

Developing a Risk-Based Environmental Management Framework for Large-Scale Infrastructure Projects in Saudi Arabia

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Abstract: Saudi Arabia's infrastructure transformation under Vision 2030 is creating an exceptional need for environmental management systems that can operate at the scale, speed, complexity and ecological sensitivity of giga- and mega-project delivery. Conventional environmental management plans often catalogue impacts and controls but do not always provide a transparent method for prioritising uncertain, cumulative and high-consequence environmental risks across the project life cycle. This paper develops a risk-based environmental management framework for large-scale infrastructure projects in Saudi Arabia. The study adopts a conceptual and structured narrative synthesis of contemporary construction-sustainability literature, international risk and environmental management standards, and Saudi regulatory and policy requirements. The proposed framework integrates ISO 31000 risk principles with the lifecycle and continual-improvement logic of ISO 14001:2026, while reflecting National Center for Environmental Compliance permitting and monitoring expectations. It introduces a six-factor adjusted environmental risk score combining likelihood, consequence, exposure, legal significance, ecological reversibility and control effectiveness. The framework is organised into eight connected stages: context and compliance definition; risk identification; analysis; evaluation; treatment planning; control execution; monitoring and assurance; and adaptive review. A practical risk taxonomy, scoring criteria, governance structure, key performance indicators and an illustrative risk register are presented. The framework is designed to strengthen traceability from environmental impact assessment through design, construction, commissioning, operation and closure, enabling project teams to concentrate resources on material environmental risks rather than treating all aspects equally. The paper contributes a Saudi-contextualised decision-support approach that links regulatory compliance, project risk governance and environmental performance. Empirical validation through expert elicitation and application to active infrastructure projects is recommended as the next research stage.

Keywords: Saudi Vision 2030; environmental risk management; infrastructure projects; environmental impact assessment; ISO 14001; ISO 31000; NCEC; sustainability; megaprojects; adaptive management.

I. INTRODUCTION

Saudi Arabia is undertaking one of the world's most extensive programs of infrastructure, urban development, tourism, transport, energy and industrial investment. Vision 2030 positions environmental protection and restoration alongside economic diversification, liveability and institutional effectiveness. The Vision 2030 Annual Report 2025 describes sustainability as an organising principle for long-term growth and highlights expanding protected areas, landscape restoration, circular-economy initiatives and other environmental programs. In parallel, the Saudi Green Initiative sets national ambitions for emissions reduction, ecosystem protection and large-scale landscape restoration. These policy directions mean that environmental performance is no longer a peripheral compliance activity for major projects; it is increasingly connected to strategic delivery, access to permits, stakeholder confidence, asset resilience and the long-term legitimacy of infrastructure investment.

Large infrastructure projects create distinctive environmental management challenges. Their footprints can span multiple ecosystems and administrative interfaces; their construction periods may last many years; their supply chains can mobilise large volumes of materials, water, fuel and waste; and the timing of works may interact with seasonal ecological or meteorological conditions. Linear infrastructure can fragment habitats and alter drainage, while ports and coastal assets can affect marine systems. Tunnelling, quarrying, batching, earthworks and haul roads introduce dust, noise, vibration, spoil

and accidental-release risks. Camps and temporary facilities add wastewater, solid-waste and resource-demand pressures. These impacts are not automatically severe, but the combination of scale, uncertainty, interfaces and cumulative effects makes conventional checklist-based environmental management inadequate for the most complex projects.

Saudi Arabia has also strengthened the regulatory architecture surrounding environmental permitting and compliance. The National Center for Environmental Compliance (NCEC) supervises environmental permits and the review of environmental impact studies, with construction activities differentiated by environmental impact category. The executive regulation governing environmental permits applies to new and existing activities across construction, operation, modification, expansion and closure, and provides for review of environmental impact assessment documentation, monitoring of environmental management plans, site inspection and self-monitoring reports. The implication for major projects is clear: environmental management must be demonstrable, documented and capable of showing that significant risks are identified, controlled, monitored and reviewed over time.

A risk-based approach provides a way to meet this need. ISO 31000:2018 defines a generic process for identifying, analysing, evaluating, treating, monitoring and communicating risk. ISO 14001:2026, the current international environmental management systems standard, places environmental aspects, compliance obligations, risks and opportunities, lifecycle thinking and continual improvement within a single management-system structure. Combining these ideas allows project teams to move beyond static environmental aspect registers toward dynamic risk governance in which environmental threats are compared on a consistent basis, ownership is assigned, controls are linked to measurable indicators and management attention is escalated according to residual risk.

Recent research reinforces the value of integration. Coskun, Dikmen and Birgonul (2023) show that megaproject sustainability risk assessment benefits from integrating environmental, social and economic

objectives and recognising cross-impacts among risks. Wuni (2025) develops a multidimensional risk assessment model for sustainable construction and finds that management, technical, stakeholder, regulatory, material and economic risks interact with sustainability performance. Waqar et al. (2025) similarly report that risk management is a significant component of integrated management systems for sustainable construction. In the Saudi context, Alazmi et al. (2025) identify weak planning, coordination gaps and limited integration of environmental waste into conventional construction waste practices, while Alotaibi, Martinez-Vazquez and Baniotopoulos (2024) identify regulatory, awareness, training and incentive barriers affecting circular-economy implementation in Saudi mega-projects. Together, these studies suggest that environmental risk cannot be isolated from project governance, planning quality, contractor capability and information systems.

The objective of this paper is therefore to develop a practical Risk-Based Environmental Management Framework (RBEMF) for large-scale infrastructure projects in Saudi Arabia. Four research questions guide the paper: (1) which environmental risk domains are most relevant across the infrastructure project lifecycle; (2) how can environmental risks be prioritised using criteria that go beyond simple probability-impact scoring; (3) how can risk treatment, monitoring, assurance and escalation be integrated with Saudi compliance requirements and international management-system practice; and (4) what governance structure can make the framework usable by owners, program managers, consultants and contractors? The contribution is conceptual rather than empirical. The paper does not claim measured project outcomes; instead, it provides a structured framework and an illustrative application that can be tested in future field research.

II. LITERATURE AND SAUDI POLICY CONTEXT

Environmental management in construction has traditionally been organised around impact assessment, environmental management plans, permit conditions and site-level controls. These remain essential, but major-project literature increasingly argues that sustainability performance depends on

treating environmental issues as interconnected risks rather than independent technical topics. Sustainable construction introduces additional requirements for low-impact materials, efficient resource use, pollution prevention, circularity, social acceptance and resilience. Wuni (2025) notes that these requirements create new layers of management, technical, stakeholder and regulatory risk. Coskun et al. (2023) similarly argue that megaproject risk assessment should reflect sustainability objectives and the relationships among threats and vulnerabilities. This systems perspective is especially relevant in Saudi giga-projects where one environmental event can propagate into schedule delay, regulatory intervention, reputational damage, redesign and cost escalation.

The literature also shows that environmental performance is strongly influenced by management quality. Waqar et al. (2025) find empirical relationships between sustainable construction management and integrated approaches to quality, safety and risk. This supports the proposition that environmental controls should not sit in a separate compliance silo. They should be connected to design management, procurement, work-package planning, change control, assurance and leadership review. Salah et al. (2023) demonstrate that construction sustainability can be assessed using weighted criteria, reinforcing the usefulness of multi-criteria decision approaches where environmental priorities cannot be represented by a single indicator.

Waste provides a clear Saudi example. Aljarallah et al. (2024) identify significant causes of waste in Saudi housing infrastructure projects and link construction inefficiencies to environmental, cost, time and productivity effects. Alazmi et al. (2025) report that Saudi construction waste practice has often focused on physical waste and productivity, with less attention to non-physical environmental impacts, and propose an integrated lean/environmental framework. Alotaibi et al. (2024), examining circular economy implementation in Saudi mega-projects, identify lack of regulation, education, training, awareness, guidance and incentives among important barriers. More recent Saudi research by Baslom et al. (2026) finds that source segregation of construction and demolition waste remains uneven, with institutional fragmentation, costs and limited awareness acting as

constraints. These findings show why an environmental risk framework must include organisational and behavioural drivers, not only direct pollution pathways.

Climate and ecological risk also require lifecycle thinking. Riera et al. (2024), in work addressing extreme weather and renewable power-water-heating systems for NEOM, illustrate the importance of planning infrastructure under climatic uncertainty. At a broader scale, Adshead et al. (2024) demonstrate that coastal infrastructure can be exposed to climate threats that affect sustainable development outcomes. Saudi projects in coastal, mountain and arid environments therefore need to consider not only impacts generated by the project but also environmental conditions acting on the project, such as extreme rainfall, flash flood, heat, dust storm, sea-level and coastal hazards. ISO 14001:2026 explicitly recognises that an environmental management system should consider both adverse environmental impacts and the adverse effect of environmental conditions on the organisation. Technology can improve the visibility and traceability of risk. Ebrahim (2025/2026) describes integrated surveying technologies for risk management at NEOM's Oxagon Port, including GIS, LiDAR, UAVs and scanning. While the study addresses wider project risks, the underlying lesson for environmental management is that digital spatial data can support pre-construction baseline mapping, sensitive-receptor identification, progress surveillance and evidence-based assurance. Remote sensing, continuous air and water monitoring, geo-tagged inspections and digital permit-to-work systems can convert environmental management from periodic reporting into near-real-time decision support. However, technology should support, not replace, professional judgement and regulatory compliance.

Saudi policy strengthens the case for a structured framework. NCEC environmental permitting requires projects to demonstrate appropriate environmental studies and management documentation according to impact classification. The executive regulation for environmental permits authorises review of environmental impact assessments, monitoring of environmental management plan implementation, field inspection and self-monitoring. The regulatory logic is therefore compatible with risk-based

management: significant aspects must be identified before activity begins, mitigation must be embedded in project execution, performance evidence must be available and corrective action must follow deviations. The framework proposed in this paper translates these expectations into a governance cycle.

Vision 2030 and the Saudi Green Initiative provide a broader strategic layer. The 2025 Vision 2030 reporting frames environmental restoration, circularity and resilience as part of national transformation. The Saudi Green Initiative identifies targets related to emissions reduction, protected areas and tree planting. Individual infrastructure projects do not directly “deliver” these national targets by themselves, but project decisions can either support or undermine them. Avoiding unnecessary habitat loss, reducing material waste, protecting water resources, preventing pollution and designing for climate resilience are therefore project-level contributions to the direction of national policy. A robust framework should connect strategic objectives to specific risks, controls and indicators rather than merely citing Vision 2030 in an environmental policy statement.

A key gap remains between environmental impact assessment and day-to-day risk management. EIA is typically prepared at defined approval stages, whereas design and construction conditions continue to evolve. New subcontractors are mobilised, temporary works change, sequencing is revised, sensitive receptors are discovered, and incidents or monitoring trends reveal new information. A static aspect-impact register can become outdated. The proposed RBEMF addresses this gap by requiring periodic reassessment, trigger-based review and explicit calculation of residual risk after controls. It also introduces legal significance and ecological reversibility as modifiers because a low-frequency event may still warrant priority where consequences are irreversible or where permit non-compliance is possible.

III. METHODOLOGICAL APPROACH TO FRAMEWORK DEVELOPMENT

This paper uses a conceptual framework-development methodology supported by structured narrative synthesis. It is not presented as a systematic review with exhaustive database screening, and no fabricated

search counts or meta-analytic claims are made. The evidence base combines three source categories: recent peer-reviewed research on sustainable construction, megaproject risk, Saudi construction environmental performance and infrastructure resilience; authoritative Saudi policy and regulatory sources; and international management-system standards. The literature was used to identify recurring requirements for risk identification, multi-criteria prioritisation, lifecycle management, integration, monitoring and continuous improvement. Saudi sources were used to define the regulatory and strategic context, while ISO 31000 and ISO 14001:2026 provided the backbone for process design. Framework development followed five design principles. First, the system had to be lifecycle-based, so that risks could be traced from feasibility and EIA through design, construction, commissioning, operation and closure. Second, it had to be proportional: high-consequence or legally significant risks should receive more management attention than low-materiality issues. Third, it had to distinguish inherent risk from residual risk, allowing decision-makers to judge whether proposed controls reduce risk to an acceptable level. Fourth, it had to be auditable, with defined owners, evidence requirements, indicators and review frequencies. Fifth, it had to remain practical enough for use within project controls and contractor management rather than existing only as an environmental specialist tool.

The framework uses a base risk score and four adjustment factors. Base risk is calculated as likelihood multiplied by environmental consequence. Likelihood is assessed on a five-point scale from rare to almost certain. Consequence is assessed from minor and readily reversible impact to severe, widespread or long-term damage. The base score is then adjusted using exposure, legal significance, ecological reversibility and control effectiveness. Exposure reflects the spatial and temporal extent of receptors potentially affected. Legal significance captures permit conditions, statutory thresholds, protected-status receptors and the potential for enforcement consequences. Reversibility reflects how readily the receiving environment can recover after the stressor is removed. Control effectiveness recognises the maturity and reliability of existing preventive and mitigative barriers.

For demonstration, this paper expresses the adjusted score as: Adjusted Environmental Risk Score = (Likelihood × Consequence) × E × Ls × Rv × Cf. The four multipliers are bounded close to 1.0 to prevent the modifiers from overwhelming the base assessment. In practical implementation, organisations may calibrate the ranges using project experience and expert validation. A suggested scale is 0.8–1.2 for exposure, 1.0–1.3 for legal significance, 0.9–1.3 for reversibility and 0.7–1.2 for control effectiveness. Strong, verified controls reduce the score, while weak or unproven controls increase it. This multiplicative structure is intentionally simple enough for spreadsheet or digital-platform use, but it is more informative than a probability-impact matrix alone.

Risk acceptance should not depend solely on numeric thresholds. Three override rules are proposed. Any credible risk of major permit breach or impact to a legally protected receptor requires management review regardless of calculated score. Any risk with

potentially irreversible ecological consequence requires application of the mitigation hierarchy—avoid, minimise, restore and, only where appropriate and legally acceptable, offset—before residual-risk acceptance. Finally, any uncertainty that could change the risk category should trigger additional baseline investigation, modelling or monitoring rather than being treated as a neutral assumption.

The framework was then stress-tested conceptually against common infrastructure environmental risk domains: land and biodiversity, surface water and groundwater, air quality and dust, noise and vibration, waste and hazardous materials, resource use, climate and extreme weather, marine/coastal environment, community receptors and cumulative impacts. The output is an eight-stage management cycle, presented in Figure 1, supported by governance requirements and a sample risk register.

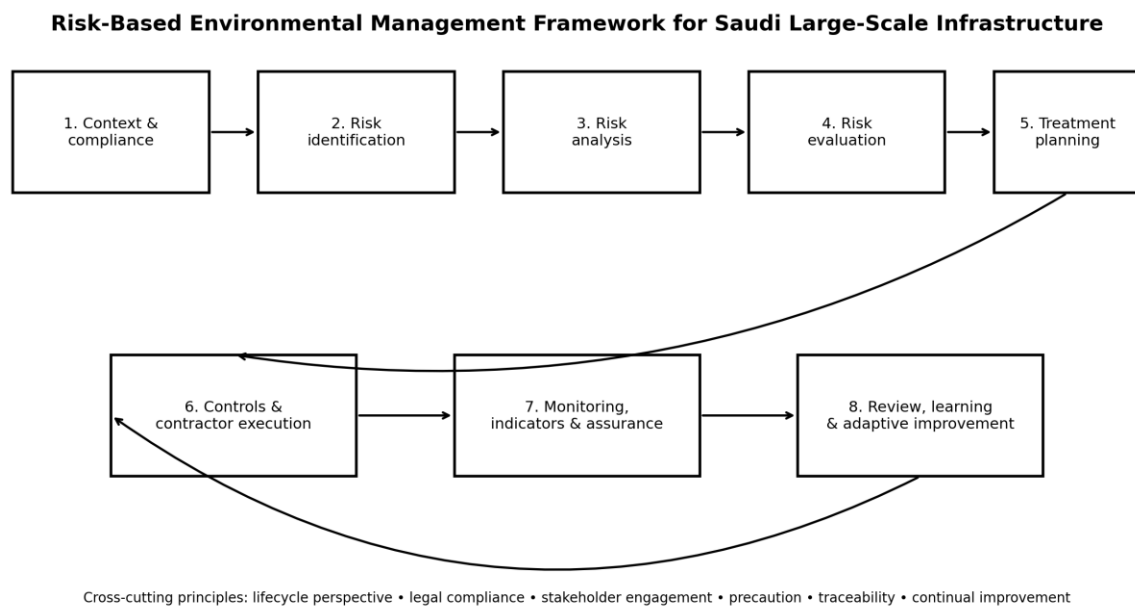


Figure 1. Proposed Risk-Based Environmental Management Framework (RBEMF).

IV. PROPOSED RISK-BASED ENVIRONMENTAL MANAGEMENT FRAMEWORK

The first stage is context and compliance definition. Before risks are scored, the project must establish its environmental context: project boundaries; construction and operational phases; sensitive receptors; applicable permits and legal requirements; commitments made through EIA; client environmental standards; contractual obligations; and strategic objectives. Baseline information should be spatially referenced where possible. The compliance register should identify not only laws and permit conditions but also monitoring, reporting and notification obligations. This stage prevents a common failure in which project teams score “generic” environmental aspects without reflecting site-specific legal or ecological sensitivity.

The second stage is risk identification. Workshops should include environment, design, construction, planning, logistics, commissioning, operations, health and safety, community/stakeholder, procurement and project controls personnel. Risks should be written in cause-event-impact format. For example: “Inadequate sediment-control capacity during an extreme rainfall event may lead to turbid runoff entering a sensitive wadi, causing water-quality deterioration and regulatory non-compliance.” This format is more useful than listing “stormwater” as an aspect because it identifies the causal mechanism and consequence. Inputs include EIA findings, design hazard reviews, method statements, lessons learned, incident data, monitoring trends, geographic information, stakeholder concerns and contractor risk registers.

The third stage is risk analysis. The project scores likelihood and consequence before additional controls, then applies modifiers for exposure, legal significance, reversibility and control maturity. Figure 2 provides the base 5×5 matrix. The assessment should capture uncertainty explicitly. Where data are weak, assessors should record confidence (high, medium or low) and identify actions needed to reduce uncertainty. For high-consequence ecological or water risks, conservative assumptions may be justified until evidence improves. The process should also identify risk interdependencies: for example, poor water

management can create erosion, habitat damage, community complaint, permit breach and schedule disruption simultaneously.

The fourth stage is risk evaluation and prioritisation. Suggested bands are low, moderate, high and critical, calibrated to the organisation’s risk appetite. Critical risks require owner-level attention and formal approval of treatment strategy. High risks require documented mitigation and frequent monitoring. Moderate risks remain actively managed within work-package controls, while low risks are subject to standard procedures and periodic verification. However, the previously described legal and irreversibility overrides remain in force. Prioritisation should also consider the opportunity side of environmental management, including water reuse, material recovery, low-emission equipment, ecological restoration and design changes that avoid future controls altogether.

The fifth stage is treatment planning using the hierarchy of controls and the environmental mitigation hierarchy. Avoidance is preferred: change alignment, footprint, timing or technology so that the risk pathway is removed. Where avoidance is not feasible, minimise through engineering controls and sequencing. Restore disturbed areas promptly and build restoration success criteria into handover. Administrative controls, training and inspection remain necessary but should not be the only barrier for high-consequence events. For accidental releases, emergency-preparedness measures must be linked to realistic scenarios, spill pathways and available response capacity. Each treatment should identify an owner, completion date, verification method and residual-risk target.

The sixth stage is execution through contracts and field controls. Environmental risk treatment fails when commitments are not translated into scopes of work, method statements, inspection and test plans, temporary works, logistics plans and procurement requirements. Contractors should inherit relevant risks through work-package environmental risk registers. Pre-activity reviews should confirm that permits, competent staff, monitoring equipment, containment, waste routes and emergency resources are available. Change control is essential: alterations in construction

sequence, source material, haul routes, dewatering, camp location or temporary facilities can materially change the risk profile and should trigger reassessment.

The seventh stage is monitoring, indicators and assurance. Monitoring should be risk-driven, not merely schedule-driven. Critical receptors may require continuous or event-triggered monitoring; lower risks may be verified through periodic inspection. Leading indicators include percentage of critical controls verified, overdue environmental actions, permit-condition compliance, training completion, waste segregation performance and preventative maintenance of pollution-control equipment. Lagging indicators include exceedances, spills, complaints, habitat disturbance, non-compliances and enforcement actions. Assurance should include first-line contractor inspection, second-line project environmental audits and selected independent or client reviews for high-risk activities.

The eighth stage is review, learning and adaptive improvement. Risk registers should be reviewed at planned intervals and when trigger events occur: incident or near miss, monitoring exceedance, permit change, design change, mobilisation of a new work

package, seasonal transition, extreme weather warning, stakeholder complaint, discovery of a sensitive receptor or repeated control failure. The purpose is not to generate paperwork but to maintain an accurate picture of residual risk. Lessons learned should feed forward to design standards, contractor requirements and future project phases. This closes the loop between risk management and ISO 14001:2026 continual improvement.

Governance is the mechanism that makes the cycle function. A project environmental director or manager should own the framework, but individual risks must be assigned to accountable operational owners. The owner's role is to ensure controls are resourced and functioning; the environmental team provides technical guidance, verification and escalation. A multidisciplinary Environmental Risk Review Board is recommended monthly for major projects, with additional reviews before high-risk milestones. Membership may include project leadership, environmental management, construction, design, logistics, HSE, quality, project controls and relevant subject-matter experts. Critical residual risks should be visible in the overall project risk register to prevent environmental issues from being hidden in a specialist subsystem.

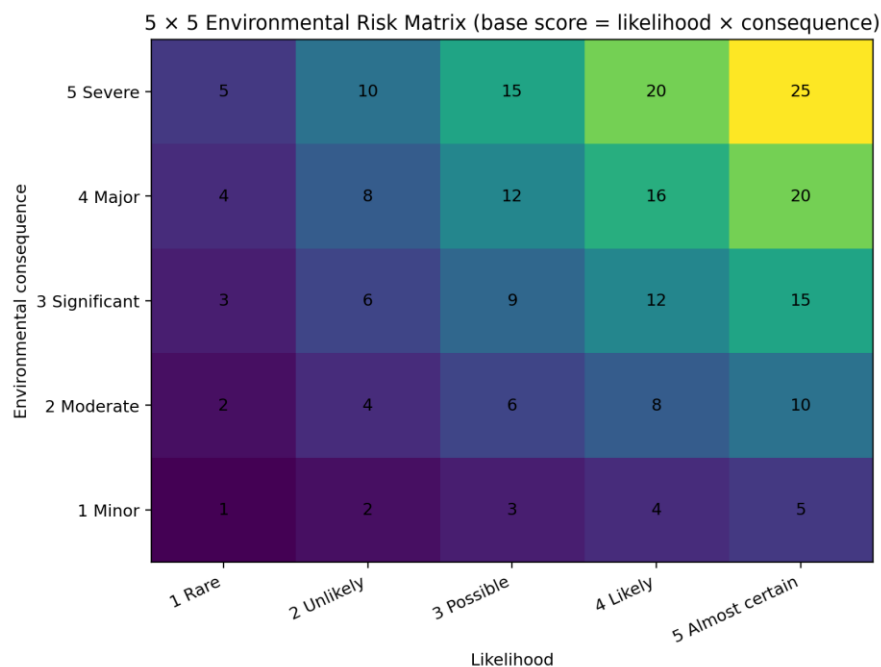


Figure 2. Base 5 × 5 environmental risk matrix used before adjustment factors

V. RISK TAXONOMY, SCORING AND PRACTICAL APPLICATION

A useful risk taxonomy supports consistency without constraining project-specific thinking. For Saudi large-scale infrastructure, ten primary domains are proposed: biodiversity and habitat; soil and land disturbance; surface water and groundwater; air quality; noise and vibration; waste and circularity; hazardous materials and spill prevention; resource use and carbon; climate and extreme weather; and community/cumulative impacts. Marine and coastal projects should add a dedicated marine domain, while projects involving major industrial processes should include emissions, process wastewater and major-accident interfaces.

Table 1 links each domain to typical causal pathways and management evidence. The taxonomy deliberately combines direct environmental pressures and enabling management failures. For example, poor planning or inadequate contractor competence may not be an “environmental impact” by itself, but Saudi construction literature demonstrates that planning, coordination and awareness significantly influence waste and sustainability outcomes. Therefore, root causes should be recorded alongside environmental consequences.

The scoring model is shown in Table 2. A project should develop descriptors relevant to its receiving environment rather than using generic language alone. A “major” consequence for a remote degraded site may differ from the same activity adjacent to a protected habitat or community receptor. Likewise, legal significance increases where a threshold, protected status or permit condition applies. The result is an adjusted score that helps distinguish two events with the same probability-impact score but different regulatory or ecological implications.

Table 3 provides an illustrative register for a hypothetical Saudi infrastructure project. The figures are demonstration values only and are not empirical data from NEOM or any other named project. Their purpose is to show how the model can focus management attention. In the example, habitat loss, uncontrolled discharge and groundwater contamination remain high priorities because of

consequence, exposure, legal significance and reversibility. Dust and waste risks can also rank highly when the project footprint and construction duration create persistent exposure. Figure 3 visualises the same illustrative priorities.

The risk register should include a confidence rating and critical-control verification field. A risk may have a moderate numerical score but low confidence because baseline data are incomplete; in such cases the project should not interpret the score as precise. Instead, uncertainty becomes an action item. For groundwater, this may require additional boreholes or hydrogeological modelling. For biodiversity, it may require seasonal surveys. For air quality, it may require baseline monitoring and dispersion modelling. This approach aligns risk management with evidence generation.

Environmental key performance indicators should similarly be linked to risk. Project-wide dashboards often overemphasise activity counts such as number of inspections or training hours. These metrics demonstrate effort but not necessarily control effectiveness. A stronger dashboard combines process measures with outcome measures. Suggested indicators include percentage of critical environmental controls verified on schedule; number of overdue high-risk actions; percentage of permit conditions with current evidence; proportion of high-risk work packages completing pre-activity environmental review; water abstraction per unit of production where relevant; percentage of construction and demolition waste segregated or recovered; dust or noise exceedance frequency; number and severity of spills; area disturbed versus rehabilitated; and number of repeat non-compliances.

Digital tools can improve implementation. GIS can map risk receptors, buffers, drainage and monitoring locations. Mobile inspection systems can require geo-tagged evidence. Remote sensors can support event-based alerts for dust, noise or water parameters. Drone and satellite data can assist disturbance and rehabilitation verification, subject to regulatory and privacy requirements. Digital systems should maintain version control so that changes in risk status can be reconstructed during audit. Automated dashboards are valuable, but algorithmic scoring should never conceal

the underlying assumptions or substitute for competent professional judgement.

The framework also supports procurement and contractor management. Tender documents should identify material environmental risks and minimum control expectations. Bid evaluation can assess contractor competence, specialist resources, proposed monitoring and past performance. During execution,

subcontractors should receive risk information relevant to their scope rather than a generic environmental induction only. High-risk subcontractors, such as blasting, dewatering, marine works, waste transport or hazardous-material handling, require scope-specific competence and assurance. This helps convert environmental risk from a client policy into a supply-chain requirement.

Table 1. Environmental risk taxonomy for large-scale infrastructure projects.

Risk domain	Typical pathways	Evidence / controls
Biodiversity & habitat	Clearing, fragmentation, lighting, collision, disturbance	Ecological surveys, exclusion zones, seasonal controls, restoration criteria
Water & groundwater	Dewatering, runoff, discharge, leaks, abstraction	Hydrogeology, treatment design, discharge monitoring, spill containment
Air quality	Earthworks, crushing, batching, traffic, generators	Dust plan, real-time PM monitoring, maintenance, speed control
Noise & vibration	Blasting, piling, plant, traffic	Modelling, receptor limits, timing controls, monitoring
Waste & circularity	Excavated material, C&D waste, hazardous waste	Waste hierarchy, segregation, licensed routes, material recovery records
Hazardous materials	Fuel, chemicals, concrete additives, contaminated media	Inventory, bunding, SDS, emergency response, inspections
Resource use & carbon	Water, fuel, electricity, virgin materials	Consumption KPIs, reuse, efficiency targets, low-carbon procurement
Climate & extremes	Flash flood, heat, dust storms, coastal hazards	Climate design basis, trigger plans, drainage capacity, emergency preparedness
Community & cumulative	Traffic, nuisance, shared receptors, overlapping projects	Stakeholder interface, complaint trends, cumulative assessment, coordination

Table 2. Proposed environmental risk scoring criteria.

Factor	Scale	Interpretation	Use
Likelihood	1–5	Rare to almost certain	Base score
Consequence	1–5	Minor/reversible to severe/long-term	Base score
Exposure	0.8–1.2	Limited to extensive receptor exposure	Modifier
Legal significance	1.0–1.3	General duty to explicit permit/protected-status sensitivity	Modifier

Reversibility	0.9–1.3	Readily recoverable to difficult/irreversible	Modifier
Control effectiveness	0.7–1.2	Verified robust controls to weak/unproven controls	Modifier

Table 3. Illustrative environmental risk register (demonstration values only).

Risk	L	C	Modifiers (E/L/R/Cf)	Adjusted score	Priority	Example treatment
Sensitive habitat loss	4	5	1.1/1.2/1.2/0.85	26.9	Critical	Avoid footprint; exclusion zones; staged clearance; restoration
Uncontrolled discharge	4	5	1.0/1.2/1.0/0.9	21.6	Critical	Treatment redundancy; discharge hold point; continuous monitoring
Groundwater contamination	3	5	1.1/1.2/1.2/0.9	21.4	Critical	Secondary containment; leak detection; groundwater monitoring
Dust / PM emissions	5	4	1.1/1.0/0.9/0.9	17.8	High	Water/suppressant; enclosure; speed control; trigger monitoring
Hazardous waste mismanagement	3	4	1.0/1.2/1.1/0.9	14.3	High	Segregated storage; manifests; licensed contractor; audit
Noise and vibration	4	3	1.0/1.0/0.9/0.9	9.7	Moderate	Timing limits; barriers; monitoring; community notification

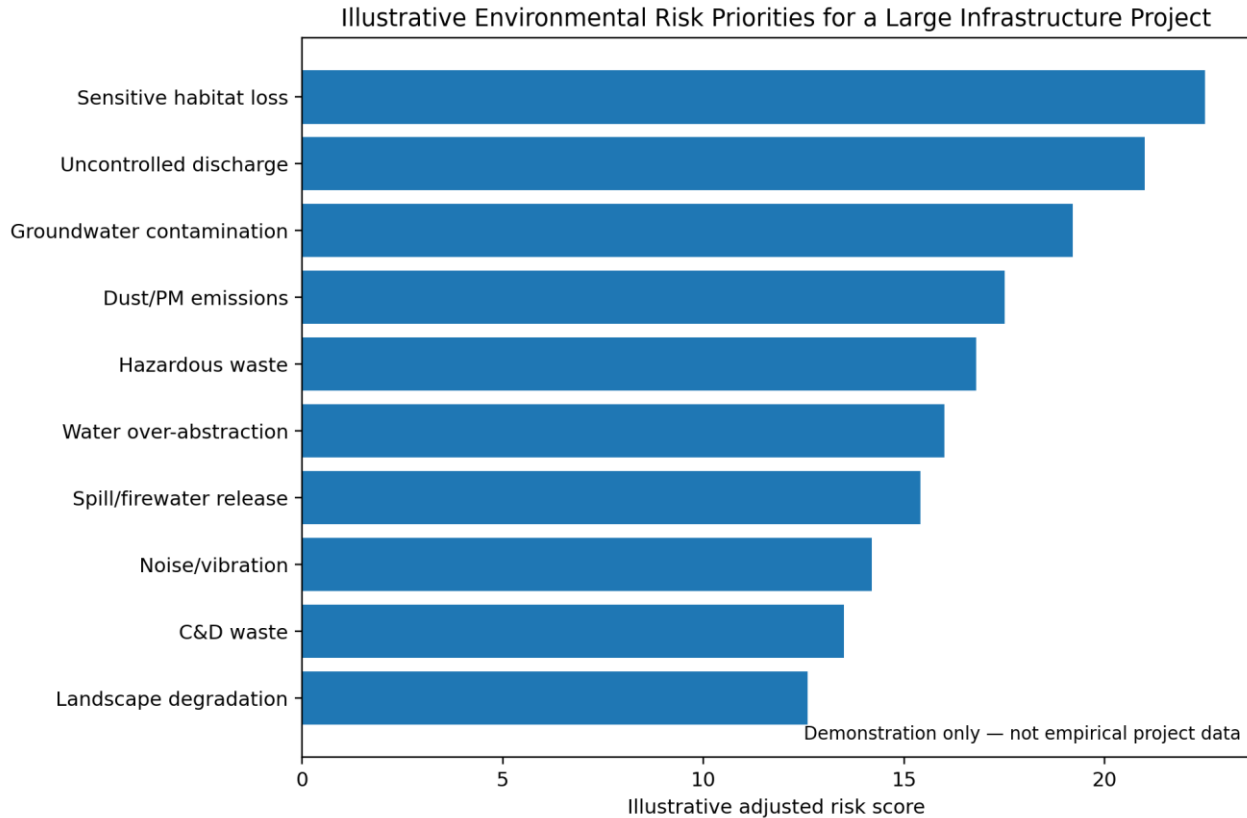


Figure 3. Illustrative risk-priority profile. Values are a demonstration of the framework and are not empirical Saudi project data.

VI. DISCUSSION

The principal contribution of the RBEMF is its integration of environmental management with project risk governance. Traditional environmental management often asks whether an aspect is “significant,” while project risk systems ask how uncertainty affects objectives. The proposed framework combines these perspectives by treating environmental harm, compliance failure and environmental conditions affecting the project as risks that require ownership, controls and residual-risk decisions. This is consistent with ISO 31000’s emphasis on integration and value protection and with ISO 14001:2026’s focus on environmental aspects, compliance obligations, risks, opportunities and lifecycle perspective.

The framework is also suited to the institutional direction of Saudi environmental regulation. NCEC permitting and monitoring expectations create a need for traceable management evidence. A risk register

linked to permit conditions, monitoring data and corrective actions can provide a coherent evidence chain. For example, an EIA commitment related to a wadi buffer can be translated into a design control, geospatial exclusion zone, work-package method statement, inspection checkpoint and restoration criterion. If the alignment changes, the risk review is reopened. This is stronger than maintaining the commitment only in a static EIA compliance matrix. A second contribution is the explicit treatment of reversibility and legal significance. Simple 5×5 matrices are popular because they are easy to use, but they can understate rare events with irreversible ecological effects or significant regulatory implications. The proposed modifiers make these attributes visible without creating an excessively complex quantitative model. The design is intentionally transparent: project teams can understand why a score changed, and auditors can inspect the assumptions. More sophisticated methods such as fuzzy synthetic evaluation, AHP or cross-impact analysis, as used in recent sustainability-risk studies,

may be appropriate for research validation or portfolio decisions, but day-to-day construction management also requires a method that field teams can apply consistently.

Third, the framework recognises that environmental risks are frequently driven by management systems. Research in the Saudi construction sector identifies poor planning, coordination, awareness and waste-management practices as important barriers to sustainability and circularity. Therefore, the risk treatment process should ask not only “what pollution-control equipment is needed?” but also “what planning, competence, information and contractual conditions are required to keep the control reliable?” A sediment basin, for instance, is not an effective barrier if maintenance is unclear, capacity is not checked before storms, pumps bypass treatment or responsibility is fragmented between contractors.

Fourth, the framework supports adaptive management under uncertainty. Saudi infrastructure projects operate in environments where baseline data may be spatially variable and extreme conditions can challenge assumptions. Climate-risk literature demonstrates the importance of planning for low-frequency, high-impact events affecting infrastructure. Rather than treating the EIA baseline as permanently fixed, the RBEMF uses confidence ratings and trigger-based reviews. Monitoring data therefore changes decisions instead of being collected only for reporting. If dust exceedances recur, the likelihood score or control-effectiveness modifier changes. If a new sensitive habitat is identified, consequence, legal significance and reversibility are reassessed.

The framework can also improve alignment with Vision 2030 by making sustainability operational. Project reports frequently state alignment with national strategies without showing the mechanism of contribution. Under the RBEMF, strategic objectives are connected to risk controls and measurable indicators: circularity is represented by material recovery and waste prevention; environmental protection by avoidance and restoration of sensitive areas; resilience by climate-risk treatment; and pollution prevention by verified controls and compliance performance. This produces a more defensible narrative than broad policy references

alone.

There are limitations. First, the proposed scoring multipliers have not yet been statistically calibrated using Saudi project data. They are design parameters intended for expert validation. Second, risk thresholds should be adapted to project type and organisational risk appetite. A coastal port, mountain development, urban metro and desert transmission corridor face different receptors and impact pathways. Third, the framework depends on governance maturity. If project leadership does not enforce ownership or if contractors treat environmental requirements as secondary, the quality of scoring will not compensate for weak execution. Fourth, the paper is a conceptual synthesis rather than a systematic review or empirical field study.

These limitations define the next research agenda. A Delphi study with Saudi environmental managers, regulators, consultants, contractors and academics could validate the risk taxonomy and scoring factors. The framework could then be piloted on multiple infrastructure projects and compared against conventional aspect-impact registers using indicators such as number of repeated non-compliances, closure time for high-risk actions, predictability of monitoring exceedances, audit findings and control-verification rates. Multi-criteria analysis could be used to derive factor weights, while sensitivity analysis could test score stability. Longitudinal research would be particularly valuable because infrastructure environmental performance changes across project phases.

There is also potential to link the framework to digital twins and geospatial environmental information systems. A digital risk layer could combine construction progress, sensitive receptors, monitoring data and permit constraints. Work packages approaching sensitive zones could trigger control verification automatically. However, future digitalisation should preserve accountability: the responsible manager must remain able to explain why a risk is acceptable and what evidence demonstrates control effectiveness.

VII. MANAGERIAL AND POLICY IMPLICATIONS

For project owners, the immediate implication is to treat environmental risk as part of core project governance. Critical environmental risks should appear in executive risk reporting, and high-risk treatment actions should be integrated with schedule and cost controls. Design gates should include environmental risk closure criteria, while construction readiness reviews should verify permits, competence and critical controls before work begins. Owners should avoid transferring all environmental responsibility contractually to contractors because legal, reputational and strategic risk often remains with the project sponsor.

For consultants and environmental managers, the framework provides a way to connect EIA commitments to operational controls. The environmental team should maintain the methodology, facilitate assessments, verify evidence and challenge risk acceptance, but operational managers should own the risks they create. This allocation helps prevent the common situation in which environmental personnel become responsible for correcting construction-management failures without authority over resources or sequencing.

For contractors, the framework supports clearer expectations. High-risk activities can be identified during tendering and mobilisation, enabling better allocation of specialists, monitoring equipment and contingency resources. Environmental requirements can be integrated into look-ahead planning, temporary-works design and method statements. Critical-control verification should focus supervision on the small number of barriers whose failure could create disproportionate impact.

For regulators and policymakers, a standardised risk-based approach could improve the comparability and transparency of environmental management across large projects. The framework is not proposed as a replacement for NCEC regulations, EIA or permit requirements. Rather, it can complement them by improving traceability from approval conditions to implementation evidence. Future guidance could encourage major projects to demonstrate risk-based

prioritisation, residual-risk acceptance and trigger-based reassessment, especially for environmentally sensitive or long-duration developments.

Finally, universities and professional bodies can use the framework as a research platform. Saudi Arabia's current infrastructure program offers an opportunity to develop locally validated environmental-risk models rather than importing generic scoring systems. Collaboration between academia, industry and regulators could produce sector-specific risk libraries, benchmark control effectiveness, and build anonymised datasets for predictive environmental management.

VIII. CONCLUSION

Saudi Arabia's large-scale infrastructure program requires environmental management systems capable of combining regulatory compliance, strategic sustainability and dynamic project risk governance. This paper develops a Risk-Based Environmental Management Framework that integrates the logic of ISO 31000, ISO 14001:2026, Saudi NCEC requirements and contemporary sustainable-construction research. The framework moves beyond static aspect registers by establishing an eight-stage cycle from context definition and risk identification through treatment, field execution, monitoring, assurance and adaptive review.

The proposed scoring method combines likelihood and consequence with modifiers for exposure, legal significance, reversibility and control effectiveness. This design highlights risks that may be infrequent but legally important, ecologically difficult to reverse or weakly controlled. The framework further emphasises risk ownership, critical-control verification, lifecycle traceability, digital evidence and management review. Its application is demonstrated through an illustrative risk register rather than fabricated project results.

The framework is particularly relevant to Vision 2030 because it translates broad sustainability ambition into operational decisions: avoiding sensitive impacts, improving resource efficiency, strengthening circularity, protecting water and air quality, improving resilience and ensuring that environmental commitments remain visible during rapid project

delivery. Its value will ultimately depend on empirical testing. Future research should validate criteria and weights with Saudi practitioners and regulators, pilot the method across different infrastructure types, and measure whether risk-based management reduces repeat non-compliance and improves environmental

performance. A validated RBEMF could then provide a scalable decision-support tool for owners, consultants and contractors managing the environmental complexity of Saudi Arabia's infrastructure transformation.

Table 4. Recommended governance and review cadence for RBEMF implementation.

Level	Primary responsibility	Typical review	Escalation trigger
Executive / program	Risk appetite; acceptance of critical residual risk	Monthly / gate reviews	Critical residual risk; major legal or reputational exposure
Project management	Integrate environmental risk with cost, schedule and change control	Monthly	High-risk trend worsening; repeated control failure
Environmental management	Methodology, facilitation, assurance, technical escalation	Weekly to monthly	Exceedance, incident, permit change, new receptor
Construction / work package	Own and implement controls	Daily / weekly	Control unavailable or ineffective; changed method
Independent/client assurance	Verify system and critical controls	Risk-based audits	Systemic weakness; repeated non-compliance

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