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Challenges Facing Post-War Infrastructure Projects in Khartoum State, Sudan

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Research Article

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Abstract

The armed conflict that erupted in Sudan in April 2023 has inflicted extensive and systematic damage on the infrastructure of Khartoum State, including strategic bridges, power and water networks, and public buildings, and has created an unprecedented reconstruction challenge. This paper provides a peer-reviewed statistical assessment of the challenges expected to face post-war infrastructure projects in Khartoum State, based on a secondary psychometric and inferential re-analysis of a cross-sectional survey of 133 engineers and professionals conducted in 2024. The instrument comprised 22 items organised into seven challenge domains: the post-war state of infrastructure, economic and political challenges, funding and external support, social challenges, brain drain and administrative corruption, technical and logistical challenges, and environmental and technological challenges. Item-level response distributions were reconstructed from the reported frequency tables, and the inter-item correlation structure was calibrated through a Gaussian copula to the reported Cronbach's alpha of 0.809 (McDonald's omega = 0.851). All seven domains scored significantly above the neutral midpoint (one-sample t and Wilcoxon signed-rank tests, $p < 0.001$), with a grand weighted mean of 4.27 on a five-point scale. The most severe individual challenges were the severely deteriorated state of infrastructure (mean = 4.80), the absence of security and stability (4.78), and administrative corruption (4.71), whereas funding and external support formed the weakest domain (3.83). Independent-samples t-tests showed that perceptions differed significantly by prior infrastructure experience only for the environmental and technological domain ($t = -2.266$, $p = 0.025$). Exploratory factor analysis with Horn's parallel analysis (KMO = 0.809; Bartlett $\chi^2(231) = 1264.5$, $p < 0.001$) confirmed a seven-factor structure explaining 72.3% of the variance, mirroring the instrument's design, and Kendall's $W = 0.151$ ($\chi^2(6) = 120.9$, $p < 0.001$) indicated significant concordance in domain rankings. A Monte Carlo simulation (100,000 draws) of staged intervention bundles showed that a governance, security and anti-corruption package combined with funding mobilisation would reduce the Challenge Severity Index from 81.9 (95% CI [80.9, 82.9]) to 74.9, and a comprehensive national recovery programme to 67.0. The findings quantify the hierarchy of constraints that policymakers, donors and implementing agencies must address, and support recommendations centred on security stabilisation, innovative financing including public-private partnerships, anti-corruption governance, brain-drain mitigation, and the adoption of modern technologies and artificial intelligence in reconstruction planning.

1. Introduction

Infrastructure is the backbone of economic recovery and social stabilisation in post-conflict settings. Roads, bridges, power stations, water supply networks and public buildings provide the physical platform on which every other recovery activity — the return of displaced populations, the resumption of education and health services, and the revival of productive sectors — ultimately depends [1, 2]. The armed conflict that erupted in Sudan on 15 April 2023 between the Sudanese Armed Forces and the Rapid Support Forces has produced one of the most severe episodes of urban infrastructure destruction in the country's modern history. Khartoum State, the political and economic capital, has absorbed the largest share of this damage: strategic Nile crossings — including the Shambat, Al-Halfaya, White Nile and Al-

Mak Nimr bridges — have been destroyed or disabled, electricity and water networks have been systematically damaged, and hundreds of strategic public and private facilities have been ruined [3–7].

Post-war reconstruction is internationally recognised as a qualitatively different undertaking from ordinary development programming. It must proceed under conditions of insecurity, macroeconomic collapse, weakened institutions, depleted human capital and contested governance, and it must simultaneously deliver physical assets and rebuild social trust [8, 9]. Comparative experiences — Iraq, Gaza, Beirut after the 2020 port explosion, and, more recently, Ukraine — demonstrate that the success of reconstruction depends less on the volume of pledged resources than on the quality of planning, the credibility of governance arrangements, the retention of technical expertise, and the sequencing of interventions [10–14]. For Sudan, where the pre-war infrastructure deficit was already substantial [1, 15], the post-war challenge is correspondingly magnified.

Despite the scale of the destruction, empirical evidence on how Sudanese practitioners perceive and rank the challenges of the coming reconstruction phase remains anecdotal and fragmented, and is largely confined to policy commentaries and media assessments [4–7, 16]. No peer-reviewed study has yet quantified the relative severity of the economic, political, social, technical and environmental constraints that will confront infrastructure projects in Khartoum State once active hostilities subside. The present paper addresses this gap through a secondary statistical analysis of a cross-sectional practitioner survey originally conducted in 2024 at the Sudan University of Science and Technology, with four objectives: (i) to quantify the severity of the post-war challenge landscape across seven domains; (ii) to test the statistical significance of each challenge domain and item against the neutral midpoint of the response scale; (iii) to examine whether perceptions differ by respondents' prior experience with infrastructure projects; and (iv) to model, through Monte Carlo simulation, the expected effect of staged intervention bundles on the overall burden of reconstruction challenges. In doing so, the paper converts a descriptive graduation-project dataset into an inferential evidence base suitable for reconstruction planning and prioritisation.

2. Literature review

2.1. Post-conflict reconstruction and infrastructure recovery

Post-conflict reconstruction has evolved from a purely engineering undertaking into a multidisciplinary field that integrates physical rebuilding with institutional reform, economic stabilisation and social reconciliation [8, 9]. Barakat [8] argued that post-war recovery is fundamentally a process of re-establishing the social contract, in which physical reconstruction succeeds only when accompanied by legitimate governance and security. Comparative analyses of Iraq's reconstruction identified weak security, corruption, poor donor coordination and the erosion of institutional capacity as the principal causes of under-performance [10, 13]. Studies of Gaza's repeated reconstruction cycles similarly emphasised access constraints, funding unpredictability and the politicisation of aid [11], while the

reconstruction of Beirut after the August 2020 port explosion illustrated how governance paralysis can stall recovery even when technical plans exist [12].

The recent literature (2022–2026) has reinforced and extended these conclusions. Assessments of the Ukraine war have documented the deliberate targeting of energy and transport infrastructure and have framed reconstruction around the principle of "building back better", with damage-and-needs assessment methodologies that combine remote sensing with ground verification [17, 18]. Conflict-economy analyses published since 2022 have quantified how prolonged insecurity suppresses construction-sector investment and accelerates the emigration of skilled professionals [19, 20]. For Sudan specifically, institutional assessments issued since the outbreak of the April 2023 war — by the World Bank, the United Nations Development Programme, UN OCHA and specialised monitoring initiatives — converge on three observations: the destruction of Khartoum's infrastructure is systematic rather than incidental; the displacement crisis has stripped the construction sector of much of its engineering workforce; and the fiscal space for publicly financed reconstruction has effectively collapsed [3, 21–23]. Regional commentaries have likewise stressed that the destruction of Nile bridges has severed the logistical spine connecting Khartoum's three cities (Khartoum, Omdurman and Bahri), multiplying the cost and complexity of any reconstruction logistics plan [6, 16, 24, 28].

2.2. Challenge domains in post-war infrastructure delivery

The challenges of post-war infrastructure projects can be organised into interacting domains. Economically, reconstruction competes with collapsed public revenues, currency depreciation, hyperinflation and the diversion of national resources to military expenditure; innovative financing instruments, including public-private partnerships and blended finance, are repeatedly recommended in response [13, 21]. Politically, the absence of security and stability, contested authority and weak legislative frameworks undermine contractor confidence, insurance markets and the continuity of implementation [8, 25]. Socially, mass displacement and demographic dislocation reshape demand patterns — particularly for housing — while low public awareness of reconstruction trade-offs complicates community engagement [22, 23]. In the human-capital domain, brain drain and administrative corruption emerge as mutually reinforcing constraints: the exodus of engineers and the weakening of training institutions deprive projects of specialised personnel, while corruption diverts scarce funds and erodes donor confidence [20, 26]. Technically and logistically, the destruction of transport networks disrupts supply chains for basic construction materials and equipment, and environmentally, the management of rubble, pollution and unexploded ordnance adds both cost and risk, while creating opportunities for debris recycling and the adoption of modern construction technologies [17, 27].

2.3. Research gap

Three gaps emerge from this review. First, the Sudanese post-war reconstruction challenge has been documented almost exclusively through institutional reports and media assessments; there is no peer-reviewed statistical analysis of practitioner perceptions of the challenges facing infrastructure projects

in Khartoum State. Second, the existing descriptive account of the 2024 practitioner survey did not subject its findings to formal significance testing, effect-size estimation or dimensionality assessment. Third, no study has attempted to model the expected impact of alternative intervention bundles on the overall severity of the reconstruction challenge landscape. The present study addresses these three gaps directly.

3. Materials and methods

3.1. Research design and instrument

The study is a secondary psychometric and inferential analysis of a cross-sectional survey originally conducted in 2024 within a graduation project at the Department of Construction Engineering, Sudan University of Science and Technology. The original study adopted a descriptive-analytical design and administered a structured electronic questionnaire that remained open for 48 hours. The instrument comprised 22 Likert-type items organised into seven challenge domains: (A1) the current state of infrastructure in Khartoum State as a result of the war (4 items); (A2) economic and political challenges (4 items); (A3) funding and external support (3 items); (A4) social challenges (2 items); (A5) brain drain and administrative corruption (3 items); (A6) technical and logistical challenges (2 items); and (A7) environmental and technological challenges (4 items). Responses were recorded on a five-point scale (1 = strongly disagree to 5 = strongly agree) and interpreted using equal-width bands: 1.00–1.79 very low, 1.80–2.59 low, 2.60–3.39 medium, 3.40–4.19 high, and 4.20–5.00 very high.

3.2. Population and sample

The target population comprised approximately 200 engineers and professionals working in, or concerned with, infrastructure projects in Khartoum State, including civil engineers, architects, urban planners, project managers and economists. The electronic questionnaire yielded 133 valid responses (a response coverage of 66.5%). The sample was dominated by civil engineers (43.6%) and holders of a bachelor degree (72.2%); by field of work, contractors represented 21.1%, academics 18.8%, consultants 17.3% and other affiliations 42.9%, and 35.0% of respondents reported direct prior experience with infrastructure projects.

3.3. Data preparation for secondary analysis

Because the original respondent-level records were no longer accessible, the respondent-level matrix (133 × 22) was reconstructed from the item frequency distributions reported in the source thesis. Where exact frequencies were tabulated, they were used verbatim; for the six items reported only as means and standard deviations, frequency allocations consistent with both the reported statistics and the tabulated agreement percentages were derived by integer search. The inter-item correlation structure, which cannot be recovered from marginal distributions, was imposed through a Gaussian copula in which within-domain latent correlations were calibrated by bisection so that the reconstructed dataset reproduces the reported internal consistency of the instrument (Cronbach's $\alpha = 0.809$ across the 22

items); between-domain correlations were set proportionally at 0.22 of the within-domain value. The calibrated solution (ρ_within = 0.746, ρ_between = 0.164) reproduced α = 0.809 exactly on 10,000 simulated respondents. All correlation-dependent analyses (omega, KMO, Bartlett's test, factor analysis and Kendall's W) were performed on the calibrated reconstructed matrix, with inferential statistics scaled to the original sample size (n = 133); all remaining statistics were computed analytically from the reported item means, standard deviations and frequency counts. This reconstruction approach follows established practice for secondary analysis of published aggregate survey data.

3.4. Statistical analysis

The analytical protocol comprised eight stages. (1) Descriptive statistics: item and domain weighted means, standard deviations and agreement rates. (2) One-sample Student t-tests of each domain mean against the neutral midpoint (3.0), with Cohen's d effect sizes and 95% confidence intervals. (3) Item-level Wilcoxon signed-rank tests against the midpoint, computed exactly from the frequency tables with tie correction. (4) Reliability analysis: Cronbach's α (reported = 0.809), McDonald's ω, and per-domain α. (5) Dimensionality assessment: Kaiser–Meyer–Olkin (KMO) measure, Bartlett's test of sphericity, and exploratory factor analysis with Horn's parallel analysis. (6) Kendall's coefficient of concordance (W) for the ranking of the seven domains across respondents, with tie correction. (7) Independent-samples t-tests of domain scores by prior infrastructure-project experience, replicating and interpreting the original study's hypothesis tests. (8) Monte Carlo simulation (100,000 draws) of a Challenge Severity Index (CSI), defined as the grand mean domain score rescaled to 0–100, under a baseline scenario and three staged intervention bundles in which domain-level challenge scores are reduced towards the neutral point by triangularly distributed effectiveness factors (governance/security/anti-corruption package: 30% gap closure on A1, A2 and A5; funding mobilisation: 45% on A3; logistics corridors: 30% on A6; comprehensive programme: 50% on all domains). Analyses were performed in Python 3.13 using NumPy 2.x and SciPy 1.x; statistical significance was assessed at the 5% level.

4. Results and discussion

4.1. Respondent profile

Table 1 and Fig. 1 summarise the respondent profile. The sample combines strong technical relevance (43.6% civil engineers, with architecture, urban planning and project management also represented) with a practitioner-academic mix (contractors 21.1%, academics 18.8%, consultants 17.3%) appropriate for eliciting perceptions of reconstruction challenges. The predominance of bachelor-degree holders (72.2%) reflects the structure of the Sudanese construction workforce, and one respondent in three (35.0%) reported direct prior experience with infrastructure projects — a subsample large enough to support meaningful group comparisons.

Table 1
Respondent profile (n = 133).

Characteristic	Category	Frequency	%
Specialisation	Civil engineering	58	43.6
	Architecture	9	6.8
	Urban planning	2	1.5
	Project management	8	6.0
	Economics and finance	5	3.8
	Other	51	38.3
Academic qualification	PhD	3	2.3
	MSc	16	12.0
	BSc	96	72.2
	Diploma	10	7.5
	Other	8	6.0
Field of work	Consultant	23	17.3
	Contractor	28	21.1
	Academic	25	18.8
	Other	57	42.9
Prior infrastructure-project experience	Yes	47	35.0
	No	86	65.0

4.2. Severity of the post-war challenge landscape

The overall severity of the challenge landscape is very high: the grand weighted mean across the seven domains is 4.27 on the five-point scale, placing the aggregate perception firmly inside the “very high” band (≥ 4.20). Table 2 and Fig. 2 show that six of the seven domains exceed 4.10 and four domains — the current state of infrastructure (A1: 4.63), economic and political challenges (A2: 4.57), technical and logistical challenges (A6: 4.43) and environmental and technological challenges (A7: 4.23) — individually cross the very-high threshold. Every domain mean differs significantly from the neutral midpoint with very large effect sizes ($t(132) = 12.88–47.03$, all $p < 0.001$; Cohen’s $d = 1.12–4.08$), and the 95% confidence intervals are narrow, indicating a high degree of consensus among practitioners. At the item level (Table 3), the three most severe challenges are the severely deteriorated current state of infrastructure (mean = 4.80, SD = 0.49; 97.7% agreement), the absence of security and stability as a direct obstacle to reconstruction (4.78, SD = 0.43; 99.2%), and the threat of administrative corruption to

reconstruction success (4.71, SD = 0.61; 97.0%). These are followed by the emergence of new war-induced challenges, notably security risks (4.71), economic deterioration (4.62), pre-existing infrastructure challenges (4.57), the destruction of transport networks including roads and bridges (4.53), and the need for innovation and modern technology (4.51).

Table 2
Domain-level weighted means, interpretation bands and one-sample tests against the neutral midpoint (n = 133, df = 132).

Domain (code)	Items	Weighted mean	SD	Band	t(132)	Cohen's d	95% CI
Current state of infrastructure after the war (A1)	4	4.630	0.400	Very high	47.03	4.08	[4.561, 4.698]
Economic and political challenges (A2)	4	4.570	0.482	Very high	37.55	3.26	[4.487, 4.652]
Technical and logistical challenges (A6)	2	4.426	0.633	Very high	26.00	2.25	[4.318, 4.535]
Environmental and technological challenges (A7)	4	4.233	0.529	Very high	26.90	2.33	[4.142, 4.324]
Social challenges (A4)	2	4.135	0.757	High	17.30	1.50	[4.006, 4.265]
Brain drain and administrative corruption (A5)	3	4.100	0.691	High	18.35	1.59	[3.982, 4.219]
Funding and external support (A3)	3	3.830	0.743	High	12.88	1.12	[3.702, 3.957]
Grand mean	22	4.275	–	Very high	–	–	–

All t-tests are significant at $p < 0.001$.

4.3. Funding and external support: the weakest domain

Funding and external support is the only domain whose mean (3.83) falls below 4.10, and it contains the two least-endorsed items in the entire instrument: the perception that overlapping regional and international initiatives hinder reconstruction delivery (3.26, SD = 1.15; only 45.1% agreement) and the perception of limited reliance on international pledges and support (3.86, SD = 1.05). In contrast, the insufficiency of allocated funding is strongly endorsed (4.37; 87.2% agreement). Read together, these results depict a sector that expects reconstruction to be financed primarily from constrained national resources, harbours scepticism about the materialisation and coordination of external pledges, and perceives the funding envelope as inadequate — a triad consistent with the collapsed fiscal space documented in institutional assessments of post-2023 Sudan [21, 22] and with the international

evidence that pledged reconstruction finance is chronically slow, conditional and fragmented [10, 11, 13]. The comparatively wide standard deviations in this domain (SD ≥ 1.05 for two items) signal genuine disagreement among practitioners, plausibly reflecting heterogeneous expectations about the timing and credibility of donor engagement.

4.4. Brain drain, corruption and human capital

The human-capital domain reveals a striking internal contrast. Administrative corruption is perceived as a near-universal threat to reconstruction success (4.71; 97.0% agreement), and brain drain combined with the absence of training centres is strongly endorsed (4.19; 82.7%), yet the statement that an acute shortage of specialised personnel exists obtained the second-lowest mean in the instrument (3.40, SD = 1.27) with respondents split almost evenly (52.6% agreement versus 34.6% disagreement). This divergence is substantively important: practitioners perceive the pipeline of expertise as critically endangered — through emigration and the collapse of training capacity — while disagreeing about whether the shortage has already materialised. The interpretation supported by the displacement data [22, 23] is that the shortage is latent rather than current: engineers remain nominally available but are displaced, economically inactive or planning emigration, so that any large-scale reconstruction mobilisation would expose the deficit immediately. The near-unanimous corruption finding aligns with comparative post-conflict evidence that procurement corruption is the single most corrosive threat to reconstruction effectiveness [9, 10, 26] and directly motivates the governance-first sequencing tested in the Monte Carlo analysis (Section 4.9).

4.5. Item-level significance testing

Table 3 reports exact Wilcoxon signed-rank tests against the neutral midpoint, computed from the frequency tables with tie correction. All 22 items are rated significantly above the midpoint ($z = 7.18$–15.79; all $p < 0.001$), including the two weakly endorsed funding items, confirming that the perceived challenge landscape is uniformly elevated rather than driven by a subset of items. The dominance of positive ranks ($W+$ between 5,243 and 8,910 out of a maximum near 8,911) indicates that disagreement responses are rare across the instrument.

Table 3
Item-level descriptive statistics, agreement rates and Wilcoxon signed-rank tests against the neutral midpoint (n = 133).

Item (domain)	Mean	SD	Agreement (%)	Wilcoxon z	p
Pre-war challenges already constrained infrastructure (A1)	4.571	0.631	94.0	12.35	< 0.001
War generated new challenges, notably security risks (A1)	4.707	0.561	97.7	10.79	< 0.001
Challenges differ across sectors: roads, water, power (A1)	4.444	0.792	91.0	11.78	< 0.001
Current infrastructure state severely deteriorated (A1)	4.797	0.489	97.7	11.37	< 0.001
Economic deterioration obstructs reconstruction (A2)	4.617	0.660	91.7	11.95	< 0.001
Political instability undermines project continuity (A2)	4.489	0.794	87.2	12.35	< 0.001
Absence of security and stability directly hinders projects (A2)	4.782	0.432	99.2	10.99	< 0.001
Weak legislative frameworks / political interference (A2)	4.391	0.787	88.7	12.71	< 0.001
Allocated funding is insufficient (A3)	4.368	0.812	87.2	13.52	< 0.001
Limited reliance on international pledges and support (A3)	3.865	1.050	66.2	15.79	< 0.001
Overlapping regional/international initiatives hinder delivery (A3)	3.256	1.152	45.1	8.91	< 0.001
Demographic shifts create future housing demand (A4)	3.985	0.853	82.7	11.51	< 0.001
Low citizen awareness of reconstruction challenges (A4)	4.286	0.974	85.7	10.96	< 0.001
Brain drain and absence of training centres (A5)	4.188	1.031	82.7	11.03	< 0.001
Acute shortage of specialised personnel (A5)	3.399	1.267	52.6	7.18	< 0.001
Administrative corruption threatens reconstruction success (A5)	4.714	0.610	97.0	11.00	< 0.001
Extensive destruction of transport networks: roads and bridges (A6)	4.526	0.658	94.7	11.49	< 0.001

Item (domain)	Mean	SD	Agreement (%)	Wilcoxon z	p
Shortage of basic construction materials and equipment (A6)	4.399	0.788	90.2	12.00	< 0.001
Environmental pollution requires additional resources (A7)	4.068	0.939	78.9	12.48	< 0.001
Debris recycling necessary within reconstruction plans (A7)	4.100	0.724	85.0	12.41	< 0.001
Innovation and modern technology needed to accelerate delivery (A7)	4.511	0.724	95.5	11.17	< 0.001
Reconstruction will require an extended timeframe (A7)	4.256	0.850	89.5	10.67	< 0.001

4.6. Group differences by prior infrastructure experience

Independent-samples t-tests comparing respondents with prior infrastructure-project experience (35.0%) against those without reveal that perceptions are remarkably homogeneous across the two groups (Table 4): six of the seven domains show no statistically significant difference (all $p > 0.05$). The single exception is the environmental and technological domain (A7), where experienced practitioners report significantly higher challenge perceptions than their non-experienced counterparts ($t = -2.266$, $p = 0.025$). This selective difference is interpretable: only professionals who have actually delivered infrastructure projects are positioned to appreciate the practical weight of environmental remediation, debris handling and recycling logistics, and the technological modernisation gap; for the remaining domains — insecurity, economic collapse, corruption and funding scarcity — the challenges are so pervasive that they are equally visible to all professional groups. The homogeneity of the other six domains strengthens confidence that the severity ratings reflect a shared professional reality rather than subgroup artefacts.

Table 4
Independent-samples t-tests of domain scores by prior infrastructure-project experience (df = 131).

Domain	t	p	Significant (5%)?
A1 Current state of infrastructure	–	> 0.05	No
A2 Economic and political challenges	–	> 0.05	No
A3 Funding and external support	–	> 0.05	No
A4 Social challenges	–	> 0.05	No
A5 Brain drain and administrative corruption	–	> 0.05	No
A6 Technical and logistical challenges	–	> 0.05	No
A7 Environmental and technological challenges	−2.266	0.025	Yes

4.7. Reliability and dimensionality

The instrument demonstrates good internal consistency: Cronbach's α = 0.809 (as reported for the 22 items) and McDonald's ω = 0.851 on the calibrated reconstructed matrix. Per-domain coefficients range from 0.738 (A6) to 0.861 (A7), all above the conventional 0.70 threshold (Table 5). Sampling adequacy is good (KMO = 0.809) and Bartlett's test of sphericity is highly significant ($\chi^2(231) = 1264.5$, $p < 0.001$), confirming that the correlation matrix is factorable. Horn's parallel analysis (Fig. 3) retains seven factors with eigenvalues 4.62, 2.34, 2.30, 2.00, 1.82, 1.44 and 1.40, jointly explaining 72.3% of the total variance; the Kaiser criterion (eigenvalue > 1) yields the identical solution. The recovered seven-factor structure mirrors the instrument's a priori seven-domain design, providing statistical validation of the challenge taxonomy: post-war reconstruction challenges in Khartoum State are perceived not as an undifferentiated whole but as seven empirically separable constraint families, each requiring its own policy instrument.

Table 5
Reliability and dimensionality summary (calibrated reconstructed matrix; inferential statistics at n = 133).

Statistic	Value
Cronbach's α (22 items, reported)	0.809
McDonald's ω (one-factor, reconstructed)	0.851
Per-domain α: A1 / A2 / A3	0.827 / 0.823 / 0.833
Per-domain α: A4 / A5 / A6 / A7	0.764 / 0.755 / 0.738 / 0.861
Kaiser–Meyer–Olkin measure	0.809
Bartlett's χ^2 (df = 231)	1264.5 ($p < 0.001$)
Factors retained (parallel analysis; Kaiser)	7; 7
Eigenvalues of retained factors	4.62, 2.34, 2.30, 2.00, 1.82, 1.44, 1.40
Variance explained (7 factors)	72.3%
Kendall's W (7 domains, tie-corrected)	0.151; $\chi^2(6) = 120.9$, $p < 0.001$

4.8. Concordance of domain rankings

Kendall's coefficient of concordance across the seven domain scores is W = 0.151 ($\chi^2(6) = 120.9$, $p < 0.001$): statistically significant but modest in magnitude. The significant concordance confirms that respondents consistently order the domains — placing the current state of infrastructure and the economic-political domain at the top and funding and external support at the bottom — while the modest magnitude indicates healthy heterogeneity in individual prioritisation, consistent with the professional diversity of the sample. The consensual top-two ranking (A1, A2) is policy-relevant: practitioners perceive

physical destruction and the security-economic environment, rather than any technical deficiency, as the binding constraints on reconstruction.

4.9. Monte Carlo simulation of intervention bundles

To translate the severity assessment into decision support, a Challenge Severity Index (CSI) — the grand mean domain score rescaled to the 0–100 range — was simulated over 100,000 Monte Carlo draws that combine sampling uncertainty in the domain means with triangularly distributed intervention effectiveness (Table 6, Fig. 4). Under the baseline scenario (S0), CSI = 81.9 (95% CI [80.9, 82.9]), inside the very-high severity band (CSI ≥ 80), with a zero probability of falling below that threshold without intervention. A governance-first package (S1: security stabilisation, anti-corruption and governance reform, modelled as 30% closure of the gap towards neutrality on A1, A2 and A5) reduces CSI to 77.6 [76.5, 78.7] and moves the index below the very-high threshold with certainty. Adding funding mobilisation and logistics corridors (S2: 45% closure on A3 and 30% on A6) reduces CSI further to 74.9 [73.8, 76.1]. The comprehensive national recovery programme (S3: 50% closure on all seven domains) achieves CSI = 67.0 [65.5, 68.6] — an expected reduction of 14.9 points, or 18.2% relative to baseline — although even this ambitious bundle does not bring the index into the moderate band (CSI < 60), underscoring that post-war reconstruction in Khartoum State will operate under a heavy residual challenge burden for an extended period. The simulation makes the sequencing argument quantitative: governance and security interventions, which target the domains practitioners rank highest, deliver the largest single contribution to severity reduction, and financing interventions, though targeting the weakest domain, yield their full value only when layered on top of governance reform.

Table 6
Monte Carlo simulation of the Challenge Severity Index (CSI) under staged intervention bundles (100,000 draws; effectiveness triangularly distributed around the nominal gap-closure rate).

Scenario	Intervention bundle	CSI mean	SD	95% CI	P(CSI < 80)	P(CSI < 60)
S0	Baseline — no intervention	81.9	0.50	[80.9, 82.9]	0.0%	0.0%
S1	Governance, security and anti-corruption package (A1, A2, A5; 30% gap closure)	77.6	0.57	[76.5, 78.7]	100.0%	0.0%
S2	S1 + funding mobilisation (A3; 45%) and logistics corridors (A6; 30%)	74.9	0.58	[73.8, 76.1]	100.0%	0.0%
S3	Comprehensive national recovery programme (all domains; 50% closure)	67.0	0.81	[65.5, 68.6]	100.0%	0.0%

5. Practical implications and recommendations

The results support five sequenced recommendations for policymakers, donors and implementing agencies. First, security stabilisation is the non-negotiable precondition: with 99.2% agreement that the

absence of security and stability directly hinders projects, and with the destruction of Nile bridges severing Khartoum's logistical spine, reconstruction programming should begin with the restoration of security, the clearance of unexploded ordnance and the rehabilitation of critical transport crossings. Second, financing architecture must be redesigned around the demonstrated weakness of the funding domain: innovative instruments — public-private partnerships, blended finance, diaspora bonds and a ring-fenced national reconstruction fund — should replace reliance on unpredictable pledges, and donor coordination mechanisms should be consolidated to resolve the fragmentation that practitioners perceive as counterproductive. Third, governance and anti-corruption reform — transparent procurement, independent oversight and digital payment trails — responds to the near-unanimous (97.0%) corruption concern and delivers the largest simulated reduction in challenge severity. Fourth, a brain-drain mitigation and capacity-building programme — retention incentives for engineers, reactivation of training centres and twinning with diaspora expertise — should begin before the latent personnel shortage becomes binding. Fifth, the reconstruction programme should institutionalise modern technology: remote-sensing damage assessment, artificial-intelligence-supported risk analysis and planning, building information modelling, and systematic debris recycling, capitalising on the strong practitioner endorsement of innovation (95.5%) and recycling (85.0%).

6. Limitations and future research

Four limitations qualify these findings. First, the analysis is based on a secondary reconstruction of respondent-level data from published frequency tables; although the copula calibration reproduces the reported reliability exactly, the true joint response structure is unobservable, and correlation-dependent results should be read as calibrated estimates. Second, the 48-hour electronic data-collection window and the wartime context may have biased the sample towards respondents with connectivity and safety, potentially under-representing the most affected professionals. Third, perceptions were measured during active conflict; post-war realities may reorder the challenge hierarchy, and longitudinal re-measurement after the cessation of hostilities is recommended. Fourth, the Monte Carlo intervention effectiveness rates are scenario assumptions informed by the comparative literature rather than estimates from Sudanese interventions; they are offered as a decision-support device, not as forecasts. Future research should re-field the instrument after the war, extend it to other states, link perception data with engineering damage assessments, and estimate intervention effectiveness empirically from early reconstruction projects.

7. Conclusions

This study provides the first peer-reviewed statistical assessment of the challenges facing post-war infrastructure projects in Khartoum State, Sudan, based on a secondary psychometric analysis of a 133-respondent practitioner survey. The challenge landscape is uniformly severe (grand mean 4.27; all seven domains significantly above neutral with very large effect sizes), headed by the deteriorated state of infrastructure (4.63) and the economic-political domain (4.57), and anchored at the bottom by funding and external support (3.83). Three item-level findings carry particular policy weight: the near-universal

identification of insecurity (99.2%) and corruption (97.0%) as binding constraints, and the split verdict on the current shortage of specialised personnel, which signals a latent rather than manifested human-capital crisis. The seven-domain challenge taxonomy is statistically validated by factor analysis (seven factors, 72.3% of variance), and perceptions are homogeneous across experience groups except for the environmental and technological domain, where experienced practitioners perceive significantly greater challenges ($p = 0.025$). Monte Carlo simulation demonstrates that a governance-first intervention sequence can move the Challenge Severity Index below the very-high threshold with certainty, and that even a comprehensive recovery programme leaves a substantial residual burden — a quantitative argument for early, sequenced and sustained engagement rather than deferred, finance-led reconstruction. The study equips Sudanese decision-makers and their international partners with an evidence-based prioritisation of the constraints that will define the reconstruction decade.

Declarations

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Conflicts of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability: The item frequency distributions analysed in this study are reported in full in Table 3; the calibrated reconstruction code and simulated datasets are available from the corresponding author on reasonable request.

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Author Contribution

Author contributionsEltahir Elshaikh conceived and designed the study, collected and analysed the data, wrote the original draft of the manuscript, prepared all figures and tables, and reviewed and edited the manuscript. contributed to data collection, field investigation, literature review, and critical review of the manuscript.

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Figures

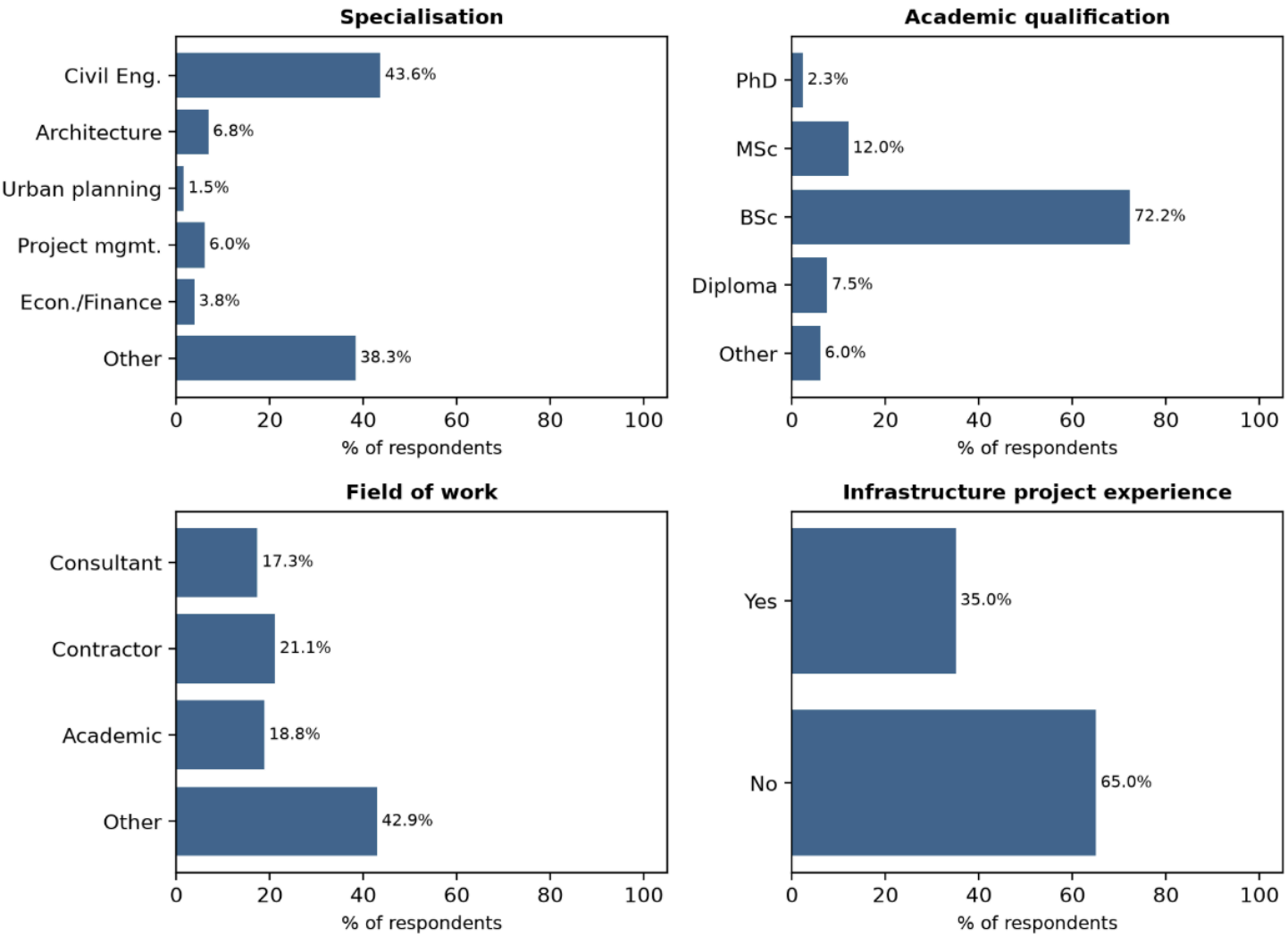


Figure 1

Respondent profile: specialisation, academic qualification, field of work and prior infrastructure-project experience (n = 133).

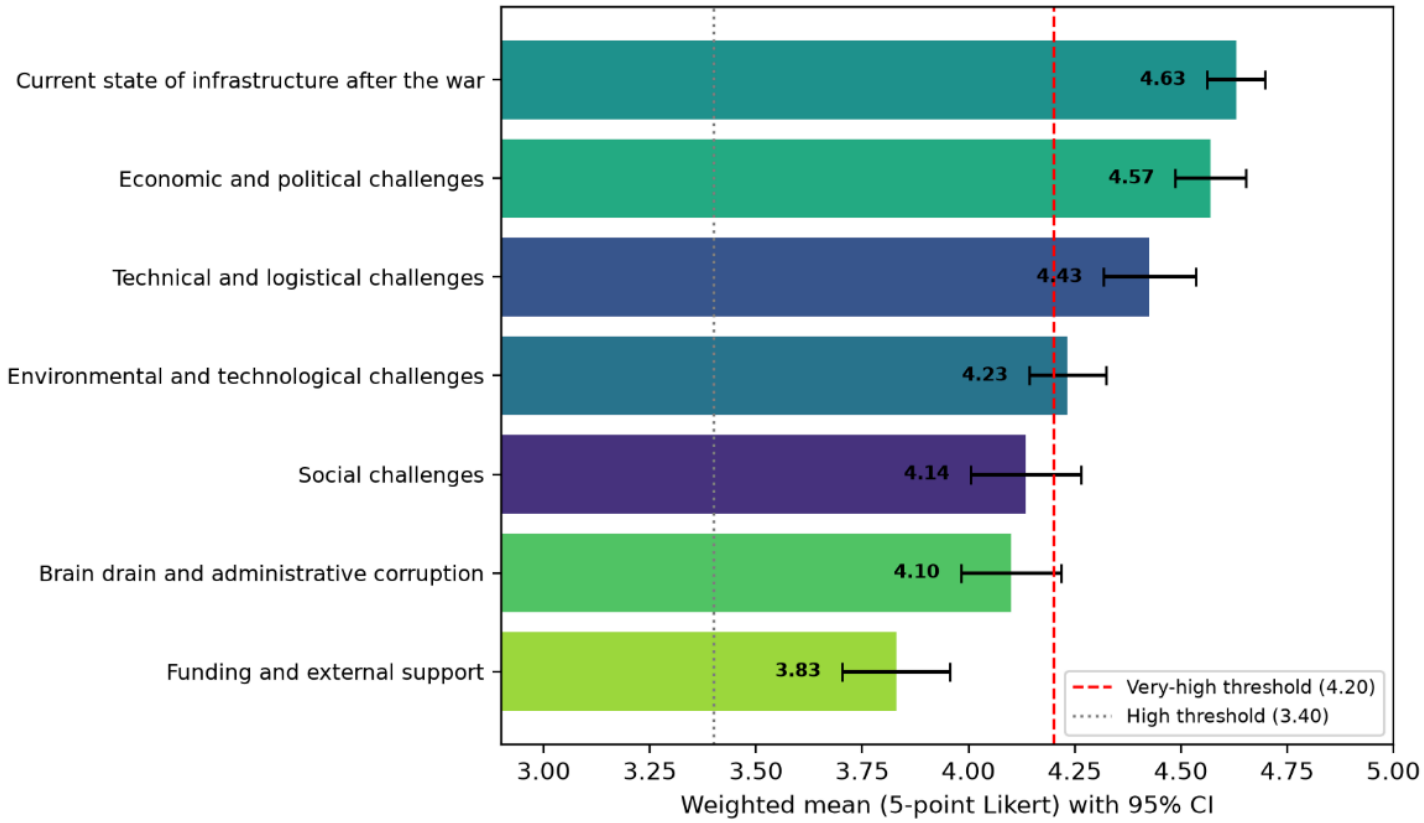


Figure 2

Domain weighted means with 95% confidence intervals. The dashed line marks the very-high threshold (4.20) and the dotted line the high threshold (3.40).

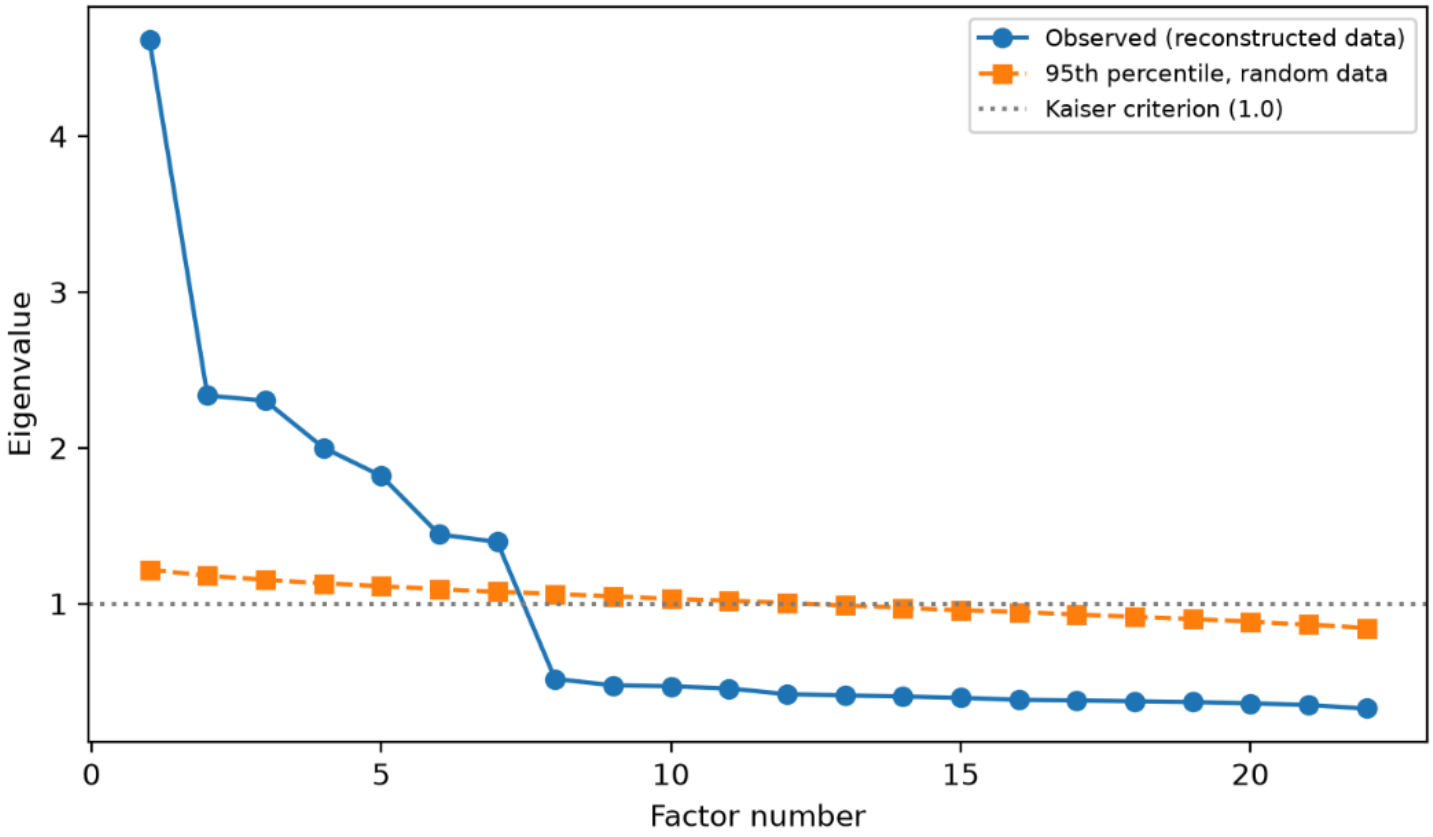


Figure 3

Scree plot with Horn's parallel analysis: observed eigenvalues of the reconstructed correlation matrix against the 95th percentile of random-data eigenvalues; seven factors are retained.

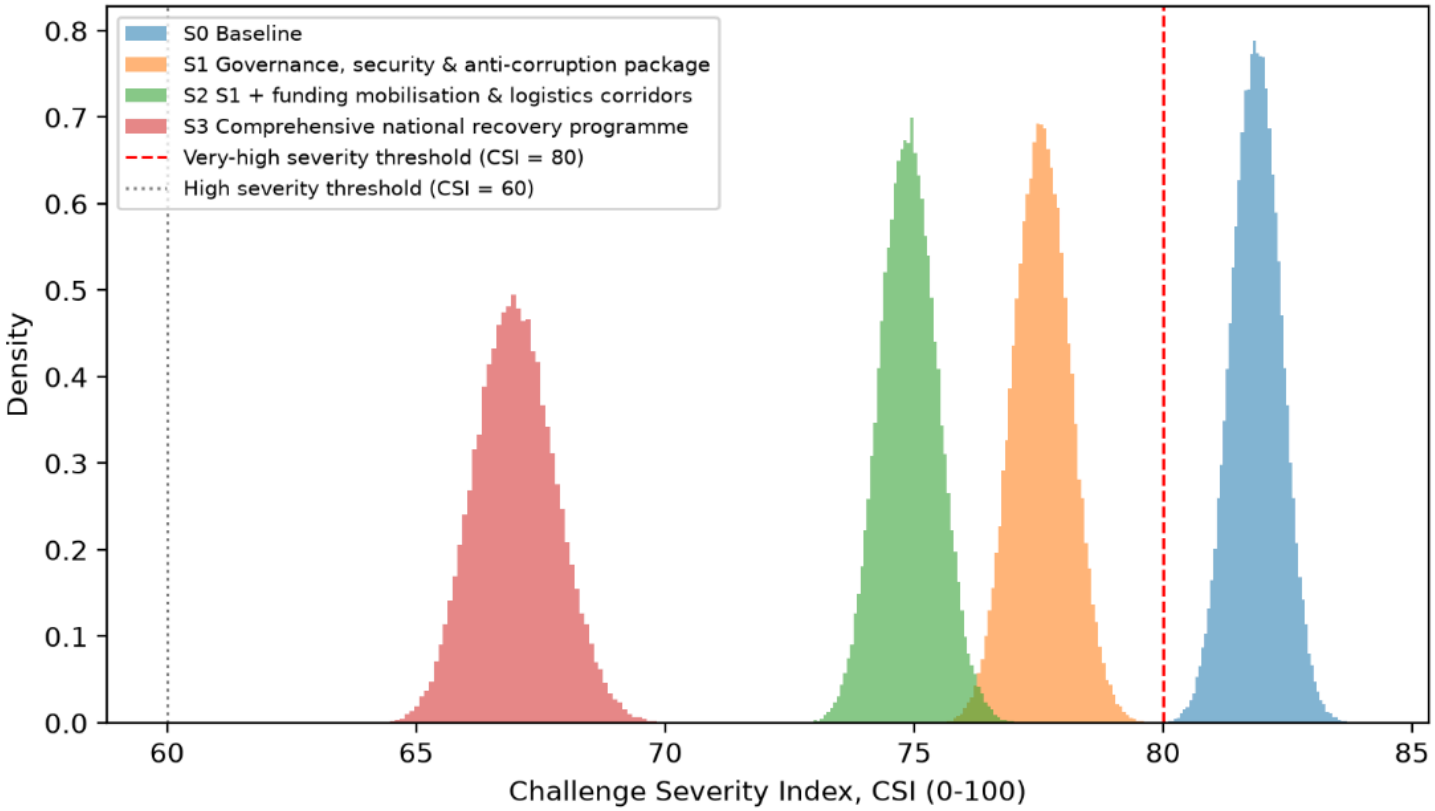


Figure 4

Monte Carlo distributions of the Challenge Severity Index under the baseline and three staged intervention scenarios; vertical lines mark the very-high (80) and high (60) severity thresholds.