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Assessment of Suppression Measures in Managing Technological Multi-hazards at International Airports in Kenya.

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ABSTRACT

Context: This study assessed suppression measures for managing technological multi-hazards at international airports in Kenya. A descriptive research design was adopted, involving a sample of 285 airport workers selected through stratified random sampling, comprising 226 respondents from Jomo Kenyatta International Airport (JKIA) and 59 from Moi International Airport (MIA). **Methods:** Primary data were collected using questionnaires, Focus Group Discussions (FGDs), observation checklists, and structured interview protocols. Quantitative data were analyzed using descriptive statistics, including means, frequencies, and percentages, and inferential statistics using the Chi-square test, while qualitative data were analyzed descriptively. **Results :** The findings on structural suppression measures indicated no statistically significant association between variations in airport facilities and the presence of suppression measures. Specifically, the Chi-square results were $\chi^2(2) = 2.81$, $p = .246$ for critical airport facilities and fire suppression systems; $\chi^2(2) = 0.49$, $p = .783$ for terminal buildings and fire sprinkler systems; and $\chi^2(2) = 0.83$, $p = .659$ for ground refuelling operations and the use of portable foam extinguishers.

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Regarding non-structural suppression measures, more than 70% of respondents acknowledged the existence of policies governing fire suppression systems and fire suppression agents at the airports. **Conclusion:** The study recommends transitioning from portable fluorinated firefighting foams to environmentally sustainable alternatives, implementing effective measures for managing legacy fluorinated foam stocks, improving sprinkler coverage in critical areas, and strengthening environmental monitoring, auditing, and compliance mechanisms to enhance fire safety and environmental sustainability at international airports in Kenya.

The study adds to existing knowledge by;

1. Demonstrating the interdependence between physical fire-suppression capacity, the environmental characteristics of suppression agents, and institutional policy controls in managing technological multi-hazards at airports.
2. It provides an understanding that airport fire-risk management should be viewed as an integrated socio-technical system rather than as a collection of independent fire suppression measures.
3. The findings also provide an empirical basis for strengthening airport fire-safety policies, harmonising suppression-agent practices, and promoting a transition towards environmentally sustainable fire-suppression technologies without compromising emergency response capability.

I. INTRODUCTION

The airport plays a major role in driving a country's economic and social development. However, technological multi-hazards have increasingly contributed to business disruptions, infrastructure damage, and loss of lives at airports around the world (Sumathi *et al.*, 2018). These technological multi-hazards range from aircraft accidents to industrial failures, including fires, hazardous material spills, and leaks. In Kenya, fatal aircraft accidents that have occurred include; the Busia (2003) Marsabit (2006), Narok (2008) and Ngong plane (2012) accidents in which prominent Kenyan civil servants and political leaders lost their lives (Mutugi and Maingi, 2011). Airport terminal building fires have also been reported, including the 2013 fire at JKIA, which destroyed the airport's arrivals terminal (Angira, 2013).

Many technological-related hazards are projected to increase in frequency and intensity as airport development progresses, leading to a heightened likelihood of simultaneous disasters and compound events. In light of this, a growing body of literature calls for multi-hazards research (Phillips *et al.*, 2020; Raymond *et al.*, 2020; Zscheischler *et al.*, 2018) recognizing that analysis and prediction of compound events are still emergent. However, to date, the wider risk management literature still focus primarily on one hazard at a time, rarely engaging with the reality of multiple hazards and risks that interact with each other and other societal forces (Raymond et al., 2020). Comprehending the adaptations that take place when a single hazard scenario becomes multi-hazard, and the structural and non-structural measures that address these, are important areas in disaster risk reduction (Tozier de la Poterie *et al.*, 2022).

The 2013 airport terminal building fire at JKIA, compounded and ended up causing cancelation of many domestic and international flights including losses of millions of shillings (Angira, 2013). Further, the use of suppression agents that are not environmentally friendly for firefighting, illustrate the reality of compounding hazards and the critical need for risk managers and other actors to plan for and respond to multiple-hazard. It also reveals a need to better understand how risk managers can quickly axis between multiple-hazard and the successes and challenges that lie therein.

Suppression agents are substances used to put out or "suppress" fires by disrupting the chemical reaction, reducing heat, or removing oxygen. Suppression agents used in aviation are categorized into two main types namely; principal and complementary suppression agents. According to International Civil Aviation Organization (ICAO), complementary suppression agents are classified as dry chemical powders (classes B and C powders); or other extinguishing agents with at least the same firefighting capability (ICAO, 2015). Some of these extinguishing agents can generate negative impacts on the environment and human health (Kreckie, 2020). It is because of the negative impact to the environment that in the year 1994, halon extinguishing agents, a complementary agent was banned by ICAO. This is the reason why there has been need to develop extinguishing agents that are effective against complex fires while remaining stable, environmentally friendly, and less polluting (Rabajczyk & Zielecka, 2022).

The principal suppression agents on the other hand, are classified as either a foam meeting the minimum performance level A; or level B; or level C; or a combination of these agents (ICAO, 2015). According to ICAO (2015) these principal foaming agents produce a permanent control, i.e. for a period of several minutes or longer. Class A foams are used to fight structural fires and wildfires, while Class B foams are designed to fight fires involving flammable liquids (Korzeniowski *et al.*, 2018). The effectiveness of Class B foams was improved significantly with the incorporation of surfactants in their composition (Hinnant *et al.*, 2020; Kreckie, 2020; Korzeniowski *et al.*, 2018) According to Kreckie (2020), the surfactants used in Class B foams are part of a group of chemicals known as Per- and Polyfluoroalkyl Substances (PFAS). Although there are a number of ways to classify extinguishing foams, from a PFAS standpoint, suppression foams can be classified into two categories: fluorinated foams containing PFAS and fluorine-free foams that do not contain PFAS (Kreckie, 2020).

Fluorinated class B foams (i.e. foams containing PFAS) are the most commonly employed suppression agents for liquid hydrocarbon fires (Kreckie, 2020). These include aqueous film forming foams, fluoroprotein foams and film forming fluoroprotein foams. This release of PFAS contaminated material has resulted in the accumulation of 'forever chemicals' in local environments. PFASs colloquially known as 'forever chemicals;' are highly stable in the environment and resistant to biodegradation, photo-oxidation, direct photolysis, and hydrolysis. They have low volatility, are soluble in water and have limited sorption to particles (Paul *et al.*, 2009). They therefore present a groundwater contamination risk when released in the environment.

Environmental assessments of PFASs near airports and industrial estates in Australia, China, Europe and the US have consistently shown drinking water levels above concentrations thought to be safe for humans (Hu *et al.*, 2016). Airports are among the largest users and emitters of these fluorinated chemicals in the world. PFAS containing extinguishing foams are still widely in use today (Glüge *et al.*, 2020). Protecting public health means preventing exposure to all PFASs that are present in water supplies and other environmental media above risk thresholds (Boston *et al.*, 2019). According to Boston *et al.* (2019), prevention may be accomplished only by controlling and decreasing exposures to PFASs that is already in the environment.

In Africa, a relatively small number of peer-reviewed research has been published in the subject area of PFAS. Hanssen *et al.* (2010) found elevated PFAS levels in the serum and cord blood of South African women. Groffen *et al.* (2018) evaluated concentrations of 15 different PFASs in various aquatic biota and water also in South Africa, finding extensive low-level contamination of multiple PFASs with PFOS presenting the most elevated levels.

Firefighting foams that do not contain fluorosurfactants or PFAS are commonly referred to as fluorine-free foams (FFF or F3) (Dahlbom *et al.*, 2022). Fluorine free foams (F3 or 3F) were initially developed by the 3M Company. The foams operate under the same principle as fluorinated class B foams however they use proprietary hydrocarbon surfactants in place of fluorinated surfactants. There are currently more than a dozen F3 products offered by 8 different companies (Allcorn *et al.*, 2018). F3 foams have not been shown to bioaccumulate and are not persistent in the environment (Dahlbom *et al.*, 2022). Considering suppression agent alternatives that reduce environmental and human health impacts is the best strategy in managing technological multi-hazards (Kreckie, 2020).

According to the ICAO (2018), people can be a solution in reducing these risks by taking appropriate actions to mitigate technological multi-hazardous situation. This can be done through the implementation of non-structural suppression measures such as knowledgeable leadership and provision of adequate structural suppression measures which can proactively contribute to the identification and minimization of these risks (Yazgan *et al.*, 2022). As long as these technological multi-hazards are kept under an appropriate level of control, a system as open and dynamic as aviation can still be kept safe (ICAO, 2018). However, the assessment of suppression measures for managing technological multi-hazards at international airports in Kenya has not been well studied and this forms the research gap of this study.

II. MATERIALS AND METHODS

II.1 Research Design

This study utilized descriptive research design. A descriptive research design involves a systematic empirical investigation in which the researcher lacks direct control over independent variables because they have already occurred or are inherently unalterable (Kothari, 2004). According to Walingo and Ngaira (2008) descriptive research helps determine the frequency with which something happens or is related to something else.

II.2 Study Area

The international airports that this study targeted were; Jomo Kenyatta International Airport (JKIA) and Moi International Airport (MIA) in Kenya. The locations of these airports are as follows: JKIA is bounded by latitude 1° 20' 1.4" South and longitude 36° 55' 37.6" East (Figure 2) and MIA is at latitude 4° 02' 05" South and longitude 39° 35' 44" East (Figure 1)



Figure 1: Map of the Study Area Showing the Geographical Location of International Airports.

Source: Author (2025)

II.3 Population

The main unit of observation was the employees at JKIA and MIA in Kenya. Based on the population size of 1,115, the sample size of 285 was extracted from the Krejcie and Morgan (1970) Table.

II.4 Sample and sampling techniques

Sampling involved choosing a representative subset of a larger population to investigate specific characteristics of the entire group. Based on the population size of 1,115, the sample size of 285 was extracted from the Krejcie and Morgan (1970) Table. From a sampling size, the proportionate sampling was used to determine the number of staff to be sampled from each section of the two airports (Barreiro and Albandoz, 2001). The formula for proportionate sampling is shown in Equation below:

$$nh = \left(\frac{Nh}{N} \right) n$$

nh = sample size of stratum

Nh = Population size of the stratum

N = Total population size

n = Total sample size

From a sampling size of 285, the proportionate sampling as shown in Table 1 was used to determine the number of staff sampled from each section of the two airports (Barreiro and Albandoz, 2001).

Table 1: Proportional Allocation of Staff by Airport

	JKIA		MIA	
	Staff population	Sample ($n_h = N_h/N \times n$)	Staff population	Sample ($n_h = N_h/N \times n$)
Ground Flight Service (GFS)	34	9	15	4
Birds and Wildlife Control (BWC)	27	7	5	1
Engineering Service	85	22	25	6
Safety Section	4	1	3	1
Aviation Security (AVSEC)	580	148	120	31
Airport Rescue and Fire Fighting Service (ARFFS)	97	25	45	11
Customer Service	56	14	19	5
Total Number	883	226	232	59

Source: Field Data (2026)

Quota sampling was used to sample Focus Group Discussion participants, which comprised of 10 participants. The researcher conducted two groups of Focus Group Discussion (FGD) in each airport, one group comprising of 10 staff working at the landside and another group of 10 staff for those working at the airside. The airside staff comprised of two (2) participants each from Ground Flight Safety (GFS), Birds and Wildlife Control (BWC), Security Service, Rescue and Fire Fighting Service (ARFFS) and Airline ground operations. The landside staff comprised of two (2) participants each from Engineering, Safety, Security Service, Customer Service and Fire Prevention Section.

The sampling methodology for the key informant interview protocol was purposive. In-depth interviews were conducted in person with the officials. Appointments for these key informants was scheduled for the qualitative follow up sample when collecting quantitative data on instruments. Table 2 shows the population size, sample size determination, sampling method and sample size.

Table 2: Population Size, Sampling Method and Sample Size

Population unit categories	Population size	Sample size determination	Sampling method	Sample size
Ground Flight Safety (GFS), Birds and Wildlife Control (BWC), Engineering, Safety, Security Service, Rescue and Fire Fighting Service (ARFFS) and Customer Service	1,115	Krejcie and Morgan's 1970 formula	Stratified random sampling	285
Airline official representative at the Emergency Operation Centre (EOC)	6	30% of the population	Purposive	2
ARFFS officials	12	30% of the population	Purposive	4
BWC officials	6	30% of the population	Purposive	2
Aviation safety officials	12	30% of the population	Purposive	4
Airport Engineering officials		10	Quota	10
Four Focus Group Discussion (FGDs)			Purposive	

II.5 Data Collection

Data were collected using structured questionnaire administered to different airport employees. Field observation was accompanied by photographic registration to substantiate the information collected. Key Informant Interview Protocol tool and Focus Group Discussions guide were also used to collect data. Both quantitative and qualitative techniques were used to process, analyze and present the data. The qualitative data generated from interview and observation guide were reported in narrative form along with quantitative presentation and were used to reinforce the quantitative data. Thematic and narration analysis techniques was used to analyze data from Focus Group Discussions and key informants.

II.6 Statistical Analysis

The quantitative data generated from questionnaire was analyzed using both descriptive, and inferential statistics. Descriptive statistics enable users to present and see the data in a more meaningful way, allowing simpler interpretation of the data. Tools such as tables, and figures are examples of tools that were used for summarizing data. Descriptive statistics include measures of central tendency such as mean (average), median and mode, as well as measures of variability such as frequency distributions. According to Gay *et al.* (2012) the most commonly used method of reporting descriptive survey is by developing frequency

distributions, calculating percentages and tabulating them appropriately. The inferential statistical procedure that was used in this study was Chi-square test. The Chi-square test was used to compare proportions of categorical values and any association or relationships. The results were considered significant when the 2-sided P-value was less than 0.05 at 95% confidence interval.

II.7 Validity and Reliability of Instruments

The instruments used for data collection, namely the structured questionnaire and semi-structured interview schedule, were validated by experts in the field of Disaster Management and Sustainable Development at Masinde Muliro University of science and Technology. This feedback informed the question refinement of clarity, relevance and comprehensiveness for the data collection instruments. The instruments were pre-tested for reliability and validity by conducting the pilot study with 30 employees from Kisumu International Airport and 30 employees from Eldoret International Airports that is not part of the study. The feedback from the pilot study helped to make minor changes to the questions to enhance comprehension and accuracy.

In determining statistical proof, Content Validity Index CVI was used to determine the validity of the instruments. All the scales had CVI above 0.9, which meant that the instruments were valid. According to Polit *et al.* (2007) The instruments are considered to be valid if the calculated CVI is above 0.7

Similarly, a split-half reliability approach was employed to ensure the reliability of the structured questionnaires. During the pilot test the researcher administered the instrument to a sample size of 30 staff at Kisumu international airport and a sample size of 30 staff at Eldoret international airport, which has the standards to weigh MIA and JKIA airports. Those selected for piloting and the two airports were not part of the main study sample. The questions were divided into odd and even-numbered, and the total mean scores calculated for each section of the Questionnaire. The data was used to conduct a correlation analysis, which gave a correlation coefficient (r) that determined whether it was reliable. A value of $r = 0.9$ was obtained, meaning the instrument was valid for research purpose.

II.8 Ethical Consideration

All ethical aspects of the research have been taken care of during the research process, to ensure the protection of the respondents as well as the validity of the results. Before the data collection, the researcher obtained an approval letter from Masinde Muliro University of science and Technology Postgraduate Studies Directorate and also obtained license No: NACOSTI/P/25/4175847 and applicant identification number 891172 to conduct the research as per the provision of science, Technology and Innovation Act, 2013 (Rev. 2014) from the National Commission of science, technology and Innovation (NACOSTI). The researcher also sought permission from the Kenya Airports Authority (KAA) to collect field data for the study.

The respondents were informed that their involvement in the study was voluntary, and that they had the right to decline or withdraw their participation at any point. They gave their consent after which they took part in the research. Respondent confidentiality and anonymity were guaranteed since there was no use of any personal identification information during data collection or presentation of results. The respondents were also assured that data gathered from them would be used solely for academic purposes and that it would not be accessible to anyone else other than authorized personnel. Also, no manipulation of data was done, thus promoting honesty and integrity.

III. RESULTS

III.1. Structural Suppression Measures for Managing Technological Multi-hazards

III.1.1 Fire Suppression System in Critical Facilities

The observed results presented in Table 3 indicate that, at JKIA, 58% (131) of the respondents reported that fire suppression systems had been installed in critical facilities, while 25% (57) were uncertain about their installation status and 17% (38) indicated that no fire suppression systems had been installed. At MIA, 52% (31) of the respondents reported the presence of fire suppression systems in critical facilities, whereas 12% (7) indicated that such systems had not been installed, and 36% (21) were uncertain. Statistical analysis (Table 3) revealed a chi-square value of $\chi^2(2) = 2.81$, $p = .246$, indicating that there was no statistically significant relationship between airport critical facilities and fire suppression systems. Furthermore, Cramer's V coefficient of 0.10 suggested a weak association between the two variables. These findings imply that variations in airport critical facilities were not significantly related to the presence of fire suppression systems within the sampled airports.

Table 3: Chi-square Test Between Fire Suppression Systems and Airport Critical Facilities

Observed frequencies									
Airport Critical Facilities	Fire System Installed	Suppression	Fire System Installed	Suppression Not Installed	Not Sure whether System is Installed	Fire	Total		
JKIA	131		38		57		226		
MIA	31		7		21		59		
Total	162		45		78		285		
Expected frequencies for perfectly independent variables									
Airport Critical Facilities	Fire System Installed	Suppression	Fire System Installed	Suppression Not Installed	Not Sure whether System is Installed	Fire	Total		
JKIA	128.46		35.68		61.85		226		
MIA	33.54		9.32		16.15		59		

Total	162	45	78	285
Chi-Square Test			Effect Size	
Chi²	df	P	Measure	Value
2.81	2	.246	Cramer's V	0.10

The key informant interviews and observation checklists at JKIA revealed that fire suppression systems had been installed in critical facilities, including the Radio Detection and Ranging (RADAR) system. Further, the key informant protocol established that the electrical substation at JKIA was protected by an FM-200 clean-agent fire suppression system, which is designed for rapid fire suppression without leaving residue. According to the key informant, the generator room was equipped with a conventional carbon dioxide (CO₂) suppression system, which is suitable for total-flooding applications in enclosed risk areas such as generator rooms. At MIA, the key informant indicated that a fire suppression system had been installed in the ICT server room. However, the key informant noted a significant challenge concerning the system, namely that it was not routinely tested. Consequently, its operational effectiveness and reliability in the event of an actual fire emergency could not be readily confirmed.

III.1.2 Sprinkler System in Airport Terminal Buildings

As illustrated in Figure 2, 85% (192) of the respondents at JKIA indicated that a sprinkler system had been installed, whereas 81% (48) of the respondents at MIA reported that no sprinkler system had been installed.

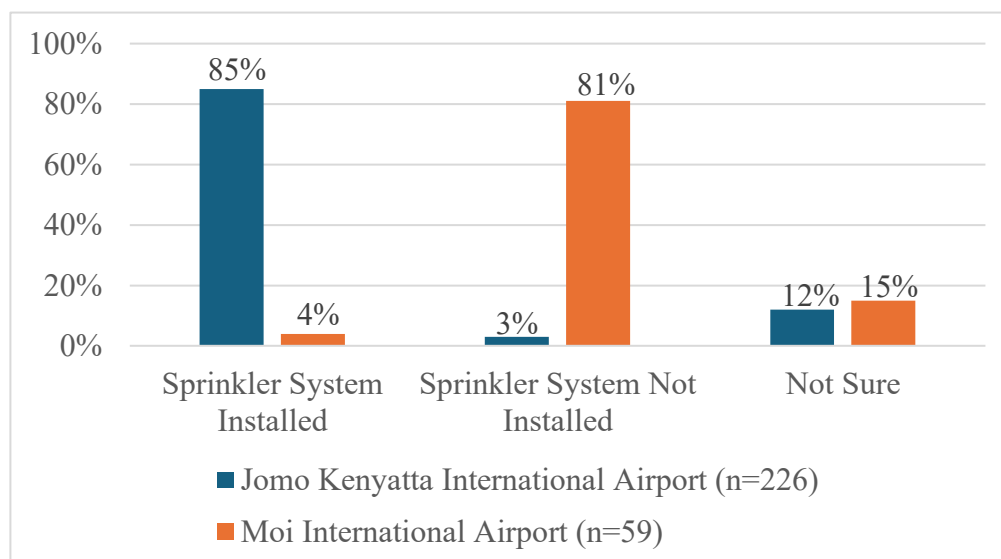


Figure 2: Sprinkler Systems in JKIA and MIA Terminal Building

Statistical analysis (Table 4) revealed a chi-square value of $\chi^2(2) = 0.49$, $p = .783$, indicating that there was no statistically significant relationship between airport terminal buildings and fire

sprinkler systems. Furthermore, Cramer's V coefficient of 0.04 suggested a weak association between the two variables. These findings imply that variations in airport terminal buildings were not significantly related to the presence of fire sprinkler systems within the sampled airports.

Table 4: Chi-square Test Between Fire Sprinkler Systems and Airport Terminal Buildings

Observed frequencies									
Airport Terminal Building	Fire System Installed	Sprinkler Installed	Fire System Installed	Sprinkler Not Installed	Not Sprinkler Installed	Sure whether System is	Fire is	Total	
JKIA	192		7		27			226	
MIA	48		2		9			59	
Total	240		9		36			285	
Expected frequencies for perfectly independent variables									
Airport Terminal Building	Fire System Installed	Sprinkler Installed	Fire System Installed	Sprinkler Not Installed	Not Sprinkler Installed	Sure whether System is	Fire is	Total	
JKIA	190.32		7.14		28.55			226	
MIA	49.68		1.86		7.45			59	
Total	240		9		36			285	
Chi-Square Test					Effect Size				
Chi²	df		P		Measure			Value	
0.49	2		.783		Cramer's V			0.04	

The key informant interviews, Focus Group Discussions (FGDs), and observation checklist conducted at JKIA revealed that sprinkler systems have been installed in the airport terminal buildings T1A, T1B, and T1C. However, T1D and the JKIA Cargo terminal are not equipped with sprinkler systems. Similarly, findings from the key informant interviews, FGDs, and observation checklist at MIA revealed that a sprinkler system has been installed only in the VIP Lounge, while the main terminal building is not equipped with a sprinkler system. According to the key informant at MIA, external experts are periodically engaged to conduct occupational safety and health audits in accordance with the Occupational Safety and Health Act, 2007 (Kenya Law, 2007). The key informant further indicated that airport management considers and acts upon the professional recommendations provided in the fire safety audit reports.

III.1.3 Portable Foam Extinguisher for Ground Refueling of Aircraft

The respondents were asked to indicate the type of portable foam extinguishing equipment used during the ground refuelling of aircraft. As presented in Figure 3, 62% (140) of respondents at JKIA and 68% (40) at MIA reported that fluorinated foam was used during aircraft ground refuelling operations at the respective airports.

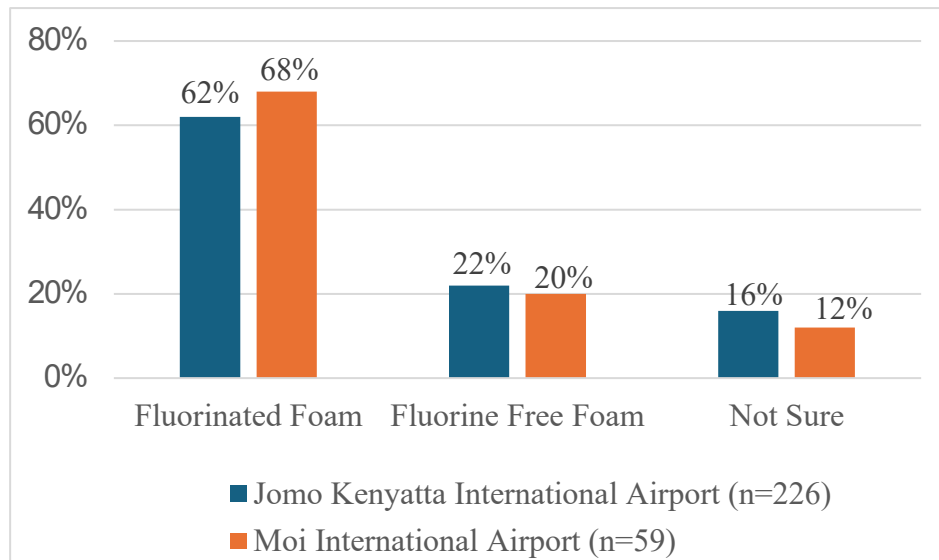


Figure 3: Portable Foam extinguishers at JKIA and MIA

Statistical analysis presented in Table 5 yielded a chi-square value of $\chi^2(2) = 0.83$, $p = .659$, indicating that there was no statistically significant association between airport ground refuelling operations and the use of environmentally friendly portable foam extinguishing equipment. Furthermore, the Cramer's V coefficient of 0.05 indicated a very weak association between the two variables. These findings suggest that differences in aircraft ground refuelling practices between the sampled airports were not significantly associated with the availability or use of environmentally friendly portable foam extinguishing equipment.

Table 5: Chi-square Test Between Portable Foam extinguishers equipment and Airport Ground Refuelling of Aircraft

Observed frequencies						
Airport	Portable	Portable Fluorine	Not	Sure	whether	Total
Ground	Fluorinated	Free	Portable	Fluorinated	is	
Refuelling of	Foam	Equipment	Fluorinated	or F3		
Aircraft	Equipment					
JKIA	140	50	36			226
MIA	40	12	7			59

Total	180	62	43	285
Expected frequencies for perfectly independent variables				
Airport Ground Refuelling of Aircraft	Portable Fluorinated Foam Equipment	Portable Fluorine Free Equipment	Not Sure whether is Fluorinated or F3	Total
JKIA	142.74	49.16	34.1	226
MIA	37.26	12.84	8.9	59
Total	180	62	43	285
Chi-Square Test			Effect Size	
Chi²	df	P	Measure	Value
0.83	2	.659	Cramer's V	0.05

The key informant interviews conducted at JKIA and MIA, together with observations from the checklist, revealed that fluorinated foam is used in portable foam extinguishing equipment during the ground refuelling of aircraft. At JKIA, the key informant indicated that most oil companies currently use Aqueous Film Forming Foam (AFFF) in portable fire extinguishers during aircraft ground refuelling operations. However, the key informant further revealed that the airport terminal building currently uses an environmentally friendly portable Cold Fire extinguisher manufactured by Fire Freeze Worldwide Incl. (2026).

III.1.4 Principal Extinguishing Agents used in Fire Trucks at International Airports

The study established the type of principal extinguishing agents used at international airports in Kenya. The results in Table 6 shows that 85% (192) of respondents at JKIA and 71% (42) of respondents at MIA indicated Jet Foam 6.

Table 6: Principal Extinguishing Agents used in Fire Trucks

Principal Extinguishing Agents	Jomo Kenyatta International Airport	Moi International Airport
	Frequency	Percentage
Aqueous Film Forming Foam (AFFF)	34	15
Film Forming Fluoroprotein Foam (FFFP)	0	0
Any other: Jet 6 Foam	192	85

Source: Researcher (2026)

The Focus Group Discussion (FGD) at JKIA indicated that sensitization of all airport stakeholders regarding the Kenya Airports Authority's transition from fluorinated foam to fluorine-free foam has been conducted. However, although Kenyan airports have transitioned to fluorine-free foam, the disposal of the existing stock of fluorinated foam has not yet been undertaken. The FGD further established that available disposal options for fluorinated foams are limited and costly, presenting a challenge to the effective phase-out of these substances. It was also reported that discussions have been held with ICAO, which has committed to assisting Kenya in developing and implementing plans for the phase-out of fluorinated compounds. The existing stock of fluorinated foam is shown in Figure 4.



Figure 4: Stock of Fluorinated Foam at Station November, JKIA

The key respondents were further asked whether the existing firefighting foam was Fluorine Free Foam (FFF). The key informants at JKIA and MIA and observation checklist corroborate the findings that the firefighting foam that was currently in use in all fire trucks at both JKIA and MIA was JetFoam 6% and is a Fluorine Free Foam (F3). According to the key informant, the website of Angus Fire Ltd provides the JetFoam 6% - B, details relating to the datasheet, Safety Data Sheet (SDS), benefits, approvals and listings and application of this foam (Angus Fire Ltd, 2026). According to the Angus Fire Ltd. (2026) website, this foam-extinguishing agent is environmentally friendly and contains no fluorosurfactants, organohalogens, fluoropolymers, perfluorocarboxylic acids (PFCAs), perfluorooctanesulfonic acid (PFOS) and no perfluorooctanoic acid (PFOA). In addition to this foam being eco-friendly it is also effective in the management of technological multi-hazards such as aircraft fire, fuel spills and leaks.

According to the key informant protocol at JKIA, Kenya has outpaced other African countries in the adoption of Fluorine-Free Foam (F3), with all airports managed by the Kenya Airports Authority having transitioned to and currently using F3 foam. The key informant further

indicated that Kenyan airports ceased using aqueous film-forming foams (AFFF) in 2016. This transition subsequently attracted a delegation from the United Nations Environment Programme (UNEP) and the International Civil Aviation Organization (ICAO), which visited JKIA to participate in a fire drill on 18 April 2026 and gain first-hand experience of the F3 solution. The claim is corroborated by the UNEP/GEF publication, *“How Jomo Kenyatta International Airport is Leading Africa’s Transition to Safer Firefighting,”* under the sub-title *“From Africa to the World,”* which notes that the 18 April 2026 fire drill at JKIA was not merely a test of emergency preparedness, but also demonstrated to Africa and the wider world that transitioning away from PFAS-based firefighting foams is achievable, safe, and replicable (UNEP, 2026). The key informants at JKIA, MIA and observation checklist corroborate the findings that the firefighting foam currently used in fire trucks at these airports is Fluorine Free Foam (FFF).

III.2 Non-Structural Suppression Measures for Technological Hazards

III.2.1 Fire Policy Governing Fire Suppression System

The respondents were asked whether there was a fire policy governing fire suppression system at their respective airports. The findings revealed that 88% (199) of the respondents at JKIA agreed that such a policy existed, while 12% (27) were unsure. At MIA, 83% (49) of the respondents agreed, whereas 17% (10) were unsure. A key informant at MIA indicated that fire suppression systems are incorporated into the Rescue and Firefighting Policy under measures aimed at mitigating fire risks. The key informant further noted that the Factories and Other Places of Work (Fire Risk Reduction) Rules, Legal Notice No. 59, subsidiary legislation enacted under the Occupational Safety and Health Act, 2007, require workplaces to undergo annual fire safety audits. According to the key informant, the findings and recommendations generated through these fire safety audits are used to assess and inform the need for installation or enhancement of fire suppression systems at the airport.

III.2.2 Fire Policy Governing Fire Suppression Agents

The respondents were further asked whether there was a fire policy governing the use of fire-extinguishing agents at the airports. The findings revealed that 77% (174) of the respondents at JKIA agreed, while 23% (52) were not sure. At MIA, 71% (42) agreed and 29% (17) were not sure. The findings from the key informant interviews conducted at JKIA and MIA, together with observations from the checklist, corroborated the respondents’ views and confirmed that the Kenya Airports Authority (KAA) has formulated a Rescue and Firefighting Services (RFFS) policy governing the procurement and use of fire-extinguishing agents. In particular, the policy requires the procurement and use of fluorine-free firefighting foam across all airports operated by the Authority. This requirement demonstrates the adoption of a non-structural fire safety measure aimed at enhancing fire protection while minimizing environmental impacts associated with conventional fluorinated firefighting foams. Therefore, the findings contribute to knowledge on non-structural measures for managing technological fire hazards

at airports and demonstrate how policy interventions can support both safety and environmental sustainability within the study region.

IV. DISCUSSIONS

This study sought to assess suppression measures for managing technological multi-hazards at international airports in Kenya. The findings revealed that various structural and non-structural suppression measures were employed in the management of technological multi-hazards at both JKIA and MIA airports. Participants consistently linked management of technological multi-hazards to the use of fire trucks, portable fire extinguisher, fire suppression and sprinkler systems to the use of fire policies. These experiences reveal that these airports use both structural and non-structural suppression measures in the management of technological multi-hazards.

IV. 1 Structural Suppression Measures for Managing Technological Multi-hazards

IV.1.1 Fire Suppression System in Critical Facilities

The findings demonstrate that critical facilities such as Radio Detection and Ranging (RADAR) system, electrical station and generator rooms have been installed with fire suppression system with the sole aim of mitigating fires. These findings support previous research by Chris Lewis Group (2022) who indicated that a fire suppression system is designed to extinguish, control, or prevent the spread of fire a facility.

A notable finding regarding the extinguishing agents used in these fire suppression systems revealed that they were varied, for instance electrical sub-station at JKIA was installed with an FM-200, a fast-acting, clean agent system. On the other hand, the generator room at the same JKIA was installed with a conventional carbon dioxide (CO₂) fire suppression system. A study by Balanyuk *et al.* (2016) on fire extinguishing efficiency of environmentally friendly binary aerosol-nitrogen mixtures, revealed that it is essential to determine the methods of extinguishing a fire in a closed area and suggested the need to use aerosol-nitrogen mixture. This aerosol-nitrogen mixtures is ecologically clean, cheap, and can be used for the fire suppression in areas of temporary stay of people without an apparent damage to them (Balanyuk *et al.*, 2016). This study underscores the positive impact of fire suppression systems in protecting critical facilities such as radar systems, electrical rooms, and server rooms in Kenyans airports.

IV.1.2 Sprinkler System Installation at International Airport Terminal Building

Although sprinkler systems remain one of the most effective means of fire suppression, the study revealed that sprinklers are lacking in significant parts of JKIA and MIA terminal buildings. A research paper by Abdulrahman *et al.* (2021) on review of fire suppression by fire sprinklers revealed that due to the thermal characteristics of water spray, it remains to be the most effective, environment-friendly and economical way of fighting fires. Further, besides the safety of the occupants that sprinkler system provides, it also extinguishes fires in isolated or less reachable areas of the airport terminal building (Chow, 2015). According to Chow (2015)

rescue and firefighting may be impeded by inadequate provisions of sprinkler system. For example, in 1998 it took several hours for the firefighters to locate the burning source in the airport fire in Hong Kong (Chow, 2015).

The increase in the demand for passenger and cargo transportation, the diversification in the range of occupant profiles and the growth in architecture, and the changes in building materials, building elements and building structures have made the airport terminals more dangerous in terms of fire (Yildirim & Demirel, 2019). While previous studies have linked the lack of sprinkler systems at airport terminal buildings to severe consequences to passengers and other economic losses (Szeto, 2022), the findings from JKIA and MIA therefore, underscore the need to assess the existing fire protection infrastructure at these airports including sprinkler systems in areas identified through risk assessment as having elevated fire hazards or requiring enhanced levels of passive and active fire protection.

IV.1.3 Portable Foam Extinguisher for Ground Refueling of Aircraft

The study revealed that the portable foam extinguishing equipment used during the ground refueling of aircraft at both JKIA and MIA was fluorinated foam. Concerns regarding fluorinated foam were common across interviews. These experiences support emerging evidence that some of the extinguishing media can generate negative impacts on the environment and human health (Kreckie, 2020). According to Kreckie, (2020) considering extinguishing agent alternatives that reduce environmental and human health impacts is the best sustainable strategy in managing hazards.

Despite these concerns, the findings revealed that both JKIA and MIA complied with the recommendation of the ICAO (2022) Annex 14 Chapter 9.6.1 which require that a fire extinguishing equipment suitable for at least initial intervention in the event of a fuel fire is readily availed during the ground refueling of an aircraft. A study by Isiuwa, (2016) on the risk assessment of aircraft fueling operation: a case study of Margaret Ekpo International Airport Calabar indicated that the main consequence, which can result in a fuel spill on the ramp during refueling, maintenance or defueling would be a pool fire if the spill was ignited. Consequently, while portable fluorinated foam extinguishing equipment plays a critical role in controlling fires during their initial stages, the use of eco-friendly agent remains as the most effective fire safety measure.

IV.1.4 Principal Extinguishing Agents used in Fire Trucks at International Airports

The findings indicated that the principal extinguishing agent used at both JKIA and MIA is JetFoam 6%, a firefighting foam that meets the ICAO minimum performance level B requirements. The use of this foam at both airports demonstrates compliance with the applicable performance requirements for aircraft firefighting and rescue operations. However, the study also identified differences between the two airports in relation to stakeholder awareness and sensitization concerning the transition from fluorinated firefighting foams to fluorine-free foam.

A comparative assessment revealed that JKIA had undertaken extensive sensitization and awareness initiatives targeting both its internal staff and other airport stakeholders on the transition from fluorinated foam to fluorine-free foam. The sensitization focused on increasing awareness of the environmental and operational benefits associated with the transition, including the reduction of environmental contamination and the potential risks associated with the continued use and disposal of fluorinated foams. The findings further suggest that the sensitization at JKIA has contributed to a broader understanding among airport stakeholders of the need to adopt environmentally sustainable firefighting agents and to support the implementation of the Authority's policy on fluorine-free foam. In contrast, the level of sensitization at MIA was comparatively less extensive, indicating a need for continued and more structured awareness programmes across airport facilities to ensure that all relevant personnel and stakeholders have a consistent understanding of the transition and its environmental significance.

While previous studies have linked other airports in the world that have converted to fluorine-free foams (F3) that include Oslo, Stockholm, Dubai, Paris, Copenhagen, London Heathrow, Stuttgart and all 27 major airports in Australia and major chemicals and oil companies such as 3M and ExxonMobil (Allcorn et al., 2018). The aerodromes managed by Kenya Airports Authority join the list of world airports that have successfully transitioned from fluorinated firefighting foams to F3 solutions. According to UNEP (2026) the Kenyan experience was a message to Africa and to the world that the transition away from PFAS-based firefighting foams is achievable, safe, and replicable.

Although this significant achievement has strengthened aviation fire safety in Kenya while promoting environmental sustainability and reducing the risks associated with per- and polyfluoroalkyl substances (PFAS), commonly referred to as "forever chemicals," the disposal of the previous stock of fluorinated foam has not been done. This suggests that airport management should incorporate effective measures for the safe management of legacy fluorinated foam stocks if they are to achieve environmental sustainability. These experiences support emerging evidence that environmental sustainability is crucial for the common benefits of the present and future generations. According to Ziaul and Shuwei (2023) practicing environmental sustainability helps create a healthy planet for the current generations and for future ones.

IV.2 Non-Structural Suppression Measures for Technological Hazards

IV.2.1 Fire Policy Governing Fire Suppression System

The findings reinforce the relevance of a fire policy in governing fire suppression system at airports. However, the study also demonstrates that the policy needs to provide a clear matrix outlining the specific criteria or risk factors that should inform decisions on the installation of fire suppression systems. A structured matrix incorporating factors such as hazard classification, occupancy type, fire load, asset criticality, potential consequences of fire,

applicable fire safety standards, environmental considerations, and the characteristics of the facility are equally important determinants for selecting appropriate fire suppression system. These findings support previous study conducted by Szeto (2022) in Hong Kong International Airport, which recommended a review to the non-structural fire code requirements in China so that the fire suppression system may be included for all other places of higher risk such in the airport and other than basements

IV.2.2 Fire Policy Governing Fire Suppression Agents

The finding indicated that the significance of a fire policy in governing fire suppression system at airports. The finding demonstrates the airport management's commitment to adopting environmentally sustainable fire safety practices while maintaining effective technological multi-hazard response capabilities. Therefore, the study contributes to existing knowledge by highlighting the non-structural policy measures implemented within the study region to strengthen aviation safety and promote environmental sustainability.

V. CONCLUSION

The study revealed that the airports employed various structural suppression measures such as the fire trucks and portable fire extinguishers. The findings also revealed that the foam used in fire vehicles were environmentally friendly while the foam in portable fire extinguishers were not eco-friendly. On non-structural measures, the findings showed that there was a fire policy requirement governing the use of fire suppression system and fire suppression agents.

VI. RECOMMENDATIONS

The study recommends replacing fluorinated portable firefighting foams with environmentally sustainable alternatives, establishing effective measures for the safe management of legacy fluorinated foam stocks, improving sprinkler system coverage in critical areas, and strengthening environmental monitoring, auditing, and compliance mechanisms to enhance fire safety and environmental sustainability.

VII. AUTHOR CONTRIBUTIONS

Conceptualization, N.O.N and N.K.M.; Formal analysis, N.K.M., N.O.N. and S.O.O.; Investigation, N.K.M; Methodology, N.O.N., S.O.O. and N.K.M.; Resources, N.O.N. and S.O.O; Supervision, N.O.N. and S.O.O.; Visualization, N.O.N. and N.K.M.; Writing-original draft, N.K.M., S.O.O. and N.O.N.; Writing- review and editing, S.O.O., N.O.N. and N.K.M; All authors have read and agreed to the published version of the manuscript.

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X. CONFLICTS OF INTEREST STATEMENT.

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XI. DATA AVAILABILITY STATEMENT.

Data generated or analyzed during this study are subject to an embargo of 12 months from the publication date of the article. Once the embargo expires the data will be available at Nelson Mneria; <https://doi.org/10.5281/zenodo.22111381>; upon reasonable request.

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