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Environmental disaster governance and rescue management performance: An exploratory quantitative evaluation of the CCMR-CL framework

Jing Han[1], Anqi Sun[2], Haitao Zhang[3], Jianxin Jiang[4], and Maria Zalina A. Rahim[5]*

[1]Faculty of Medicine, University of Cyberjaya, Cyberjaya, Selangor, Malaysia

[2]Department of Business Administration, D'Amore-McKim School of Business, Northeastern University, Boston, Massachusetts, United States

[3]Biomedical Artificial Intelligence Laboratory, Shanghai East Hospital, School of Medicine, Tongji University, Shanghai, China

[4]Department of Neurosurgery, Taizhou Fourth People's Hospital, Taizhou, Jiangsu, China

[5]Department of Psychiatry and Mental Health, Faculty of Medicine, University of Cyberjaya, Cyberjaya, Selangor, Malaysia

***Corresponding author:**
Maria Zalina A. Rahim
(maria@cyberjaya.edu.my)

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Abstract

Disaster rescue performance reflects not only hazard severity but also the management systems that organise command authority, inter-organisational coordination, resource allocation, rescue-team standardisation, institutional learning, and the integration of digital information. These functions are usually studied separately, and their joint contribution to observed performance has rarely been tested against outcomes independent of how the functions themselves are coded. This study develops an interdisciplinary framework, CCMR-CL, integrating six management dimensions, and tests it against 38 major disaster events in China (2006–2025), each coded from official investigation reports and corroborating sources. A documentary performance index, built from four outcome components, was explained jointly by the six dimensions, with an adjusted R^2 of 0.82; command coordination was the only dimension whose association survived bootstrap resampling, and the dimensions were intercorrelated enough that the result is best read as joint rather than separable influence. Because two of the four outcome components are conceptually close to two of the six predictors, the dimensions were also tested against an independent outcome index built only from activation delay, exposure-adjusted casualties, and economic loss; against this measure the joint explanatory power fell to 0.17, indicating that the documentary-index result substantially reflects shared construct content rather than a demonstrated relationship with objective outcomes. Closed-loop evaluation, measured from post-event activity, shows the weakest concurrent association, consistent with its temporal position in the framework. Performance differed by disaster type after adjusting for hazard severity, and mean performance did not rise after the 2018 national reform under formal testing. The study offers a measurable, interdisciplinary description of the documented rescue-management process, while treating its relationship to independently measured outcomes as not yet established.

Keywords: Environmental disaster; Emergency governance; Public management; Resource allocation; China; Institutional learning

1. Introduction

Disaster losses remain large and unevenly distributed, and the way states organise their response is increasingly treated as a question of governance rather than of engineering alone. The Centre for Research on the Epidemiology of Disasters recorded 387 disaster events worldwide in 2022, resulting in roughly 30,704 deaths and economic losses of USD 223.8 billion, a burden borne disproportionately by Asia.[1] China reported 95.44 million people affected and direct economic losses of RMB 345.45 billion in 2023.[2] Numbers of this magnitude make a strong case for management systems whose performance can be observed, compared, and improved based on evidence rather than impression.

Disaster rescue is, at its core, an interdisciplinary management problem. It engages public authority and the speed with which it is exercised, coordination across agencies and levels of government, the distribution of resources under acute scarcity, the standardisation of operational teams, the conversion of experience into revised practice, and, increasingly, the integration of digital information into command and warning. Research on disaster management has often examined these functions singly, drawing on collaborative governance, incident command, humanitarian logistics, organisational learning, and information systems in turn.[3,4] That work clarifies each function, but it leaves underspecified how the functions operate together and how much, jointly, they account for the performance that managers actually observe.

This study addresses that gap by developing the CCMR-CL framework and examining it empirically. The framework integrates six dimensions: unified command coordination, multi-actor collaboration, operational resource allocation, rescue-team standardisation, closed-loop evaluation, and digital information integration. The integration of digital information reflects the growing role of early-warning systems, satellite and unmanned-aerial monitoring, geographic information systems, and unified command applications in contemporary Chinese disaster response. Rather than treating the dimensions descriptively, the study measures them across a substantial set of events and estimates how strongly, in combination, they explain observed rescue-management performance.

The empirical base is a dataset of 38 major disasters in China between 2006 and 2025, spanning floods, earthquakes, landslides, and typhoons. Each event was coded from official investigation reports and corroborating documentary sources, and a composite performance index was constructed from four outcome components. The analysis is deliberately observational and associational. It uses descriptive statistics, a correlation matrix, and a multiple regression model, and it interprets the regression with explicit attention to the strong intercorrelation among the dimensions, which limits what can be claimed about any single one.

Four questions guide the work. First, how do the six management dimensions vary across disaster types and over time in China? Second, how are the dimensions related to one another and to measured rescue-management performance? Third, how much of the variation in performance do the dimensions account for jointly, and which carry the strongest independent association? Fourth, what does the framework offer for diagnosis and priority-setting in emergency governance and public management? The remainder of the article develops the framework (Section 2), describes the data and methods (Section 3), reports the results (Section 4), discusses their meaning and limitations (Section 5), and concludes the study (Section 6).

2. Theoretical background and framework development

The CCMR-CL framework draws on six connected bodies of scholarship. Read together rather than separately, they describe a system of management functions whose joint operation, rather than any single component, shapes rescue performance. This section reviews those literatures and then sets out the framework and its measurable dimensions.

2.1. Collaborative governance and inter-agency coordination

The collaborative-governance literature treats coordination among autonomous organisations as a matter of building shared rules, mutual understanding, and joint capacity rather than imposing hierarchy.[5,6] Disaster response engages national and local government, the military and armed police, professional rescue services, and social organisations, none of which can simply direct the others. Studies of emergency-management networks show that coordination quality depends on prior investment in

shared platforms, joint exercises, and trust.[4,7] This finding informs the multi-actor collaboration dimension.

Recent empirical work in China has begun to test this collaborative-governance logic directly against measured performance rather than treating it as a background assumption. Using structural equation modelling on 110 emergency-drill cases in Shanghai, Liu and Fan[8] found that collaboration networks are positively associated with emergency performance, and that this association is mediated by both formal contingency planning and organisational absorptive capacity, with the latter exerting the stronger effect. This finding is consistent with the multi-actor collaboration dimension used here, while also indicating that the performance benefit of collaboration operates partly through institutional and adaptive-capacity channels that the present framework does not separately model.

2.2. Incident command systems and command authority

The incident-command tradition addresses how authority is established and exercised when many organisations must act at once. Scalable command structures with defined roles and escalation procedures, exemplified by the National Incident Management System[9] and codified in International Organisation for Standardisation (ISO) 22320,[10] aim to make authority clear under pressure. Their effectiveness varies with context, training, and the network properties of the responders.[11,12] The recurring insight that clear command shapes how the rest of the response unfolds underpins the unified command coordination dimension.

2.3. Humanitarian logistics and resource allocation

Humanitarian logistics has produced an extensive body of work on how relief resources are pre-positioned, matched to need, and distributed under time pressure.[13,14] The speed of activation and the adequacy of deployed personnel, vehicles, and supplies bear directly on outcomes. This literature informs the operational resource-allocation dimension while leaving open the upstream governance conditions that allow rapid deployment.

2.4. Organisational learning and closed-loop governance

The organisational-learning literature treats the conversion of experience into improved future practice as a determinant of performance.[15] Applied to emergency management, after-action review, the codification of lessons, and the tracked implementation of revisions form a closed loop of continuous improvement, an idea rooted in the plan–do–check–act cycle.[16] China's post-2018 institutional reforms can be interpreted as an attempt to strengthen this loop at the national level.[17] The framework represents this capacity as the closed-loop evaluation dimension.

2.5. Information systems and digital integration in response

A more recent strand concerns the integration of digital information into emergency management, including early warning systems, satellite and unmanned aerial monitoring, geographic information and mapping systems, real-time monitoring, and unified command applications.[7] In Chinese practice, these capabilities have expanded quickly, and they increasingly mediate how command decisions are made and how warnings reach the public. The framework adds digital information integration as a distinct sixth dimension, recognising that information infrastructure now conditions the performance of the other five functions rather than sitting outside them.

Quasi-experimental evidence supports this reading. Using a difference-in-differences design across 275 Chinese prefecture-level cities and exploiting the staggered rollout of the national smart-city pilot policy as a natural experiment, Guo and Zhou[18] found that smart-city construction produced a statistically significant improvement in municipal emergency management capability, with digital-technology application mediating most of the estimated effect. That result is consistent with treating digital information integration as an enabling condition for the other management functions rather than as an independent driver of outcomes in its own right, a distinction the present framework adopts and returns to in the discussion.

2.6. Recent empirical measurement of emergency and rescue performance

A parallel and more recent literature has begun to measure emergency and rescue performance directly, rather than inferring it from institutional design alone, and this work sharpens what an integrated framework such as CCMR-CL needs to add. Zhou *et al.*[19] traced the evolution of China's national disaster-management policy across 250 central-government instruments issued between 1954 and 2022, documenting a shift from agriculture- and economy-centred policy towards integrated, technology-enabled governance; that account describes how the institutional environment for the six CCMR-CL dimensions has changed over time but stops short of measuring realised performance in individual events. Yi *et al.*[20] made the relevant distinction explicit, separating a region's potential emergency capability, the expected capability implied by static resources and institutions, from its emergency performance, the dynamic performance actually exhibited during a specific response; using a Delphi-assessed case

library of 1,240 Chinese emergency events, they showed that potential capability and realised performance frequently diverge, and that statistical methods built only on institutional or resource indicators can misstate a region's true responsiveness.

CCMR-CL is positioned within this second, performance-measurement strand rather than the first, institutional-design strand. Its contribution is not the six management functions themselves, each of which is already established in its own literature, but the joint, event-level measurement of all six from documentary evidence and the empirical test of how much of the variation in observed rescue performance they explain together, applied consistently across a documented, multi-hazard set of Chinese events. This addresses a gap that recent measurement studies leave open: Yi *et al.*[20] and Zhou *et al.*[19] demonstrated that potential capability, policy design, and realised performance are conceptually and empirically distinct, but neither offers an integrated, multi-dimensional coding instrument that can be applied event by event and tested with standard regression diagnostics. Whether the six-dimension measurement used here in fact behaves as an outcome-independent predictor set, rather than partly reproducing its own dependent variable, is examined directly in Sections 3 and 4.

2.7. The CCMR-CL framework

The framework integrates the six dimensions into a single structure for analysis and decision support. Each dimension is defined by its theoretical basis, its management function, an observable indicator, and its expected effect on rescue performance. The dimensions are summarised in Table 1, and the architecture, linking the foundations to the dimensions, to the performance index, and to decision-support outputs, is shown in Figure 1.

The logic connecting the six dimensions is both sequential and additive. Unified command coordination and multi-actor collaboration together determine whether authority and effort are aligned across responding organisations; this alignment is the condition under which operational resource allocation can translate decisions into deployed personnel, vehicles, and supplies. Rescue-team standardisation operates alongside these functions rather than after them, since interoperable, certified teams are what allocated resources are deployed through. Digital information integration cuts across all four of these functions rather than sitting downstream of them, because early-warning, monitoring, and command-platform

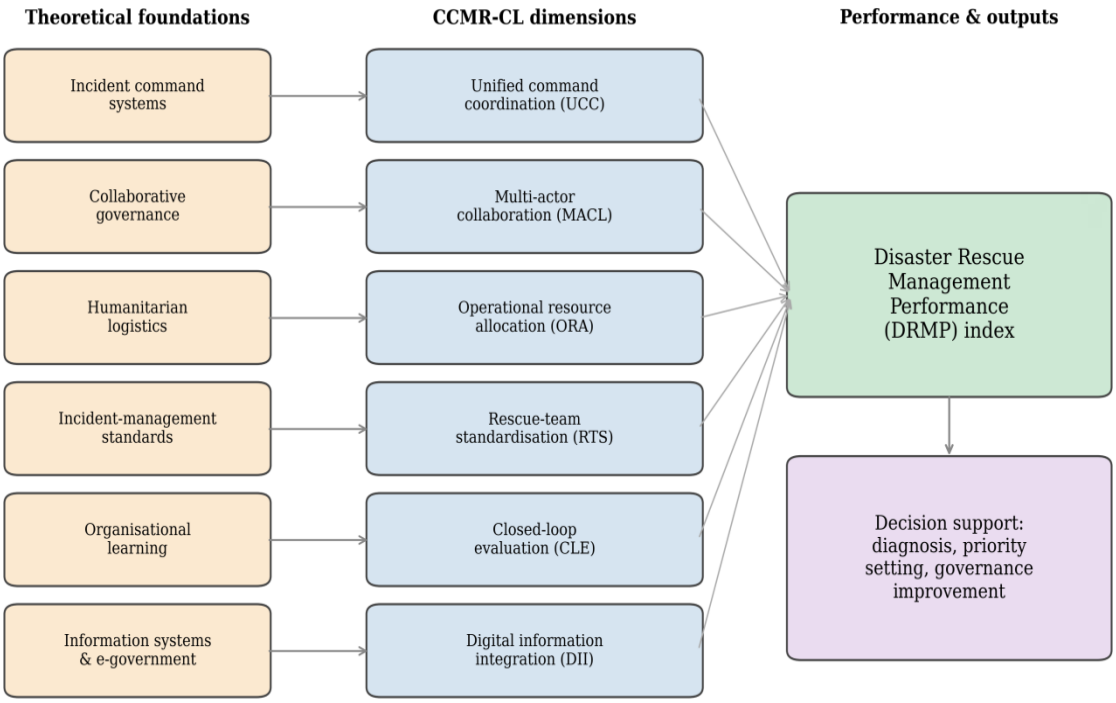

Figure 1. The CCMR-CL interdisciplinary disaster rescue management framework, linking six theoretical foundations to six management dimensions, the Disaster Rescue Management Performance index, and the resulting decision-support outputs

Table 1. Components of the CCMR-CL framework

Dimension	Theoretical basis	Management function	Observable indicator	Expected effect
Unified command coordination (UCC)	Incident command systems	Establish and escalate command authority	Predefined triggers; unified command; activation order	Sets conditions for coordination and resource flow
Multi-actor collaboration (MACL)	Collaborative governance	Align action across agencies and actors	Departments involved; joint coordination mechanism	Translates command into coordinated field action
Operational resource allocation (ORA)	Humanitarian logistics	Pre-position, match, and deploy resources	Personnel, vehicles, supplies; pre-positioning	Direct effect on speed and adequacy of response
Rescue-team standardisation (RTS)	Incident-management standards	Ensure interoperable, certified teams	Professional teams; training and equipment standards	Raises reliability of field operations
Closed-loop evaluation (CLE)	Organisational learning	Convert experience into revised practice	Investigation reports; accountability; plan revision	Drives longer-term system improvement
Digital information integration (DII)	Information systems	Integrate warning, monitoring, and command data	Early warning; satellite/UAV; GIS; command platforms	Conditions the speed and quality of the other functions

Notes: Each dimension is coded on a 0–3 scale from documentary evidence, where 0 denotes no evidence of the function, and 3 denotes strong, well-documented presence. UCC, MACL, ORA, RTS, CLE, and DII are the dimension labels used throughout.
Abbreviations: GIS: Geographic information system; UAV: Unmanned aerial vehicle.

data condition how quickly command is exercised, how collaboration is coordinated, and how resources are matched to need. Closed-loop evaluation sits structurally apart from the other five: it does not act on the same event it measures, but on the documentary record the event leaves behind, and its output, revised plans, retrained teams, and adjusted pre-positioning, feeds forward into how the other five dimensions are configured for the next event. The framework is therefore better interpreted as one concurrent sub-system (command, collaboration, resources, standardisation, conditioned throughout by digital integration) coupled to one intertemporal feedback mechanism (closed-loop evaluation), rather than as six functions of the same kind measured on the same timescale. This distinction is used directly in Section 3.3, where it motivates checking the six-dimension measurement against an outcome index built from variables outside the predictor set, and in Section 5.3, where it explains why closed-loop evaluation behaves differently from the other five dimensions in the results.

3. Materials and methods

3.1. Research design

The study used a quantitative, observational design. It measured six management dimensions and a performance index across a set of disaster events and then examined their associations through correlation and multiple regression. The design supports claims about association and joint explanatory power, not about causation, and the analysis is reported with that limit in view throughout.

3.2. Data sources and scope

The dataset comprised 38 major disasters in China recorded between 2006 and 2025, covering 18 floods, 9 earthquakes, 6 landslides, and 5 typhoons across 25 provinces and regions. Events were compiled primarily from official sources, including State Council investigation reports, Ministry of Emergency Management releases, and provincial government records, supplemented by academic studies and major-media coverage. Events were selected for the availability of documentary evidence sufficient to code each dimension and for diversity of hazard type, so that the framework is not tuned to a single kind of event. Each record also carries an evidence-confidence rating reflecting the number and authority of its sources.

3.3. Measurement and the performance index

Each of the six dimensions was coded on a 0–3 scale from the documentary record, where 0 indicates no evidence of the function, 1 indicates weak or partial evidence, 2 indicates substantial evidence, and 3 indicates strong and well-documented evidence. The dependent measure, the Disaster Rescue Management Performance index, was constructed as the mean of four outcome components,

each coded on the same 0–3 scale: response speed, coordination quality, resource efficiency, and public-service continuity. For the paired case comparison only, dimension scores were rescaled to a 1–5 range using the linear transformation:

$$s' = s \times 4/3 + 1 \quad (1)$$

to aid interpretation; all statistical analysis used the original 0–3 coding. The scores are evidence-coded structured judgements rather than physical measurements, and they were interpreted accordingly.

Two of the four outcome components, coordination quality and resource efficiency, are conceptually close to two of the six predictor dimensions, multi-actor collaboration and operational resource allocation, respectively, because both the predictor and the outcome components describe the same underlying process from a documentary record. This overlap risks partial circularity: correlations and regression fit computed against this documentary performance index may be inflated by shared construct content rather than by a genuine empirical relationship. To address this directly, Section 3.5 introduces an independent outcome measure built only from variables that play no part in the six predictor scores, activation delay in hours, casualty counts scaled by the exposed population, and direct economic loss, and Section 4 reports the six dimensions against both the documentary index and this independent measure so that the extent of any inflation can be seen rather than assumed away.

3.4. Paired case selection

Two events were selected for closer comparison: the 2021 Henan Zhengzhou 7.20 flood, with 398 deaths and 14.79 million people affected,[21,22] and the 2022 Sichuan Luding M6.8 earthquake, with 93 deaths.[23] Both occurred within the same national governance system but under different command and information conditions, which allows variation in management quality to be examined while the broad institutional context is held constant. Differences in hazard type and exposure are acknowledged as confounders.

3.5. Analytical procedures

Three procedures were applied. Descriptive statistics summarised the distribution of each dimension and the performance index, overall and by disaster type. Pearson correlations described the bivariate associations among the dimensions and with the index. An ordinary least-squares regression then estimated the joint association between the six dimensions and the performance index. Because the dimensions are conceptually and empirically intercorrelated, variance inflation factors were computed to gauge multicollinearity, and the regression was interpreted in terms of joint explanatory power rather than the magnitudes of individual coefficients. Two robustness checks were run: a restriction to events from 2018 onwards, and a restriction to high-confidence events. Given the sample size, all estimates are read as descriptive of this dataset rather than as inferences to a larger population.

Because the six dimensions are highly intercorrelated, three additional checks were added specifically to address this constraint. First, principal component analysis was applied to the six standardised dimensions to establish how much of their shared variance loads onto a single latent factor, and the performance index was regressed on the first principal component alone. Second, ridge regression with the penalty parameter selected by leave-one-out cross-validation was estimated as a regularised alternative to ordinary least squares to gauge how the coefficient pattern changes when collinearity is explicitly penalised. Third, percentile bootstrap confidence intervals (3,000 resamples) were computed for every ordinary least-squares coefficient, in place of relying on the restricted 2018-onwards and high-confidence subsamples as stand-alone robustness evidence; the high-confidence subsample in particular comprised only 13 events against 6 correlated predictors and is reported for transparency rather than treated as a confirmatory check, since a model of that size relative to its predictors is highly susceptible to overfitting. Fourth, the comparison of performance across disaster types and across the pre- and post-2018 period was re-estimated with hazard-severity score and disaster type entered as covariates, and tested with an incremental *F*-test rather than compared only as unadjusted group means.

3.6. Validity, reliability, and limitations

Several features bear on credibility. Coding from documentary sources is subject to reporting bias, since better-documented events may appear better managed; the evidence-confidence rating and the use of official investigation reports mitigate but do not eliminate this bias. The dimension and outcome scores are structured judgements, and independent double-coding would allow inter-rater reliability to be reported. The design is observational, so the associations reported below cannot be interpreted as causal effects. The strong intercorrelation among the dimensions, documented in Section 4, is the central analytical constraint and is treated explicitly rather than set aside. These limitations are revisited in Section 5.

Internal-consistency reliability was assessed for each dimension by computing Cronbach's α across its constituent documentary indicators (for example, the seven yes/no indicators underlying digital information

integration). This step evaluates whether the sub-indicators feeding into a given dimension score cohere with one another; it is a different and weaker form of evidence than inter-rater reliability, which requires two or more coders to independently score the same events and is not yet available for this dataset. Independent double-coding of the full event set, with agreement quantified by Cohen's κ or the intraclass correlation coefficient, is identified here as a necessary next step before the coded scores can be treated as more than a single analyst's structured reading of the documentary record, and is not represented as complete in the present study.

3.7. Supplementary materials

The full event-level dataset is provided in Table S1, comprising, for each of the 38 events, the event identifier, disaster type, province, and date; all six dimension scores and the four outcome-index components; the independent variables used to construct the validation outcome measure (activation delay, fatalities, affected population, direct economic loss, hazard-severity score); the evidence-confidence rating; counts of official, media, and academic sources; and the primary official source consulted. This is intended to allow the coding to be inspected and, where a reader has access to the same primary sources, checked event by event.

4. Results

4.1. Distribution of the dimensions and performance

Across the 38 events, the dimensions differed markedly in their average level (Table 2). The coordination-related functions scored highest, with multi-actor collaboration, operational resource allocation, and command coordination all near a mean of 2.0 on the 0–3 scale. Rescue-team standardisation (mean 1.61), closed-loop evaluation (mean 1.45), and digital information integration (mean 1.21) scored lower, indicating that the more institutional and informational capabilities are, on average, less well developed than the front-line coordination functions. The performance index averaged 1.80, ranging from 0.75 to 2.75.

Performance also varied by hazard type (Figure 2). Earthquakes recorded the highest mean performance index (2.22), followed by typhoons (1.75), floods (1.69), and landslides (1.50). The same ordering held across most dimensions, with earthquakes scoring highest on command, collaboration, and digital integration, consistent with the large, nationally coordinated responses that major seismic events attract.

These differences are not solely an artefact of hazard severity. Re-estimating the performance index as a function of disaster type with the hazard-severity score entered as a covariate, the type effect remained significant after this adjustment (incremental $F(3, 33) = 4.60$, $p = 0.009$), with floods and landslides scoring significantly lower than earthquakes (both $p < 0.01$) and typhoons marginally lower ($p = 0.09$); the hazard-severity covariate itself is not a significant predictor once type is included, which reflects its coarse two-to-three-point range in this dataset and is noted as a measurement limitation rather than evidence that severity is irrelevant. The full model is reported in Table 3. The ordering by type should accordingly be interpreted as a controlled but still partial comparison, since duration, accessibility, and regional response capacity are not separately measured here.

Table 2. Descriptive statistics for the six dimensions and the performance index ($N = 38$)

Variable	Mean	SD	Minimum	Maximum
Command coordination	2.03	0.49	1.00	3.00
Multi-actor collaboration	2.11	0.45	1.00	3.00
Operational resource allocation	2.05	0.52	1.00	3.00
Rescue-team standardisation	1.61	0.68	1.00	3.00
Closed-loop evaluation	1.45	0.65	1.00	3.00
Digital information integration	1.21	0.58	0.00	3.00
Disaster Rescue Management Performance index	1.80	0.47	0.75	2.75

Notes: All variables are coded on a 0–3 scale. The performance index is the mean of four outcome components: response speed, coordination quality, resource efficiency, and public-service continuity.

4.2. Associations among the dimensions and with performance

The correlation matrix (Table 4, Figure 3) shows that every dimension was positively associated with the performance index, but the strength varied widely. Command coordination ($r = 0.85$) and multi-actor collaboration ($r = 0.84$) were the strongest correlates, followed by operational resource allocation ($r = 0.74$) and rescue-team standardisation ($r = 0.74$). Digital information

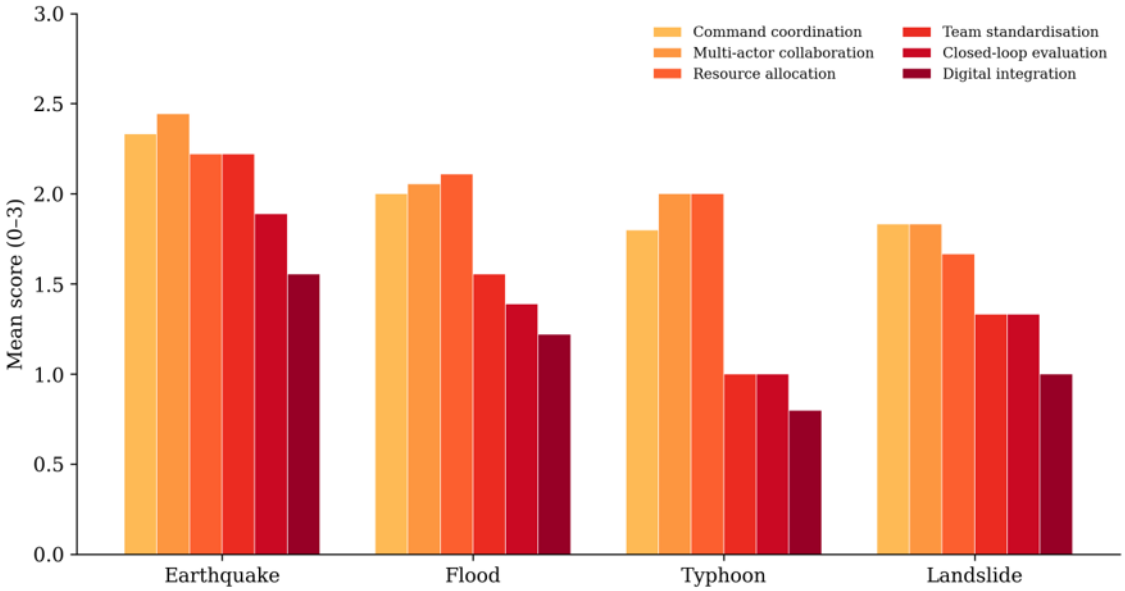

Figure 2. Mean CCMR-CL dimension scores by disaster type. Earthquakes show the strongest profile across most dimensions; landslides the weakest.

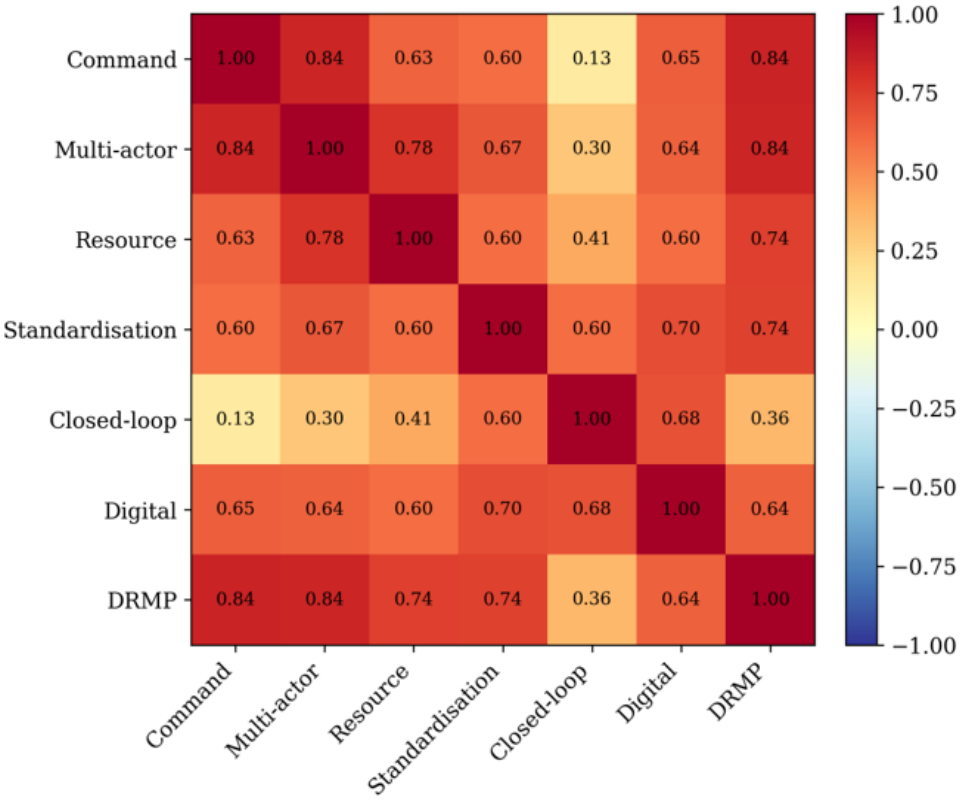

Figure 3. Correlation heatmap of the six management dimensions and the Disaster Rescue Management Performance (DRMP) index across the 38 events. Warmer cells denote stronger positive associations.

integration was moderately associated (r = 0.64). Closed-loop evaluation showed the weakest association with concurrent performance (r = 0.36), a result that runs against its prominence in conceptual treatments and is taken up in the discussion.

Table 3. Performance index regressed on disaster type with hazard-severity score as a covariate (N = 38; baseline category = Earthquake)

Predictor	Coefficient	p
Intercept (earthquake baseline)	1.930	0.004
Hazard-severity score	0.105	0.630
Flood	−0.545	0.004
Landslide	−0.746	0.002
Typhoon	−0.433	0.088

Note: Incremental F-test for disaster type after hazard severity: $F(3, 33) = 4.60$, $p = 0.009$. $R^2 = 0.296$.

The dimensions were also strongly correlated with one another. Command coordination and multi-actor collaboration correlated at r = 0.84, and several other pairs exceeded 0.65. This shared variance means that the bivariate correlations with performance overlap substantially, which is why the regression below is interpreted with care.

4.3. Joint explanatory power: regression evidence

When entered together into an ordinary least-squares regression, the six dimensions accounted for a large share of the variation in the performance index, with R^2 = 0.85 and adjusted R^2 = 0.82 (Table 5, Figure 4). The model as a whole is a strong fit for these data. The individual coefficients, however, must be interpreted against the multicollinearity already noted: variance inflation factors reached 5.5 for command coordination and multi-actor collaboration, indicating that their separate contributions cannot be cleanly distinguished. Command coordination was the only dimension with a clearly significant independent coefficient, and rescue-team standardisation was marginal. The remaining coefficients were not individually distinguishable from zero, and the negative coefficient on digital information integration, in contrast to its positive bivariate correlation, was a textbook sign of shared variance rather than evidence that digital integration depresses performance.

Two robustness checks support the overall fit while

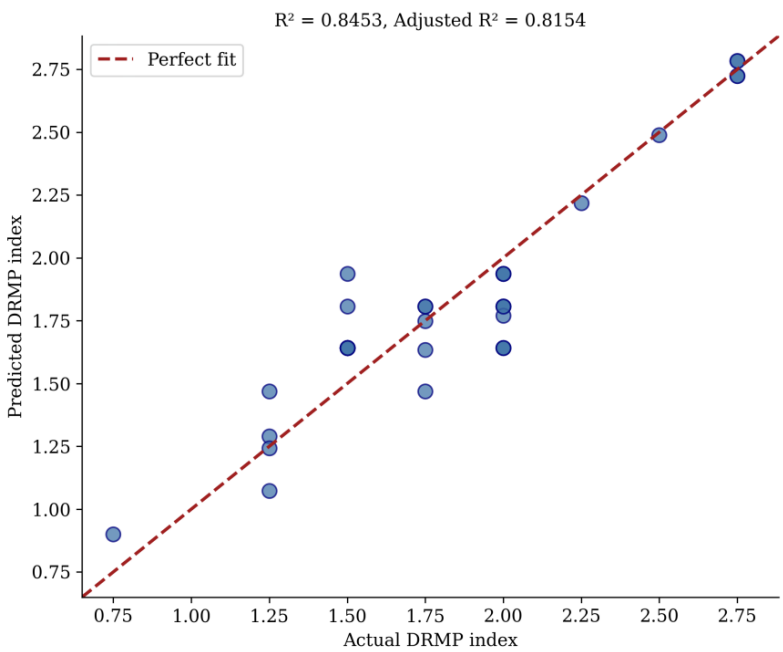

Figure 4. Predicted versus actual Disaster Rescue Management Performance (DRMP) index for the 38 events. The dashed line marks a perfect fit; predictions cluster closely around it, reflecting the model's high overall explanatory power.

Table 4. Pearson correlations among the six dimensions and the performance index (N = 38)

Variable	UCC	MACL	ORA	RTS	CLE	DII	DRMP
UCC	1.00	0.84	0.63	0.60	0.13	0.65	0.85
MACL	0.84	1.00	0.78	0.67	0.30	0.64	0.84
ORA	0.63	0.78	1.00	0.60	0.41	0.60	0.74
RTS	0.60	0.67	0.60	1.00	0.60	0.70	0.74
CLE	0.13	0.30	0.41	0.60	1.00	0.68	0.36
DII	0.65	0.64	0.60	0.70	0.68	1.00	0.64
DRMP	0.85	0.84	0.74	0.74	0.36	0.64	1.00

Note: Coefficients are descriptive associations for this dataset.
Abbreviations: CLE: Closed-loop evaluation; DII: Digital information integration; DRMP: Disaster Rescue Management Performance index; MACL: Multi-actor collaboration; ORA: Operational resource allocation; RTS: Rescue-team standardisation; UCC: Unified command coordination.

Table 5. Ordinary least-squares regression of the performance index on the six dimensions (N = 38)

Predictor	Coefficient	Standard error	t	p	VIF
Command coordination	0.588	0.158	3.72	<0.001	5.52
Multi-actor collaboration	0.110	0.171	0.64	0.526	5.50
Operational resource allocation	0.172	0.108	1.59	0.121	2.86
Rescue-team standardisation	0.166	0.082	2.01	0.053	2.85
Closed-loop evaluation	0.129	0.099	1.31	0.200	3.70
Digital information integration	−0.188	0.123	−1.53	0.137	4.61
Intercept	−0.205	0.206	−0.99	0.329	–

Notes: R^2 = 0.845; adjusted R^2 = 0.815; $F(6, 31) = 28.24$, $p < 0.001$. Coefficients describe joint association in this dataset; given the high intercorrelation among predictors, the model is interpreted through its overall fit rather than individual coefficient magnitudes.
Abbreviation: VIF: Variance inflation factor.

underscoring the limits of the individual coefficients. Restricting the sample to the 30 events from 2018 onwards yielded a comparable fit (R^2 = 0.87), and restricting to the 13 highest-confidence events yielded a higher fit still (R^2 = 0.97), though the latter rests on too few cases to bear much weight. Across these subsets, the dimension that appeared most strongly associated shifted between command coordination and rescue-team standardisation, which is the expected consequence of estimating six correlated predictors on a small sample, and a further reason to interpret the evidence as joint rather than dimension-specific.

These two subsamples were reported for transparency about how the estimates moved under different inclusion rules, not as confirmatory robustness evidence; the 13-event high-confidence subsample in particular was too small relative to six correlated predictors to support that role, and its very high fit (R^2 = 0.97) is better interpreted as a symptom of overfitting than as a stronger result. Three additional checks, reported in Table 6, were used instead to characterise the model's stability. Principal component analysis shows that the six dimensions loaded heavily onto a single latent factor, which accounted for 66.4% of their shared variance; regressing the performance index on this first component alone yielded R^2 = 0.75, close to the full six-predictor model's R^2 = 0.85, indicating that most of the model's explanatory power reflects one general management-quality factor rather than six separable effects. Ridge regression with the cross-validated penalty

(alpha = 0.5) shrank the coefficients only modestly and left command coordination as the dominant predictor. Percentile bootstrap 95% confidence intervals confirm this pattern directly: the interval for command coordination excluded zero (0.24 to 0.78), while the intervals for all five remaining dimensions included zero, providing a more defensible basis for judging which associations are distinguishable from noise than the coefficient *p*-values alone.

4.4. Digital information integration

Digital information integration is the lowest-scoring dimension on average, yet it tracked performance positively at the bivariate level (Figure 5). Events with stronger digital integration, concentrated among recent earthquakes, tended to perform better, while the typhoon and landslide events clustered at the low end of both measures. The pattern is consistent with the rapid but uneven adoption of early-warning, monitoring, and command platforms across hazard types and regions, and it suggests that information infrastructure is better understood as enabling the other functions than as an independent lever.

4.5. Performance over time and the 2018 reform

The mean performance showed no clear upward trend over the period (Figure 6), with an overall mean of 1.80. A comparison around the 2018 establishment of the Ministry of Emergency Management is instructive: events before 2018 recorded a mean performance index of 1.84, and events from 2018 onwards recorded 1.78. The reform did not produce a measurable rise in mean rescue-management performance in this sample. This does not imply that consolidation was without effect, since the post-2018 period includes a wider range of smaller events and the measure captures management quality rather than outcomes such as lives saved, but it cautions against narratives that treat the reform as a decisive break.

This description is now supported by formal testing rather than a comparison of unadjusted means alone. An independent-samples *t*-test found no significant difference between the pre-2018 mean (1.84, $n = 8$) and the 2018-onwards mean (1.78, $n = 30$; $t = 0.38$, $p = 0.71$), and the null result held after adjusting for hazard-severity score and disaster type in a regression framework (post-2018 coefficient = 0.07, $p = 0.69$). The absence of a measurable post-reform improvement is therefore not an artefact of comparing raw group means over event mixes of different composition.

4.6. Paired comparison: Henan and Luding

The paired comparison illustrates the dimension profile behind the index (Table 7). On the rescaled 1–5 measure, the Luding earthquake response scored at the ceiling across all six dimensions, yielding a composite score of 5.0, while the Henan flood response scored 3.67, yielding a ratio of 1.36. The Henan profile was uneven rather than uniformly weak: its closed-loop evaluation score was high, reflecting the thorough official investigation that followed, but its command coordination score was the lowest of its dimensions, consistent with the documented delay in escalating command during the event. The contrast captures the framework's central point, that strong

Table 6. Dimension-reduction and regularisation checks for the six-predictor regression ($N = 38$)

Predictor	OLS coefficient	Bootstrap 95% CI	Ridge coefficient (α = 0.5)
Command coordination	0.588	[0.24, 0.78]	0.460
Multi-actor collaboration	0.110	[−0.15, 0.50]	0.163
Operational resource allocation	0.172	[−0.11, 0.44]	0.169
Rescue-team standardisation	0.166	[0.00, 0.34]	0.176
Closed-loop evaluation	0.129	[−0.12, 0.31]	0.071
Digital information integration	−0.188	[−0.38, 0.10]	−0.102

Notes: Bootstrap intervals are percentile intervals from 3,000 resamples. Ridge α selected by leave-one-out cross-validation. Principal component analysis: the first component explains 66.4% of the shared variance across the six dimensions; when regressing performance on this component alone, $R^2 = 0.75$.
Abbreviation: OLS: Ordinary least squares.

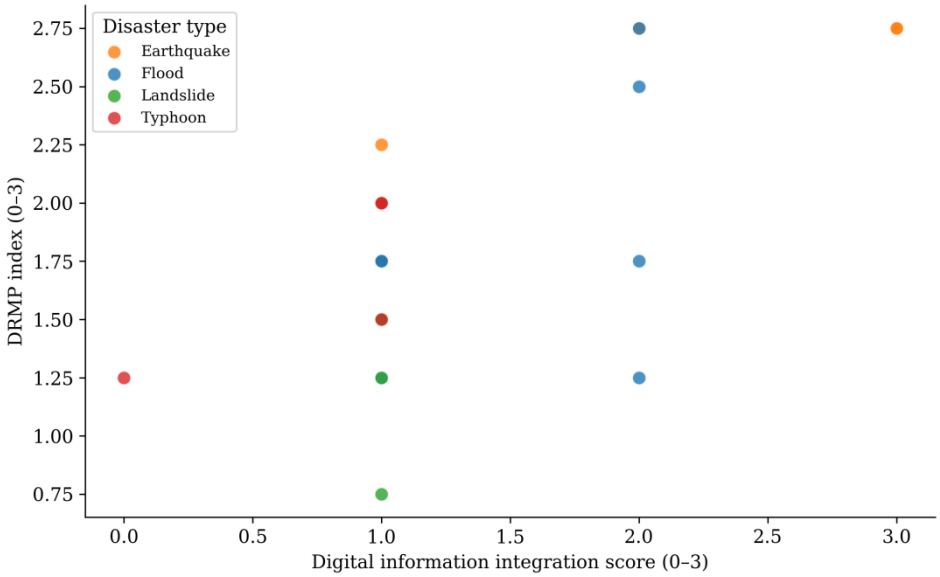

Figure 5. Digital information integration by disaster type, against the performance index. Higher digital integration is associated with higher performance, with recent earthquakes at the upper end of the range.

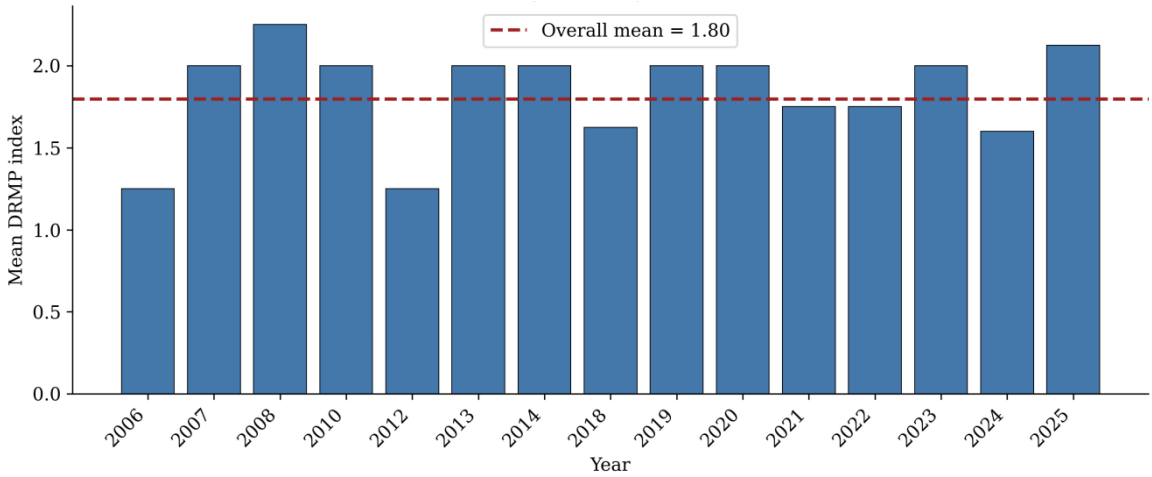

Figure 6. Mean Disaster Rescue Management Performance (DRMP) index by disaster year, 2006–2025 ($N = 38$). The dashed line marks the overall mean of 1.80; no clear temporal trend is evident.

performance requires the dimensions to operate together rather than compensating for one another after the fact.

4.7. Validation against an independent outcome measure

Because two of the four components of the documentary performance index are conceptually close to two of the six predictor dimensions (Section 3.3), the analysis was repeated against an outcome measure built only from variables outside the six predictor scores: activation delay in hours, casualty counts scaled by the exposed population, and direct economic loss, each log-transformed and combined into a single index (Table 8). Against this independent measure, the correlations fell sharply: command coordination, the strongest correlate of the documentary index ($r = 0.85$), fell to $r = 0.25$; multi-actor collaboration fell from $r = 0.84$ to $r = 0.18$; operational resource allocation fell from $r = 0.74$ to $r = 0.15$; and rescue-team standardisation fell from $r = 0.74$ to $r = 0.02$. Closed-loop evaluation was weakly negative ($r = -0.22$).

When regressed jointly on this independent outcome, the six dimensions explained only R^2 = 0.17 (adjusted R^2 = 0.01), compared with R^2 = 0.85 for the documentary index.

Table 7. Dimension profiles for the two reference events (rescaled 1–5)

Dimension	Henan flood (2021)	Luding earthquake (2022)	Difference
Unified command coordination	2.33	5.00	+2.67
Multi-actor collaboration	3.67	5.00	+1.33
Operational resource allocation	3.67	5.00	+1.33
Rescue-team standardisation	3.67	5.00	+1.33
Closed-loop evaluation	5.00	5.00	0.00
Digital information integration	3.67	5.00	+1.33
Composite (mean of six)	3.67	5.00	+1.33

Notes: Scores are rescaled from the 0–3 coding to a 1–5 range for interpretability. The composite is the mean across the six dimensions; the Luding-to-Henan ratio on the composite is 1.36.

This gap is the single most important result in the study for judging what the earlier associations can support. It indicates that a substantial share of the documentary model's apparent explanatory power reflects the conceptual overlap between two predictors and two outcome components rather than a demonstrated relationship between the six coded management dimensions and independently measured disaster outcomes. The documentary index remains informative as a measure of coded process quality, and the six dimensions do relate to it coherently, but the independent-outcome check does not support a claim that the framework predicts objective rescue outcomes with the strength implied in Section 4.3, and the interpretation offered throughout Sections 4 and 5 is qualified accordingly.

5. Discussion

5.1. Rescue performance as an interdependent system

The results support the framework's central premise that rescue performance reflects a system of management functions rather than any one capability. The six dimensions jointly account for most of the variation in the performance index and are strongly intercorrelated, as one would expect if they operate as parts of a single managerial whole. The practical reading is that capability development is most effective when balanced across the dimensions, because a deficit in one is rarely offset by strength in another, as the Henan profile illustrates.

Table 8. Correlation of the six management dimensions with the documentary performance index and with an independent outcome index built from activation delay, exposure-adjusted casualties, and direct economic loss (N = 38)

Dimension	r with documentary index	r with independent outcome index
Command coordination	0.85	0.25
Multi-actor collaboration	0.84	0.18
Operational resource allocation	0.74	0.15
Rescue-team standardisation	0.74	0.02
Closed-loop evaluation	0.36	−0.22
Digital information integration	0.64	0.09
Joint R^2 (all six dimensions)	0.845	0.174

Notes: The independent outcome index is constructed only from variables that are not used in any of the six predictor scores. Joint R^2 is from an ordinary least-squares regression of each outcome on all six dimensions simultaneously.

5.2. Command coordination as the anchor

Command coordination is the strongest correlate of performance and the only dimension with a clearly independent regression coefficient. This is consistent with the incident-command and network-governance literatures, in which the clarity and speed of command condition everything downstream.[11,12] The Henan and Luding comparison reinforces the point, since the widest gap between the two responses lies in command coordination and coincides with the difference in how quickly each response escalated. For public managers, investment in predefined escalation triggers and unified command arrangements is therefore likely to carry benefits beyond command itself.

5.3. The closed-loop evaluation puzzle

The weak association between closed-loop evaluation and concurrent performance ($r = 0.36$) is the study's most counterintuitive result, and it deserves a careful rather than a dismissive reading. Closed-loop evaluation is measured through investigation reports, accountability measures, and plan revision, all of which occur after an event. A high score therefore reflects the quality of institutional learning that follows a disaster, not the management performance observed during it. The Henan flood is the clearest case: it ranked highest in closed-loop evaluation because of a thorough post-event investigation, yet its concurrent performance was constrained by weak command. When interpreted this way, the finding does not diminish institutional learning; it indicates that its benefits accrue to future events rather than to the event under review, which is precisely what a closed loop implies. Establishing that link would require tracking whether lessons from one event raise performance in later ones, which the present cross-sectional design cannot test.

This temporal mismatch is best treated as a construct-validity limitation of the closed-loop evaluation dimension as currently operationalised, rather than as evidence against the underlying learning mechanism: a variable defined by post-event activity cannot, by construction, explain concurrent performance in the same event, and the weak correlation reported in Section 4.2 is in part a direct consequence of that definition. A longitudinal redefinition, scoring closed-loop evaluation from an event and testing it against performance in subsequent events within the same jurisdiction, would test the mechanism on its own terms and is a priority for future work rather than a revision attempted here.

5.4. Interpreting digital information integration

Digital information integration correlates positively with performance but carries a negative coefficient once the other dimensions are held constant. This divergence is a consequence of shared variance, not evidence that digital tools harm response. Digital integration is the least developed dimension on average, and when it is strong, it tends to accompany strong command and collaboration, making its independent contribution difficult to isolate in a small, collinear sample. The sensible interpretation is that information infrastructure enables coordination functions rather than substituting for them, and that its value will grow as adoption deepens and becomes less confounded with the maturity of the surrounding system.

5.5. Institutional reform without measured improvement

Mean performance did not rise after the 2018 creation of the Ministry of Emergency Management. This is a sober finding that should be stated plainly and interpreted with restraint. The measure captures management quality rather than ultimate outcomes; the post-2018 sample includes a broader mix of event sizes, and consolidation may yield benefits that are slow to register or appear in dimensions, such as digital integration, that are still maturing. The result nonetheless cautions against treating administrative reorganisation as a sufficient condition for better field performance, and it points to implementation, training, and information capability as the places where reform must ultimately be realised.

This absence of improvement is not merely a visual impression from the year-by-year figure; it is supported by both an unadjusted test and a regression that controls for hazard severity and disaster type (Section 4.5), neither of which finds a significant post-2018 effect. The finding should still be interpreted as limited: the outcome measured is a coded management process, not final human or economic outcomes, and 30 post-2018 events against 8 pre-2018 events is not a large basis for a policy evaluation.

5.6. What the analysis can and cannot establish

The strength of the study is its measured, multi-event base and the high joint explanatory power of the framework. Its limits are equally clear. The strong intercorrelation among the dimensions indicates that the regression captures joint rather than separable influences, and the shifting prominence of individual dimensions across subsamples confirms that no single coefficient should be over-interpreted. The design is observational, and the scores are documentary judgements, so the associations are not causal effects, and reporting bias towards better-documented events cannot be fully excluded. These constraints qualify what the central finding can support: the six dimensions cohere strongly with one another and with the documentary performance index, but that index shares construct content with two of the predictors, and the analysis should not be interpreted as a demonstrated, outcome-independent relationship without the check reported next.

The most consequential limitation is the one addressed directly in Section 4.7. Against an outcome measure built only from variables outside the six predictor scores, the joint explanatory power of the framework falls from

R^2 = 0.85 to R^2 = 0.17, and every bivariate correlation weakens substantially. This does not mean the CCMR-CL dimensions are unrelated to rescue outcomes, but it does mean that the strength of the documentary-index results reported in Sections 4.1 to 4.4 cannot be attributed to the six management dimensions alone; part of it reflects the conceptual proximity between two predictors and two outcome components. The framework's demonstrated achievement in this study is a coherent, jointly measurable description of documented management process across 38 events, not a confirmed model of objective rescue outcomes, and the two should not be conflated in reading the results.

The paired Henan–Luding comparison illustrates a related caution. Because the Luding earthquake response received the maximum score on every one of the six dimensions, the comparison cannot show whether Luding was distinguishable from other strong responses, only that it was clearly stronger than Henan; a coding instrument in which the better case sits at the ceiling on every dimension has limited room to discriminate among strong performances, and the choice of these two events, selected in part because they contrast sharply, carries some risk of confirmation bias. The comparison is retained as an illustrative pairing that motivated and helped interpret the framework, not as independent confirmatory evidence for it.

5.7. Implications and future research

Three implications follow for practice. Because command coordination anchors the system, predefined command and escalation arrangements deserve priority. Because the dimensions move together, capability investment should be balanced rather than concentrated. Furthermore, because digital integration and standardisation are the least developed dimensions, they offer the clearest room for improvement. For research, the priorities are independent double-coding to establish reliability, a longitudinal design that tests whether institutional learning raises performance in subsequent events, and the addition of hazard, exposure, and outcome variables so that management quality can be related to lives and losses rather than to documented process alone.

6. Conclusion

This study developed the CCMR-CL framework, integrating command coordination, multi-actor collaboration, operational resource allocation, rescue-team standardisation, closed-loop evaluation, and digital information integration, and evaluated it against 38 major disaster events in China between 2006 and 2025, selected for documentary availability rather than randomly sampled. The evidence is observational, based on a single analyst's structured coding of documentary sources, and the six dimensions cohere strongly with a documentary performance index built from the same kind of evidence, with a full-model adjusted R^2 of 0.82. That result should be interpreted as a description of how consistently the coded management dimensions and a coded performance index move together, not as a demonstration that the framework predicts objective rescue outcomes: when the same six dimensions were tested against an outcome measure built only from variables outside the predictor set, activation delay, exposure-adjusted casualties, and economic loss, the joint explanatory power fell from R^2 = 0.85 to R^2 = 0.17, and every individual correlation weakened substantially. Command coordination remains the one dimension whose association with the documentary index survives bootstrap resampling with a confidence interval excluding zero; no dimension can yet be shown to predict independently measured outcomes with comparable confidence.

Several findings qualify the conventional picture without conclusively establishing it. Closed-loop evaluation, often placed at the centre of disaster-management thinking, shows the weakest association with concurrent performance, a result attributable in part to the fact that it is measured from post-event activity and so cannot, by construction, explain performance in the same event; a longitudinal test against subsequent events is needed before this dimension's role can be assessed properly. Digital information integration is the least developed dimension on average, and its role is better read as enabling the other functions than as an independent driver. Performance differs by disaster type even after adjusting for hazard severity, and mean performance did not rise after the 2018 institutional reform under either an unadjusted test or one that controls for hazard severity and disaster type, though both comparisons rest on a modest number of events. The paired Henan–Luding comparison is retained as an illustrative pairing rather than confirmatory evidence, since the stronger case sits at the ceiling on every dimension. Taken together, the study offers a measurable, interdisciplinary instrument for describing documented disaster rescue management processes across a substantial set of Chinese events, and a transparent account of where that instrument's evidence is strong (its internal coherence and its association with a documentary performance index) and where it is not yet established (inter-rater reliability, and a demonstrated relationship with independently measured outcomes). Strengthening the evidence will require independent double-coding with reported agreement statistics, a larger and more representative event sample, longitudinal tracking of closed-loop learning across subsequent events,

and continued testing against outcome measures that share no construct content with the predictor dimensions.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualization: Jing Han
Data curation: Anqi Sun
Formal analysis: Jing Han
Investigation: Jianxin Jiang
Methodology: Jing Han
Resources: Haitao Zhang
Supervision: Maria Zalina Abdul Rahim
Validation: Jianxin Jiang
Visualization: Maria Zalina Abdul Rahim, Haitao Zhang
Writing–original draft: Jing Han
Writing–review & editing: Anqi Sun, Maria Zalina Abdul Rahim

Availability of data

The data were compiled from publicly available EM-DAT records and official government reports. Supporting coding matrices and analysis files are available from the corresponding author upon reasonable request.

Further disclosure

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