between authorities, fire service agencies, and community members. It also requires on-going review of fire safety plans. An example of such a collaborative model is the IFSS-CP which provides a systematic framework for fire safety, assessing potential outcomes, and identifying appropriate solutions (Ouache et al., 2021). The IFSS-CP framework underscores the interdependence among infrastructure, operations, and human factors (Forcellini, 2023). The use of the IFSS-CP framework will allow the evaluation of fire safety levels in tertiary institutions in Khulna. It will also help identify existing safety problems. In addition, it will support data-driven changes aimed at improving overall fire safety conditions (Fire Safety Research Institute, 2016). This study is among the few that examine fire safety in tertiary institutions. It is also among the first to assess fire safety in tertiary institutions located outside Dhaka, as most existing fire safety studies in Bangladesh have focused on Dhaka city (Ehsan, 2021).

As mentioned, prior studies on the topic of fire safety within tertiary institutions in Khulna are quite limited or absent, and numerous studies have considered fire hazards within the city or on the university-scale (Sabo et al., 2025). This study aims to assess the fire safety measures in tertiary institutions in Khulna City by using the IFSS-CP Framework coupled with the use of Geographic Information Systems (GIS)-based hazard mapping. These results support the need to use evidence-based and behaviourally informed solution to improve fire safety resilience and promote sustainable development of the infrastructure in the sector of higher education.

2. METHODOLOGY

2.1 Study Area

This study was conducted across four universities in Khulna City, including Khulna University (KU), Khulna University of Engineering & Technology (KUET), North Western University (NWU), and Northern University of Business and Technology Khulna (NUBTK). This location is significant to research the potential for fire due to a large number of universities in close proximity, a mix of land uses and some challenges with infrastructure that can contribute to the risk of fires occurring. Figure 1 shows the study area and has been mapped to provide evidence on the potential areas of higher fire risk, which institutions are at a greater risk for fires and how well these institutions have prepared or complied with fire safety regulations.

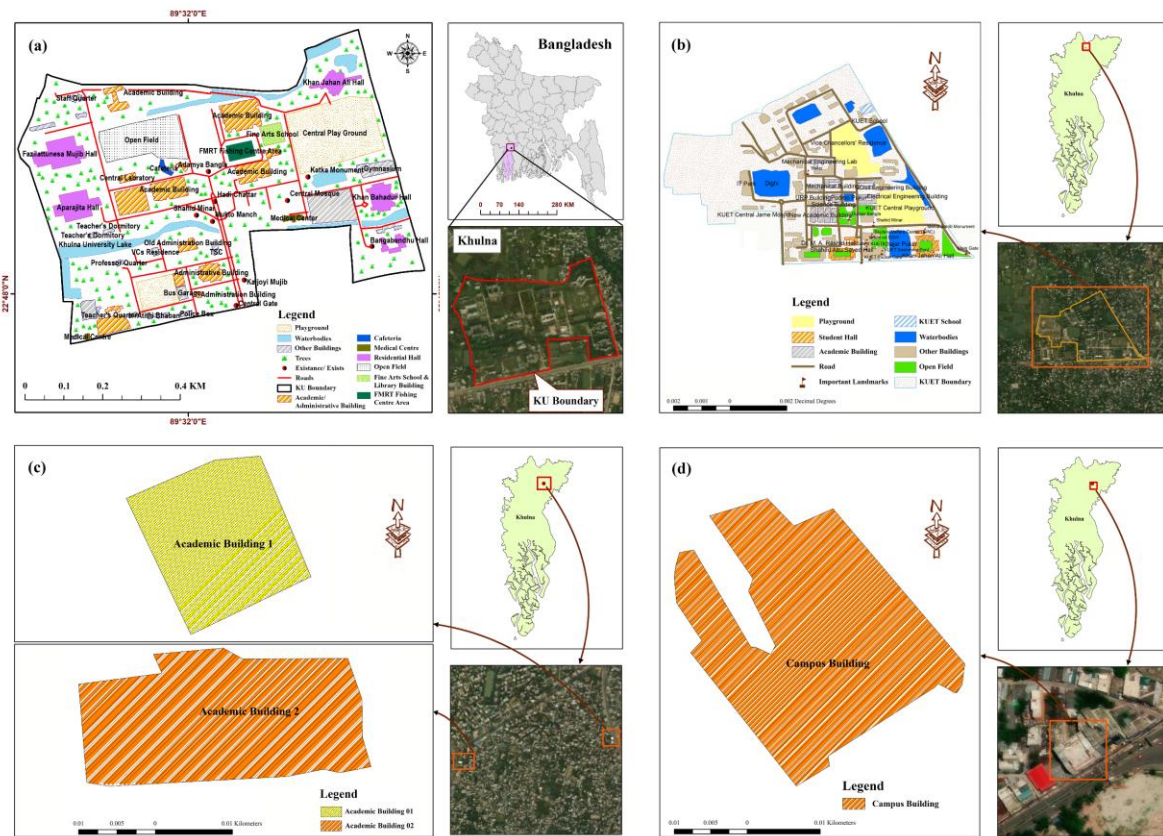


Figure 1: Study area map of (a) KU, (b) KUET, (c) NWU, and (d) NUBTK

2.2 Conceptual Framework

2.2.1 Incident and Hazard Mapping with Institutional Fire Safety Assessment

The research took an interdisciplinary methodology of integration of GIS-based incident and hazard mapping and evaluation of institutional infrastructure (Figure 2). Fire incidences in the past were geospatially mapped in order to detect recurring areas of hazards and the field survey and a visit to the site using the IFSS-CP framework visualized the degree of compliance whereby buildings were classified as either high (green), moderate (yellow), or low (red) on the safety practices. An additional structured questionnaire consisting of 17 binary protocols further measured important safety factors like fire exit, emergency routes, alarms, extinguishers, and signage, which made the evaluation across all institutions the same and comparable.

2.2.2 Evaluation of Institutional Fire Safety Practices Using IFSS-CP Framework

The institutional buildings are evaluated in accordance with the five domains of the IFSS-CP framework (UNECE, 2020), and the combination of these domains represent the crucial dimensions of fire safety:

- i. Prevention: Interventions to reduce ignition dangers.
- ii. Detection and Communication: Communication mechanisms of early warning and alerts.
- iii. Occupant Protection: Security escape routes and safety provisions.
- iv. Containment: Fire inhibiting structural features.
- v. Extinguishment: Accessibility and availability of firefighting resources.

This scheme offers a universal and structured benchmark on which the performance of institutional fire safety is measured. It is used on four tertiary institutions in Khulna (KU, KUET, NWU, and NUBTK)

to assess adherence to the set fire safety standards. The evaluation includes the infrastructural sufficiency and procedural readiness, which provide comparative information about the differences in the safety culture, operational preparedness, and compliance of protocols. It uses seventeen binary indicators that are graded as 1 (compliant) or 0 (non-compliant) enabling a quantitative comparison of the institutions and domains to determine areas that require improvements and policy intervention (Figure 2).

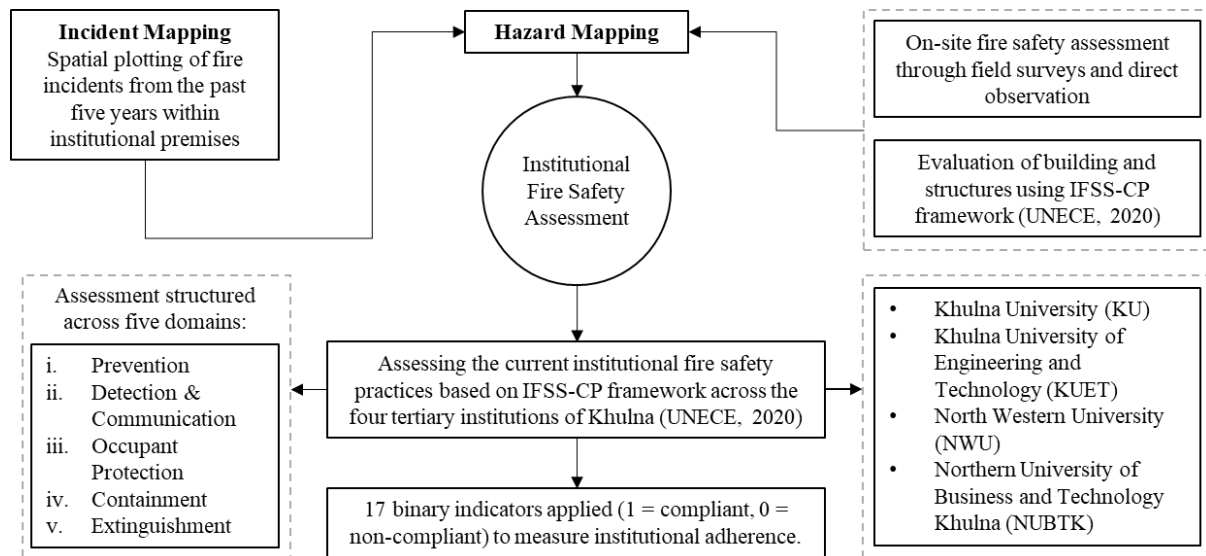


Figure 2: Conceptual framework for analysing fire safety practices in tertiary institutions of Khulna using GIS and IFSS-CP

2.3 Data Collection and Sampling

2.3.1 Data Collection

The research primarily uses primary data gathered by way of field surveys, institutional observations and a structured questionnaire. The researcher conducted data collection personally in four tertiary institutions in Khulna to guarantee a sense of accuracy, consistency, and contextual awareness of site-specific conditions on fire safety. There were four major stakeholder groups in which respondents were chosen:

- i. Administrative official – in charge of fire safety and institutional management;
- ii. Faculty member – as an academic leadership and daily building users;
- iii. Support official – including maintenance and security personnel directly involved in operational safety measures; and
- iv. Student – the largest occupant group, most exposed during fire incidents.

2.3.2 Fire Safety Practices Assessment (Based on IFSS-CP Framework)

A structured questionnaire was used to assess fire safety practices and was in line with the IFSS-CP framework with the focus on the in-use phase of institutional buildings. The evaluation focused on 17 protocols in 5 domains, Prevention (4 protocols), Detection and Communication (3), Occupant Protection (3), Containment (3), and Extinguishment (4). They were all rated with binary scale (0 = absent, 1 = present) with equal weight to preserve the analytical consistency and comparability. Equal weighting in Fire Safety Practice Index (FSPI) is reasonable because there is no scientifically grounded universalized system of assigning the dissimilar significance to fire safety signals in differing circumstances and alternative weighting plans are thus methodologically arbitrary (Hassanain et al., 2017). The equal weighting, therefore, is an understandable and justifiable default (Greco et al., 2019).

The total score was the FSPI which was a composite measure of organisational compliance to fire safety standards and offered a structured and reproducible foundation to assess organisational preparedness in the face of operational readiness in tertiary institutions. This is mathematically given as:

$$FSPI = \sum_{i=1}^{17} S_i \quad (1)$$

where $S_i = 1$, indicates the presence of a safety feature and $S_i = 0$, indicates its absence.

Cumulative FSPI score is a level of fire safety performance of the institution with the range of 0 to 17. When the score is higher, it means that it has better procedural and operational compliance with fire safety standards. FSPI scores are divided into three levels of preparedness:

Table 1: Fire safety practice index (FSPI) grading scale

FSPI score range	FSPI grade	Interpretation of fire safety standard
0 – 5	Low	Deficient implementation and inadequate preparedness.
6 – 11	Moderate	Partial compliance with identifiable procedural gaps.
12 – 17	High	Strong compliance with comprehensive fire safety measures.

FSPI grading facilitates comparative assessment of fire safety standards between institutions, which brings structural, procedural, and behavioural elements of the resilience into the framework of the IFSS-CP.

2.3.3 Sampling

The stratification random sampling technique was adopted to make sure that the proportions of sample represented the four stakeholder groups (students, teaching staff, administrative staff and support staff) in the four tertiary institutions in Khulna City. This method enhanced representativeness, analytical rigor, and inferential accuracy. The sample population was 25,321, and the final number of respondents was determined to be 1,480 using the Slovin formula with a 5 % margin of error ($e = 0.05$), which has been applied in survey-based research in higher educational institutions (Aluwis and Putra, 2022).

$$n = \frac{N}{1+Ne^2} \quad (2)$$

Where:

n = required sample size

N = total population size

e = margin of error (0.05)

Table 2: Population distribution and desired sample size by institution and stakeholder group

University	Total population (N)	Students	Teaching staff	Administrative official	Support staff	Desired sample size (n)
KU	9,488	8,131	518	330	509	384
KUET	8,939	7,876	430	234	399	383
NWU	2,689	2,500	115	20	54	348
NUBTK	4,205	4,000	130	30	45	365
Total	25,321	22,507	1,193	614	1,007	1,480

Once the desired sample size for each institution was determined, proportional allocation was then used to allocate respondents to the stakeholder categories using the following formula:

$$n_h = n \times \frac{N_h}{N} \quad (3)$$

Where:

n_h = sample size of each stratum

n = total sample size for the institution

N_h = population of the specific stratum

N = total population of the institution

This made sure that the representation of each stakeholder group was based on the group percentage in the population of the institution.

Table 3: Final sample distribution by institution and stakeholder group

University	Sample size (n)	Students	Teaching staff	Administrative official	Support staff
KU	384	329	21	13	21
KUET	383	338	18	10	17
NWU	348	323	15	3	7
NUBTK	365	347	11	3	4
Total	1,480	1,337	65	29	49

To evaluate the instrument, a pilot survey was done to determine the level of clarity, reliability, and internal consistency. The questionnaire was a closed-ended questionnaire based on 17 binary protocols of the IFSS-CP in which the structured and objective assessment of five fire safety areas was possible. There was adherence to all the ethical standards. Informed consent was obtained and confidentiality and anonymity were upheld during the research.

2.4 Analytical Approach

A multi-level analytical approach of integrating incident mapping, hazard mapping and institutional fire safety assessment was adopted to quantify resilience in tertiary institutions in Khulna City. The spatial documentation of the past occurrence of fire incidents was considered in incident mapping and the spatial mapping of past fire incidents in ArcGIS Desktop Version 10.7 in which historical fire incidences in short-circuit fires at KU, a canteen fire in NWU, and an office fire in NUBTK were geospatially mapped (historical fire events). In contrast, hazard mapping reflected the spatial distribution of the current fire risk situations and was performed on-site, as per the frame of IFSS-CP, in which 17 binary protocols were considered on buildings. To achieve a quantitative measure (FSPI-based compliance assessment) of institutional compliance with fire safety standards, the FSPI was employed to categorize buildings as being high, moderate, and low compliance buildings.

The institutional fire safety practices were evaluated through the use of structured questionnaires that were given to 1,480 respondents who represented the four stakeholder groups (administrative official, teaching staff, support staff and students). The coded responses were analysed with the help of Microsoft Excel 2019 (MSO Version 2509 Build 16.0.19231.20138, 64-bit, Windows 11) to provide the descriptive computations, and the comparative analyses were performed with the assistance of Python-based quantitative processing to guarantee the accuracy of the analysis. Combining GIS-based spatial mapping with the quantitative evaluation derived by FSPI has yielded a solid, evidence-based conceptualization of the institutional preparedness and weaknesses.

3. RESULTS AND DISCUSSION

3.1 Incident Mapping

In Figure 3, the incident mapping shows how the events of recorded fire incidences are spatially dispersed in the four tertiary institutions and study subjects in this research: KU, KUET, NWU, and NUBTK. The mapping was done by use of ArcGIS Version 10.7 that is on the basis of primary field data gathering by direct on-site observation and institutional records validation. All the incidents were georeferenced on their specific locations and a visualization of the events with uniform fire symbols to offer uniformity and interpretability, following established GIS-based fire risk mapping practices (Zhang et al., 2024).

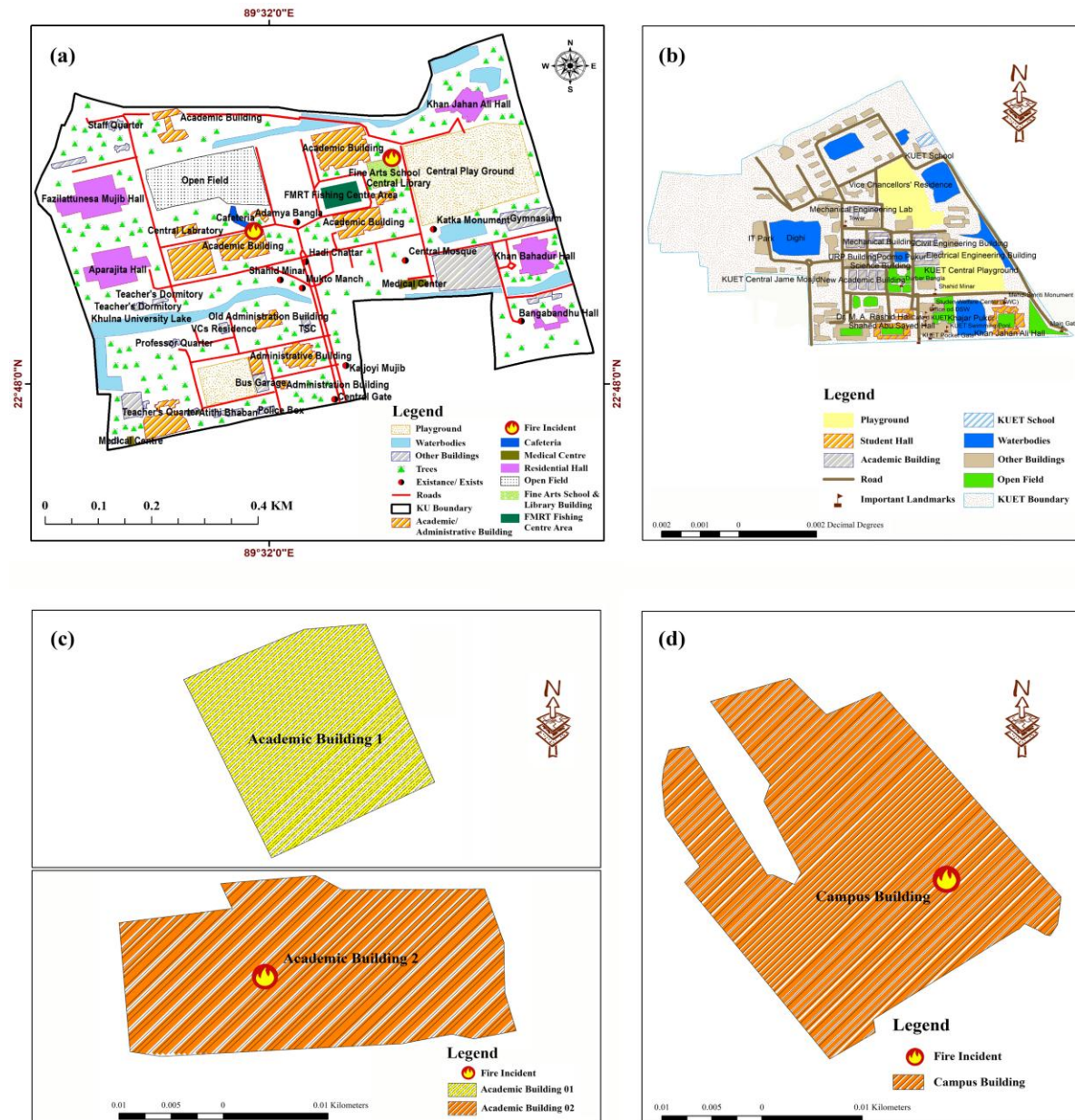


Figure 3: Incident mapping of (a) KU, (b) KUET, (c) NWU, and (d) NUBTK

The incident maps indicate in a graphic manner the spatial distribution of fire events which is identified by fire symbols that are specific to the exact geographic location of the incident. The summary of identified fire incidents from 2019 to 2024 is presented in Table 4.

Table 4: Overview of reported fire incidents by field survey (2019-2024)

Institution	Location of incident	Type of fire	Approximate period
KU	Academic Building 02	Short-circuit fire	April 2024
KU	Central Library	Short-circuit fire	December 2023
NWU	Canteen Area	Cooking-related fire	Pre-COVID-19 period
NUBTK	Administrative Office	Electrical fire	Early 2023
KUET	—	—	—

3.2 Hazard Mapping

The hazard mapping is the spatial evaluation of the institutional fire safety compliance based on FSPI and is calculated with the utilization of the IFSS-CP framework, as shown in Figure 4. On-site assessments of buildings and structural units were conducted based on 17 binary protocols to generate cumulative FSPI scores and classify them into three levels of compliance High, Moderate and Low.

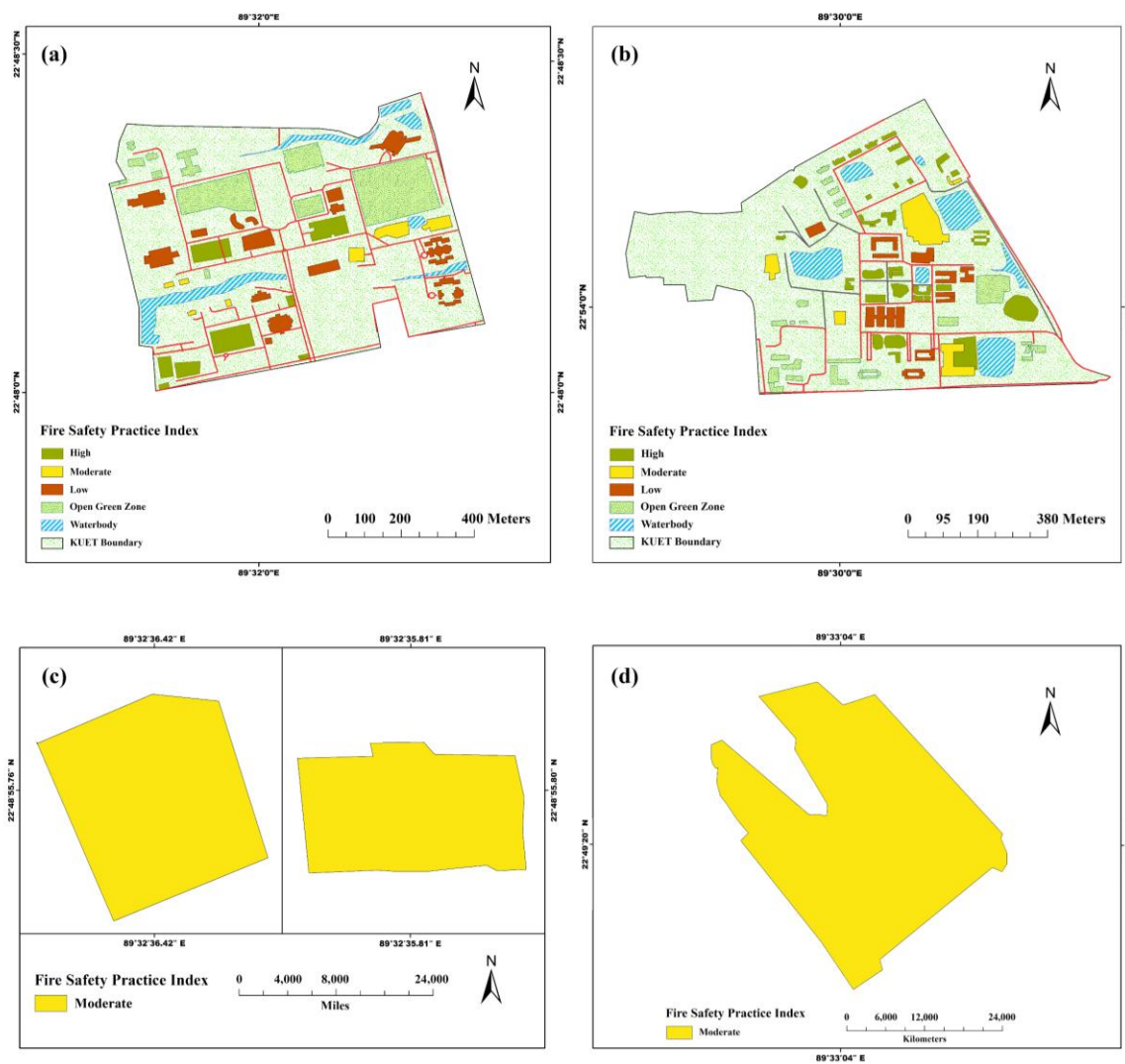


Figure 4: GIS-based hazard mapping of (a) KU, (b) KUET, (c) NWU, and (d) NUBTK

The four institutions have spatial variations of fire safety as illustrated in the maps with high indicating high compliance, moderate indicating semi-compliance, and low representing high-risk areas.

3.3 Institutional Fire Safety Assessment

According to the IFSS-CP and FSPI-based evaluation, it is clear that the four institutions have significant gaps in fire safety concerns. Out of 1,480 stakeholders, 65.54 per cent of them were classified under the low-compliance range, and the average FSPI was 4.95 ± 4.70 (out of 17), which confirmed systemic weaknesses in procedural, infrastructural, and operational preparedness. These outcomes are also consistent with the evidence in LMICs at large, as researchers also claim the absence of detection/suppression systems, non-compliant exits, and a general lack of institutional preparedness, meaning that the gaps in this study are not isolated instances of problems but structural ones (Ahmed et al., 2019).

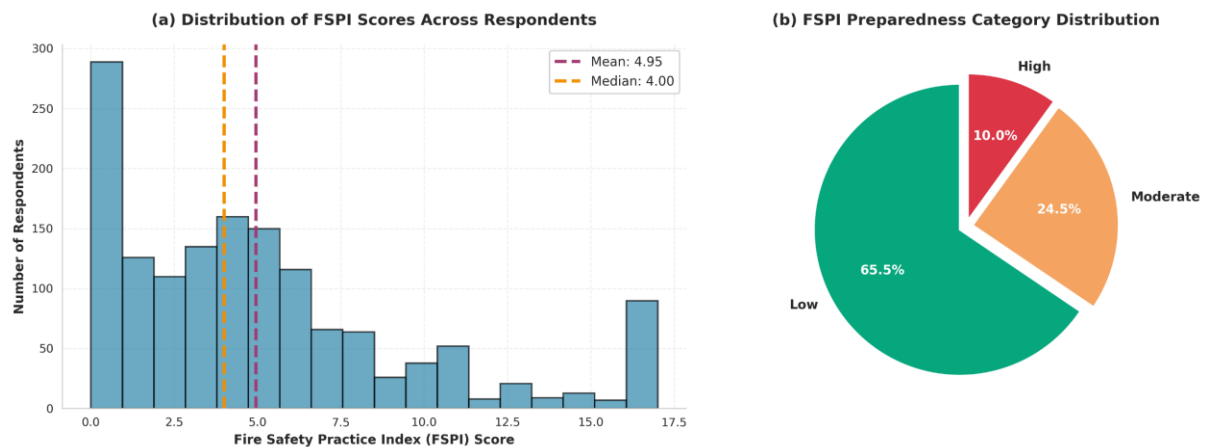


Figure 5: FSPI distribution & category breakdown

The actual preparedness distribution is shown in Figure 5, with 65.54 % of the respondents in the low (score 0-5) category, 24.46 % in moderate (score 6-11), and 10.00 % in high (score 12-17) category of preparedness. The average FSPI of $4.95 (\pm 4.70)$ indicates poor performance of institutions compared to average value of 8.5.

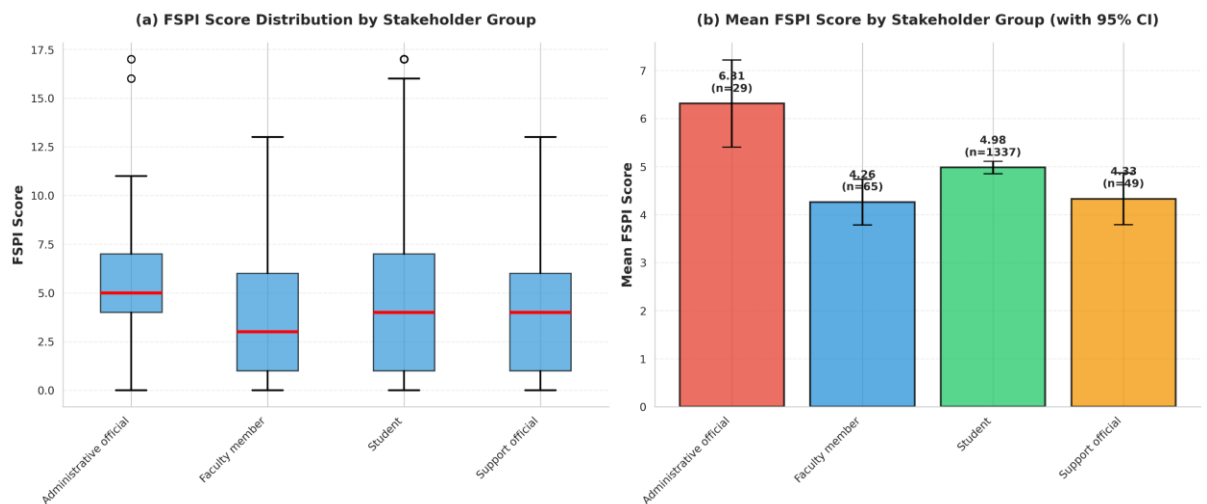


Figure 6: Stakeholder group comparison

Figure 6 illustrates comparative FSPI levels among stakeholder categories. Although administrative officials show a higher mean FSPI (6.31), differences across faculty members (4.26), support official

(4.33), and students (4.98) are statistically insignificant ($F = 1.58, p = 0.192$), validating systemic safety inadequacy rather than role-based disparity.

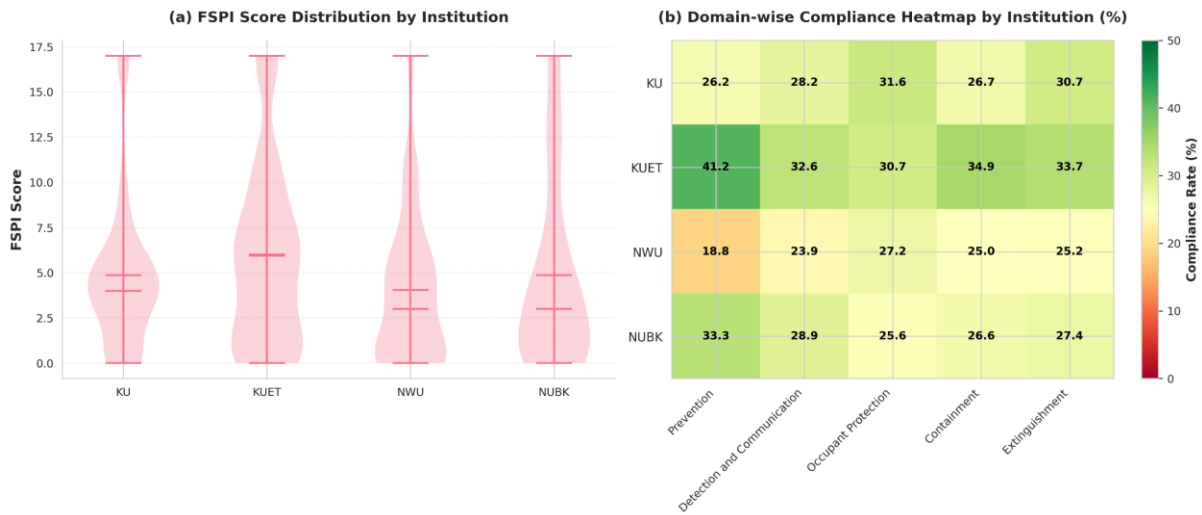


Figure 7: Institutional comparative analysis

Figure 7 shows statistically significant differences ($H = 33.95, p < 0.001$), with KUET demonstrating higher preparedness (Mean FSPI = 5.95; 50.4 % moderate-to-high compliance), while KU (73.96 %), NWU (71.26 %), and NUBTK (67.95 %) remain mostly in the low compliance category.

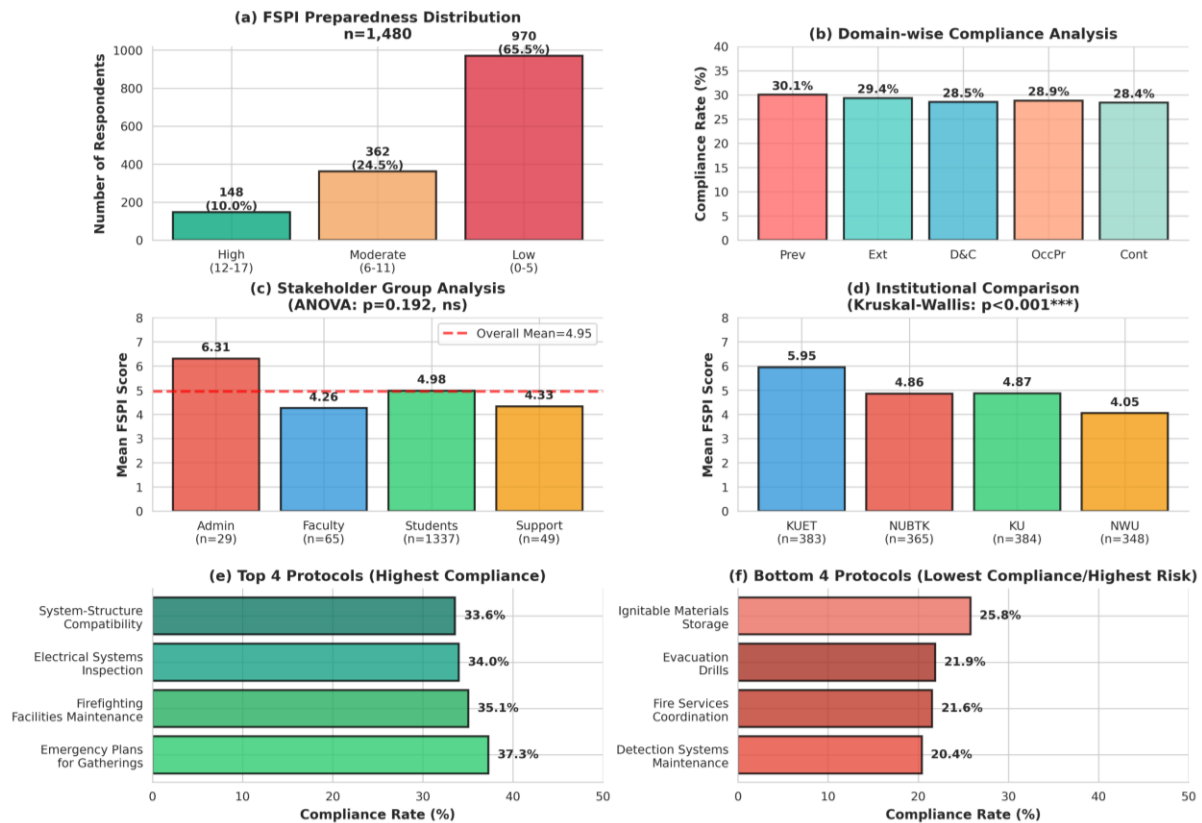


Figure 8: Integrated research framework and findings summary of the fire safety practices assessment

Figure 8 integrates all analytical dimensions into a single interpretative framework, summarizing institutional performance, stakeholder variation, and domain compliance in a publication-ready visualization. Likewise, the patterns of poor preparedness and ad hoc system provision have been observed in other academic institutions, especially amongst the hostel and campus testing (Onyekwere et al., 2024).

4. CONCLUSIONS

This study identified the key fire safety vulnerabilities within the surveyed tertiary institutions by combining incident mapping, hazard mapping, and institutional fire safety assessment. The four reported fire incidents were mainly electrical short circuit, canteen related ignition sources, malfunctions within administrative blocks that were contained within the ageing and high utility buildings. Similar cluster of high-risk areas was identified in the densely populated academic buildings and older infrastructure through the use of hazard mapping. The compliance with the existing fire safety practices is still of crucial insufficiency since low-preparedness stakeholders are about 65.54 %, and the average FSPI score was 4.95 out of 17, a critical inadequate compliance. The lapses that were the most obvious were regarding the maintenance of detection systems, collaboration with fire services, and a regular evacuation drill. There was also a high inter-institutional difference ($H = 33.95$, $p < 0.001$) that placed KUET at a relatively higher position, but still in unsatisfactory levels. This paper illustrates the importance of using spatial risk analysis alongside compliance-based indices to measure physical and institutional aspects of fire risk. As far as the policy implications, the findings indicate that specific interventions, i.e. infrastructure upgrading, institutional coordination, and routine preparedness activities, are required. The findings also indicate the need to explore more regarding the behavioural factors of fire safety compliance, including institutional cues, environmental facilitators, and motivation, to inform evidence-based intervention and longitudinal monitoring models, which can be used to support safety culture and increase fire resilience in tertiary institutions.

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DECLARATION OF USE OF AI

No artificial intelligence (AI) tools were used in the preparation of this manuscript. All work was conducted by the authors.

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