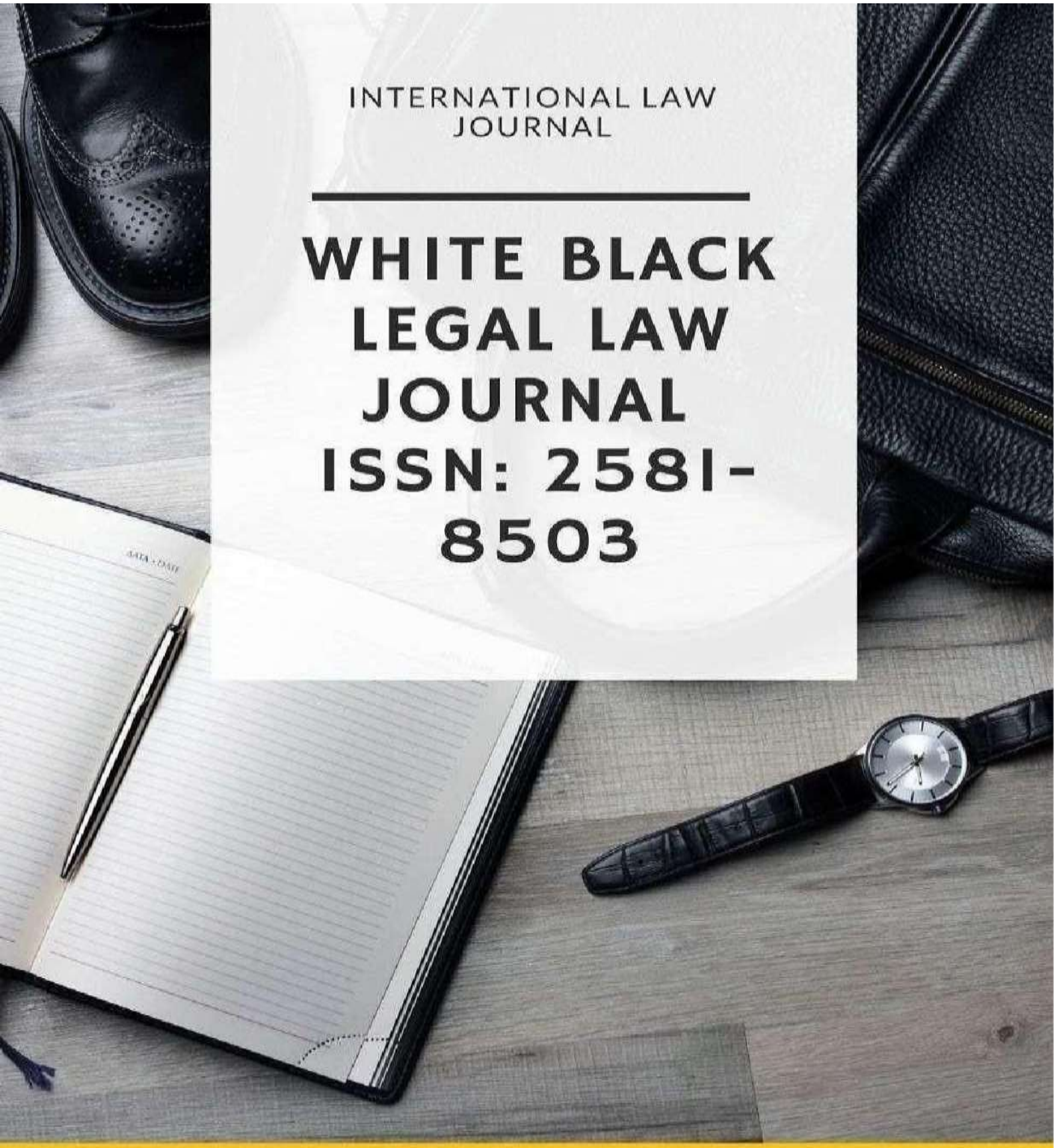

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"FROM EXPLORATION TO POLLUTION: THE LEGAL CRISIS OF SPACE DEBRIS GOVERNANCE"

AUTHORED BY - ANANYA SHUKLA

ABSTRACT

The rapid expansion of human activity in outer space has transformed Earth's orbital environment into an increasingly congested and hazardous domain. Space debris, comprising defunct satellites, fragmented remnants of collisions, and mission-related objects, poses a serious threat to operational spacecraft, human life, and the long-term sustainability of space exploration. This article critically examines the issue of space debris cleaning through the lens of international and comparative space law, highlighting the inadequacies of existing legal frameworks in addressing contemporary challenges. It analyses key international treaties such as the United Nations-backed Outer Space Treaty, Liability Convention, and Registration Convention, while also evaluating the role of non-binding guidelines developed by bodies like the United Nations Committee on the Peaceful Uses of Outer Space and the Inter-Agency Space Debris Coordination Committee.

Through detailed case studies, including the 2007 Chinese anti-satellite test, the 2009 Iridium-Cosmos collision, and India's Mission Shakti, the article illustrates the legal and environmental consequences of debris-generating activities and the limitations of current liability regimes. It further explores the emerging field of active debris removal (ADR), identifying key technological advancements alongside unresolved legal issues relating to sovereignty, dual-use concerns, and accountability. The growing involvement of private actors and the resulting regulatory challenges are also critically assessed. A dedicated focus on India examines its evolving legal and policy framework, institutional mechanisms led by the Indian Space Research Organisation, and its potential role in shaping global governance norms.

The article ultimately argues for the urgent development of a binding international legal regime, supported by effective enforcement mechanisms, space traffic management systems, and economic incentives for debris mitigation and removal. It emphasizes that the sustainability of outer space is a shared responsibility, requiring coordinated global action grounded in principles of environmental stewardship, intergenerational equity, and collective security. The future of space exploration depends not only on technological innovation but also on the willingness of the international community to adopt a cooperative and forward-looking legal

approach.

KEYWORDS

Space Debris; Space Law; Active Debris Removal (ADR); Outer Space Treaty; Liability Convention; Space Governance; Orbital Sustainability; Space Traffic Management; International Law; India Space Policy; Satellite Collisions; Environmental Ethics in Space; Private Space Industry; Global Commons.

I. INTRODUCTION

The story of humanity's relationship with space is one of wonder, ambition, and, increasingly, consequence. For centuries, the sky represented something distant and pure, a realm untouched by human interference. However, in less than a century since the launch of the first artificial satellite, that perception has dramatically changed. Today, the region surrounding Earth is crowded with thousands of artificial objects, many of which no longer serve any purpose. What was once a symbol of limitless potential is now slowly becoming a zone of congestion and risk. Space debris, often casually referred to as "space junk,"[1] is not merely an environmental inconvenience, it is a structural threat to the future of space exploration, satellite-based services, and even human safety. Every piece of debris, whether a defunct satellite or a microscopic fragment, travels at speeds so high that even the smallest particle can cause catastrophic damage. As humanity becomes increasingly dependent on space-based technologies for communication, navigation, climate monitoring, disaster management, and national security, the risks posed by debris become more tangible and immediate. Yet, the issue of space debris is not confined to engineering or science. At its heart lies a complex web of legal, political, and ethical questions. The governance of outer space was largely shaped during the Cold War, at a time when only a handful of nations had access to space technology. The legal framework that emerged during that era was visionary in many respects, emphasizing cooperation and peaceful use. However, it did not anticipate the scale of modern space activity or the challenges posed by debris accumulation.

Today, space is no longer the exclusive domain of superpowers. Private corporations, emerging economies, and even universities are active participants in space missions. This democratization of space has brought innovation and opportunity, but it has also intensified the problem of debris. The absence of binding international rules on debris removal, coupled with

[1] United Nations, *Convention on International Liability for Damage Caused by Space Objects*, 1972.

unclear liability regimes and competing national interests, has created a governance gap that threatens the sustainability of space activities.

This article seeks to explore the issue of space debris cleaning through the lens of international and comparative space law, while grounding the discussion in real-world case studies and human concerns. It examines how the problem has evolved, how different legal systems address it, and what reforms are necessary to ensure that space remains accessible for future generations. Ultimately, it argues that the challenge of space debris is not just about cleaning up the past, but about reimagining how humanity approaches the shared domain of outer space.

II. UNDERSTANDING SPACE DEBRIS

A. Meaning And Scope Of Space Debris

Space debris encompasses all non-functional, human-made objects orbiting Earth. This includes inactive satellites, fragments from collisions, discarded rocket stages, and even tiny particles produced by wear and tear. While the term may suggest something trivial, the reality is far more serious. Each piece of debris represents a potential hazard, capable of damaging operational spacecraft or triggering further fragmentation.

The scale of the problem is staggering. Tens of thousands of objects larger than 10 centimeters are tracked regularly, but millions of smaller fragments remain undetected. These smaller pieces, despite their size, are often more dangerous because they cannot be easily monitored or avoided.

B. Sources Of Space Debris

1. Operational activities

Routine space operations, including satellite deployment and rocket launches, generate debris. Components such as bolts, covers, and protective layers may detach and remain in orbit.

2. Accidental collisions

Collisions between satellites or debris objects create large clouds of fragments. These events significantly increase the density of debris in certain orbital regions.

3. Intentional destruction

Anti-satellite (ASAT) tests and deliberate destruction of spacecraft contribute heavily to debris creation. These actions raise both environmental and legal concerns.

C. The Kessler Syndrome Explained

1. Concept and implications

The Kessler Syndrome refers to a scenario in which the density of objects in orbit becomes so high that collisions trigger a chain reaction, generating more debris and further collisions. Over time, this could render certain orbital zones unusable.

2. Long-term risks

Such a scenario would have profound consequences, including the loss of satellite services and restrictions on future space missions. It represents a tipping point beyond which recovery becomes extremely difficult.

III. INTERNATIONAL SPACE LAW FRAMEWORK

The international legal framework governing outer space has evolved through a combination of binding treaties and non-binding guidelines, reflecting both the aspirations and limitations of global cooperation in this domain. At its core lie the foundational treaties developed under the auspices of the United Nations, particularly during the Cold War era when space activities were limited to a few technologically advanced states. The **Outer Space Treaty, 1967**[2] forms the cornerstone of this framework, establishing fundamental principles such as the non-appropriation of outer space, the peaceful use of celestial bodies, and the concept of international responsibility for national space activities. While visionary in its emphasis on space as the "province of all mankind," the treaty does not explicitly address space debris, as the issue had not yet emerged as a significant concern at the time of its drafting. Complementing this is the **Liability Convention, 1972**,[3] which introduces a system of liability for damage caused by space objects. It creates a distinction between absolute liability for damage caused on Earth and fault-based liability for damage occurring in outer space. However, its practical application to debris-related incidents remains limited, primarily due to the inherent difficulties in tracing the origin of debris and establishing fault in an environment where multiple actors operate simultaneously. Similarly, the **Registration Convention, 1975** [4]seeks to enhance transparency and accountability by requiring states to maintain a registry of objects launched into outer space. Although this mechanism aids in identifying ownership and jurisdiction, it does not provide solutions for the growing problem of defunct or abandoned satellites that continue to orbit the Earth.

[2] United Nations, *Outer Space Treaty, 1967*
[3] United Nations, *Liability Convention, 1972*
[4] United Nations, *Registration Convention, 1975*

Beyond these binding instruments, the regulatory landscape is supplemented by a range of soft law mechanisms that aim to guide state behavior without imposing legally enforceable obligations. Notably, the debris mitigation guidelines developed under the United Nations Committee on the Peaceful Uses of Outer Space encourage states to adopt practices that minimize the creation of space debris, such as limiting the release of mission-related objects and ensuring the safe disposal of satellites at the end of their operational life. In parallel, technical standards formulated by bodies like the Inter-Agency Space Debris Coordination Committee play a significant role in shaping national regulations and industry practices. These guidelines, while influential, ultimately rely on voluntary compliance, which leads to uneven implementation across different jurisdictions.

Despite these efforts, significant structural gaps persist within the existing legal regime. One of the most critical shortcomings is the absence of binding obligations specifically addressing space debris, resulting in a regulatory framework that lacks enforceability and uniformity. This is compounded by the so-called "ownership paradox," wherein space objects, even after they become non-functional, remain under the jurisdiction and control of the launching state. This legal principle creates substantial obstacles for active debris removal initiatives, as no other state or entity can interfere with or remove such objects without consent. Furthermore, the absence of a centralized international authority to monitor compliance or enforce regulations exacerbates the problem, leaving the governance of space debris largely dependent on the goodwill and cooperation of individual states. Collectively, these limitations highlight the urgent need for a more robust, cohesive, and forward-looking legal framework capable of addressing the complexities of an increasingly congested orbital environment.

IV. CASE STUDIES IN SPACE DEBRIS AND LEGAL IMPLICATIONS

The realities of space debris are best understood not merely through abstract legal principles but through concrete incidents that have shaped global awareness and policy discourse[5]. One of the most significant events was the 2007 Chinese anti-satellite test [6]conducted by China, in which a defunct weather satellite was deliberately destroyed using a missile. This single act generated more than 3,000 trackable debris fragments, along with countless smaller particles that continue to orbit the Earth today. The scale and persistence of the debris created immediate and widespread international concern, not only because of the physical danger it posed but also

[5] NASA, *Orbital Debris Quarterly News*, Vol. 11, Issue 2 (2007).
[6] Brian Weeden, "2007 Chinese Anti-Satellite Test Fact Sheet," Secure World Foundation (2010).

because it exposed a glaring gap in international law, there were no binding legal prohibitions explicitly restricting such actions. The incident highlighted how military activities in space could have long-term environmental consequences, thereby underscoring the urgent need for enforceable norms governing debris-generating behavior.

A similar wake-up call came in 2009 with the collision between an operational satellite owned by Iridium Communications and a defunct Russian satellite, an event now widely referred to as the Iridium-Cosmos collision[7]. This accidental crash produced a massive cloud of debris, dramatically increasing the risk of further collisions in low Earth orbit. What made this case particularly significant from a legal standpoint was the absence of any formal liability claim, despite the clear damage incurred. Under existing frameworks, particularly the Liability Convention, establishing fault in such scenarios is exceedingly complex, especially when both objects involved belong to different states and one is no longer operational. The incident revealed the practical limitations of current liability regimes and emphasized the need for better coordination, communication, and tracking mechanisms among spacefaring entities.

India's entry into the anti-satellite domain through Mission Shakti in 2019 [8]added another important dimension to the debate. Conducted by India, the test involved the destruction of one of its own satellites in low Earth orbit. While Indian authorities maintained that the operation was carefully planned to minimize long-term debris risks, the international community responded with a mix of recognition and concern. The test reignited discussions on the legality and ethical implications of ASAT activities, particularly in light of their potential to generate debris. From a legal perspective, Mission Shakti demonstrated that even responsible conduct within national boundaries can raise broader questions about global sustainability and the adequacy of existing legal norms.

Another compelling example is the case of the Envisat satellite, operated by the European Space Agency[9]. Once one of the largest and most sophisticated Earth observation satellites, Envisat became non-functional in 2012 and has since remained in orbit as a massive piece of uncontrolled debris. Its size and location make it a particularly dangerous object, with the potential to generate a significant amount of fragmentation if it were to collide with another object. The legal challenges associated with its removal are emblematic of the broader "ownership paradox" in space law, despite being defunct, the satellite remains under the jurisdiction of its launching authority, meaning that any attempt to remove it would require

[7] Nicholas L. Johnson et al., "The Iridium–Cosmos Collision," NASA (2009).
[8] Indian Space Research Organisation (ISRO), *Mission Shakti Press Release*, 2019.
[9] European Space Agency (ESA), *Envisat Mission Status Report*, 2012–present.

explicit consent. This situation illustrates the urgent need for legal frameworks that facilitate active debris removal while balancing concerns of sovereignty and liability.

V. ACTIVE DEBRIS REMOVAL AND LEGAL COMPLEXITIES

Active debris removal (ADR)[10] represents one of the most promising yet legally complicated solutions to the growing problem of space debris. From a technological standpoint, significant progress has been made in developing methods to capture and eliminate debris. These include robotic arms capable of physically grabbing objects, net and harpoon systems designed to secure debris, and even laser technologies that can alter the trajectory of smaller fragments. Additionally, deorbiting techniques aim to safely guide debris back into Earth's atmosphere, where it can burn up without causing harm. While these innovations demonstrate the feasibility of large-scale cleanup efforts, they also introduce a host of legal challenges that cannot be ignored.

At the forefront of these challenges is the issue of sovereignty. Under existing international law, space objects remain the property of the launching state, regardless of whether they are operational or defunct. This means that removing another state's satellite without permission could be interpreted as a violation of sovereignty, even if the object in question poses a clear risk to others. Compounding this issue is the dual-use nature of many ADR technologies. Systems designed to capture or disable debris could potentially be repurposed as anti-satellite weapons, raising concerns about militarization and strategic misuse. Furthermore, the question of liability becomes particularly complex in the context of ADR operations. If a debris removal mission inadvertently causes damage, either by failing to capture an object or by generating additional fragments, determining responsibility would be far from straightforward. These legal uncertainties highlight the need for a carefully crafted regulatory framework that can support technological innovation while ensuring accountability and trust among nations.

VI. THE ROLE OF PRIVATE ACTORS

The rapid expansion of private sector participation in space has fundamentally altered the dynamics of space governance. Companies are now launching large constellations of satellites to provide global communication and internet services, significantly increasing the number of objects in orbit. While this has democratized access to space-based technologies and driven innovation, it has also intensified the problem of space debris. The sheer scale of these

[10] RemoveDEBRIS Consortium, *Final Report on Active Debris Removal Demonstration Mission*, 2020.

operations means that even minor lapses in debris mitigation can have far-reaching consequences.

From a regulatory perspective, private actors operate under national licensing regimes, which vary widely in their requirements and enforcement mechanisms. This lack of uniformity creates inconsistencies in how debris risks are managed across different jurisdictions. Moreover, while many companies voluntarily adopt best practices for sustainability, the absence of binding international standards means that compliance is not universal. This raises important ethical questions about the balance between profit and responsibility. As commercial interests continue to expand in space, ensuring that private actors contribute to, rather than undermine, long-term sustainability becomes an increasingly urgent priority.

VII. INDIA AND SPACE DEBRIS: LAW, POLICY AND PRACTICE

India's growing prominence in the global space sector brings with it both opportunities and responsibilities. Over the past few decades, the country has established itself as a reliable and cost-effective provider of space services, with a strong track record of successful missions. This expansion has naturally led to greater involvement in issues related to space debris and sustainability.

At the institutional level, the Indian Space Research Organisation[11] plays a central role in managing India's space activities. It has adopted various measures to minimize debris creation, including adhering to international guidelines on post-mission disposal and designing satellites with end-of-life strategies. In addition to ISRO, India has begun developing a broader regulatory framework to oversee commercial space activities, reflecting the increasing participation of private entities in the sector.

From a legal standpoint, India is in the process of formulating comprehensive space legislation that aims to address key issues such as licensing, liability, and environmental responsibility. This development is particularly significant, as it represents a shift towards a more structured and accountable approach to space governance. The legacy of Mission Shakti continues to influence this discourse, highlighting the tension between strategic objectives and environmental considerations. At the same time, India's consistent emphasis on the peaceful use of space positions it as a potential leader in shaping global norms for debris management. By leveraging its experience and diplomatic engagement, India has the opportunity to

[11] Indian Space Research Organisation (ISRO), *Annual Report*, latest edition.
Government of India, *Draft Space Activities Bill*, 2017.

contribute meaningfully to the development of a more sustainable and cooperative space environment.

VIII. LIABILITY AND ACCOUNTABILITY

The question of liability lies at the heart of any legal framework addressing space debris. Existing principles distinguish between absolute liability for damage caused on Earth and fault-based liability for incidents occurring in space. While this distinction provides a basic structure, its practical application is fraught with challenges. Identifying the origin of debris, proving fault, and navigating the involvement of multiple actors all complicate the process of assigning responsibility.

These difficulties are further compounded by the increasing number of private participants in space activities. As more actors enter the domain, the risk of disputes grows, making it essential to develop clearer and more effective mechanisms for accountability. Reforming the liability regime to address these complexities is not just a legal necessity but a prerequisite for maintaining trust and cooperation among spacefaring entities.

IX. ETHICAL AND ENVIRONMENTAL DIMENSIONS

The issue of space debris extends beyond legal and technical considerations into the realm of ethics and environmental responsibility. The characterization of space as the "province of all mankind" [12]implies a collective duty to preserve it for future generations. This principle aligns closely with the concept of intergenerational justice, which emphasizes the rights of those yet to come.

From an environmental perspective, space debris can be understood as a form of pollution, albeit in a domain far removed from Earth's ecosystems. The parallels with terrestrial environmental challenges are striking, particularly in terms of the need for collective action and sustainable practices. Addressing space debris, therefore, is not just about protecting infrastructure but about upholding a broader ethical commitment to responsible stewardship.

X. FUTURE OF SPACE DEBRIS GOVERNANCE

Looking ahead, the future of space debris governance will depend on the ability of the international community to move beyond voluntary guidelines and establish binding legal

[12] United Nations, Outer Space Treaty, Article I

frameworks.[13] There is growing recognition that enforceable rules are necessary to ensure compliance and accountability. In addition, the development of space traffic management systems will be crucial for coordinating the movement of satellites and reducing collision risks. Economic incentives also have a role to play in encouraging investment in debris removal technologies. By aligning financial interests with sustainability goals, policymakers can foster innovation while addressing environmental concerns. Ultimately, however, the success of these efforts will depend on global cooperation. The shared nature of outer space means that no single nation can solve the problem alone, making collaboration among states and private actors essential for ensuring the long-term sustainability of space activities.

XI. CONCLUSION

The issue of space debris forces humanity to confront a fundamental paradox. Space, once imagined as infinite and untouched, is now showing clear signs of strain from human activity. The accumulation of debris is not merely a technical failure but a reflection of governance gaps, competing interests, and delayed collective action.

What makes this challenge particularly complex is its inherently global nature. No single nation can solve the problem alone, and yet every nation contributes to it in some way. The legal framework, built on ideals of cooperation, must now evolve to address the realities of a crowded and contested orbital environment. Cleaning space debris is not just about removing objects; it is about redefining responsibility in a shared domain. It requires nations to move beyond narrow self-interest and recognize that the sustainability of space is a common good. It demands innovation, not only in technology but also in law and policy.

The future of space depends on decisions made today. If the international community can come together to address the debris problem, it will demonstrate that global cooperation is still possible in an increasingly fragmented world. If it fails, the consequences may extend far beyond space, affecting communication, security, and the very infrastructure of modern life. In the end, the question is not whether we have the capability to clean up space. The question is whether we have the collective will to do so.

[13] United Nations Office for Outer Space Affairs (UNOOSA), *Long-Term Sustainability Guidelines*, 2019.