

Article

Governance Failure and Wildfire Escalation: A Multi-Level Analysis of Institutional Preparedness, Corruption, and Emergency Response

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Abstract

Wildfire escalation is increasingly threatening ecosystems and communities in Khyber Pakhtunkhwa (KP), Pakistan, particularly in forest and rangeland landscapes where ecological flammability interacts with human activity. While environmental and climatic drivers are well studied, governance factors remain underexplored despite their decisive role in shaping how ecological risk translates into disasters. Regional forests show considerable ecological diversity, including chir pine-dominated stands, mixed temperate conifer forests, broadleaved oak-associated systems, and shrub rangeland mosaics, each differing in fuel structure and fire behavior. Dependence on fuelwood collection, grazing, and forest access further influences ignition probability and fire spread. This study examines how governance failures influence wildfire risk and severity through a Governance-Fire Risk Framework. Governance is treated as a determining institutional condition affecting prevention capacity, regulation of hazardous land use, fuel management, and emergency response effectiveness. A cross-sectional survey of 540 stakeholders from rural (Dir Lower, Dir Upper) and peri-urban districts (Swat, Mansehra, Abbottabad) was analyzed using SPSS (version 26) and AMOS (version 24) (CFA and SEM). Governance failure significantly escalates wildfire risk through delayed emergency response, regulatory non-compliance, political interference, and weak institutional coordination. Institutional preparedness and response capacity reduce risks, whereas corruption intensifies them. Corruption functions through illegal land conversion, diversion of fire management resources, procurement irregularities, nepotistic staffing, and selective enforcement, increasing ignition sources, fuel accumulation, and response delays. Rural districts show stronger governance-fire linkages. Wildfire escalation in KP is governance-driven in interaction with ecological conditions and community dependence on forest resources. Effective mitigation requires anti-corruption measures, rapid response systems, stronger enforcement, and improved preparedness. The study offers a transferable governance-focused framework for wildfire management in fire-prone developing regions.



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1. Introduction

Wildfires have emerged as one of the most severe and rapidly intensifying global hazards of the twenty-first century, driven by the combined effects of climate change, land-use transformation, and the expansion of human settlements into fire-prone landscapes. Rising global temperatures, prolonged droughts, erratic precipitation patterns, and increasing heatwave frequency have substantially altered fire regimes worldwide, resulting in more frequent, intense, and difficult-to-control wildfire events [1,2]. Recent catastrophic fires in Australia, the western United States, Southern Europe, and South America demonstrate that wildfires are no longer isolated ecological disturbances but complex socio-environmental disasters with profound economic, public health, and ecological consequences.

These events predominantly involve forest and rangeland wildfires, where vegetation composition, forest structure, and human interaction with landscapes determine ignition probability, fire spread, and suppression difficulty [3]. Forest ecosystems differ markedly in flammability depending on species composition, canopy density, fuel continuity, litter accumulation, and management practices [4,5]. Even species within the same genus can exhibit different fire responses depending on stand age, moisture regime, and anthropogenic disturbance [6]. Therefore, wildfire risk is not only a climatic phenomenon but also an outcome of ecological structure interacting with human and institutional systems.

While climate change is widely recognized as a primary driver of wildfire escalation, much of the existing fire research continues to prioritize biophysical and meteorological determinants such as fuel loads, vegetation composition, temperature anomalies, and wind dynamics. In contrast, the role of governance structures in shaping wildfire risk, escalation, and response outcomes remains comparatively underexamined. Emerging empirical evidence, however, suggests that similar climatic and ecological conditions can produce markedly different wildfire outcomes depending on governance quality, institutional preparedness, regulatory enforcement, and emergency response capacity [7–10]. This variation underscores why governance is not a peripheral factor but a determining condition that shapes how ecological risks translate into disasters. Governance failures manifested through weak institutional coordination, corruption, political interference, inadequate enforcement of land-use and fire safety regulations, and delayed emergency response often act as critical multipliers that transform manageable fire incidents into large-scale disasters. Studies from Southern Europe and Latin America show that ineffective forest governance and regulatory non-compliance significantly increase wildfire frequency and severity, even in regions with comparable climatic exposure [11–13]. Similarly, post-fire assessments in the United States highlight how underfunded agencies, fragmented authority, and bureaucratic delays contribute to containment failures and fire escalation [14,15]. These findings underscore the need to reconceptualize wildfires not merely as natural or climate-induced events but as governance-sensitive risks embedded within institutional and political systems.

In South Asia, wildfire risk is intensifying under conditions of rapid climate change, deforestation, agricultural expansion, and population pressure. The region is experiencing rising temperatures, prolonged dry spells, and seasonal heat extremes that heighten fire susceptibility in forested, peri-urban, and rural landscapes [16–19]. Countries including India, Nepal, Bangladesh, and Sri Lanka report increasing trends in forest and rangeland fires, with significant impacts on biodiversity, livelihoods, air quality, and public health [20–22].

Many of these fires occur in ecologically diverse forest systems ranging from dry deciduous and chir pine-dominated stands to mixed broadleaved forests and shrub–rangeland mosaics, each exhibiting different fuel characteristics and fire behavior [23,24]. Grazing, fuelwood collection, resin tapping, and understory clearing alter fuel structure and continuity, often increasing surface fuel loads and ignition probability, thereby linking livelihood practices with fire regimes [25,26]. Despite these trends, wildfire governance across South Asia is constrained by chronic institutional weaknesses such as limited financial resources, outdated fire management policies, weak inter-agency coordination, and insufficient community participation. Empirical studies from India reveal how poor enforcement of forest protection laws, land encroachment, and political interference in forest administration contribute to recurring fire incidents and delayed suppression [27–29]. In Nepal, fragmented institutional mandates and the absence of effective early warning systems have been identified as major barriers to wildfire preparedness and response [30,31].

Corruption and informal power structures further complicate wildfire governance in the region. In the context of wildfire management, corruption operates through specific functional mechanisms rather than as an abstract governance label. These include bribery enabling illegal land conversion in forest zones, patronage networks protecting unauthorized logging and encroachment, embezzlement or diversion of firefighting funds and equipment, nepotistic recruitment limiting technical competence, and regulatory capture that weakens enforcement against hazardous land-use practices such as unauthorized burning. Such practices increase ignition sources, fuel accumulation, and response delays, thereby directly linking corruption to fire occurrence and escalation. Illegal logging, land grabbing, and unauthorized agricultural burning persist in several South Asian contexts due to weak accountability mechanisms and regulatory capture, increasing ignition risks and fuel accumulation [32–34]. These governance deficiencies disproportionately affect rural and peri-urban areas, where institutional presence is limited and communities depend heavily on natural resources for livelihoods. Despite these vulnerabilities, wildfire research in South Asia remains heavily skewed toward ecological assessments and remote sensing-based fire mapping, with limited attention to governance quality as a determinant of fire escalation. This imbalance constrains the development of comprehensive wildfire risk management strategies that address both environmental and institutional drivers.

Pakistan represents a particularly critical yet understudied case within this regional context. The country is highly vulnerable to climate change and is experiencing rising temperatures, prolonged droughts, erratic rainfall, and increasing frequency of extreme weather events. Forest and rangeland fires have become more frequent in Khyber Pakhtunkhwa, Balochistan, Gilgit-Baltistan, and parts of Punjab, resulting in ecological degradation, loss of wildlife habitat, and threats to rural livelihoods. The forest ecosystems of Khyber Pakhtunkhwa include chir pine (*Pinus roxburghii*) dominated subtropical forests, mixed temperate conifer forests (e.g., deodar, blue pine, fir), and broadleaved oak-associated stands, alongside shrublands and alpine rangelands [35,36]. These systems differ in litter characteristics, resin content, canopy continuity, and understory density, which influence flammability and fire spread. High community dependence on fuelwood, grazing, fodder collection, and seasonal resource extraction increases human presence and ignition probability, particularly in accessible forest margins. Empirical evidence indicates that a substantial proportion of these fires are anthropogenic in origin, linked to agricultural residue burning, grazing practices, land clearing, and human negligence [37,38]. However, the escalation of such fires into large-scale disasters is closely associated with governance-related shortcomings. Studies document weak institutional preparedness, limited firefighting infrastructure, inadequate training, and delayed emergency response as persistent challenges in Pakistan's fire management systems [39–41].

Corruption and political interference further undermine wildfire governance in Pakistan. At the operational level, corruption may manifest through misallocation of disaster response funds, procurement irregularities affecting equipment quality, selective enforcement of forest regulations, and political pressure to overlook illegal land conversion, all of which reduce institutional capacity to prevent and control fires. Ineffective enforcement of forest and land-use regulations, coupled with informal patronage networks, enables illegal land conversion and unregulated resource exploitation, increasing fire susceptibility. Disaster management authorities also suffer from fragmented mandates, weak coordination between provincial and district institutions, and insufficient integration of early warning and risk assessment systems. Despite these challenges, wildfire governance remains marginal within Pakistan's broader disaster risk reduction and climate adaptation frameworks, which tend to prioritize floods, earthquakes, and heatwaves.

Khyber Pakhtunkhwa (KP) is one of Pakistan's most fire-prone provinces and provides a critical empirical setting for examining governance dimensions of wildfire escalation. The province contains extensive forest cover, complex mountainous terrain, and a high proportion of peri-urban and rural communities dependent on forest resources. Districts such as Dir Lower, Dir Upper, Swat, Mansehra, and Abbottabad have experienced recurrent wildfire incidents, most of which are human induced. These districts also exhibit significant variation in institutional preparedness, enforcement capacity, and emergency response effectiveness. Weak regulation, political interference, expanding tourism, and remoteness-induced response delays interact with climatic stressors to exacerbate wildfire risk, making KP an ideal case for governance-focused wildfire research.

Despite the increasing frequency and severity of forest and rangeland wildfires in KP, empirical research has largely focused on fire occurrence and ecological impacts, with limited attention to governance quality as a central explanatory factor. This study addresses this gap by advancing and empirically applying a Governance Fire Risk Framework, positioning governance failure as a key driver of wildfire escalation.

Research Objectives

Based on the above context, this study aims to:

1. Examine the role of governance systems and institutional arrangements in shaping wildfire risk and severity in Khyber Pakhtunkhwa.
2. Analyze how institutional preparedness, corruption, regulatory enforcement, and emergency response effectiveness influence wildfire outcomes in Dir Lower, Dir Upper, Swat, Mansehra, and Abbottabad.
3. Develop and apply a Governance-Fire Risk Framework integrating governance indicators with wildfire occurrence and severity.
4. Assess differential governance-related impacts on wildfire escalation across peri-urban and rural districts of KP.
5. Provide policy-relevant recommendations to strengthen institutional resilience and wildfire governance in Khyber Pakhtunkhwa and comparable fire-prone regions.

2. Materials and Methods

2.1. Study Area

This study was conducted in Khyber Pakhtunkhwa (KP), Pakistan, with a focused investigation of five fire-prone districts: Dir Lower, Dir Upper, Swat, Mansehra, and Abbottabad. These districts were purposively selected due to their high wildfire exposure, ecological sensitivity, and pronounced governance variability, which directly aligns with the study's objective of examining governance failure as a multiplier of wildfire escalation. KP contains a substantial proportion of Pakistan's coniferous and mixed forest cover,

characterized by steep mountainous terrain, dry spring–summer seasons, and increasing human pressure. According to provincial forest and disaster management reports, KP consistently records one of the highest numbers of forest and rangeland fire incidents in Pakistan, particularly during March–June. The selected districts experience recurrent anthropogenic fires, primarily linked to grazing practices, agricultural residue burning, tourism-related activities, and human negligence.

From a governance perspective, these districts exhibit heterogeneous institutional capacity, making them analytically valuable. Swat, Mansehra, and Abbottabad represent peri-urban and tourism-intensive districts with relatively higher institutional presence, but challenges related to selective enforcement and political interference. In contrast, Dir Lower and Dir Upper are predominantly rural and mountainous, where limited institutional outreach, delayed emergency response, and weak regulatory enforcement are common. This intra-provincial variation enables a multi-level analysis of institutional preparedness, corruption, regulatory enforcement, and emergency response effectiveness, consistent with the Governance-Fire Risk Framework developed in this study.

2.2. Research Design

The study adopted a positivist research paradigm, employing a quantitative, cross-sectional research design. Positivism was selected because the study seeks to objectively measure and statistically test relationships between governance-related factors (institutional preparedness, corruption, enforcement, and emergency response) and wildfire escalation outcomes [42,43]. This paradigm is appropriate for such research where variables are operationalized, quantified, and analyzed using inferential statistical techniques.

A quantitative approach was chosen to allow systematic comparison across districts and to generate generalizable evidence regarding governance failures and wildfire risk. The cross-sectional design involves collecting data at a single point in time, which is suitable for examining existing institutional conditions, perceptions, and response mechanisms associated with recent wildfire experiences. This design is widely used in disaster governance and fire risk studies, particularly in contexts where longitudinal institutional data are limited. The chosen design aligns directly with the study objectives by enabling empirical assessment of governance dimensions and their association with wildfire escalation across multiple districts within KP.

2.3. Population and Sampling Techniques

The target population comprised key stakeholders directly involved in wildfire governance and response in the selected districts. This includes:

- Officials from the Forest Department
- Personnel from the Provincial and District Disaster Management Authorities (PDMA/DDMA)
- Local government representatives
- Community-level responders and forest guards
- Residents of fire-affected peri-urban and rural communities

These groups were selected because they possess direct knowledge and experience of institutional preparedness, regulatory enforcement, emergency response, and governance challenges related to wildfire management.

According to provincial administrative statistics and district records, the combined population of the five selected districts exceeds 6.5 million residents, with a substantial proportion living in rural and forest-adjacent areas. The Forest Department and disaster management institutions collectively employ several thousand officials across these

districts, forming an appropriate and relevant population frame for governance-focused wildfire research.

In addition to institutional roles, the socio-cultural characteristics of respondents were treated as analytically significant because wildfire governance and response in Khyber Pakhtunkhwa operate within socially structured community systems that directly shape governance effectiveness and fire risk pathways. The study area is predominantly rural, with livelihoods closely linked to agriculture, livestock rearing, forest resource use, and seasonal migration. These livelihood patterns increase routine human presence in forest and rangeland environments, thereby influencing ignition exposure, fuel-use practices, and compliance with fire regulations key variables examined within the Governance Fire Risk Framework.

Respondents therefore represent communities where fuelwood collection, grazing, fodder harvesting, and informal forest access are common practices that shape both fire occurrence and perceptions of regulatory enforcement. Social organization in these areas is largely based on extended family systems, village councils, and locally influential elders, which structure decision-making, information dissemination, and collective action. These socio-political arrangements affect how early warnings are interpreted, how trust in institutions is formed, and how communities mobilize during wildfire emergencies, directly linking socio-cultural systems to emergency response effectiveness and institutional preparedness.

Educational backgrounds among community respondents range from no formal schooling to tertiary education, influencing levels of fire risk awareness, understanding of regulations, and engagement with formal governance mechanisms. In contrast, institutional respondents include technically trained forestry and disaster management personnel, providing insight into operational capacity, enforcement constraints, and coordination challenges.

Overall, socio-cultural diversity is not treated as background description but as a contextual factor shaping governance perceptions, regulatory legitimacy, institutional trust, and human fire interaction patterns. These dimensions mediate the relationship between governance failure and wildfire escalation and are therefore essential for interpreting perceptions of governance effectiveness and emergency response outcomes in the study area.

A multi-stage sampling technique was employed. In the first stage, purposive sampling was used to select KP province and the five districts based on wildfire exposure and governance relevance. In the second stage, stratified random sampling was applied to ensure proportional representation of institutional actors and community respondents across districts. Stratification was carried out by district and stakeholder category, allowing balanced inclusion of governance actors and affected populations. This approach reduces sampling bias and enhances the representativeness of the data, particularly in heterogeneous governance environments.

The sample size was determined using Sekaran and Bougie's sample size determination guidelines, which recommend a minimum sample of approximately 384 respondents for large populations to achieve statistical reliability [44]. To account for non-response and district-level comparison, the sample size was increased (Table 1).

Table 1. Sampling Frame, Demographic Structure and Sample Distribution.

District	Estimated Population	Population < 18 (%)	Population ≥ 18 (%)	Target Respondents	Final Sample	Male Respondents (n)	Female Respondents (n)
Dir Lower	~1.4 million	52%	48%	110	100	68	32
Dir Upper	~1.1 million	54%	46%	110	100	70	30
Swat	~2.3 million	50%	50%	130	120	75	45
Mansehra	~1.6 million	49%	51%	120	110	66	44
Abbottabad	~1.3 million	47%	53%	120	110	64	46
Total	~6.5 million	≈50%	≈50%	590	540	343	197

The final sample of 540 respondents was considered sufficient for statistical analysis, including multivariate techniques. All survey participants were aged 18 years or above, as the study focused on adult stakeholders involved in governance, forest use, disaster management, and community decision-making. The added columns clarify the district-level age structure to contextualize the sampling frame. Both men and women were included in the survey, and gender distribution of respondents is now explicitly reported to improve transparency and representativeness assessment.

2.4. Data Collection Tool

A structured questionnaire was employed as the primary data collection instrument, in line with the quantitative and positivist orientation of the study. The use of a structured tool allowed for systematic measurement of governance-related variables and wildfire escalation outcomes across multiple districts. The questionnaire was developed based on established literature on disaster governance, fire management systems, and institutional resilience, and human dimensions of wildfire risk and was carefully adapted to reflect the socio-institutional and administrative context of Khyber Pakhtunkhwa. This ensured content relevance and construct alignment with the study objectives.

The questionnaire consisted of five core sections. Section 1 captured respondents' socio-demographic characteristics and institutional affiliations. Section 2 focused on institutional preparedness, including aspects related to training, availability of firefighting equipment, and inter-agency coordination mechanisms. Section 3 examined regulatory enforcement and overall governance quality, with specific emphasis on rule enforcement, political interference, and corruption-related challenges. Section 4 assessed emergency response effectiveness, including response time, coordination among relevant agencies, and operational capacity during wildfire incidents. Section 5 measured wildfire escalation outcomes, such as fire frequency, severity, spatial spread, and associated socio-ecological damage.

In response to the system-specific nature of wildfire risk, additional items were included to capture social and behavioral drivers of fire ignition and spread. These items assessed practices such as agricultural residue burning, pasture renewal burning, fuelwood collection, grazing-related vegetation modification, land clearing, and accidental ignitions linked to human negligence. Respondents were also asked about community dependence on forest resources, seasonal livelihood pressures, and traditional land-use practices that may increase exposure to fire-prone environments. These factors were included because wildfire mitigation is not solely a governance issue but also shaped by socio-economic needs, livelihood strategies, and human environment interactions that influence ignition probability and fuel conditions.

All items were measured using a five-point Likert scale, ranging from strongly disagree (1) to strongly agree (5), to capture the intensity of respondents' perceptions in a standardized manner.

Data were collected through online administration using digital survey platforms. Online data collection was selected due to the geographical dispersion of the study districts, the mountainous and difficult terrain of the region, and the need for cost-efficient and time-effective data gathering. This approach also enhanced respondent accessibility, minimized manual data entry errors, and improved overall data accuracy. The survey instrument consisted of a structured questionnaire comprising closed-ended items organized around clearly defined governance, institutional, and wildfire outcome constructs. The questionnaire explicitly included items measuring weak institutional coordination, political interference, regulatory non-compliance, delayed emergency response, institutional preparedness, regulatory enforcement, and corruption. Corruption was operationalized through concrete, function-specific indicators such as bribery affecting enforcement, misuse or diversion of wildfire management funds, favoritism in staffing and resource allocation, and accountability gaps in fire-related institutions, rather than as an abstract or generalized perception.

In addition, the questionnaire incorporated items capturing social and behavioral fire drivers such as agricultural residue burning, pasture renewal burning, grazing-related vegetation modification, fuelwood collection, land clearing, and accidental ignitions recognizing that wildfire mitigation is shaped by both governance performance and human environment interactions. All survey items were derived from established disaster governance, fire management, and transparency literature and were adapted to the institutional and socio-ecological context of Khyber Pakhtunkhwa to ensure content validity.

For transparency and reproducibility, the complete survey questionnaire, including all items and response scales, is provided as an attached Appendix A, allowing readers to directly assess how corruption, institutional functioning, and wildfire-related variables were measured.

The data collection process was carried out over a three-month period from June to August 2025, which corresponds with the peak wildfire season in Khyber Pakhtunkhwa. Conducting the survey during this period enhanced the relevance and reliability of respondents' perceptions and experiences related to wildfire governance and emergency response.

2.5. Indexation and Measurement of Variables

Table 2 presents the indexation, measurement, and statistical testing framework for all variables used in the study, clearly linking each construct to the study objectives and analytical techniques. Governance-related variables including weak institutional coordination, political interference, regulatory non-compliance, and delayed emergency response were measured using multi-item Likert-scale indicators and analyzed through descriptive statistics, correlation analysis, multiple regression, and Structural Equation Modeling (SEM). These indicators were further combined to form a latent Governance Failure index, validated using reliability analysis and Confirmatory Factor Analysis (CFA). Institutional preparedness, corruption, regulatory enforcement, and emergency response effectiveness were treated as key governance dimensions influencing wildfire outcomes and were examined using regression and SEM to assess both direct and latent effects.

Table 2. Indexation and Measurement of Study Variables.

Variable Category	Construct/Variable	Code	Measurement Indicators (Indexation)	No. of Items	Scale	Statistical Test(s) Used	Role in Analysis	Source/Adaptation
Governance Failure	Weak Institutional Coordination	WIC	Inter-agency coordination, information sharing, clarity of roles, joint response planning	4	5-point Likert	Descriptive stats, Pearson correlation, Multiple regression, SEM (factor loading)	Independent	Disaster governance literature
	Political Interference	PI	Political pressure, biased decisions, influence on enforcement	4	5-point Likert	Descriptive stats, Correlation, Multiple regression, SEM	Independent	Governance studies
	Regulatory Non-Compliance	RNC	Fire law violations, land-use breaches, illegal encroachment	4	5-point Likert	Descriptive stats, Correlation, Multiple regression, SEM	Independent	Fire regulation literature
	Delayed Emergency Response	DER	Response delays, mobilization inefficiency, logistics failure	4	5-point Likert	Descriptive stats, Correlation, Multiple regression, SEM	Independent	Emergency management studies
	Overall Governance Failure (Index)	GF	Composite of WIC, PI, RNC, DER	16	Standardized score	Cronbach's α , CFA, SEM (structural path)	Latent	Author-constructed
Institutional Capacity	Institutional Preparedness	IP	Training adequacy, equipment, staffing, preparedness plans	5	5-point Likert	Reliability analysis, Correlation, Multiple regression, SEM	Independent/Latent	Fire preparedness studies
Governance Quality	Corruption	COR	Bribery, fund misuse, favoritism, accountability gaps	5	5-point Likert	Reliability analysis, Correlation, Regression, SEM, Effect size (f^2)	Independent/Latent	Transparency literature
	Regulatory Enforcement	RE	Inspection strength, penalty enforcement, monitoring	4	5-point Likert	Reliability analysis, Correlation, Regression	Independent	Regulatory compliance studies

Table 2. Cont.

Variable Category	Construct/Variable	Code	Measurement Indicators (Indexation)	No. of Items	Scale	Statistical Test(s) Used	Role in Analysis	Source/Adaptation
Emergency Management	Emergency Response Effectiveness	ERE	Coordination, response capacity, communication systems	5	5-point Likert	Reliability analysis, Correlation, Regression, SEM	Independent/Latent	Disaster response literature
Wildfire Outcomes	Wildfire Frequency	FREQ	Frequency of fire events	2	5-point Likert	Descriptive stats, CFA, SEM	Dependent	Fire risk literature
	Wildfire Severity	SEV	Intensity, duration, difficulty of control	3	5-point Likert	Descriptive stats, CFA, SEM	Dependent	Fire severity studies
	Spatial Spread	SPREAD	Area burned, rate of spread, containment failure	3	5-point Likert	Descriptive stats, CFA, SEM	Dependent	GIS & fire modeling
	Socio-Ecological Damage	DAM	Property loss, forest damage, livelihood disruption	4	5-point Likert	Descriptive stats, CFA, SEM	Dependent	Impact assessment studies
	Wildfire Escalation (Index)	WFE	Composite of FREQ, SEV, SPREAD, DAM	12	Standardized score	Multiple regression, SEM (endogenous latent)	Dependent/Latent	Author-constructed
Spatial Context	District Type	DT	Rural vs. Peri-Urban	—	Dummy (0/1)	Independent samples <i>t</i> -test, Multi-group SEM	Moderator/Grouping	Administrative classification
Policy Impact	Governance Priority Index	GPI	β coefficients, effect size (f^2)	—	Continuous	Regression analysis, SEM, Effect size analysis	Policy model	Derived analytically

Wildfire escalation was operationalized as a composite construct encompassing frequency, severity, spatial spread, and socio-ecological damage, serving as the primary dependent variable across regression and SEM analyses. Spatial heterogeneity was addressed by incorporating district type (rural versus peri-urban) as a grouping variable, tested using independent samples *t*-tests and multi-group SEM. Finally, policy relevance was assessed through effect size (f^2) and standardized coefficients, enabling the prioritization of governance predictors with the greatest practical impact.

2.6. Ethical Considerations

Ethical approval for the study was obtained from the Department of Sociology, University of Malakand (Approval Reference No.: SOC/UM/2025/17). Formal permission was secured from relevant district administrations and departmental authorities prior to data collection. Participation was entirely voluntary. Informed consent was obtained from all respondents, who were assured of anonymity, confidentiality, and the right to withdraw at any stage without penalty. No personal identifiers were collected, and data were used solely for academic purposes in compliance with ethical research standards.

2.7. Data Analysis and Models of the Study

The collected data were systematically analyzed using SPSS (Version 26) and AMOS (Version 24) to address the study objectives. SPSS was employed for preliminary and inferential analyses, including data screening, descriptive statistics (means and standard deviations), reliability analysis using Cronbach's alpha, correlation analysis, multiple regression models, and independent samples *t*-tests to examine governance-related differences across district types. AMOS was used to conduct Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM), enabling the estimation of latent constructs, testing of the Governance–Fire Risk Framework, and assessment of model fit indices. The overall models of the study are given as under:

2.7.1. Model 1: Governance Systems and Wildfire Escalation (Objective 1)

The aim of Model 1 is to examine how governance systems and institutional arrangements influence wildfire risk and severity in Khyber Pakhtunkhwa. Specifically, the model evaluates how institutional coordination, political and administrative dynamics, regulatory compliance, and emergency response capacity both collectively and individually shape wildfire escalation outcomes.

$$\text{Model Equation: } WFE_i = \beta_0 + \beta_1 WIC_i + \beta_2 PI_i + \beta_3 RNC_i + \beta_4 DER_i + \varepsilon_i$$

Denotations

- WFE_i = Wildfire escalation (frequency, severity, spatial spread, and damage)
- WIC_i = Weak institutional coordination
- PI_i = Political interference
- RNC_i = Regulatory non-compliance
- DER_i = Delayed emergency response
- β_0 = Intercept
- β_1 – β_4 = Regression coefficients
- ε_i = Error term

2.7.2. Model 2: Institutional Preparedness, Corruption, Enforcement, and Response (Objective 2)

Model 2 aims to analyze the influence of institutional preparedness, corruption, regulatory enforcement, and emergency response effectiveness on wildfire outcomes across

Dir Lower, Dir Upper, Swat, Mansehra, and Abbottabad. This model identifies governance components that significantly mitigate or exacerbate wildfire escalation.

Model Equation: $WFE_i = \beta_0 + \beta_1 IP_i + \beta_2 COR_i + \beta_3 RE_i + \beta_4 ERE_i + \varepsilon_i$

Denotations

- IP_i = Institutional preparedness
- COR_i = Corruption
- RE_i = Regulatory enforcement
- ERE_i = Emergency response effectiveness
- Other symbols retain their meanings as defined above

2.7.3. Model 3: Governance–Fire Risk Framework (Structural Equation Model) (Objective 3)

The objective of Model 3 is to develop and empirically test a Governance–Fire Risk Framework that integrates governance indicators with wildfire occurrence and severity. The model captures both direct and latent effects of governance constructs on wildfire escalation using Structural Equation Modeling.

Model Equations

Measurement Model:

1. $GF = \lambda_1 WIC + \lambda_2 PI + \lambda_3 RNC + \lambda_4 DER + \zeta$
2. $WFE = \lambda_5 FREQ + \lambda_6 SEV + \lambda_7 SPREAD + \lambda_8 DAM + \zeta$

Structural Model: $WFE = \gamma_1 GF + \gamma_2 IP + \gamma_3 COR + \gamma_4 ERE + \xi$

Denotations

- GF = Latent governance failure construct
- $FREQ, SEV, SPREAD, DAM$ = Observed wildfire indicators
- λ = Factor loadings
- γ = Structural path coefficients
- ζ, ξ = Measurement and structural errors

2.7.4. Model 4: Differential Governance Impacts Across District Types (Objective 4)

Model 4 assesses whether governance-related impacts on wildfire escalation differ significantly between rural and peri-urban districts of Khyber Pakhtunkhwa. This model captures spatial heterogeneity in governance effectiveness and wildfire risk.

Model Equation (Mean Comparison Model): $GF_{Rural} - GF_{PeriUrban} = \Delta GF$

Multi-Group SEM Equation: $WFE = \gamma_{Rural} GF + \varepsilon$; $WFE = \gamma_{PeriUrban} GF + \varepsilon$

Denotations

- GF = Mean governance failure score
- ΔGF = Mean difference between district types
- $\gamma_{Rural}, \gamma_{PeriUrban}$ = Group-specific path coefficients

2.7.5. Model 5: Policy-Relevant Governance Predictors of Wildfire Escalation (Objective 5)

The aim of Model 5 is to identify governance predictors with the strongest policy relevance for strengthening institutional resilience and wildfire governance. Effect sizes are incorporated to prioritize interventions based on their practical impact.

Model Equation: $WFE_i = \beta_0 + \beta_1 COR_i + \beta_2 DER_i + \beta_3 RNC_i + \beta_4 IP_i + \varepsilon_i$

Denotations

- f^2 = Effect size indicating magnitude of predictor impact
- β coefficients indicate policy leverage strength
- Other terms retain previously defined meanings

3. Results

Table 3 presents the results of the multiple regression analysis conducted to examine the role of governance system in escalating forest and rangeland wildfire risk and severity in Khyber Pakhtunkhwa, directly addressing Objective 1 of the study. The findings provide strong empirical evidence that governance-related deficiencies significantly contribute to wildfire escalation, both individually and collectively, even within ecologically diverse forest systems such as chir pine stands, mixed temperate conifer forests, oak-associated broadleaved forests, and shrub–rangeland mosaics where fuel structure, resin content, litter accumulation, and canopy continuity differ substantially. This indicates that governance effects operate alongside ecological flammability conditions rather than replacing them.

Table 3. Multiple Regression of Governance System and Wildfire Escalation (Objective 1).

Variable	Mean	SD	β	t-Value	p-Value
Weak Institutional Coordination	4.12	0.73	0.29	8.61	<0.001
Political Interference	3.98	0.76	0.25	7.84	<0.001
Regulatory Non-Compliance	4.05	0.69	0.31	9.27	<0.001
Delayed Emergency Response	4.21	0.65	0.34	10.18	<0.001
Overall Governance Failure	4.01	0.71	0.48	12.96	<0.001

The results indicate that weak institutional coordination has a statistically significant and positive effect on wildfire escalation ($\beta = 0.29$, $t = 8.61$, $p < 0.001$). This suggests that inadequate coordination among forest departments, disaster management authorities, local administrations, and emergency services leads to fragmented responses, delayed decision-making, and inefficient resource mobilization, thereby intensifying wildfire frequency and severity. In ecologically heterogeneous terrains such as KP's mountainous districts, where access to pine-dominated slopes, mixed conifer stands, and grazing-affected rangelands varies, poor coordination further delays suppression in high-fuel areas, allowing surface fires to develop into crown or landscape-level fires. This finding aligns closely with the study's central premise that institutional fragmentation functions as a critical risk multiplier in wildfire-prone regions.

Political interference also demonstrates a significant positive association with wildfire escalation ($\beta = 0.25$, $t = 7.84$, $p < 0.001$). This result highlights how politically driven decision-making, undue influence on enforcement agencies, and preferential treatment can undermine professional fire management practices. Such interference may weaken control over illegal land clearing, unauthorized burning for pasture renewal, and encroachment in forest margins activities that increase ignition sources and alter fuel continuity. Within the context of this study, political interference weakens accountability mechanisms and compromises timely enforcement of fire safety regulations, thus exacerbating wildfire risks across the study districts.

The analysis further reveals that regulatory non-compliance is a strong predictor of wildfire escalation ($\beta = 0.31$, $t = 9.27$, $p < 0.001$). This finding underscores the critical role of ineffective enforcement of land-use regulations, forest protection laws, and fire safety standards in increasing both the likelihood and intensity of wildfire events. Non-compliance permits grazing-induced vegetation modification, fuelwood extraction, and residue burning practices that increase surface fuel loads and ignition probability, particularly in forest-adjacent rural communities. In line with the study's focus, weak regulatory compliance allows hazardous land practices and illegal encroachments to persist, creating conditions conducive to uncontrolled fire spread.

Among the individual governance indicators, delayed emergency response emerges as the most influential factor ($\beta = 0.34$, $t = 10.18$, $p < 0.001$). This indicates that slow

mobilization of firefighting resources, logistical constraints, and delayed communication significantly magnify wildfire severity and spatial spread. In fuel-rich conifer forests such as chir pine ecosystems with resinous litter and dense understory, even short delays allow rapid upslope fire spread, demonstrating how governance capacity interacts with ecological fire behavior. This result strongly supports the study's argument that emergency response capacity is a decisive governance component in determining wildfire outcomes, particularly in mountainous and remote areas of Khyber Pakhtunkhwa.

The composite measure of overall governance failure exhibits a very strong and statistically significant effect on wildfire escalation ($\beta = 0.48$, $t = 12.96$, $p < 0.001$). This confirms that governance failure operates not merely through isolated deficiencies but as an interconnected system of institutional weaknesses that collectively amplify wildfire risks. Within this system, corruption functions through concrete pathways: enabling illegal land conversion in forest zones, weakening enforcement through bribery and patronage networks, diverting fire management resources, compromising equipment procurement, and facilitating selective regulatory application. These processes increase ignition sources, fuel accumulation, and suppression delays, demonstrating how corruption translates into operational fire risk rather than remaining an abstract governance variable. The magnitude of this coefficient highlights governance failure as a dominant explanatory factor in understanding wildfire escalation in the province.

The model explains a substantial proportion of variance in wildfire escalation outcomes ($R^2 = 0.53$), indicating that more than half of the observed variation in wildfire frequency, severity, spatial spread, and damage can be attributed to governance-related factors. This does not diminish the importance of ecological drivers; rather, it demonstrates that governance conditions mediate how flammable landscapes and human dependence on forest resources translate into disaster outcomes. The overall model is highly significant ($F = 120.4$, $p < 0.001$), demonstrating strong explanatory power.

Table 4 presents the results of the multiple regression analysis examining how institutional preparedness, corruption, regulatory enforcement, and emergency response effectiveness influence forest and rangeland wildfire outcomes across Dir Lower, Dir Upper, Swat, Mansehra, and Abbottabad, thereby directly addressing Objective 2 of the study. The analysis is based on survey data from 540 stakeholders and is interpreted in relation to the ecological characteristics of the study area, which includes Chir pine (*Pinus roxburghii*) forests, moist temperate conifer stands (*Pinus wallichiana*, *Abies pindrow*, *Cedrus deodara*), mixed oak–conifer systems, and adjoining rangelands. These ecosystems differ in canopy density, litter accumulation, resin content, grazing pressure, and fuel continuity, all of which shape flammability and fire spread. The results provide empirical evidence on the differential roles of governance capacities and failures in shaping wildfire escalation.

Table 4. Multiple Regression of Institutional Preparedness, Corruption, Enforcement, and Response (Objective 2).

Construct	Cronbach's α	β	t-Value	R^2	p-Value
Institutional Preparedness	0.88	−0.31	−8.92	0.56	<0.001
Corruption	0.91	0.37	10.44	0.56	<0.001
Regulatory Enforcement	0.85	−0.29	−8.11	0.56	<0.001
Emergency Response Effectiveness	0.89	−0.34	−9.76	0.56	<0.001

The findings indicate that institutional preparedness has a statistically significant and negative effect on wildfire escalation ($\beta = -0.31$, $t = -8.92$, $p < 0.001$). This suggests that higher levels of preparedness—reflected in adequate training, availability of firefighting equipment, staffing capacity, and preparedness planning—substantially reduce wildfire frequency, severity, and spread. Preparedness is particularly critical in pine-dominated

and heavily grazed forest–rangeland interfaces where dry needle litter, reduced understory moisture, and human access routes increase ignition probability. This result supports the study’s assumption that proactive institutional capacity functions as a protective factor against wildfire escalation and highlights preparedness as a critical pillar of effective wildfire governance in the study region.

In contrast, corruption emerges as a strong and statistically significant positive predictor of wildfire escalation ($\beta = 0.37$, $t = 10.44$, $p < 0.001$). In this study, corruption is operationalized through specific mechanisms directly affecting fire outcomes: diversion or misallocation of fire-management funds, bribery allowing illegal timber extraction and land encroachment that increase fuel loads, political pressure preventing enforcement against hazardous burning practices, and nepotistic staffing that reduces technical response capacity. These practices weaken fuel management, delay suppression, and permit unsafe land-use behaviors, thereby increasing ignition likelihood and fire intensity. Thus, corruption functions as a structural risk amplifier rather than an abstract governance issue. The analysis further demonstrates that regulatory enforcement is significantly and negatively associated with wildfire escalation ($\beta = -0.29$, $t = -8.11$, $p < 0.001$). This indicates that stronger enforcement of fire-related regulations, land-use controls, and forest protection laws plays a critical role in reducing wildfire risks. Effective enforcement limits uncontrolled grazing, illegal fuelwood extraction, and open burning, all of which alter vegetation structure, reduce canopy moisture buffering, and increase surface fuel continuity. The finding aligns with the study’s emphasis on governance quality, suggesting that consistent monitoring, inspections, and penalties can effectively deter unsafe practices that contribute to wildfire ignition and spread.

Similarly, emergency response effectiveness exhibits a statistically significant negative effect on wildfire escalation ($\beta = -0.34$, $t = -9.76$, $p < 0.001$). This implies that timely response, effective inter-agency coordination, and adequate operational capacity significantly mitigate wildfire severity and spatial expansion, especially in mountainous terrain where steep slopes, resinous conifers, and fragmented access routes accelerate fire spread. This result reinforces the study’s focus on emergency response systems as a decisive governance mechanism in wildfire-prone areas, particularly in districts with challenging terrain and limited accessibility.

All constructs demonstrate high internal consistency, with Cronbach’s alpha values ranging from 0.85 to 0.91, indicating strong reliability of the measurement scales. The overall model explains 56% of the variance in wildfire outcomes ($R^2 = 0.56$), reflecting substantial explanatory power and confirming the central role of governance-related factors in determining wildfire escalation. Within ecologically fire-prone forest and rangeland systems shaped by human dependence on fuelwood, grazing, and forest access.

Table 5 presents the results of the Structural Equation Modeling (SEM) analysis developed to test the proposed Governance–Forest and Rangeland Wildfire Risk Framework, thereby directly addressing Objective 3 of the study. The SEM approach enables simultaneous examination of multiple governance-related pathways influencing wildfire escalation, offering a comprehensive and theory-driven assessment of how governance failures and capacities shape wildfire risk across the study districts of Khyber Pakhtunkhwa.

Table 5. Structural Equation Modeling of Governance Fire Risk Framework (Objective 3).

Path	Standardized β	CR	p -Value
Governance Failure $\rightarrow$ Wildfire Escalation	0.59	11.82	<0.001
Institutional Preparedness $\rightarrow$ Wildfire Escalation	−0.42	−9.36	<0.001
Corruption $\rightarrow$ Wildfire Escalation	0.47	10.71	<0.001
Emergency Response $\rightarrow$ Wildfire Escalation	−0.44	−9.89	<0.001

The results indicate that governance failure has a strong, positive, and statistically significant direct effect on wildfire escalation ($\beta = 0.59$, $CR = 11.82$, $p < 0.001$). This large, standardized coefficient confirms the study's central argument that systemic governance weaknesses such as poor coordination, political interference, regulatory non-compliance, and delayed responses substantially intensify wildfire frequency and severity. In fire-prone pine and forest–rangeland interface zones, these failures permit hazardous land practices, unmanaged fuel accumulation, and delayed suppression, directly linking institutional dysfunction with ecological fire dynamics. This finding validates the conceptual framework of the study by empirically demonstrating that governance failure operates as a core structural driver of wildfire risk rather than a peripheral contextual factor.

In contrast, institutional preparedness shows a significant negative effect on wildfire escalation ($\beta = -0.42$, $CR = -9.36$, $p < 0.001$). This result highlights the protective role of preparedness-related capacities, including planning, training, resource availability, and institutional readiness. Within the study context characterized by fire-prone chir pine forests, mixed temperate conifer and broadleaved stands, and shrub–rangeland mosaics higher preparedness reduces wildfire escalation by improving early containment in fuel-rich environments and limiting fire spread along forest–settlement interfaces. Analytically, this demonstrates that implementation capacity is not merely a policy concern but a measurable governance attribute with significant explanatory power in wildfire risk modeling. The analysis further reveals that corruption exerts a strong positive influence on wildfire escalation ($\beta = 0.47$, $CR = 10.71$, $p < 0.001$). Rather than treating corruption as an abstract governance deficit, the SEM results capture its effects through empirically grounded functional mechanisms identified in the data collection instrument, including bribery-enabled land encroachment, selective enforcement of forest regulations, diversion of fire management funds and equipment, procurement irregularities affecting firefighting capacity, nepotistic recruitment reducing technical competence, and political protection of unauthorized logging, grazing, and burning practices. The magnitude of this coefficient indicates that corruption is not only statistically significant but also substantively important in shaping wildfire outcomes across both rural and peri-urban districts. The strength of this pathway demonstrates that corruption operates as a concrete escalation mechanism linking governance failure to wildfire outcomes, rather than as a diffuse or symbolic variable.

Similarly, emergency response effectiveness is found to have a significant negative effect on wildfire escalation ($\beta = -0.44$, $CR = -9.89$, $p < 0.001$). This demonstrates that timely and well-coordinated emergency responses significantly limit wildfire spread and severity. In districts characterized by difficult terrain, resin-rich coniferous fuels, and high community dependence on forests for grazing and fuelwood, response delays allow surface fires to transition into more intense fire behavior, amplifying damage. Analytically, this result reinforces the study's contribution to disaster governance theory by empirically linking operational response capacity to hazard escalation pathways.

The overall model fit indices indicate an excellent fit between the proposed governance–fire risk model and the observed data. The χ^2/df value of 2.31 falls within the acceptable threshold, while the CFI (0.94) and TLI (0.93) exceed recommended benchmarks, confirming strong comparative and incremental fit. Additionally, the RMSEA (0.048) and SRMR (0.041) are well below conventional cut-off values, indicating minimal approximation and residual errors. Collectively, these indices confirm the analytical strength of the Governance–Fire Risk Framework as an empirically validated model that integrates governance failure, institutional capacity, corruption mechanisms, emergency response effectiveness, and socio-ecological context in explaining forest and rangeland wildfire escalation in Khyber Pakhtunkhwa.

Table 6 presents the results of the Independent Samples *t*-test and complementary multi-group Structural Equation Modeling (SEM) analysis used to assess Objective 4, which focuses on identifying differential governance-related impacts on forest and rangeland wildfire escalation across rural and peri-urban districts of Khyber Pakhtunkhwa. This analysis directly responds to the study's premise that governance capacity and failure do not operate uniformly across spatial and administrative and ecological contexts.

Table 6. Independent Samples *t*-Test of Differential Impacts Across District Types (Objective 4).

District Type	Mean Governance Failure Score	SD	t-Value	p-Value
Rural (Dir Lower & Dir Upper)	4.22	0.64	6.18	<0.001
Peri-Urban (Swat, Mansehra, Abbottabad)	3.71	0.68	6.18	<0.001

The independent samples *t*-test reveals a statistically significant difference in mean governance failure scores between rural and peri-urban districts. Specifically, rural districts (Dir Lower and Dir Upper) report a higher mean governance failure score ($M = 4.22$, $SD = 0.64$) compared to peri-urban districts (Swat, Mansehra, and Abbottabad), which exhibit a lower mean score ($M = 3.71$, $SD = 0.68$). The observed difference is highly significant ($t = 6.18$, $p < 0.001$), indicating that governance failures are more severe and pervasive in rural districts.

This finding is particularly important when interpreted alongside ecological and socio-resource conditions. Rural districts are dominated by Chir pine (*Pinus roxburghii*) forests with resin-rich litter, dry understories, and continuous surface fuels, as well as forest–rangeland interfaces where grazing, fuelwood collection, and fodder harvesting are common. These practices modify fuel structure, create ignition sources, and increase human access to flammable landscapes. In contrast, peri-urban districts have comparatively fragmented forest patches, better road access, and closer proximity to administrative and emergency services. Thus, governance failure interacts with forest composition, structure, and human dependence on forest resources, amplifying wildfire risk more severely in rural settings. To further substantiate these differences, a multi-group SEM analysis was conducted to compare the strength of governance failure effects on wildfire escalation across district types. The results show a stronger standardized path coefficient in rural districts, with a difference of $\Delta\beta = +0.14$, which is statistically significant ($p < 0.01$). This indicates that governance failure not only occurs more frequently in rural areas but also has a more pronounced impact on wildfire escalation compared to peri-urban districts. Importantly, corruption-related governance failure in rural districts operates through concrete mechanisms: diversion of forest and disaster management funds reducing firefighting capacity, bribery enabling illegal logging and encroachment that increase fuel loads, political shielding of unsafe burning and grazing practices, and nepotistic recruitment limiting technical expertise. These pathways directly link governance dysfunction with fuel accumulation, ignition probability, and delayed suppression.

Linking these findings to the broader objectives of the study, the results of Table 6 confirm that rural districts face compounded wildfire risks due to both higher levels of governance failure and stronger governance–fire risk linkages. In contrast, peri-urban districts benefit from relatively better institutional access, infrastructure, and emergency services, which partially buffer the effects of governance shortcomings.

Table 7 synthesizes the findings from multiple regression and Structural Equation Modeling (SEM) to address Objective 5, which aims to identify policy-relevant governance predictors of forest and rangeland wildfire escalation and translate empirical evidence into

actionable governance priorities for Khyber Pakhtunkhwa. By combining standardized regression coefficients (β) with effect size estimates (f^2), the table not only indicates statistical significance but also the practical magnitude of each governance factor in shaping wildfire outcomes.

Table 7. Regression and SEM of Policy-Relevant Governance Predictors.

Predictor	Standardized β	Effect Size (f^2)	Policy Priority
Corruption	0.41	0.31 (Large)	Very High
Emergency Response Delay	0.38	0.28 (Large)	Very High
Weak Enforcement	0.33	0.24 (Medium–Large)	High
Low Institutional Preparedness	0.29	0.23 (Medium)	High

The results show that corruption emerges as the most influential predictor of wildfire escalation, with a standardized β of 0.41 and a large effect size ($f^2 = 0.31$), both highly significant ($p < 0.001$). Corruption operates through concrete wildfire-related pathways: diversion of forest and disaster management funds reducing equipment procurement and fuel-break maintenance; bribery allowing illegal logging and encroachment that increase combustible biomass; political protection of unsafe grazing and burning practices; and nepotistic recruitment limiting technical firefighting expertise. These mechanisms directly increase fuel accumulation, ignition likelihood, and suppression delays. This indicates that higher levels of corruption such as misuse of fire management funds, favoritism in resource allocation, and weak accountability substantially increase wildfire severity and spread. Within the context of this study, corruption undermines regulatory enforcement, delays preparedness measures, and weakens institutional coordination, thereby amplifying wildfire risk. Thus, corruption is not treated abstractly but as a functional driver linking governance failure to ecological fire behavior. Its classification as a “Very High” policy priority reflects its system-wide amplification effect.

The second most influential factor is emergency response delay, which demonstrates a strong positive association with wildfire escalation ($\beta = 0.38$) and a large effect size ($f^2 = 0.28$). In mountainous Chir pine zones with steep slopes and continuous surface fuels, even short delays allow surface fires to transition into crown fires, increasing intensity and spatial spread. This demonstrates that response inefficiency interacts with forest structure and topography, reinforcing its designation as a Very High policy priority. This finding underscores that delayed mobilization of fire services, inadequate early warning dissemination, and poor inter-agency coordination significantly worsen wildfire outcomes. In line with the study’s objectives, this result highlights operational governance failures rather than merely structural ones, reinforcing the need for time-sensitive institutional reforms. Given its large effect and consistent significance, emergency response delay is also designated as a Very High policy priority.

Weak regulatory enforcement shows a moderately strong positive effect on wildfire escalation ($\beta = 0.33$; $f^2 = 0.24$), indicating a medium-to-large practical impact. Poor enforcement enables uncontrolled grazing, fodder harvesting, fuelwood extraction, and land clearing at forest margins activities that alter fuel structure, create ignition sources, and heighten human–fire interactions. This links governance quality directly to vegetation structure and community dependence on forest resources, confirming its high policy relevance.

Finally, low institutional preparedness exhibits a significant but comparatively moderate effect on wildfire escalation ($\beta = 0.29$; $f^2 = 0.23$). In fire-prone coniferous forests with high litter loads, lack of pre-season fuel management and preparedness planning increases vulnerability to rapid fire escalation. Preparedness therefore acts as a preventive ecological risk-reduction mechanism. This finding points to deficiencies in training, equipment availability, risk mapping, and preparedness planning across governance institutions. While

its effect size is lower than other predictors, it still represents a meaningful governance leverage point, justifying its classification as a High policy priority. This result supports the study's broader argument that proactive preparedness is essential for mitigating wildfire risks before emergencies occur.

Taken together, the results of Table 7 provide a clear empirical hierarchy of governance priorities, grounded in a sample size ($n = 540$), strong measurement reliability (Cronbach's $\alpha \geq 0.70$), and rigorous SEM estimation using Maximum Likelihood. The findings demonstrate academic relevance by integrating governance mechanisms with vegetation flammability, forest structure, and human dependence on forest resources, showing that wildfire risk is produced through governance–ecology interactions rather than climate factors alone. Anti-corruption reforms, rapid response systems, stronger enforcement, and improved preparedness thus represent the most impactful governance strategies for reducing wildfire escalation in Khyber Pakhtunkhwa.

4. Discussion

The findings related to Objective 1 provide compelling empirical evidence that governance system is a central driver of forest and rangeland wildfire escalation in Khyber Pakhtunkhwa. The significant positive effects of weak institutional coordination, political interference, regulatory non-compliance, and delayed emergency response confirm that wildfire risk is not solely an ecological phenomenon but is deeply embedded within governance structures that mediate human interaction with fire-prone forest and rangeland ecosystems.

The strong association between weak institutional coordination and wildfire escalation supports prior studies emphasizing that fragmented governance arrangements hinder effective disaster risk management [45–47]. Similar findings have been reported in Mediterranean Europe and Australia, where poor coordination among forestry agencies, disaster management authorities, and local governments resulted in delayed responses and inefficient resource deployment [48]. In Khyber Pakhtunkhwa, this coordination deficit is particularly consequential because fire-prone landscapes include resin-rich chir pine (*Pinus roxburghii*) forests, mixed temperate conifer–broadleaved stands, and shrub–rangeland mosaics, where delayed suppression allows surface fires to intensify and spread rapidly across administrative boundaries. The rugged terrain and administrative fragmentation further magnify the consequences of weak coordination, making this factor especially salient.

The significant role of political interference aligns with governance and disaster literature from developing countries, which highlights how politicization of institutions undermines technical decision-making and accountability [49,50]. In Pakistan, political influence over postings, budget allocations, and enforcement agencies has been widely documented, and this study empirically demonstrates how such interference reduces operational readiness, weakens regulatory enforcement, and delays suppression actions, thereby directly translates into heightened wildfire risks.

Similarly, regulatory non-compliance emerged as a strong predictor of wildfire escalation, corroborating earlier research showing that ineffective enforcement of land-use regulations and forest protection laws significantly increases ignition risks [51–53]. The persistence of illegal land clearing, grazing, and unregulated tourism activities in KP reflects governance gaps rather than regulatory absence. These activities increase ignition probability and fuel continuity in both forests and adjacent rangelands, particularly where community dependence on forest resources is high, reinforcing the study's argument that implementation failure is more critical than policy design.

Among all indicators, delayed emergency response exhibited the strongest individual effect, echoing global evidence that response time is a decisive determinant of wildfire

severity [54,55]. In mountainous and remote regions such as Dir and Swat, logistical constraints and delayed mobilization exacerbate fire spread, making emergency response capacity a crucial governance lever. In fire-adapted coniferous forests and heavily grazed rangelands, even short delays allow fires to transition from low-intensity surface fires to more destructive events, underscoring the governance ecology interaction shaping wildfire outcomes.

The strong effect of overall governance failure and the high explanatory power of the model ($R^2 = 0.53$) reinforce the study's central proposition that wildfire escalation is a systemic governance failure, not a collection of isolated administrative lapses. This finding advances the governance–risk literature by empirically demonstrating how cumulative institutional weaknesses amplify environmental hazards across ecologically heterogeneous forest and rangeland systems.

Objective 2 disaggregated governance into functional components, revealing both protective and risk-amplifying mechanisms. The negative relationship between institutional preparedness and wildfire escalation is consistent with disaster preparedness literature, which emphasizes the importance of training, equipment readiness, and contingency planning [56,57]. Similar results have been observed in wildfire-prone regions of the United States and Southern Europe, where preparedness investments significantly reduced fire impacts [58]. Analytically, this finding demonstrates that implementation capacity constitutes a theoretically meaningful governance variable rather than merely a managerial concern, as it directly conditions fire behavior trajectories once ignitions occur.

In contrast, corruption emerged as the most damaging governance factor, exerting a strong positive influence on wildfire outcomes. While corruption affects multiple sectors, this study moves beyond abstract treatment by identifying specific functional pathways through which corruption amplifies wildfire risk, consistent with studies linking corruption to poor environmental governance [59,60]. Empirically, corruption manifests through bribery-enabled illegal land clearing, selective enforcement of grazing and burning regulations, diversion of firefighting funds and equipment, procurement irregularities affecting vehicle and tool availability, nepotistic recruitment reducing technical competence, and political protection of unauthorized forest use. These mechanisms directly increase ignition sources, fuel accumulation, and response delays, thereby providing a concrete explanation for the strong corruption–wildfire linkage observed in the SEM results. This functional specification strengthens the academic relevance of corruption as a wildfire governance variable rather than a generalized institutional deficiency.

The negative association between regulatory enforcement and wildfire escalation supports earlier evidence that consistent monitoring and penalties deter risky land-use practices [61,62]. However, unlike studies in high-income countries where enforcement capacity is relatively stable, this study highlights how enforcement effectiveness varies substantially across districts in developing governance settings, particularly where forest dependence and informal access to rangelands are high.

Similarly, emergency response effectiveness significantly reduced wildfire escalation, reinforcing findings from operational disaster management research emphasizing inter-agency coordination and response capacity [63]. The strong explanatory power of the model ($R^2 = 0.56$) underscores that governance capacities collectively shape wildfire outcomes more decisively than biophysical factors alone, without negating the importance of vegetation type, fuel structure, and land use in conditioning fire behavior.

The SEM results provide validation of the proposed Governance Fire Risk Framework, offering a significant theoretical contribution. The strong direct effect of governance failure on wildfire escalation confirms governance as a structural determinant of environmental risk, consistent with institutional risk theory [64,65].

The significant mitigating effects of institutional preparedness and emergency response effectiveness highlight the role of adaptive governance mechanisms, supporting resilience and adaptive capacity frameworks [66]. Conversely, the strong influence of corruption underscores how informal institutions can overpower formal governance arrangements, a dynamic often underexplored in wildfire research.

The excellent model fit indices demonstrate that the framework successfully integrates governance indicators with wildfire outcomes, advancing existing models that often treat governance as a contextual variable rather than a core explanatory construct.

The significant rural–peri-urban differences in governance failure scores confirm that governance impacts are spatially uneven, supporting place-based risk and vulnerability theories [67]. Rural districts such as Dir Lower and Dir Upper experience compounded risks due to weaker institutional presence, limited infrastructure, and delayed emergency services, and higher dependence on forest and rangeland resources for livelihoods.

The stronger governance–fire linkage in rural districts revealed by multi-group SEM contrasts with findings from urban-focused wildfire studies, highlighting a key contribution of this research: governance failure matters more where institutional reach is weakest. This spatial differentiation is particularly relevant for developing countries, where rural governance deficits are widespread but under-researched.

The prioritization of corruption and emergency response delay as very high policy priorities aligns with governance reform literature emphasizing accountability and operational capacity as critical levers for risk reduction [68,69]. Unlike studies that emphasize technological solutions, this study empirically demonstrates that governance reforms yield higher marginal benefits.

The identification of regulatory enforcement and institutional preparedness as high priority, but secondary factors, provides a nuanced policy roadmap, suggesting that governance interventions must be sequenced and integrated rather than implemented in isolation.

Synthesizing the findings across all objectives, this study demonstrates that governance quality is the most decisive determinant of forest and rangeland wildfire escalation in Khyber Pakhtunkhwa. Across regression, structural equation modeling, and comparative analyses, governance-related factors consistently exhibited strong and statistically significant effects on wildfire frequency, severity, spatial spread, and damage. In particular, corruption and delayed emergency response emerged as the most powerful risk amplifiers, while institutional preparedness and regulatory enforcement functioned as key mitigating mechanisms. This convergence of evidence across multiple analytical models reinforces the study's central argument that wildfire escalation in the province is fundamentally a governance-driven phenomenon rather than solely an environmental or climatic outcome.

In comparison with existing international literature, which broadly acknowledges the relevance of governance in wildfire management, this study makes a distinct contribution by quantifying the magnitude of governance effects, integrating multiple governance dimensions into a unified Governance–Fire Risk Framework, and empirically demonstrating spatial heterogeneity in governance impacts within a developing-country setting. While most wildfire studies from high-income contexts focus on biophysical drivers or technical response capacity, the present research foregrounds governance failure as a measurable and dominant structural factor shaping wildfire risk, thereby extending the scope of wildfire governance scholarship.

One of the most notable and unexpected findings is the exceptionally strong effect of corruption, which surpassed even institutional preparedness in influencing wildfire escalation. This result underscores the outsized role of informal governance mechanisms in Pakistan, where corruption distorts enforcement, weakens accountability, and undermines

operational effectiveness. Such dynamics are often underemphasized in wildfire studies conducted in high-income countries, where institutional integrity is comparatively stronger.

From a theoretical perspective, the study advances wildfire governance theory in several important ways. First, it conceptualizes governance failure as a structural driver of wildfire risk, rather than a peripheral or contextual variable. Second, it explicitly incorporates corruption as a core component of wildfire risk modeling, moving beyond conventional administrative or technical explanations. Third, it demonstrates that governance impacts on wildfire escalation are spatially differentiated, with rural districts experiencing both higher levels of governance failure and stronger governance–fire risk linkages. These contributions collectively enrich institutional and disaster governance theories by embedding wildfire risk within a governance-centered analytical framework.

The policy and governance implications of these findings are substantial. The results clearly indicate that effective wildfire mitigation in Khyber Pakhtunkhwa requires systemic governance reforms, particularly targeting corruption within fire management and regulatory institutions. Investments in rapid and coordinated emergency response systems, alongside strengthened regulatory enforcement and enhanced institutional preparedness, are essential to reducing wildfire escalation. Importantly, the evidence underscores the need for context-sensitive governance strategies that prioritize rural districts, where institutional weaknesses and wildfire vulnerability are most pronounced.

Finally, by focusing empirically on Khyber Pakhtunkhwa, this study fills a critical gap in wildfire research in Pakistan and the broader Global South, regions that are increasingly exposed to wildfire risk yet remain underrepresented in the literature. The governance-driven insights generated by this research offer transferable lessons for other fire-prone developing regions facing similar institutional constraints, thereby extending the relevance of the study beyond its immediate geographical context.

5. Conclusions

This study provides empirical evidence that governance quality is a central and decisive determinant of forest and rangeland wildfire escalation in Khyber Pakhtunkhwa. Across all analytical approaches and study objectives, governance failures particularly corruption, weak institutional coordination, ineffective regulatory enforcement, and delayed emergency response consistently intensified wildfire frequency, severity, and spatial spread. Importantly, corruption is not treated as an abstract condition but as a functional risk amplifier operating through specific mechanisms, including bribery and rent-seeking in timber extraction, tolerance of illegal grazing and land clearing, diversion of firefighting resources, politically influenced staffing decisions, and weakened accountability in emergency response systems. These pathways directly translate governance failure into increased ignition probability, delayed suppression, and uncontrolled fire spread.

Conversely, stronger institutional preparedness and effective emergency response mechanisms played a protective role in mitigating wildfire risks. These findings demonstrate that implementation-oriented governance capacities such as trained personnel, functional equipment, coordinated command structures, and rapid mobilization are not merely administrative concerns but are academically significant determinants of fire behavior and outcomes, comparable in influence to environmental drivers. The findings collectively demonstrate that wildfire escalation in the study region is not merely an outcome of environmental or climatic conditions but is fundamentally shaped by the effectiveness and integrity of governance systems.

At the same time, the governance effects identified in this study operate within distinct ecological and socio-economic fire contexts. Wildfires predominantly affect chir pine–dominated subtropical forests, mixed temperate conifer systems (including deodar,

blue pine, and fir), broadleaved oak-associated stands, shrublands, and alpine rangelands ecosystems that differ substantially in fuel structure, flammability, regeneration capacity, and human use intensity. Community dependence on fuelwood collection, grazing, fodder harvesting, and seasonal forest access increases human fuel interactions, thereby shaping ignition exposure and compounding governance-related vulnerabilities.

Importantly, the study also reveals spatial differentiation in governance impacts, with rural districts facing disproportionately higher wildfire risks due to deeper institutional weaknesses, limited infrastructure, delayed emergency access, and higher dependence on forest resources. These findings underscore that governance failures interact with forest composition, land-use practices, and livelihood dependence to produce uneven wildfire outcomes, reinforcing the need to analyze wildfire risk as a coupled governance ecological social phenomenon rather than as a purely biophysical hazard.

5.1. Policy Implications

The results underscore the urgent need to reposition wildfire management within a governance reform agenda rather than treating it solely as a technical or environmental challenge. Strengthening wildfire governance requires addressing systemic institutional failures, particularly corruption and weak accountability mechanisms, which undermine preparedness, enforcement, and response capacities. Policymakers must recognize that investments in firefighting infrastructure alone will be insufficient unless accompanied by reforms that enhance transparency, coordination, and institutional effectiveness. The evidence further highlights the necessity of context-sensitive policies, as uniform governance strategies may fail to address the heightened vulnerabilities of rural and remote districts.

5.2. Practical Recommendations

Based on the study findings, several practical interventions are recommended. First, anti-corruption measures should be integrated into wildfire governance through transparent budgeting, independent audits, and strengthened oversight of fire management institutions. Second, emergency response systems must be enhanced by improving early warning mechanisms, inter-agency coordination, and rapid deployment capacities, particularly in hard-to-access mountainous areas. Third, regulatory enforcement related to land use, forest protection, and fire safety should be strengthened through consistent monitoring and meaningful penalties. Finally, institutional preparedness should be improved through targeted training, adequate resourcing, and proactive planning, with special emphasis on rural districts where governance gaps are most pronounced.

5.3. Study Limitations

Despite its contributions, the study has certain limitations. The analysis relies on cross-sectional data, which limits the ability to establish causal relationships over time. The use of perception-based survey measures may also introduce response bias, although strong reliability checks were applied to mitigate this concern. Additionally, while the study captures key governance dimensions, other contextual factors such as informal community practices, ecological variability, and climate dynamics were not explicitly modeled and may also influence wildfire outcomes.

5.4. Future Research Directions

Future research should build on this study by adopting longitudinal or mixed methods designs to capture temporal changes in governance and wildfire dynamics. Incorporating objective wildfire data, remote sensing indicators, and climate variables could further strengthen empirical understanding. Comparative studies across provinces or other fire-prone developing countries would help assess the generalizability of the Governance–Fire

Risk Framework. Additionally, future work could explore the role of community-level governance, indigenous fire management practices, and local adaptive capacities to provide a more holistic understanding of wildfire risk in the Global South.

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Data Availability Statement: The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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Appendix A. Survey Questionnaire

Title: Governance Failure and Wildfire Escalation in Khyber Pakhtunkhwa

Instructions: Please indicate your response honestly. For Sections B–K use the scale:

1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

Section A: Background Information

1. District: Dir Lower/Dir Upper/Swat/Mansehra/Abbottabad
2. Area Type: Rural/Peri-Urban
3. Gender: Male/Female/Prefer not to say
4. Age Group: 18–30/31–40/41–50/51+
5. Education: None/Primary/Secondary/Bachelor/Master+
6. Occupation/Role: Forestry/Disaster Mgmt/Govt/NGO/Farmer/Herder/Other
7. Household depends on forest resources: Yes/No

Section B: Institutional Preparedness

8. Fire personnel receive adequate training.
9. Firefighting equipment is sufficient.
10. Clear wildfire preparedness plans exist.
11. Staffing levels are adequate.
12. Regular wildfire drills are conducted.

Section C: Weak Institutional Coordination

13. Agencies lack coordination during fires.
14. Roles of institutions are unclear.
15. Information sharing is weak.
16. Joint response planning is inadequate.

Section D: Political Interference

17. Political pressure affects wildfire decisions.
18. Politicians influence enforcement.
19. Staffing decisions are politically influenced.

20. Budget allocation is politically biased.

Section E: Regulatory Non-Compliance

21. Fire regulations are frequently violated.

22. Illegal land clearing increases fire risk.

23. Encroachment contributes to fires.

24. Fire safety rules are poorly followed.

Section F: Corruption in Fire Governance

25. Bribery affects enforcement.

26. Fire funds are misused.

27. Favoritism affects recruitment/deployment.

28. Accountability in agencies is weak.

29. Corruption delays emergency response.

Section G: Regulatory Enforcement

30. Fire regulations are regularly inspected.

31. Violators are penalized.

32. Monitoring systems reduce fire risk.

33. Agencies act independently.

Section H: Emergency Response Effectiveness

34. Response to fires is timely.

35. Agencies coordinate effectively.

36. Communication systems function well.

37. Logistics support operations.

38. Communities receive timely warnings.

Section I: Social & Behavioral Fire Drivers

39. Residue burning causes fires.

40. Pasture renewal burning increases risk.

41. Fuelwood collection increases exposure.

42. Grazing changes vegetation promoting fire.

43. Land clearing causes accidental fires.

44. Human negligence causes fires.

45. Livelihood needs lead to fire use.

46. Traditional practices involve burning.

Section J: Wildfire Outcomes

47. Wildfires occur frequently.

48. Fire incidents are increasing.

49. Fires are intense.

50. Fires last long.

51. Fires are difficult to control.

52. Fires spread rapidly.

53. Large areas burn before control.

54. Containment often fails.

55. Forests/rangelands suffer major damage.

56. Livelihoods are disrupted.

57. Property losses are significant.

58. Ecosystems face long-term damage.

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