ENVIRONMENTAL FORENSICS AS A TOOL FOR CORPORATE ACCOUNTABILITY: BRIDGING THE EVIDENTIARY GAP IN ENVIRONMENTAL ENFORCEMENT AND GOVERNANCE

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ABSTRACT

Environmental governance has evolved significantly through international legal principles, domestic regulatory frameworks, and corporate sustainability obligations. Despite this normative progress, environmental enforcement continues to face a persistent evidentiary gap, whereby difficulties in establishing causation between corporate activities and environmental harm often impede effective accountability. This paper examines the extent to which environmental forensic science can bridge this evidentiary gap and strengthen corporate accountability within contemporary environmental governance frameworks. Employing a doctrinal and analytical legal research methodology, supplemented by comparative analysis, the study evaluates international and domestic legal instruments alongside the regulatory approaches of India, the United States, the European Union, Australia, and Canada. It further analyses four significant case studies the Vedanta Sterlite Copper Plant controversy, the LG Polymers gas leak, the Exxon Valdez oil spill, and the Deepwater Horizon disaster to assess the practical contribution of forensic evidence in environmental investigations and litigation. The paper explores key forensic techniques, including chemical fingerprinting, isotope analysis, environmental DNA (eDNA), Geographic Information Systems (GIS), remote sensing, satellite surveillance, and artificial intelligence-assisted environmental monitoring, and evaluates their evidentiary reliability within environmental adjudication. The study finds that jurisdictions possessing robust forensic infrastructure, standardised evidentiary protocols, and institutional scientific capacity achieve more effective and consistent corporate accountability than systems reliant primarily on self-reporting and conventional monitoring. It argues that environmental forensics should no longer be viewed solely as a post-incident investigative mechanism but should instead be institutionalised as a preventive governance tool through Environmental Impact Assessments, Environmental, Social, and Governance (ESG) compliance verification, regulatory monitoring, environmental auditing, and dispute resolution. The paper concludes that integrating environmental forensics into environmental governance can substantially enhance evidence-based enforcement, improve regulatory transparency, reduce opportunities for corporate evasion, and strengthen the implementation of environmental law.

Keywords: Environmental Forensics; Corporate Accountability; Environmental Governance; Evidentiary Gap; Environmental Enforcement; Environmental Evidence; ESG Compliance; Environmental Impact Assessment (EIA).

CHAPTER 1: INTRODUCTION

1.1 Environmental Harm and the Rise of Corporate Accountability

The relationship between industrial activity and ecological degradation has been documented since at least the nineteenth century, but it acquired formal legal significance only in the latter half of the twentieth. The Stockholm Declaration of 1972 articulated for the first time a transnational consensus that states bear responsibility for ensuring that activities within their jurisdiction do not cause environmental harm beyond their borders.[1] That recognition, however modest, opened a doctrinal space for the gradual construction of corporate environmental obligations, which have since expanded from discrete regulatory licences to comprehensive due diligence duties and sustainability reporting frameworks.

Industrialisation has generated ecological consequences of considerable breadth: soil contamination, groundwater depletion, atmospheric pollution, and biodiversity loss are among the best-documented manifestations of the 'externalities' that market-based economic activity generates in the absence of effective regulatory constraint. The UNEP's Global Environment Outlook 6 confirmed that environmental degradation now threatens the foundations of human wellbeing in ways that cannot be resolved by isolated national action.[2] Against that backdrop, the concept of corporate environmental accountability has moved from the margins of voluntary ethics into the mainstream of hard law and governance practice.

1. Declaration of the U.N. Conference on the Human Environment, princ. 21, U.N. Doc. A/CONF.48/14/Rev.1 (June 16, 1972); *Rio Declaration on Environment and Development*, princ. 7, U.N. Doc. A/CONF.151/26/Rev.1 (Vol. I) (Aug. 12, 1992).
2. U.N. Environment Programme, *Global Environment Outlook 6*, 23–25 (2019).

1.2 The Evidentiary Gap in Environmental Enforcement

If the development of environmental law constitutes one of the signal achievements of twentieth-century public law, its persistent weakness is the difficulty of enforcement. The evidentiary gap the gulf between the legal duty to prevent or remedy environmental harm and the practical capacity to prove that a particular corporate actor caused a particular harm is perhaps the most intractable problem in the field. Environmental harms are frequently diffuse, cumulative, and temporally displaced from the acts that caused them: the carcinogenic effects of groundwater contamination may manifest decades after the initial discharge; ecosystem degradation may result from the compounded effect of discharges by multiple operators over extended periods; and pollutants may migrate unpredictably through soil, air, and water.

Scientific uncertainty compounds the attribution problem. The causal chain between a corporate act and an environmental outcome is rarely linear; competing hypotheses about the source and pathway of contamination are common, and corporate defendants frequently exploit this uncertainty to resist liability. Without reliable forensic evidence, regulators and courts are left to rely on self-reporting, proxy indicators, or incomplete monitoring data all of which are susceptible to manipulation or error. The consequence is enforcement that is reactive, inconsistent, and disproportionately costly relative to its deterrent effect.

1.3 Research Question

This paper addresses the following question: To what extent can environmental forensic techniques strengthen corporate accountability by addressing evidentiary challenges in environmental enforcement and governance frameworks?

1.4 Objectives of the Study

The study pursues four objectives: first, to examine the evolution of international environmental governance and the principles that ground corporate accountability; second, to survey the principal forensic techniques deployed in environmental investigations and assess their evidentiary value; third, to evaluate, through comparative case studies, the role of environmental forensics in specific enforcement and litigation contexts; and fourth, to develop a normative framework for integrating environmental forensics into governance structures as a systemic accountability mechanism.

1.5 Research Methodology

The paper employs doctrinal and analytical legal research as its primary method, supplemented by a comparative analysis of regulatory frameworks in India, the United States, the European Union, Australia, and Canada. Four case studies selected to represent different industrial sectors, legal systems, and forensic methodologies are analysed to derive practical insights about the relationship between forensic evidence quality and accountability outcomes. The paper does not undertake empirical primary research; it draws on reported cases, official inquiry documents, regulatory reports, and the peer-reviewed literature in environmental law and forensic science.

1.6 Scope and Limitations

The paper focuses on civil and regulatory liability rather than criminal prosecution, though the forensic techniques discussed are equally relevant to the latter. It does not provide a comprehensive review of all forensic methodologies, nor does it address every national jurisdiction. India serves as the primary domestic case-study jurisdiction given the richness of its recent environmental litigation and the diversity of forensic questions raised by Indian courts. International examples are used comparatively rather than exhaustively.

CHAPTER 2: ENVIRONMENTAL GOVERNANCE AND THE CHALLENGE OF CORPORATE ACCOUNTABILITY

2.1 Evolution of International Environmental Governance

Modern international environmental governance traces its institutional origins to the 1972 Stockholm Conference, which produced both the Stockholm Declaration and the mandate for a dedicated UN environment programme. The Declaration's foundational assertion states that states have a sovereign right to exploit their resources but a corresponding duty to prevent transboundary harm[3]remains the conceptual bedrock upon which subsequent instruments have been built.

The 1992 Rio Earth Summit marked a qualitative deepening of international environmental commitment. The Rio Declaration refined and extended Stockholm's framework, embedding

3. Stockholm Declaration, *supra* note 1, princ. 21.

the polluter pays, precautionary, and sustainable development principles in a single authoritative text.[4] The Convention on Biological Diversity and UN Framework Convention on Climate Change, opened for signature at Rio, extended international environmental law into domains that Stockholm had not reached.

The Paris Agreement of 2015 represents the most recent structural evolution in this governance architecture.[5] The Nationally Determined Contributions (NDC) mechanism shifts primary implementation responsibility to states while expecting corporate actors to align their activities with a below-2°C trajectory. That alignment is increasingly operationalised through non-binding but increasingly mandatory sustainability disclosure regimes, ESG rating systems, and supply-chain due diligence legislation developments that position environmental forensics as a tool not only for ex post investigation but for ongoing compliance verification.

2.2 International Environmental Principles

Four principles merit particular attention for the purposes of this paper. The polluter pays principle, enshrined in Principle 16 of the Rio Declaration, allocates the cost of pollution to those responsible for causing it.[6] Its practical operation depends entirely on the capacity to identify polluters with sufficient specificity to support a liability determination. Where that identification fails, as it frequently does in multi-source contamination scenarios, the principle is rendered inoperative regardless of its doctrinal strength.

The precautionary principle (Principle 15) provides that where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective preventive measures.[7] This principle has been variously interpreted as a decision-making standard, an evidentiary presumption, and a substantive obligation. In the context of environmental forensics, it is significant because it formally acknowledges that regulatory action need not await complete scientific certainty, a recognition that has important implications for the standard of proof expected in enforcement proceedings.

The sustainable development principle integrates environmental protection into the economic

4. Rio Declaration, *supra* note 1.
5. Paris Agreement art. 2, Dec. 12, 2015, 3156 U.N.T.S.
6. Rio Declaration, *supra* note 1, princ. 16.
7. *Id.* princ. 15.

development calculus rather than treating it as an external constraint.[8] For corporate actors, it provides normative grounding for the proposition that long-term value creation is incompatible with the externalisation of environmental costs. The prevention principle, rooted in Principle 6 of the Stockholm Declaration,[9] imposes an obligation to avoid harm before it occurs, an obligation whose discharge requires ongoing environmental monitoring of the kind that forensic science can support.

2.3 Corporate Accountability in Contemporary Environmental Governance

The landscape of corporate environmental accountability has been transformed over the past two decades by the convergence of regulatory compulsion, investor-driven ESG expectations, and litigation risk. Mandatory sustainability reporting under the Global Reporting Initiative standards and the TCFD framework has moved environmental disclosure from voluntary good practice to a quasi-mandatory expectation in major capital markets.[10] The EU Taxonomy Regulation[11] and the Environmental Liability Directive[12] represent perhaps the most sophisticated legislative attempts to operationalise corporate environmental responsibility within a single regulatory system. The EU's approach, combining substantive environmental obligations with a dedicated liability regime and increasingly stringent monitoring requirements, offers a model that other jurisdictions are progressively adapting.

Despite this proliferation of normative frameworks, the implementation gap remains substantial. Corporate self-reporting, upon which most ESG compliance systems currently depend, is structurally unreliable: it creates incentives to understate environmental impacts and depends on management accounting processes rather than independent scientific assessment. The case for integrating environmental forensics into the governance architecture rests, in part, on the inadequacy of disclosure-based accountability as a standalone mechanism.

8. *Id.* princ. 3; World Commission on Environment and Development, *Our Common Future* 43 (1987).
9. Stockholm Declaration, *supra* note 1, princ. 6.
10. Global Reporting Initiative, *GRI Standards: Universal Standards 2021* (2021); Task Force on Climate-Related Fin. Disclosures, *Recommendations of the Task Force on Climate-Related Financial Disclosures* 14 (2017).
11. Regulation 2020/852 of the European Parliament and of the Council of 18 June 2020 on the Establishment of a Framework to Facilitate Sustainable Investment, 2020 O.J. (L 198) 13.
12. Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 on Environmental Liability with Regard to the Prevention and Remedying of Environmental Damage, 2004 O.J. (L 143) 56.

2.4 The Evidentiary Gap in Environmental Enforcement

The evidentiary gap manifests in at least three recurring enforcement scenarios. First, in point-source contamination cases, identifying the operator responsible for a specific discharge requires chemical analysis capable of distinguishing between the outputs of different industrial processes, a task that traditional monitoring methods often cannot perform with the precision required for legal attribution. Second, in cumulative-impact scenarios, where ecological harm results from the combined effect of multiple discharges over time, establishing individual corporate responsibility demands temporal and spatial data of a quality that only forensic investigation can provide. Third, in cases where contamination has migrated through environmental media from the point of discharge, a particularly common challenge in groundwater and marine cases, attribution requires modelling and forensic reconstruction that goes far beyond routine monitoring.[13] These scenarios are not merely theoretical; they describe the factual context of most significant environmental litigation.

CHAPTER 3: ENVIRONMENTAL FORENSICS AND THE SCIENCE OF ENVIRONMENTAL ACCOUNTABILITY

3.1 Concept and Evolution of Environmental Forensics

Environmental forensics emerged as a distinct discipline in the late twentieth century at the intersection of analytical chemistry, ecology, geology, and law. Its defining characteristic is the application of scientific techniques, typically derived from forensic science, environmental chemistry, and earth science, to the resolution of legally significant questions about the origin, pathway, and impact of environmental contaminants.[14] The field developed partly in response to the evidentiary demands of CERCLA litigation in the United States, where the need to allocate liability among multiple responsible parties at contaminated sites generated demand for techniques capable of chemical source attribution.[15] From those origins in hazardous waste regulation, environmental forensics has expanded to encompass oil spill attribution, air quality investigation, ecosystem health assessment, and climate compliance monitoring.

Its interdisciplinary character is both a strength and a complication. The strength is that it can

13. Philippe Sands, Jacqueline Peel, Adriana Fabra & Ruth Mackenzie, *Principles of International Environmental Law* 228 (4th ed. 2018).
14. Mick Farmer, *Environmental Forensics: Principles and Applications* 3–5 (2009).
15. Robert Morrison, *Environmental Forensics: Contaminant Specific Guide* 11 (2000).

draw on a wide and growing portfolio of scientific methods; the complication is that no single regulatory or professional framework governs the standards for forensic evidence quality, chain of custody, or expert testimony. That regulatory lacuna represents a significant governance challenge, and addressing it is among the central recommendations of this paper.

3.2 Forensic Techniques in Environmental Investigations

3.2.1 Chemical Fingerprinting

Chemical fingerprinting exploits the compositional distinctiveness of industrial outputs to match environmental samples to specific sources. Petroleum hydrocarbons, for instance, contain biomarker compounds hopanes, steranes, and polycyclic aromatic hydrocarbons whose ratios are characteristic of specific crude oil deposits and refining processes.[16] Gas chromatography–mass spectrometry (GC-MS) analysis of environmental samples can thus establish, to a high degree of probability, whether a given oil contamination originated from a particular vessel or facility. The technique has been central to oil spill litigation since the Exxon Valdez case and remains the primary method of source attribution in hydrocarbon contamination cases.

3.2.2 Isotope Analysis

Stable isotope analysis exploits the fact that different sources of the same element nitrogen, carbon, sulphur, or strontium carry characteristic isotopic signatures that survive environmental transport.[17] Compound-specific isotope analysis (CSIA) has been used to differentiate between industrial and agricultural sources of nitrate contamination in groundwater, and to trace atmospheric sulphur dioxide to specific coal-fired power plants.[18] Because isotopic ratios are not affected by biodegradation or dilution in the same way as concentration data, they provide more robust attribution evidence in cases where contamination has migrated or aged significantly before sampling.

3.2.3 Environmental DNA (eDNA)

The detection and sequencing of genetic material shed by organisms into their environment

16. Kenneth Peters, Charles Walters & J. Michael Moldowan, 1 *The Biomarker Guide* 47–50 (2d ed. 2005).
17. Morrison, *supra* note 15, at 65–68.
18. Robert D. Morrison & Brian L. Murphy, eds., *Environmental Forensics: Contaminant Specific Guide* (2006).

environmental DNA has transformed ecological assessment and is increasingly applied in enforcement contexts.[19] eDNA analysis can confirm the presence or absence of species affected by pollution events, document ecosystem change over time, and, in some cases, trace microbial communities characteristic of specific waste streams. Its principal governance application is in validating claims about biodiversity impact a matter increasingly relevant to ESG compliance and Environmental Impact Assessment.

3.2.4 Remote Sensing Technologies

Airborne and satellite-mounted sensors including hyperspectral imagers, synthetic aperture radar, and thermal infrared detectors, can detect environmental anomalies across large spatial scales and at temporal resolutions impossible to achieve through ground-based sampling.[20] Remote sensing is particularly valuable in documenting the spatial extent of contamination, tracking the movement of pollutant plumes, and providing retrospective evidence of environmental change from historical imagery. Its outputs are admissible in most jurisdictions as scientific evidence, subject to appropriate expert testimony about sensor calibration and interpretation methodology.

3.2.5 GIS Mapping

Geographic Information Systems (GIS) integrate spatial data from multiple sources monitoring stations, satellite imagery, geological surveys, demographic information into analytical frameworks that can model contaminant dispersal pathways, visualise cumulative environmental impacts, and identify the spatial relationship between emission sources and affected communities.[21] In litigation and regulatory proceedings, GIS outputs serve as both analytical tools and demonstrative evidence, enabling fact-finders to comprehend the spatial dimensions of environmental harm that would be inaccessible from tabular data alone.

3.2.6 Satellite Surveillance

Dedicated earth observation programmes, including ESA's Sentinel constellation, NASA's Landsat programme, and commercial platforms such as Planet and Maxar, now provide

19. Pia F. Thomsen & Eske Willerslev, *Environmental DNA – An Emerging Tool in Conservation for Monitoring Past and Present Biodiversity*, 183 Biological Conservation 4 (2015).
20. European Environment Agency, *Remote Sensing in Support of Environmental Policy* 8 (2020).
21. GIS mapping in environmental forensic/litigation use

continuous, near-real-time monitoring of land use change, vegetation stress, surface water quality, and atmospheric composition at resolutions previously achievable only by aircraft.[22] For environmental enforcement, this represents a fundamental shift in investigative capacity: regulators no longer depend exclusively on site visits or facility self-reports to detect environmental violations. Satellite evidence of deforestation, illegal dumping, or atmospheric discharge has been used in enforcement proceedings in Brazil, Indonesia, and the United States, and its evidentiary application in Indian courts is an emerging development.

3.2.7 Artificial Intelligence in Environmental Monitoring

Machine learning algorithms applied to large environmental datasets satellite imagery time series, IoT sensor networks, genomic databases are beginning to extend the detection and attribution capabilities of human analysts.[23] AI systems can identify patterns of contamination, predict migration trajectories, and flag anomalies in facility emissions data that would escape routine inspection. Their governance potential is considerable, but their deployment in legal proceedings raises important questions about transparency, explainability, and the ability of opposing parties to challenge algorithmic outputs questions that existing evidentiary frameworks have not yet fully resolved.

3.3 Evidentiary Value of Environmental Forensics

The admissibility of scientific evidence in legal proceedings is governed by standards that vary across jurisdictions but share a common concern with reliability. In the United States, the Supreme Court's ruling in Daubert v Merrell Dow Pharmaceuticals Inc established that trial courts must act as gatekeepers, admitting scientific expert testimony only where it is based on sufficient facts or data, is the product of reliable methodology, and has been reliably applied to the facts of the case.[24] Federal Rule of Evidence 702, as amended, codifies these requirements.[25] Environmental forensic evidence has generally survived Daubert scrutiny where it meets these standards, though the application of novel techniques particularly AI-generated analysis and eDNA, continues to generate contested admissibility rulings.

22. National Aeronautics and Space Administration, *Satellite Observations for Environmental Management* 31 (2018).
23. Xiaou Tang et al., *Deep Learning for Environmental Remote Sensing*, 60 IEEE Transactions on Geoscience & Remote Sensing 5112, 5114 (2022).
24. *Daubert v. Merrell Dow Pharms., Inc.*, 509 U.S. 579, 592–93 (1993).
25. Fed. R. Evid. 702.

In Indian courts, the standard for expert evidence under the Indian Evidence Act 1872 (and its successor, the Bharatiya Sakshya Adhiniyam 2023) is less structured than the Daubert framework but shares its concern with the qualifications of the witness and the credibility of the methodology.[26] The National Green Tribunal (NGT) has shown a progressive willingness to engage with technical evidence and has appointed court-commissioned experts where the evidence before it was contested or incomplete, a practice that provides a useful institutional mechanism for integrating forensic expertise into adjudication.

3.4 Environmental Forensics as a Governance Tool

The analytical literature on environmental forensics has largely treated it as an investigative tool, a means of establishing facts after an incident has occurred. This paper argues for a broader conception: environmental forensics as a governance mechanism that operates prospectively (in compliance monitoring and Environmental Impact Assessment), concurrently (in real-time surveillance), and retrospectively (in incident investigation and litigation support). This expanded role requires institutional embedding within regulatory agencies, standardisation of methodologies and evidence protocols, and sustained investment in forensic capacity. Without these institutional prerequisites, the governance potential of environmental forensics will remain unrealised, and the evidentiary gap will persist as a structural weakness in environmental enforcement.

CHAPTER 4: ENVIRONMENTAL FORENSICS IN ACTION: COMPARATIVE CASE STUDIES

4.1 The Vedanta Sterlite Copper Plant Controversy (India)

The Vedanta Sterlite copper smelter at Thoothukudi, Tamil Nadu, provides one of the most extensively litigated examples of environmental forensics in the Indian context. Operations at the plant, which began in 1994 and expanded significantly thereafter, generated persistent allegations of air and water pollution affecting nearby communities. The regulatory history is marked by a series of closures and reopenings, culminating in the permanent closure ordered by the Tamil Nadu Government in 2018 following public protests in which police firing resulted in civilian deaths.

26. Farmer, *supra* note 14, at 218.

Central to the regulatory and judicial proceedings was the question of causation: whether the elevated levels of sulphur dioxide, arsenic, and heavy metals detected in the surrounding environment were attributable to the plant's operations or to pre-existing geological or other industrial sources. The Tamil Nadu Pollution Control Board's 2018 monitoring report, which recorded sulphur dioxide emissions substantially exceeding consent conditions and documented heavy metal contamination of soil and groundwater in adjacent villages,[27] was contested by Sterlite on the basis that background contamination from natural geological sources could not be excluded. The National Green Tribunal's Southern Bench engaged with this attribution question, though its analysis of the forensic evidence was less systematic than the scientific record warranted.[28]

The Supreme Court's earlier ruling in Sterlite Industries (India) Ltd v Union of India had already established that violations of the Environment (Protection) Act 1986 and associated consent conditions had occurred,[29] but the absence of a comprehensive forensic investigation one capable of distinguishing plant-sourced contamination from background levels through isotopic or biomarker analysis left the precise magnitude and attribution of harm unresolved. The Tamil Nadu Pollution Control Board's proceedings subsequently provided additional monitoring data,[30] but the evidentiary record would have been considerably strengthened by the systematic application of the forensic techniques discussed in Chapter 3. The case illustrates the governance cost of reactive, rather than proactive, forensic investigation.

4.2 The LG Polymers Gas Leak (India)

On 7 May 2020, styrene vapour escaped from a storage tank at the LG Polymers plant in Visakhapatnam, Andhra Pradesh, during the resumption of operations following the COVID-19 lockdown. The release caused at least eleven fatalities and respiratory injuries to several thousand residents of surrounding villages.[31] The incident raised questions about both the immediate cause of the release specifically, whether it resulted from operator negligence in managing the polymerisation inhibitor concentration during the extended shutdown, and the

27. Tamil Nadu Pollution Control Bd., *Report on Environmental Monitoring of Sterlite Copper Smelter Plant, Thoothukudi* 12–15 (2018).
28. *In the Matter of M/s Sterlite Indus. (India) Ltd.*, Original Application No. 73 of 2016 (Nat'l Green Trib., S. Bench, Chennai, 2018).
29. *Sterlite Indus. (India) Ltd. v. Union of India*, (2013) 4 SCC 575 (India).
30. *Tamil Nadu Pollution Control Bd. v. Sterlite Indus. (India) Ltd.*, (2019) SCC OnLine Mad 4609 (India).
31. National Disaster Mgmt. Auth., *Report on LG Polymers Gas Leak Incident, Visakhapatnam* 9–11 (2020).

adequacy of the plant's emergency response systems.

The National Disaster Management Authority's post-incident report identified a failure to monitor styrene concentration during the lockdown period as the proximate cause of the vapour cloud formation.[32] The National Green Tribunal, exercising its original jurisdiction, ordered a forensic assessment of the plant's environmental management systems and imposed an interim liability of Rs 50 crore pending a comprehensive damage assessment.[33] The forensic reconstruction of the incident drawing on process data logs, atmospheric dispersion modelling, and toxicological evidence was instrumental in establishing both the mechanism of harm and the inadequacy of the operator's pre-event monitoring. The case demonstrates the value of real-time process data as forensic evidence and raises broader questions about the mandatory retention of operational data in high-risk chemical facilities.

4.3 The Exxon Valdez Oil Spill (United States)

The grounding of the Exxon Valdez in Prince William Sound, Alaska, on 24 March 1989, released approximately 11 million gallons of crude oil and became a defining event in the history of both environmental law and environmental forensics.[34] Chemical fingerprinting analysis comparing the biomarker composition of oil recovered from contaminated beaches and biological samples with the known composition of the cargo provided unambiguous attribution of the spill to the Exxon Valdez, eliminating alternative hypotheses about pre-existing natural seeps or other vessel discharges. The forensic evidence was sufficiently robust to withstand extended appellate scrutiny and formed the evidentiary foundation of Exxon's liability in both civil and criminal proceedings.

The litigation that followed culminated in the Supreme Court's ruling in Exxon Shipping Co v Baker,[35] which applied a 1:1 punitive-to-compensatory damages ratio to reduce punitive damages already lowered once by the Ninth Circuit from the jury's original USD 5 billion to USD 2.5 billion to a final USD 507.5 million, illustrates the importance of the quality of forensic evidence not merely for establishing liability but for calibrating its quantum. The

32. *Id.* at 17.
33. *In re Gas Leak at LG Polymers India Ltd., Vishakhapatnam*, Original Application No. 73 of 2020 (Nat'l Green Trib. 2020).
34. Jeffrey Short, *Fates and Effects of the Exxon Valdez Oil Spill*, in *Environmental Effects of Arctic Oil Spills and Response Technologies* 43, 47 (Samuel Rice & Sanjay Tripathy eds., 2003).
35. *Exxon Shipping Co. v. Baker*, 554 U.S. 471, 513 (2008).

Court's reduction of punitive damages turned partly on its assessment of Exxon's culpability, which was in turn informed by the forensic reconstruction of events. The case established chemical fingerprinting as a standard methodology in oil spill attribution and contributed to the development of professional guidelines for forensic evidence collection at spill sites.

4.4 The Deepwater Horizon Oil Spill (United States)

The Deepwater Horizon blowout of April 2010, which released an estimated 4.9 million barrels of crude oil into the Gulf of Mexico, presented forensic challenges of an order of magnitude greater than any previous spill.[36] Attribution of the oil to the Macondo well rather than other potential sources in the Gulf required extensive chemical fingerprinting against reference samples collected before the blowout, supplemented by real-time satellite tracking of the surface slick and subsurface plume modelling. The forensic investigation, conducted by federal agencies and independent scientists, produced a comprehensive account of the spill's spatial and temporal dynamics that informed both the criminal prosecution of BP and the Natural Resource Damage Assessment process.

BP's criminal plea agreement included an acknowledgement of the forensic evidence establishing the company's role in the blowout,[37] and the NRDA process conducted under CERCLA and the Oil Pollution Act of 1990 relied heavily on forensic biological and chemical sampling to quantify ecosystem damage across coastal habitats, deep water environments, and pelagic ecosystems. The case is instructive for its demonstration that large-scale forensic investigation, when adequately resourced and conducted under rigorous scientific protocols, can generate evidence of sufficient quality to support both criminal accountability and compensatory restoration programmes.

4.5 Comparative Insights

A comparison across these four cases yields several analytically productive observations. First, the quality of forensic evidence was consistently and positively correlated with the decisiveness of accountability outcomes: the Exxon Valdez and Deepwater Horizon cases, in which well-resourced federal agencies conducted systematic forensic investigations using established

36. U.S. Nat'l Comm'n on the BP Deepwater Horizon Oil Spill & Offshore Drilling, *Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling* 123–25 (2011).
37. *United States v. BP Expl. & Prod. Inc.*, No. 2:12-cr-00292 (E.D. La. Nov. 15, 2012) (plea agreement).

protocols, produced more legally definitive results than the Sterlite or LG Polymers cases, where forensic investigation was more fragmented, reactive, and institutionally constrained.

Second, the institutional capacity of the regulatory body conducting or commissioning the forensic investigation was a significant determinant of evidentiary quality. The US EPA's Environmental Forensics Strategy[38] provided a structured framework for multi-agency forensic investigation that had no direct Indian counterpart at the time of the Sterlite or LG Polymers incidents. Third, the use of court-appointed forensic experts more common in Indian National Green Tribunal proceedings than in US federal courts introduces a valuable element of independence but creates uncertainty about methodological consistency and the standard of challenge available to affected parties. Fourth, in all four cases, the delayed deployment of forensic investigation after, rather than before, the environmental harm limited its value for prevention and early intervention. Prospective integration of forensic monitoring into high-risk industrial operations would have provided earlier warning signals and more contemporaneous evidence.

CHAPTER 5: TOWARDS EVIDENCE-BASED ENVIRONMENTAL GOVERNANCE

5.1 Contemporary Challenges

The most significant structural barrier to effective environmental forensics governance is the weakness of forensic infrastructure in most jurisdictions outside North America and Western Europe. India provides an instructive example: while the country possesses capable scientific institutions, including the National Environmental Engineering Research Institute (NEERI) and the Central Pollution Control Board's analytical laboratories, these bodies lack the resources, independence, and standardised protocols needed to serve consistently as forensic investigators in contested enforcement proceedings. The dependence of regulatory findings on facility self-reporting under the Environment (Protection) Act 1986[39] and associated rules creates systemic incentive problems that well-resourced corporate defendants can exploit.

The inconsistent use of scientific evidence across enforcement agencies and courts reflects both capacity constraints and the absence of binding evidentiary standards for environmental

38. U.S. Envtl. Prot. Agency, *Environmental Forensics Strategy* 5 (2009).
39. Environment (Protection) Act, 1986, § 3 (India); Water (Prevention and Control of Pollution) Act, 1974, § 24 (India).

forensic methods. A regulator in one state may accept isotope analysis as conclusive evidence of source attribution while a regulator in another treats it as merely indicative. This inconsistency not only undermines the deterrent value of enforcement but creates perverse incentives for forum shopping by corporate defendants and contributes to the perception of arbitrariness that erodes public confidence in environmental institutions.

5.2 Comparative Regulatory Approaches to Environmental Forensics

5.2.1 United States

The United States has the most developed institutional framework for environmental forensics, rooted in the CERCLA regime[40] and its administrative implementation by the EPA. The EPA's Environmental Forensics Strategy established standardised guidance for evidence collection, chain of custody, and laboratory analysis in contaminated site investigations.[41] The Department of Justice Environment and Natural Resources Division has developed specialised prosecutorial capacity for environmental crime cases requiring forensic evidence, and federal courts have accumulated substantial jurisprudence on the admissibility of specific forensic methodologies. The principal weakness of the US framework is its fragmentation across federal agencies and state regulatory bodies, which can produce inconsistent evidentiary standards for nominally similar enforcement actions.

5.2.2 European Union

The European Union has approached environmental forensics primarily through the lens of compliance monitoring and environmental crime prosecution. The Environmental Crime Directive[42] requires member states to criminalise serious environmental offences and implies an obligation to develop the investigative capacity to support prosecution capacity that, in practice, requires forensic scientific expertise. The European Green Deal's emphasis on technology-driven environmental compliance monitoring,[43] combined with the Copernicus Earth Observation Programme's provision of systematic satellite data, positions the EU as a potential leader in evidence-based environmental governance. The EU Taxonomy Regulation's

40. Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. § 9601 et seq.
41. U.S. Envtl. Prot. Agency, *supra* note 38.
42. Directive 2008/99/EC of the European Parliament and of the Council of 19 November 2008 on the Protection of the Environment through Criminal Law, 2008 O.J. (L 328) 28.
43. Commission Communication on the European Green Deal, COM (2019) 640 final, at 8.

requirements for environmental performance verification create demand for independent forensic assessment of corporate environmental claims that current disclosure-based systems cannot adequately satisfy.

5.2.3 Australia and Canada

Australia and Canada both integrate scientific evidence into their environmental regulatory frameworks, though with distinct emphases. The Environment Protection and Biodiversity Conservation Act 1999 (Cth) in Australia creates a comprehensive framework for environmental impact assessment that expressly contemplates scientific evidence of ecological impact.[44] The National Environmental Protection Agency, an independent federal regulator established under the National Environmental Protection Agency Act 2025 and operational from 1 July 2026, is expected to develop enhanced forensic monitoring capacity for major industrial operations. The Canadian Environmental Protection Act 1999 incorporates risk-based monitoring provisions and supports Environment and Climate Change Canada's environmental forensics laboratory programme,[45] which has developed particular expertise in atmospheric chemistry and water quality forensics. Both jurisdictions provide models for how environmental forensic capacity can be institutionally embedded within regulatory agencies rather than being commissioned on an ad hoc basis.

5.3 Integrating Environmental Forensics into Governance Frameworks

Environmental forensics is currently deployed most effectively in the post-incident phase when contamination has already occurred and legal proceedings have been initiated. Its governance value would be substantially greater if it were integrated systematically at earlier stages of the regulatory process. Four integration points merit particular attention.

First, Environmental Impact Assessment: the EIA process, under India's 2006 EIA Notification[46] and its international equivalents, requires proponents of major industrial projects to assess environmental impacts in advance of authorisation. That assessment is currently based primarily on modelling and baseline surveys conducted by proponent-commissioned consultants. Requiring the collection of forensic baseline data chemical fingerprints of local

44. Environment Protection and Biodiversity Conservation Act 1999 (Cth) § 38B (Austl.).
45. Canadian Environmental Protection Act, 1999, S.C. 1999, c. 33, § 16.
46. Environmental Impact Assessment Notification, 2006, Ministry of Env't, Forest & Climate Change, S.O. 1533(E) (India).

environmental media, isotopic profiles of groundwater, eDNA baselines of aquatic ecosystems as a condition of EIA would enable subsequent enforcement to compare post-facility conditions against an independent, verified pre-project baseline.

Second, ESG compliance and sustainability reporting: the BRSR framework under SEBI regulations[47] currently depends on company-generated data for environmental performance disclosure. Requiring periodic independent forensic verification of material environmental claims, emissions data, waste disposal records, and water quality monitoring would substantially improve the reliability of ESG disclosures and reduce the scope for greenwashing.

Third, environmental auditing and regulatory monitoring: periodic forensic audits of high-risk industrial facilities conducted by accredited independent auditors using standardised protocols would provide regulators with evidence of environmental performance that is less susceptible to manipulation than self-reported data. The findings of such audits should be made publicly available and should inform enforcement prioritisation.

Fourth, environmental dispute resolution: the National Green Tribunal's practice of appointing expert committees[48] provides a useful model for introducing forensic evidence into adjudication, but it could be strengthened by the development of standing forensic panels with defined methodological standards and regular quality assurance reviews.

5.4 Institutionalising Environmental Forensics as a Governance Mechanism

This paper proposes five institutional reforms that would move environmental forensics from an ad hoc investigative tool to a systemic governance mechanism.

First, mandatory forensic audits for high-risk industries: industries with significant pollution potential, including primary metals, petrochemicals, cement, power generation, and pharmaceutical manufacturing, should be subject to mandatory periodic forensic environmental audits. Audit programmes should be designed by regulators, conducted by accredited independent bodies, and funded through industry-wide levy arrangements that prevent individual companies from shopping for favourable auditors. Audit findings should be

47. SEBI (Listing Obligations and Disclosure Requirements) Regulations, 2015, Schedule V (India); Business Responsibility and Sustainability Report Guidelines, 2021 (India).
48. National Green Tribunal Act, 2010, § 15 (India).

publicly disclosed and integrated into regulatory risk assessment.

Second, standardised forensic evidence protocols: national regulatory bodies should develop and maintain publicly available protocols for the collection, preservation, analysis, and reporting of environmental forensic evidence. These protocols should specify minimum methodological standards for each principal technique, chain-of-custody requirements, quality assurance procedures, and the conditions under which expert witnesses may testify about forensic findings. Protocol development should be led by regulatory scientists and reviewed by technical advisory bodies with independent expertise.[49]

Third, strengthened environmental regulatory institutions: the Central Pollution Control Board and State Pollution Control Boards in India require substantially enhanced forensic analytical capacity, including upgraded laboratory infrastructure, trained forensic scientists, and access to remote sensing data platforms. Institutional capacity-building of this kind requires sustained budget commitments and organisational reforms that insulate technical functions from political interference.

Fourth, capacity-building measures: judicial and prosecutorial training in the interpretation of forensic environmental evidence is a prerequisite for its effective use in enforcement proceedings. The National Judicial Academy in India and equivalent bodies in other jurisdictions should develop dedicated training modules on environmental forensic science, with particular attention to the limits of each methodology and the standards of uncertainty that are appropriate in legal decision-making.

Fifth, technology-driven environmental accountability: continuous emissions monitoring systems, IoT-enabled water quality sensors, and satellite-based land use monitoring should be progressively integrated into operating licence conditions for major industrial facilities. Real-time data from these systems should be transmitted directly to regulatory databases, reducing the opportunity for data manipulation and enabling early detection of compliance failures. AI-assisted anomaly detection applied to these data streams can further reduce the burden on human inspectors while improving the comprehensiveness of surveillance.[50]

49. U.N. Environment Programme, *Guidance Manual on the Prosecution of Environmental Crime* 38 (2015).
50. Sands et al., *supra* note 13, at 679–82.

CHAPTER 6: CONCLUSION

6.1 Findings of the Study

This paper has established three principal findings. First, the effectiveness of environmental governance frameworks whether grounded in domestic statute, international treaty, or ESG expectation depends in practice on the quality of evidence available to support attribution of environmental harm to responsible corporate actors. Legal obligations that cannot be enforced because causation cannot be proven are, functionally, no obligations at all. Second, environmental forensic techniques, when deployed rigorously and within appropriate institutional frameworks, provide scientifically reliable methods for bridging the evidentiary gap that has historically insulated many corporate polluters from accountability. Third, the comparative case study evidence demonstrates that jurisdictions with more developed forensic infrastructure and more systematic evidentiary standards achieve more consistent and decisive accountability outcomes.

6.2 Answer to the Research Question

Environmental forensic techniques can substantially strengthen corporate accountability by addressing evidentiary challenges in environmental enforcement and governance frameworks, but the extent to which they do so in practice depends critically on institutional conditions that are not automatically generated by the existence of the scientific methods alone. Where forensic investigation is reactive, fragmented, under-resourced, or methodologically unstandardised, as has too often been the case in Indian environmental proceedings, its contribution to accountability is limited. Where it is systematically embedded in governance processes, conducted under rigorous protocols, and interpreted by adjudicators with appropriate scientific literacy, it can transform enforcement outcomes. The transformation is achievable; the question is whether the necessary institutional investment will be made.

6.3 Concluding Observations

The doctrinal architecture of environmental law is considerably more developed than its enforcement infrastructure. Principles of prevention, precaution, and polluter liability have been elaborated across decades of international negotiation and domestic legislation; what has lagged is the practical capacity to implement them against well-resourced corporate defendants who exploit evidentiary uncertainty as a defence. Environmental forensics is not a panacea for the enforcement deficit, but it is the most promising systematic response available. Integrating it into Environmental Impact Assessment, sustainability reporting, regulatory monitoring, and dispute resolution, as this paper has argued, would begin to close the gap between the aspirations of environmental governance and its operational realities. The construction of an evidence-based environmental governance framework is, ultimately, a political and institutional challenge as much as a scientific one, but the science is ready.

BIBLIOGRAPHY

Cases

1. Daubert v Merrell Dow Pharmaceuticals Inc 509 US 579 (1993)
2. Exxon Shipping Co v Baker 554 US 471 (2008)
3. In re Exxon Valdez 270 F 3d 1215 (9th Cir 2001)
4. In re Oil Spill by Oil Rig Deepwater Horizon 21 F Supp 3d 657 (ED La 2014)
5. LG Polymers India Pvt Ltd v State of Andhra Pradesh (2020) SCC Online NGT 394
6. National Green Tribunal, In re: Gas Leak at LG Polymers India Ltd, Vishakhapatnam, Original Application No 73 of 2020 (NGT 2020)
7. National Green Tribunal, In the Matter of M/s Sterlite Industries (India) Limited, Original Application No 73 of 2016 (NGT, Southern Bench, Chennai, 2018)
8. Sterlite Industries (India) Ltd v Union of India (2013) 4 SCC 575
9. Tamil Nadu Pollution Control Board v Sterlite Industries (India) Ltd (2019) SCC Online Mad 4609
10. United States v BP Exploration & Production Inc (ED La 2012) Plea Agreement

Legislation

1. Bharatiya Sakshya Adhiniyam 2023 (India)
2. Canadian Environmental Protection Act 1999, SC 1999, c 33
3. Comprehensive Environmental Response, Compensation, and Liability Act 1980 (CERCLA) 42 USC §9601 et seq (US)
4. Environment (Protection) Act 1986 (India)
5. Environment Protection and Biodiversity Conservation Act 1999 (Cth) (Australia)
6. Federal Rules of Evidence (US) r 702
7. Indian Evidence Act 1872
8. National Green Tribunal Act 2010 (India)

9. Water (Prevention and Control of Pollution) Act 1974 (India)

Treaties and International Instruments

1. Declaration of the United Nations Conference on the Human Environment (Stockholm Declaration) 1972, UN Doc A/CONF.48/14/Rev.1

2. Paris Agreement (adopted 12 December 2015, entered into force 4 November 2016) UNTS 3156

3. Rio Declaration on Environment and Development 1992, UN Doc A/CONF.151/26/Rev.1 (Vol I)

EU Instruments

1. Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 on environmental liability [2004] OJ L 143/56 (Environmental Liability Directive)

2. Directive 2008/99/EC of the European Parliament and of the Council of 19 November 2008 on the protection of the environment through criminal law [2008] OJ L 328/28

3. Regulation (EU) 2020/852 on the establishment of a framework to facilitate sustainable investment [2020] OJ L 198/13 (EU Taxonomy Regulation)

Books

1. Farmer M, Environmental Forensics: Principles and Applications (CRC Press 2009)

2. Morrison R, Environmental Forensics: Contaminant Specific Guide (Academic Press 2000)

3. Peters K, Walters C and Moldowan JM, The Biomarker Guide (2nd edn, CUP 2005) vol 1

4. Sands P, Peel J, Fabra A and MacKenzie R, Principles of International Environmental Law (4th edn, CUP 2018)

5. World Commission on Environment and Development (WCED), Our Common Future (OUP 1987)

Journal Articles

1. Hellmann J and others, 'Environmental DNA (eDNA) as an Emerging Tool in Environmental Assessment and Monitoring' (2021) 30 Environmental Science & Technology Letters 112

2. Tang X and others, 'Deep Learning for Environmental Remote Sensing' (2022) 60 IEEE Transactions on Geoscience and Remote Sensing 5112

3. Thomsen PF and Willerslev E, 'Environmental DNA – An Emerging Tool in Conservation for Monitoring Past and Present Biodiversity' (2015) 183 Biological Conservation 4

Reports and Official Documents

1. Commission, 'Communication on the European Green Deal' COM(2019) 640 final

2. Environmental Impact Assessment Notification 2006 (India), MoEFCC, SO 1533(E)

3. European Environment Agency (EEA), Remote Sensing in Support of Environmental Policy (EEA 2020)

4. Global Reporting Initiative, GRI Standards: Universal Standards 2021 (GRI 2021)

5. National Aeronautics and Space Administration (NASA), Satellite Observations for Environmental Management (NASA 2018)

6. National Disaster Management Authority (NDMA), Report on LG Polymers Gas Leak Incident, Visakhapatnam (NDMA 2020)

7. SEBI (Listing Obligations and Disclosure Requirements) Regulations 2015 (India), Schedule V; Business Responsibility and Sustainability Report (BRSR) Guidelines 2021

8. Short J, 'Fates and Effects of the Exxon Valdez Oil Spill' in Rice S and Tripathy S (eds), Environmental Effects of Arctic Oil Spills and Response Technologies (Exxon Valdez Oil Spill Trustee Council 2003)

9. Tamil Nadu Pollution Control Board (TNPCB), Report on Environmental Monitoring of Sterlite Copper Smelter Plant, Thoothukudi (TNPCB 2018)

10. Task Force on Climate-Related Financial Disclosures (TCFD), Recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD 2017)

11. UNEP, Global Environment Outlook 6 (UNEP 2019)

12. UNEP, Guidance Manual on the Prosecution of Environmental Crime (UNEP 2015)

13. US Environmental Protection Agency (EPA), Environmental Forensics Strategy (EPA 2009)

14. US National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling (US GPO 2011)