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Theoretical Construct: Investigating the Critical Factors of Informality (CFOI) Impacting Fire Risk & Vulnerabilities (FRVS) in Informal Settlements (INSE)

Farheen Alam , Virendra Kumar Paul
Department of Building Engineering and Management,
School of Planning and Architecture, 4B, I.P Estate, New Delhi, India - 110002

Abstract
This paper seeks to identify the multi-thematic complexities (MTC) begetting thematic risk factors (TRF) and critical factors of informality (CFOI) in informal settlements, impacting fire risks and fire hazards in informal settlements. To accomplish the aim, forty-two CFOI have been extracted through extensive literature, case studies, focused group discussion (FGDs) and hierarchy of Delphi surveys and expert's input, clustered into six thematic risk factors (TRF), under six multi-thematic complexities (MTC), specific to the context of fire risks and fire hazards in informal settlements. Further, the forty-two CFOI are processed and rationalised to demonstrate the impacts and correlations with Fire risk & vulnerabilities (FRV) in informal settlements. Attribution models were developed to understand the theoretical constructs between the critical factors of informality (CFOI) and fire risk and vulnerabilities (FRV). The understanding of the impacts and correlations between CFOI and FRVs can form a strong foundation or a gateway to the policy & planning and strategic interventions for fire safety model and the technical comprehension of fire safety engineering and fire dynamics in informal settlements.

KeyWords: **Informal Settlements (INSE), Multi-thematic Complexities (MTC), Thematic Risk Factors (TRF), Critical Factors of Informality (CFOI), Fire Risk and Vulnerabilities (FRV), Fire Hazards, Fire safety Model**

1. INTRODUCTION

Fire hazard is a proliferating issue in informal settlements, in tandem with mushrooming phenomenon of urbanisation and urban development begetting informal urbanization and urban informal settlements (UIS). (Kassahun, 2010; Suhartini and Jones, 2023). The consequences of fire hazards in informal settlements are long lasting and cataclysmic. Informal settlement fires accounts for only 11.5% (on an average) of total fires but they cause approximately 45% of the total number of fatalities related to fire hazards (Walls, et al., 2020). Globally, over 95% of fire related fatalities and injuries occur in low- and middle-income countries of global south (Rush et al., 2020).

The suggested projections by UN states that by 2050 close to 7 billion people (6.7 billion approx.) will be living in urban areas with total projected population of 9.8 billion (Approx 2 billion in addition), leaving the rural or informal settings of about 3.1 billion (Approx.), With a quarter of the world's urban population living in informal settlements, fire safety and quantification of fire risks and vulnerabilities in informal settlements is the dire necessity and requires timely remedy (Antonellis et al., 2020a) .

The risk perspectives of fire hazards in informal settlements areas are "very high". Although, the qualitative word "very high" has never been measured, evaluated, or used to comprehend the sources or variables creating, facilitating, and impacting fire risks and vulnerabilities (FRV) in informal settlements ((Hu et al., 2022). There is lacuna in research when it comes to an inclusive and pragmatic fire safety model for informal settlements supported by the established fire safety engineering and deliberated impacts and correlations between the critical factors of informality (CFOI) and the fire risk and vulnerabilities (FRV), which is partly due to the lack of relevant information, historical data, capacity and potential resources for quantitative, qualitative and empirical data collection, technical analysis, simulations and modelling(Twigg et al., 2017) and majorly due to the subject apathy.

The issue and negligence of fire risk and safety significantly co-exist in a country like India with over 34% of its population now living in urban areas, facing number of challenges in ensuring fire safety in its cities. From 2004 to 2019, 3,200 to 5,544 cases of fire hazards were reported in informal settlements of South Africa (Walls, et al., 2020). In December 2020, A massive fire in the Masiphumelele (Masi) informal settlements in Cape Town burned over 1050 dwellings leaving over 5,000 people homeless.

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In 2018, in Khayelitsha informal settlement located in Cape Town, over 500 homes were burned to ashes and around 155 homes were damaged in a fire hazard. The database by the University of Edinburgh [2021] states that In 2018 in South Africa, almost half of the fire deaths occurred in informal dwellings, with a fire death rate of 5 deaths /100 fires (Walls. et al., 2020). However, there is a significant boost in research for fire safety engineering and fire dynamics in South Africa, Bangladesh and many countries of global south due to the rising issues of fire risks and vulnerabilities. There is no one single, linear root cause that creates the fire risk, but rather a complex entangled systems of multiple factors or variables that interact to strengthens the fire risks and vulnerabilities (FRV) in informal settlements (Underhill et al., 2023). There is growing acknowledgements that urban fires are not just technical and physical challenges , standing in isolation but rather have a complex systems comprising of multi thematic systems e.g. social, political, and economic factors etc., and more researches are required to take these factorial understandings into account(Antonellis et al., 2020a). This research entails to cluster all the critical factors of informality (CFOI) into the respective thematic risk factors (TRF) begetting from Mult-thematic complexities (MTC) in informal settlements and to establish the impact and correlation of each CFOI impacting fire risks and vulnerabilities (FRV) in informal settlements. The research will act as an inception to conduct the quantitative, qualitative, semi-probabilistic and probabilistic analysis and fire risk assessments in informal settlements.

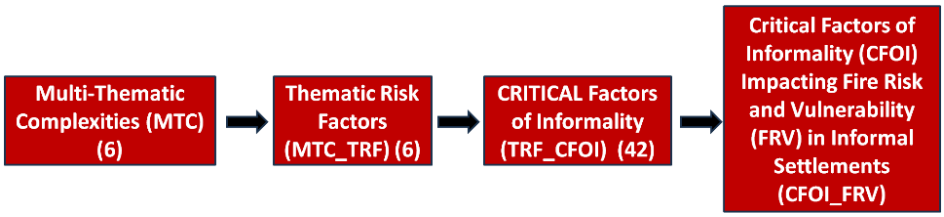

Figure 1-1 The correlation of MTC, TRF, CFOI & FRV

2. LITERATURE REVIEW

2.1 Thematic Analysis: Determining the multi-thematic complexities in informal settlements (INSE)

Fire risk and fire safety are understood to emerge because of dynamic, adaptive, nonlinear processes and relations between different elements and agents in a context. Fire risk emerges from a complex system of processes of inequitable urbanisation, where fire hazards and multiple socio-economic vulnerabilities are created and reinforce each other (Antonellis et al., 2022).

There is plethora of qualitative research defining the urban informality or informal settlements, taking in consideration the multiple dispersed attributes or features (or factors) of informal settlements such as poverty, education, unemployment, poor sanitation, lack of solid waste management, inadequate water supply, scarce housing units, and inadequate infrastructure (Finn & Kobayashi, 2020; UN-Habitat, 2004).

However, this paper aims to collate all the identified critical factors of informality (CFOI) into clustered thematic risk factors (TRF), classified under multi-thematic complexities (MTC). Thematic complexities are known to have the dynamism and longevity with the potential to evolve and expand over a period like the dynamism of fire risks in informal settlements, impacting fire risk and vulnerabilities (FRVs) in informal settlements.

The fundamentals of fire risk and fire hazards are rooted in the multi-thematic complexities (MTC) of informal settlements, therefore it is cardinal to understand the root causes of fire risks and fire hazards through a systematic classification of multi-thematic complexities (MTC), begetting thematic risk factors (TRF) and critical factors of informality (CFOI), so that the remedial measurements could be more conspicuous.

In this research, Multi-thematic complexities (MTC) are described as theme based (observed) issues and challenges specific to informal settlements. MTC are interconnected and impact each other in complex ways and may even govern the likelihood of fire hazards.

The current research acknowledges six types of multi-thematic complexities in informal settlements e.g. Socio-economic complexities (S), Behavioural complexities (B), Physical complexities (P), Administrative complexities (A), Environmental complexities (E) and Complexities of fire safety infrastructure (F) as shown the attribution model (Figure 2-1).

The understanding of multi-thematic complexities (MTC) will facilitate the understanding of profile of informal settlement and to curate the short term and long-term strategies and an in-depth planning and decision-making, concerning fire safety in informal settlements.

The idea to classify MTC is to group and analyse the underlying common grounds and to understand the interconnected, independent and interdependent challenges that may have a shared impact across different areas e.g.

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Socio-economic complexities(S) comprise of poor income or low income as one indicator, poor income develops a Behavioural complexity (B) in informal dwellers , leading to opt for comparatively cheap or poor of construction material choices , which consequentially escalates the physical complexities (P) of the dwelling unit making it more susceptible to fire hazards.

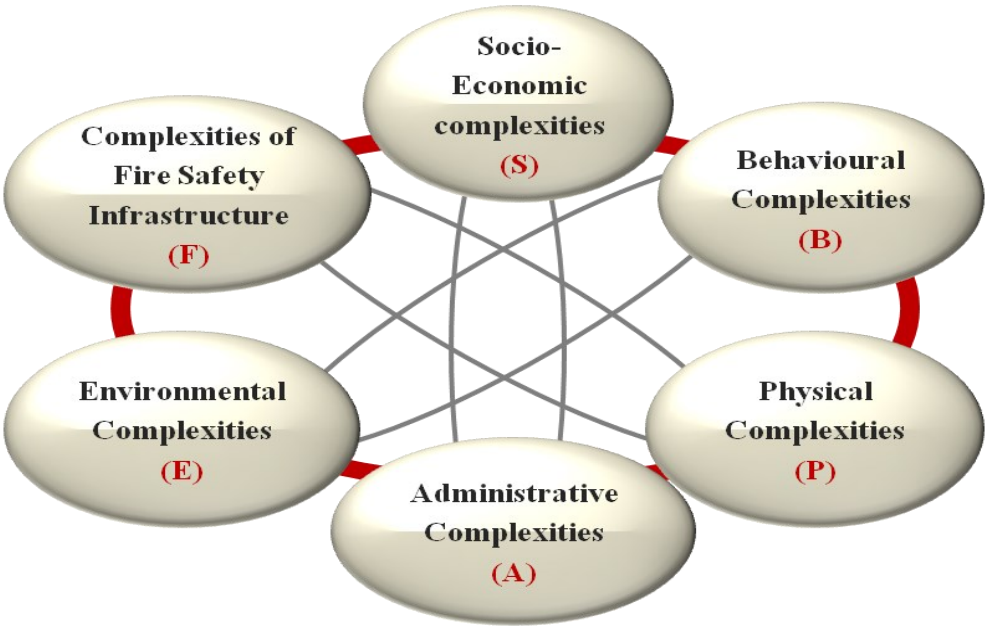

Figure 1-1 Multi- Thematic Complexities (MTC) in Informal Settlements (Source: Author)

Therefore, the understanding of MTC is significant to understand the root causes of fire hazards and the implicit fire risks and vulnerabilities (FRVs) in informal settlements at different stages of fire and at different scale of damage, however the stages of fire and the scale of damage are exclusive of this research scope.

Figure 1-2 Fire in Informal Settlement (Source: File picture; Leon Muller/African News Agency (ANA) Archives)

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Figure 1-3:Post-fire Scene at Imizamo Yethu IS in 2017 (Source: Bruce Sutherland from City of Cape Town)

Table 1: Attributes of Multi -Thematic Complexities (MTC) in Informal Settlements (Source: Author)

S. No	Multi Thematic Complexities (MTC)	Attributes
1	Socio-economic complexities **(S)**	**Socio-economic complexities(S)** are attributed to the existing complexities associated with the social disparities and inequitable urbanization (Antonellis et al., 2020b) e.g. poverty, low income, unemployment, inequality, social exclusion, social practices , demographic changes, health crises, marginality ,high density & overcrowding, political instability and negligence, economic downturns, inflation , fiscal instability , operational viability of business (International Monetary Fund, 2021) etc.
2	Behavioural complexities **(B)**	**Behavioural complexities (B)** are attributed to the specific behaviour that the informal dwellers showcase in informal settlements. The behaviour may be governed by multiple factors e.g. Personal and emotional factors, ethical factors, environmental factors, physical factors and cultural factors etc. The behavioural complexity is a strong factor responsible either for the occurrences of multiple hazards/fire hazards or may have aggravate them.
3	Physical complexities **(P)**	**Physical complexities (P)** are attributed to the existing physical conditions of informal dwellings and informal settlements. The physical conditions may have different attributes e.g. the shape and composition of informal dwellings, the geometry and constructs of the informal settlements. Physical complexities may also be referred as the status of infrastructural facilities present in informal settlements e.g. presence of water and pucca roads etc. Physical complexities also indicate a strong factor responsible either for the occurrences of multiple hazards/fire hazards or may have aggravate them.
4	Administrative complexities **(A)**	**Administrative complexities(A)** are attributed the lack of governing authorities and decision-making bodies to process the standards, policies, codes, bye laws to govern the development of informal settlements and to further device the uncontrolled urban growth. Uncontrolled urban growth exacerbates multiple hazards/fire hazards ,risks and vulnerabilities (Parnell, 2001; Spaliviero, 2006; UN-HABITAT, 2007a;Report,world cities, 2020)
5	Environmental complexities **(E)**	**Environmental complexities(E)** are attributed to the conditions and possibility of location of Informal settlements, which are mostly situated on hazardous grounds and around the challenging premises with higher possibility of fire risks and fire hazards. The environmental complexities also refer to the local weather conditions e.g. high rise in temperature, environmental pressure and lack of moisture. Environmental complexities impact the occurrence and facilitation of multiple hazards/fire hazards..
6	Complexities of fire safety infrastructure **(F)**	**Complexities of fire safety infrastructure (F)** are attributed to the failure of defence mechanism for the fire safety and fire Risks due to lack or inadequacy of fire safety infrastructure in informal settlements e.g. lack of fire detection, fire suppression, Fire Resilience Features, fire evacuation, communication systems, modern firefighting equipment and technology etc. The complexities of fire safety infrastructure not just impact the fire risks and vulnerabilities, but it also effects the fire rescue operations and fire risk management processes, which further aggravates the impact of fire hazards and damages in informal settlements.

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2.2 Determining Thematic Risk Factors (TRF)

The Multi-thematic complexities (MTC) beget the thematic risk factors (TRF). Thematic risk factors can be described as the existing factors in informal settlements developed due to the multi-thematic complexities, facilitating fire hazards and fire risks at different risk stages of fire e.g. ignition risk stage, growth risk stage , development risk stage ,evacuation risk stage and spread risk stage.

Thematic risk factors (TRF) further impact the underlying socio-economic, physical and environmental vulnerabilities and scales of damage. To establish the aim of the research, six thematic risk factors were identified from the literature, case studies and focused group discussions (FGD) e.g. Socio-economic Risk Factors (RS), Behavioural Risk Factors (RB), Physical Risk Factors (RP), Administrative Risk Factors (RA), Environmental Risk Factors (RE) and Risk Factors of Fire Safety Infrastructure (RF). These thematic risk factors (TRF) further bifurcate to form critical factors of informality (CFOI) impacting fire risk and vulnerabilities (FRV).

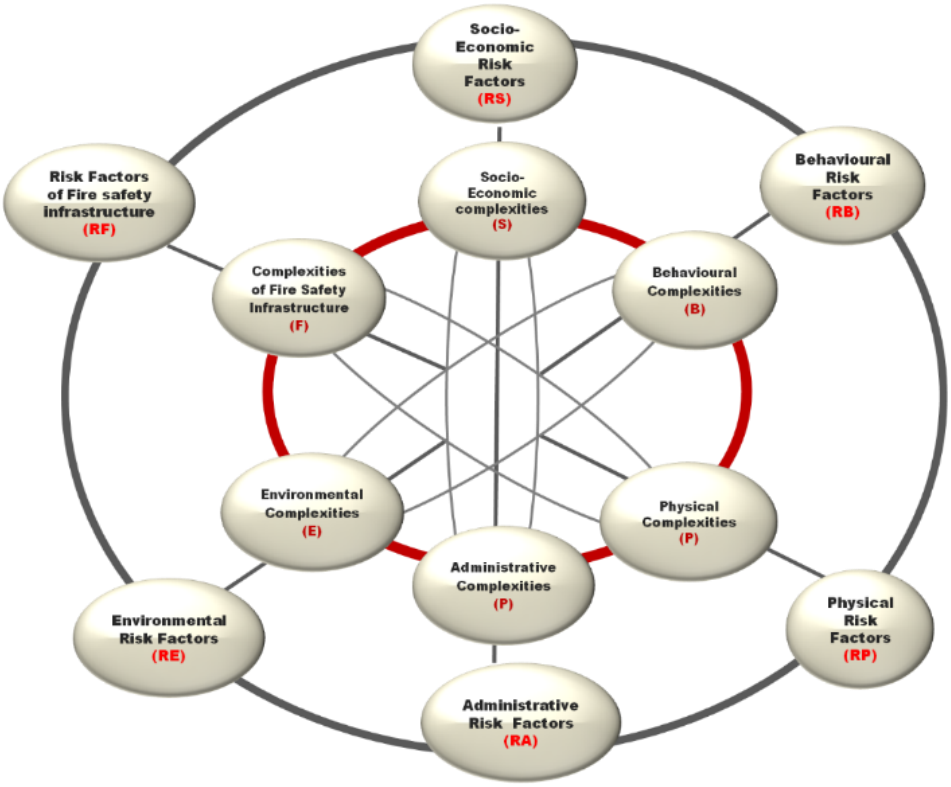

Figure 2-0-4 Attribution model showing correlations between Multi-Thematic Complexities (MTC) and Thematic Risk Factors (TRF) in Informal Settlements (Source: Author)

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Table 2 Attributes of Thematic Risk Factors (TRF) in Informal Settlements (Source: Author)

S. No	Thematic Risk Factors (TRF)	Attributes
1	Socio-Economic Risk Factors **(RS)**	**Socio-Economic Risk Factors (RS)** are developed by socio-economic complexities(S) in informal settlements. Socio-Economic Risk Factors (RS) are attributed to existing socio-economic conditions, facilitating multiple hazards and impacting risk and vulnerabilities in informal settlements.
2	Behavioural Risk Factors **(RB)**	**Behavioural Risk Factors (RB)** are developed by behavioural complexities(B) in informal settlements. Behavioural risk factors are attributed to the specific behaviour of the informal dwellers facilitating multiple hazards and impacting the risk and vulnerabilities in informal settlements.
3	Physical Risk Factors **(RP)**	**Physical Risk Factors (RP)** are developed by the physical complexities (P). Physical risk factors (RP) are attributed to the existing physical conditions facilitating multiple hazards and impacting risk and vulnerabilities in informal settlements. The physical risk factors either acts as an igniter or fuel or a facilitator to fire risks and hazards.
4	Administrative Risk Factors **(RA)**	**Administrative Risk Factors (RA)** are developed by the administrative complexities(A). Administrative risk factors (A) are attributed the to the existing administrative conditions facilitating multiple hazards and impacting the risk and vulnerabilities in informal settlements.
5	Environmental Risk Factors **(RE)**	**Environmental Risk Factors (RE)** are developed from the environmental complexities(E). Environmental risk factors (RE) are attributed to the existing environmental conditions facilitating multiple hazards and impacting the risk and vulnerabilities in informal settlements
6	Risk factors of fire safety Infrastructure **(RF)**	**Risk Factors of Fire Safety Infrastructure (RF)** are developed from the complexities of fire safety infrastructure(F). Risk factors of fire safety Infrastructure (RF) are attributed to the existing condition of the fire safety infrastructure, facilitating multiple hazards and impacting the risk and vulnerabilities in informal settlements.

2.3 Determining theoretical construct of multi-thematic complexities (MTC) forming thematic risk factors (TRF) resulting in critical factors of informality (CFOI)

With urbanization and development of urban informal settlements (UIS), multi-thematic complexities (MTC) (Table 1) in informal settlements burgeons into thematic risk factors (TRF) (Table 2). TRF are attributed to multiple hazards in informal settlements (INSE) and further bifurcates to form the critical factors of informality (CFOI). Forty-two critical factors of informality (CFOI) were identified specific to the fire risks and vulnerabilities (FRV) in informal settlements. The MTC, TRF, and CFOI exhibit linear correlations and direct proportionality with one other, indicating that as multi-thematic complexities (MTC) increases, the thematic risk factors and critical factors of informality (CFOI) also increases, thus increasing the likelihood of fire hazards and impacts on fire risk and vulnerabilities (FRV) in informal settlements.

2.4 Determining critical factors of informality (TRF_CFOI)

The critical factors of informality (CFOI) can be described as existing socio-economic, behavioural, physical, administrative, environmental and infrastructural conditions or parameters or circumstances in informal settlements (INSE) that either facilitates hazards within INSE or constitute a direct significant impact on the general risk and vulnerabilities in INSE. Since, the research revolves around the fire risk and vulnerabilities in INSE, forty-two CFOI were identified and were further clustered into six thematic risk factors (TRF) (Figure 0-4) (Table 3), impacting fire risk and vulnerabilities(FRV) in informal settlements at different stage of fire risk e.g. Ignition risk stage (I^R), Growth risk stage (G^R), Development risk stage (D^R), Evacuation risk stage (E^R) & Spread

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risk stage (S^R) (Hu et al., 2022) and at different scales of damage e.g. informal Dwelling scale and settlement or community scale (Antonellis et al., 2018). Seven CFOI were identified under the socio-economic risk factors (RS) e.g. lack of education & fire safety knowledge (RVS1), High density & overcrowding (RVS2), Low level of maintenance (RVS3), No. of children present (0-6 years) (RVS4), No. of women present (RVS5), Presence of elderly (65 years or above), disabled and sick family member (RVS6), Lack of monitoring & surveillance (RVS7). Four major CFOI were identified under behavioral risk factors (RB) e.g. Smoking cigarette / disposed half-lit cigarette butts/drug Consumption/alcohol consumption (RVB1), Potential arsonists (RVB2), Operation with sparks and open flames (RVB3), Repairing of informal dwelling (RVB4). Twelve CFOI were identified under physical risk factors (RP) e.g. Structural Composition & combustibility (RVP1), Structural age & fragility (RVP2), Non-structural composition & combustibility (RVP3), Ventilation Profile of informal dwellings / informal settlement (RVP4), Proximity & distance (RVP5), Separation distance (average minimum distance to nearest neighbor) (NN) (RVP6), Lack of water resources, water supply and water drainage systems (RVP7), External fuel load (RVP8), Lack of accessibility & egress (RVP9), Presence of any unique characteristic (e.g. makeshift stairs /paths etc.) (RVP10), Critical patch size /patch density (RVP11), Edge density & Landscape density (PLAND) (RVP12). Two major CFOI were identified under administrative risk factors (RA) e.g. Non-compliance of standards and byelaws (RVA1) and lack of control & funding (RVA2). Seven CFOI were identified under environmental risk factors (RE) e.g. Rising temperature /heat (RVE1), wind velocity/speed and wind direction (RVE2), Humidity/Moisture (RVE3), Slope/Topography (RVE4), Month of the year (RVE5). Time of the day (RVE6), Presence of potential wildland-urban interfaces (WUI) (RVE7). Lastly, ten CFOI were identified under the risk factors of fire safety Infrastructure (RF) e.g. Lack of publicly provided fire safety infrastructure (Protection, suppression & evacuation plan) (RVF1), Lack of community-based fire awareness & fire management training programs (RVF2), Lack of communication systems & linguistic barriers (RVF3), non-competence of fire rescue team & firefighting infrastructure (RVF4), Equipment faults and non-compliance (RVF5), Equipment vandalization & thievery (RVF6), Speed of response and rescue (RVF7), Distance from fire stations and response time (RVF8), Lack of firebreaks/buffer zones and open areas (RVF9), Lack of fire data, analysis and availability (RVF10). All above mentioned CFOI impacts the fire hazards and fire risks and vulnerabilities in informal settlements. The attribute of each CFOI with fire risk and vulnerabilities (FRV) has been provided in Table 4.

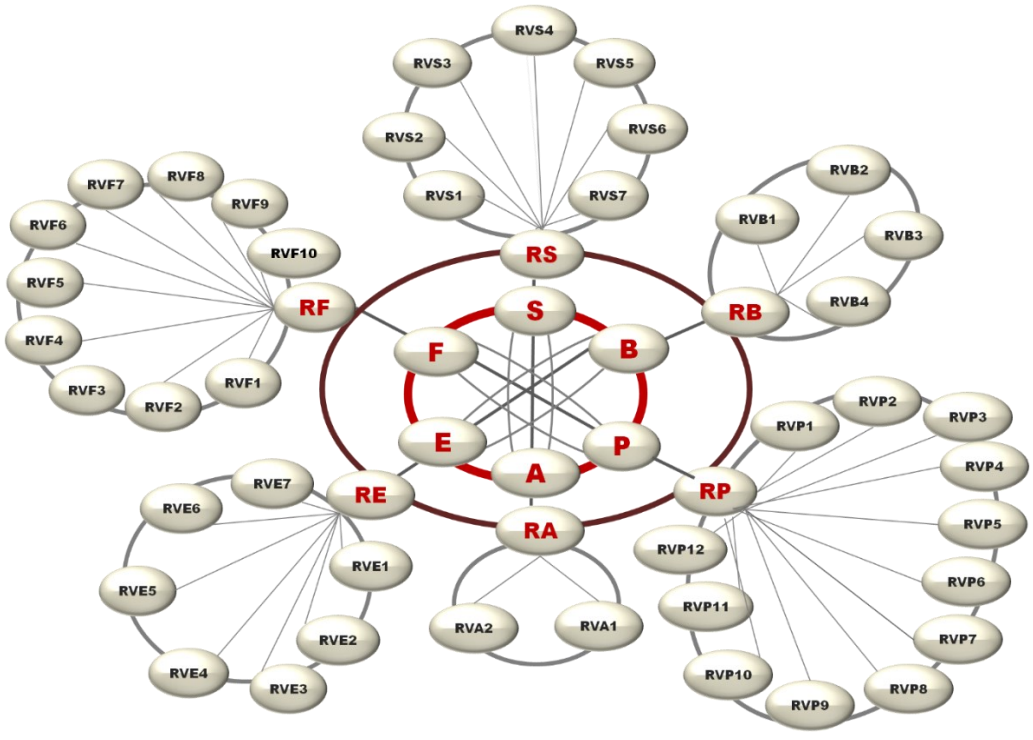

Figure 0-5 Critical Factors of Informality (CFOI) attributed to Thematic Risk Factors (TRF) associated with Multi- Thematic Complexities (MTC) (Source: Author)

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Table 3 Critical Factors of Informality (TRF_CFOI) attributed to Thematic Risk Factors (MTC_TRF) associated with Multi-Thematic complexities (MTC) in informal settlements (Source: Author)

Multi Thematic Complexities (MTC)	Thematic Risk Factors (TRF)	Critical Factors of informality (CFOI)
Socio-economic complexities **(S)**	Socio-Economic Risk Factors **(RS)**	1. Lack of education & fire safety knowledge **(RVS1)** 2. High density & overcrowding **(RVS2)** 3. Low level of maintenance **(RVS3)** 4. No. of children present (0-6 years) **(RVS4)** 5. No. of women present **(RVS5)** 6. Presence of elderly (65 years or above), disabled and sick family member **(RVS6)** 7. Lack of monitoring & surveillance **(RVS7)**
Behavioural complexities **(B)**	Behavioural Risk Factors **(RB)**	8. Smoking cigarette / disposed half-lit cigarette butts/drug Consumption/alcohol consumption **(RVB1)** 9. Potential arsonists **(RVB2)** 10. Operation with sparks and open flames **(RVB3)** 11. Repairing of informal dwelling **(RVB4)**
Physical complexities **(P)**	Physical Risk Factors **(RP)**	12. Structural Composition & combustibility **(RVP1)** 13. Structural age & fragility **(RVP2)** 14. Non-structural composition & combustibility **(RVP3)** 15. Ventilation Profile of informal dwellings / informal settlement **(RVP4)** 16. Proximity & distance **(RVP5)** 17. Separation distance (average minimum distance to nearest neighbour) (NN) **(RVP6)** 18. Lack of water resources, water supply and water drainage systems **(RVVP7)** 19. External fuel load **(RVP8)** 20. Lack of accessibility & egress **(RVP9)** 21. Presence of any unique characteristic (e.g. makeshift stairs /paths etc.) **(RVP10)** 22. Critical patch size /patch density **(RVP11)** 23. Edge density & Landscape density (PLAND) **(RVP12)**
Administrative complexities **(A)**	Administrative Risk Factors **(RA)**	24. Non-compliance of standards and byelaws **(RVA1)** 25. Lack of control & funding **(RVA2)**
Environmental complexities **(E)**	Environmental Risk Factors **(RE)**	26. Rising temperature /heat **(RVE1)** 27. wind velocity/speed and wind direction **(RVE2)** 28. Humidity/Moisture **(RVE3)** 29. Slope/Topography **(RVE4)** 30. Month of the year **(RVE5)** 31. Time of the day **(RVE6)** 32. Presence of potential wildland-urban interfaces (WUI) **(RVE7)**
Complexities of fire safety Infrastructure **(F)**	Risk factors of fire safety Infrastructure **(RF)**	33. Lack of publicly provided fire safety infrastructure (Protection, suppression & evacuation plan) **(RVF1)** 34. Lack of community-based fire awareness & fire management training programs **(RVF2)** 35. Lack of communication systems & linguistic barriers **(RVF3)** 36. Non-competence of fire rescue team & firefighting infrastructure **(RVF4)** 37. Equipment faults and non-compliance **(RVF5)** 38. Equipment vandalization & thievery **(RVF6)** 39. Speed of response and rescue **(RVF7)** 40. Distance from fire stations and response time **(RVF8)** 41. Lack of firebreaks/buffer zones and open areas **(RVF9)** 42. Lack of fire data, analysis and availability **(RVF10)**

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2.5 Critical Factors of Informality (CFOI) attributed to fire risk & Vulnerabilities (FRV) in informal settlements

For the current research, forty-two critical factors of informality (CFOI) were identified and clustered into six thematic risk factors (TRF) (Table 3). The attribution of each CFOI with its attributes to Fire risks and vulnerabilities (FRV) has been provided (Table 4,5,6,7,8 & 9).

2.5.1 Critical factor of informality (CFOI) attributed to Socio-Economic Risk Factors (RS) Impacting fire risk and vulnerabilities (FRV)

Table 4 CFOI attributed to Socio-Economic Risk Factors (RS), Impacting Fire Risk and Vulnerabilities (FRV)

Critical Factors Of Informality (CFOI)	Attributes Of Critical Factors Of Informality (FOI) Impacting Fire Risk And Vulnerabilities (FRV) ~ CFOI_FRV
Lack of education & fire safety knowledge **(RVS1)**	***The critical factor of 'Lack of education & fire safety knowledge (RVS1)'*** *is attributed to the inability and obscurity of informal dwellers/communities to understand the consequences of their actions that may lead to fire risks and fire Hazards due to low level of education and knowledge. The factor is also attributed to the inability of informal dwellers to take prompt action and to make informed decisions during fire hazards due to the lack of fire safety knowledge and formal training, necessary for effective fire safety measures and rescue operations.*
High density & overcrowding **(RVS2)**	***The critical factor of 'High density & overcrowding (RVS2)'*** *is attributed indirectly to low level of income, high level of rent affordability, and high rate of rental tenure ship resulting in high density and overcrowding of informal settlements, affecting the social vulnerabilities and damage. High density and overcrowding as a critical factor of informality also increases the likelihood of fire hazards and possibility of high damage.*
Low level of maintenance **(RVS3)**	***The critical factor of 'Low level of maintenance (RVS3)'*** *is attributed to the poor maintenance of informal dwellings and settlements. Easy access to scrap markets, selection of cheap and affordable resources, and usage of highly flammable & combustible materials surges the combustible fuel load of informal dwellings. The high rate of rental tenure ship in informal settlements results in a lack of sense of belonging and results in low level of maintenance of services and repair work in informal dwellings, compromising safety and aggravating fire risks and vulnerabilities.*
No. of children present (0-6 year) **(RVS4)**	***The critical factor of 'No. of children present (0-6 year) (RVS4)'*** *is attributed to the presence of children (below 6 years) in informal settlements with the possibility of them playing with fire ignition sources (e.g. matchsticks, firecrackers and candles, etc.). Many cases of lack of surveillance or monitoring of children have been reported in informal settlements, as the lack of surveillance and monitoring of children playing with combustibles and ignition resources significantly increases the fire risks and vulnerabilities in informal settlements (Kahanji et al., 2019).*
No. of women present **(RVS5)**	***The critical factor of 'No. of women present (RVS5)'*** *is attributed to the presence of women in informal settlements depicting certain activities involving fire e.g. Cooking, heating and burning, etc., significantly increasing the risk and vulnerability of fire hazards.*
Presence of elderly (65 years or above), disabled and sick family member **(RVS6)**	***The critical factor of 'Presence of elderly (65 years or above), disabled and sick family member (RVS6)'*** *is attributed to the presence of geriatric golden agers, disabled or sick family members who might be more vulnerable at times of fire hazards due to their inability to identify the danger and self-defence e.g. a deaf, blind, and physically challenged person might not be able to protect themselves in case of fire. The factor impacts the social vulnerabilities in informal settlements.*
Lack of monitoring & surveillance **(RVS7)**	***The critical factor of 'Lack of monitoring & surveillance (RVS7)'*** *is attributed to the observed behaviour of informal dwellers, signifying their casual approach in acting, thinking, observing, and decision-making in terms of fire safety and fire hazards. e.g. the dwellings are built too close to each other, the curtains are placed too close to the stoves, children are playing with fires in neglect and the dangerous premises of explosives, and the dwellings are loaded with combustible and flammable sources, etc and there is no monitoring and control system to govern this behaviour. Attributed to the uninhibited working/economic Profile of the informal dwellers, impacting the fuel load and combustibility (e.g. storing scrap, manufacturing clothes, rubbers, and papers, etc.).* Attributed to the Social & Religious activities or practices that provoke fire hazards and impact the fire risk and vulnerabilities if left unsupervised or unmonitored.

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2.5.2 Critical factor of informality (CFOI) attributed to Behavioural Risk Factors (RB), Impacting fire risk and vulnerabilities (FRV)

Table 5 TRF_CFOI attributed to Behavioural Risk Factors (RB), Impacting Fire Risk and Vulnerabilities (FRV)

Critical Factors Of Informality (TRF_CFOI)	Attributes Of Critical Factors Of Informality (FOI) Impacting Fire Risk And Vulnerabilities (FRV) ~ Cfoi_Frv
Smoking cigarette / disposed half-lit cigarette butts/drug Consumption/alcohol consumption **(RVB1)**	***The critical factor of 'Smoking cigarette / disposed half-lit cigarette butts/drug Consumption/alcohol consumption (RVB1)'*** *is attributed to the observed behaviour of informal dwellers where people carelessly smoke cigarettes in a fire-vulnerable zone or dispose of the half-lit cigarette butts casually. The factor is also attributed to the consumption of drugs and alcohol resulting in unconscious or unsupervised actions, significantly increasing fire risk and vulnerabilities in informal settlements.*
Potential arsonists **(RVB2)**	***The critical factor of 'Potential arsonists (RVB2)'*** *is attributed to the observed substance misuse problems e.g. mental stress or mental health issues (e.g., had threatened suicide or committed, Community Violence, Domestic violence, vandalization, Riots, Conflicts, and Crimes resulting in the possibility of fire hazards in informal settlements.*
Operation with sparks and open flames **(RVB3)**	***The critical factor of 'Operation with sparks and open flames (RVB3)'*** *is attributed to the operations, including welding, cutting, open flames and smelting, the sparks generated by improper operation that escalate the fire risks and may cause fire hazards (FPASA, 2018) (DMFRS 2015). The factor is also attributed to the observed behaviour of informal dwellers of using open flames, where they adopt certain practices e.g. Cooking methods (e.g. Cookers, electricity stoves, Paraffin Stoves, LPG Stoves, and Gas Bottle, etc.), lighting methods (e.g. electricity lights, open-flame candles, Paraffin Lamps, etc.) and Heating methods (e.g. paraffin Stoves and coal stoves & mosquito coils, etc.) due to poor access to safe energy resources. Informal dwellers also conduct malpractices related to the stolen electricity or electric connections (due to limited access to "legal" energy for lighting) resulting in a high frequency of "jumpers" leading to short circuits. The factor also indicates an observed behaviour of informal dwellers for the Usage of Cheap or second-hand Appliances. Second-hand appliances may catch fire easily by getting overheated*
Repairing of informal dwelling **(RVB4)**	***The critical factor of 'Repairing of informal dwelling (RVB4)'*** *is attributed to the observed repairing behaviour and techniques adopted by informal dwellers (e.g. use of papers, sandbags, or plastics to seal the openings in ceilings or walls), which forms the leaky details resulting in fire spread (Cicione et al., 2019).*

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2.5.3 Critical factor of informality (CFOI) attributed to Physical Risk Factors (RP), Impacting fire risk and vulnerabilities (FRV)

Table 6 TRF_CFOI attributed to Physical Risk Factors (RP), impacting fire risk and vulnerabilities (FRV)

Critical Factors Of Informality (TRF_CFOI)	Attributes Of Critical Factors Of Informality (FOI) Impacting Fire Risk And Vulnerabilities (FRV) ~ Cfoi_Frv
Structural Composition & combustibility **(RVP1)**	***The critical factor of 'Structural Composition & combustibility (RVP1)'*** *is attributed to the application of sub-standard and low-cost material, informal dwelling composition, and structural elements (e.g. Wall, columns, foundation, roof, and flooring) with poor & leaky details consisting of low fire resistance, high combustibility, and light-weight material (e.g. thermally thin steel, corrugated sheets, timber, fabrics, plastic sheets, cement sheets, Tarpaulin sheets, cardboard, or any readily available materials in the scrap market or premises). The presence of fuel load in the informal dwelling is one of the physical complexities e.g. the fuel load in informal settlements is comparatively very, research has suggested the average fuel load ranging between 400-500 MJ/m2* (Maree 2015).
Structural age & fragility **(RVP2)**	***The critical factor of 'Structural age & fragility (RVP2)'*** *is attributed to the age of the informal dwelling, age is a significant factor responsible for fire risks, as older structures are often more susceptible to fire hazards due to outdated electrical systems, deteriorated services, lack of fire safety features and inability to get equipped with fire safety infrastructure.*
Non-structural composition & combustibility **(RVP3)**	***The critical factor of 'Non-structural composition & combustibility (RVP3)'*** *is attributed to the presence and distribution of fuel load inside the informal dwelling unit e. g or arrangement of highly flammable, hazardous & combustible material, either movable or immovable assets (e.g. furniture, electrical appliances, cheap insulation, paraffin stoves, gas, cooking equipment, rubber, fabric, tyres, plastic, PVC, tarpaulin, wood /bamboo, bottles, cardboard, clothes/fabrics, bedding, explosive chemicals etc.), which provokes the fire growth and development by acting as food or fuel load during fire hazards. The factor is also attributed to the non-structural or internal surface applications like the lining of floor, ceiling, and walls (e.g. paints, curtains, U foam, timber, carpets, plastic sheets, cardboard, papers, shade netting, tires, Masonite timber, corrugated galvanized steel sheets, timber board, unlined metal walls, or timber walls, cladding, plastic layers, insulations, fabrication, and steel sheets, etc.), also feeding fires as fuel load. Attributed to the stored waste or scrap material inside the dwellings acting as a fuel load during fire hazards.*
Ventilation Profile of informal dwellings / informal settlement **(RVP4)**	***The critical factor of 'Ventilation Profile of informal dwellings / informal settlement (RVP4)'*** *is attributed to the Presence of openings inside the dwelling units (e.g. doors, windows, shafts, Ventilators & chimneys, etc.). Openings and opening size influence the size of the flames omitted, the spread of fire, and the oxygen concentration in the atmosphere. The door and windows remain a weaker point for ignition resistance (Wang, Gibson, & Beshir, 2020).*
Proximity & distance **(RVP5)**	***The critical factor of 'Proximity & distance (RVP5)'*** *is attributed to the proximity of the informal dwelling/settlement to any hazardous source e.g. an electric pole, transmission line,*

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	Electric Substation, HT & LT Lines, forest/crop/bushes and industrial area, etc. that might facilitate the possibility of fire risk and fire hazard (Walls & Zweig, 2017).
Separation distance (average minimum distance to nearest neighbour) (NN) **(RVP6)**	***The critical factor of 'Separation distance (average minimum distance to nearest neighbour) (NN) (RVP6)'*** *is attributed to the distance between neighbouring dwellings or closely spaced buildings/ Co-dwelling/clusters/Attached adjacent walls etc., signifying the possibility of high fire spread involving multiple dwellings and exacerbating the Risk of Secondary Fires.*
Lack of water resources, water supply and water drainage systems **(RVP7)**	***The critical factor of 'Lack of water resources, water supply and water drainage systems (RVP7)'*** *is attributed to unreliable Sourcing and insufficient water supply. The factor is also attributed to the inadequate quantity of water to quell fire and inefficient Water Drainage Systems (Pucca/Covered /Underground)*
External fuel load **(RVP8)**	***The critical factor of 'External fuel load (RVP8)'*** *is attributed to the fuel load arrangement or combustible material present outside the informal dwellings (e.g. woods, tires, rubbers, scrap, plastic, etc.). The factors is attributed to the presence of trees, Shrubs, and Dry leaves outside the dwelling units, the vegetation or greenery often acts as fuel and bridge to fire spread from one dwelling to another. The factor is also attributed to the Practice of Storage of waste/waste disposal System /open dumping, observed behavior of informal dwellers of storing scrap material and waste outside the dwellings. The waste too acts as an external fuel load and fire bridge outside the informal dwelling resulting in possible high fire spread rates.*
Lack of accessibility & egress **(RVP9)**	***The critical factor of 'Lack of accessibility & egress (RVP9)'*** *is attributed to the number of Sides directly accessible to roads and open areas. The factor is also attributed to narrow, irregular, densely populated, and overcrowded roads and lanes.* (Milke, Gallo and Wong, 2020)
Presence of any unique characteristic (e.g. makeshift stairs /paths etc.) **(RVP10)**	***The critical factor of 'Presence of any unique characteristic (e.g. makeshift stairs /paths etc.) (RVP10)'*** *is attributed to the observed scenarios in informal settlements, where the informal dwellers self-invent new structures as per their convenience or usage e.g. temporary staircases, shelter panels, etc.*
Critical patch size /patch density **(RVP11)**	***The critical factor of 'Critical patch size /patch density (RVP11)'*** *is attributed 'to the group of dwellings that all lie within a given critical distance (CD) of a fire spread if a fire originates anywhere in the critical patch, there are high probabilities that the fire may spread to all other dwellings within that critical patch due to connectivity and distance.*

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Edge density & Landscape density (PLAND) **(RVP12)**	***The critical factor of 'Edge density & Landscape density (PLAND) (RVP12)'*** *is attributed to the sum of all dwelling perimeter (P) divided by the settlement area(A), the more the edge density, the more the crowdedness of the informal dwelling making it more vulnerable to fire risk and hazards. Landscape density (PLAND) is attributed to the Sum of the Area of all dwelling footprints divided by the settlement area and multiplied by 100 calculated total in percentage) (Rush et al., 2022).Just like edge density, landscape density also signifies the physical congestion and complexities within informal settlements validating and comprehending the high density and over crowdedness.*

2.5.4 Critical factor of informality (CFOI) attributed to Administrative Risk Factors (RA), Impacting fire risk and vulnerabilities (FRV)

Table 7 TRF_CFOI attributed to Administrative Risk Factors (RA), impacting fire risk and vulnerabilities (FRV)

Critical Factors Of Informality (TRF_CFOI)	Attributes Of Critical Factors Of Informality (FOI) Impacting Fire Risk And Vulnerabilities (FRV) ~ Cfoi_Frv
Non-compliance of standards and byelaws **(RVA1)**	***The critical factor of 'Non-compliance of standards and byelaws (RVA1)'*** *is attributed to the construction and development of informal dwellings and settlements with infringement of fire safety codes, byelaws, development standards, guidelines, building regulations & Legislations, etc..*
Lack of control & funding **(RVA2)**	***The critical factor of 'Lack of control & funding (RVA2)'*** *is attributed to the lack of municipal control and fire regulation enforcement in informal settlements. Attributed to the lack of local governance, institutions, and the respective roles and responsibilities. Attributed to the lack of funding for the provision of fire safety infrastructure in informal settlements.*

2.5.5 Critical factor of informality (CFOI) attributed to Environmental Risk Factors (RE), Impacting fire risk and vulnerabilities (FRV)

Table 8 TRF_CFOI attributed to Environmental Risk Factors (RE), impacting fire risk and vulnerabilities (FRV)

Critical Factors Of Informality (TRF_CFOI)	Attributes Of Critical Factors Of Informality (FOI) Impacting Fire Risk And Vulnerabilities (FRV) ~ Cfoi_Frv
Rising temperature /heat **(RVE1)**	***The critical factor of 'Rising temperature /heat (RVE1)'*** *is attributed to increased heat exposure, drought, and dry conditions often resulting in electrical overload and fire ignition, exacerbating the risk of fire hazards in informal settlements. The factor is also attributed to the less capacity of informal settlements to retain heat. The factor is also attributed to the collective capacity of informal settlements to transform into one combustible entity over a period (Conduction, convection, and radiation) of time due to higher fuel load and Heat Release Rate (HRR).*
Wind velocity/speed and wind direction **(RVE2)**	***The critical factor of 'Wind velocity/speed and wind direction (RVE2)'****is attributed to the wind speed, velocity and direction causing spread of Flames, Smoke, toxic gases and Ember Transport etc, impacting the fire risk and vulnerability of informal settlements.*

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Humidity/Moisture **(RVE3)**	***The critical factor of 'Humidity/Moisture (RVE3)'*** *is attributed to mainly low humidity (e.g. building materials such as wood, thatch, or paper in informal settlements can dry out the moisture content, becoming more susceptible to ignition and rapid combustion). Dry conditions or lower humidity may also contribute to static electricity buildup or increased resistance in electrical systems, leading to overheating and sparking.*
Slope/Topography **(RVE4)**	***The critical factor of 'Slope/Topography (RVE4)'*** *is attributed to Steep slopes having the potential to accelerate and spread fires by allowing flames to rapidly climb uphill. Topographical features such as ridges or valleys can funnel wind and carry burning embers over long distances, igniting fires in new areas of the settlement. Sloped areas often have diverse vegetation and organic debris accumulation, which can act as additional fuel during fires.*
Month of the year **(RVE5)**	***The critical factor of 'Month of the year (RVE5)'*** *is attributed to the atmospheric temperature in different seasons and its impact on the activities, environment, and possibilities of fire hazards. Different months experience different sunshine hours and weather conditions. The probability of fire hazards caused by spontaneous combustion and lightning strikes is different. The use of air conditioners and other electric heating equipment is also different in various summer seasons. The outdoor fireworks in the winter season accelerate the possibility of fire hazards. Meanwhile, Higher temperatures during summer months can lead to increased use of open flames for cooking or heating. Dry Months or dry seasons with lower precipitation and higher temperatures coincide with increased fire risk as vegetation becomes more flammable. Seasonal celebrations or events may lead to increased use of fireworks or outdoor cooking, which can pose fire hazards if not managed properly.*
Time of the day **(RVE6)**	***The critical factor of 'Time of the day (RVE6)'*** *is attributed to the daytime or nighttime, the frequency of human behavior and usage of electrical appliances varies at different times of the day e.g. Electrical fires caused by overloaded circuits or faulty wiring are more likely to occur at night when electrical appliances and lighting systems are in use or left unattended. Sometimes, nighttime activities like social gatherings or recreational activities, Cooking, and Heating involving open flames increase the likelihood of fire incidents. Nighttime fires can pose greater risks to residents who may be asleep and unaware of the danger until it is too late to escape safely, especially in densely populated informal settlements with limited escape routes. Emergency Response often gets impacted at night times due to reduced visibility, navigation challenges in narrow alleys or informal pathways, and potential obstacles hindering access to affected areas.*
Presence of potential wild land-urban interfaces (WUI) **(RVE7)**	***The critical factor of 'Presence of potential wild land-urban interfaces (WUI) (RVE7)'*** *is attributed to the presence of transitional zones or wilderness (unoccupied land) e.g. Crop fields, forests, orchards, etc. The WUI facilitates the possibility of fire spread due to fuel load characteristics, and ignition capacity, and by acting as an ember transporter on larger scales, beyond informal settlements. The risk impacts can also be reversed when the wildland-urban interfaces (WUI) become the source of ignition and danger to the neighbouring informal settlements.*

2.5.6 Critical factor of informality (CFOI) attributed to Risk factors of fire safety Infrastructure (RF), Impacting fire risk and vulnerabilities (FRV)

Table 9 TRF_CFOI attributed to Risk factors of fire safety Infrastructure (RF), impacting fire risk and vulnerabilities (FRV)

Critical Factors Of Informality (TRF_CFOI)	Attributes Of Critical Factors Of Informality (FOI) Impacting Fire Risk And Vulnerabilities (FRV) ~ Cfoi_Frv
Lack of publicly provided fire safety infrastructure (Protection, suppression & evacuation plan) **(RVF1)**	***The critical factor of 'Lack of publicly provided fire safety infrastructure (Protection, suppression & evacuation plan) (RVF1)' is a****ttributes to Poor Allocation of Resources & Services (e.g. informal dwellers do not have access to essential firefighting equipment, such as fire hydrants, automatic fire/smoke detection systems, or dedicated fire stations). As a result, fires can spread unchecked, causing extensive damage and putting lives at greater risk due to delayed or inadequate emergency response measures. Lack of fire suppression systems e.g. fire extinguishers, water supplies, sand, fire hydrants, fire*

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	hoses, sprinklers, etc. Attributed to the absence or inadequate plans to prevent, detect, and respond to fires effectively in informal settlements (e.g. emergency plan, evacuation plan, fire safety plan, etc). Lack of signages & emergency lights, attributing to navigational challenges, evacuation Difficulties, visibility issues, and communication barriers. Risk of injury due to lack of General signage in informal settlements. Lack of public lighting attributed to the obfuscating entrance and exit pathways, impacting the fire evacuation, egress, and rescue operations.
Lack of community-based fire awareness & fire management training programs **(RVF2)**	***The critical factor of 'Lack of community-based fire awareness & fire management training programs (RVF2)*** *is attributed to practicing evacuation plans, Providing fire safety training for residents, employees, and emergency personnel, and Conducting regular fire drills to ensure everyone knows what to do in case of a fire, etc.*
Lack of communication systems & linguistic barriers **(RVF3)**	***The critical factor of 'Lack of communication systems & linguistic barriers (RVF3)'*** *is attributed to Limited or absent means to communicate and notify informal dwellers during the fire safety and rescue operations e.g. early warning systems. Linguistic barriers are attributed to the migrating characteristics of informal settlements. Informal dwellers are very often the migrated labour class workers from different states, making it challenging for them to understand certain commands or techniques during fire hazards or fire rescue operations, resulting in possible miscommunications and misunderstandings not just among themselves but with the fire rescue operation team as well.*
Non-competence of fire rescue team & firefighting infrastructure **(RVF4)**	***The critical factor of 'Non-competence of fire rescue team & firefighting infrastructure (RVF4)'*** *is attributed to the possibility that Firefighters may not be trained enough or well-equipped to deal with informal fires due to the complexities of informal settlements and the inadequate publicly available fire safety infrastructure.*
Equipment faults and non-compliance **(RVF5)**	***The critical factor of 'Equipment faults and non-compliance (RVF5)'*** *is attributed to the possible faults in equipment (e.g. malfunctioning of electrical components and internal faults) used for fire safety operations resulting in failed functioning. The factor is also attributed to the non-compliance of equipment in informal settlements (e.g. insufficient length of the hose, insufficient space for fire tenders, fire trucks or fire vehicle and extinguishers etc.).*
Equipment vandalization & thievery **(RVF6)**	***The critical factor of 'Equipment vandalization & thievery (RVF6)'*** *is attributed to the observed behaviour and activities in informal settlements in terms of vandalization and thievery of equipment during the fire rescue operations by the team.*
Speed of response and rescue **(RVF7)**	***The critical factor of 'Speed of response and rescue (RVF7)'*** *is attributed to the obstructions responsible for the delay and elongated response time e.g. narrow alleys, congested pathways, lack of reliable communication networks, and makeshift structures that can impede the rapid deployment of firefighting vehicles and personnel increasing the risk of fire spread. Even if the distance from a fire station is less, it might take time to respond and rescue due to the above-mentioned challenges.*

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Distance from fire stations and response time **(RVF8)**	***The critical factor of 'Distance from fire stations and response time (RVF8)' is attributed*** *to the direct distance between the settlements and the allotted fire stations and the average time in which the fire stations respond.*
Lack of firebreaks/buffer zones and open areas **(RVF9)**	***The critical factor of 'Lack of firebreaks/buffer zones and open areas (RVF9)' is attributed*** *to inadequate evacuation spaces, lack of refugee areas, open spaces, or punctures, resulting in limited access for firefighters, challenges in developing fire containment lines, and obstructed firefighting operations.*
Lack of fire data, analysis and availability **(RVF10)**	***The critical factor of 'Lack of fire data, analysis and availability (RVF10)'*** *is attributed to the post-hazard investigations and data generation e.g. fire causes, damage assessment, required support services, identification of impacts, and strategies followed. The factor is also attributed to the lack of protocols for fire safety and the lack of required preventive measures to avoid future incidents.* *- also Attributed to the absence of Fire research and development (R&D) for the review and future improvements in informal settlements, the urgent need for targeted research, technological innovations, identification of key stakeholders, and community engagement strategies to enhance fire safety and resilience in these informal communities.*

3 RESEARCH METHODOLOGY

The objective of the research entails to amalgamate the collected data through literature, case studies, focused group discussions (FGD) and the responses from the experts in the field of fire safety and research. The analysis of data have been used to develop the theoretical constructs of the identified factors and to form the correlations between the multi thematic complexities (MTC), thematic risk factors (TRF) and critical factors of informality (CFOI). The research further investigates the attributes of critical factors of informality (CFOIs) to fire risk and vulnerabilities (FRVs) in informal settlements. The aim of the research is to prepare a theoretical construct to facilitate the development of strategic roadmap to build an inclusive fire safety model with mitigation strategies aligned with better understandings of profile of informal settlements.

4 CONCLUSION

Fire safety in informal settlements is a multifaceted issue, intricately tied to the interplay between critical factors of informality (CFOI) and the resulting fire risks and vulnerabilities(FRV). The construct of inclusive fire safety model should be based on the pragmatic aspects, this research highlights the importance of adopting a holistic and context-specific approach to fire safety in informal settlements by addressing the root causes of fire risks. The active and passive fire safety strategies should be based on the established knowledge of impact and correlations of factors of informality impacting the fire risk in informal settlements. This conclusion supports the necessity of targeted research and interventions, emphasizing that a one-size-fits-all approach is inadequate for addressing the unique challenges of fire safety and fire hazards faced by informal settlements. It calls for comprehensive, Context-centric strategies to improve fire safety and resilience in these vulnerable areas. The research suggests that the fire behaviour is highly variable in informal settlements. Therefore, inclusive considerations of all the socio-economic, behavioural, physical, environmental and administrative factors should be considered in access to the technical factors. Considering such discussions above it is hoped that those developing solutions for informal settlements can better understand fire dynamics and produce more suitable interventions, whilst understanding that there is no "quick-fix" to this massive socio-technical problem. The future publications will focus on providing qualitative and quantitative correlations of CFOI with the fire risk and vulnerabilities at different risk stages and different scales of damage.

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