

SPACE DEBRIS: A GROWING CHALLENGE TO SUSTAINABLE SPACE ACTIVITIES

by

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1. Abstract

Space debris has emerged as one of the most significant challenges to the long-term sustainability of outer space activities. The rapid expansion of satellite launches, commercial space ventures, anti-satellite (ASAT) weapon tests, and abandoned spacecraft has led to an alarming increase in artificial objects orbiting the Earth. These objects pose serious risks to operational satellites, crewed missions, and critical infrastructure that supports communication, navigation, weather forecasting, scientific research, and national security. Although international space law recognises the responsibility of States for activities conducted in outer space, the existing legal framework does not specifically impose binding obligations regarding the prevention, mitigation, or removal of space debris. Most international guidelines, including those adopted by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), remain voluntary and lack effective enforcement mechanisms.

This research examines the concept of space debris and analyses the adequacy of the existing international legal regime governing its management. Using a doctrinal research methodology, the study analyses primary legal instruments, including the Outer Space Treaty (1967), the Liability Convention (1972), the Registration Convention (1975), and relevant international guidelines, alongside scholarly literature and reports issued by international organisations such as the United Nations, NASA, and the European Space Agency. The study identifies significant legal and regulatory gaps concerning liability, enforcement, active debris removal, and space traffic management. It concludes that the existing legal framework has not kept pace with the rapid commercialisation and militarisation of outer space. The paper recommends the development of a binding international treaty on space debris, stronger international cooperation, mandatory debris mitigation standards, enhanced liability mechanisms, and effective space traffic management systems to ensure the sustainable and peaceful use of outer space for present and future generations.

Keywords: Space Debris, International Space Law, Outer Space Treaty, Liability Convention, UNCOPUOS, Space Sustainability, Active Debris Removal, Space Traffic Management.

2. Introduction

The exploration and utilisation of outer space have transformed modern society by facilitating global communication, navigation, weather forecasting, disaster management, scientific research, and national security. Since the launch of Sputnik 1 in 1957, space activities have expanded significantly, with governments, private corporations, and international organisations increasingly relying on satellite technology. The emergence of commercial space enterprises and mega-constellations has accelerated the number of objects placed into Earth's orbit, contributing to unprecedented growth in space operations.¹ While these developments have generated immense economic and scientific benefits, they have also intensified the problem of space debris, which has become one of the most pressing challenges to the sustainability of outer space activities.

Space debris refers to non-functional, human-made objects in Earth orbit,² including defunct satellites, spent rocket stages, fragments generated by satellite collisions, and debris resulting from anti-satellite (ASAT) weapon tests. Even the smallest fragments travel at extremely high velocities, making them capable of causing catastrophic damage to operational spacecraft and satellites. The accumulation of debris increases the probability of collisions, creating additional fragments through a cascading phenomenon commonly known as the Kessler Syndrome, thereby threatening the long-term usability of outer space.³

The legal regulation of outer space is primarily governed by international treaties developed under the auspices of the United Nations. The Outer Space Treaty, 1967, establishes the foundational principles governing the exploration and use of outer space, while the Liability Convention, 1972, and the Registration Convention, 1975, provide mechanisms relating to liability and registration of space objects. However, these treaties were drafted during the early stages of space exploration and do not specifically address the contemporary challenges posed by the exponential increase in space debris, commercial satellite constellations, and active debris removal technologies. Furthermore, the existing international debris mitigation guidelines adopted by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and the Inter-Agency Space Debris Coordination Committee (IADC) are largely voluntary, limiting their effectiveness in ensuring compliance by States and private space operators.

3. Review of Literature

The issue of space debris has attracted considerable attention from legal scholars, scientists, international organisations, and policymakers due to its growing implications for the sustainability of outer space activities. Existing literature highlights that while technological advancements have significantly expanded access to space, the corresponding legal framework has not evolved at the same pace. The following review examines major scholarly contributions and institutional reports relevant to space debris and international space law.

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Nicholas L. Johnson, a former Chief Scientist for Orbital Debris at NASA, is regarded as one of the foremost authorities on space debris. His research explains the origin, evolution, and environmental consequences of orbital debris and emphasises that the increasing density of debris threatens the safety of present and future space missions. Johnson argues that effective debris mitigation measures are essential to preserve the long-term usability of Earth's orbital environment.⁴

Donald J. Kessler introduced the widely recognised Kessler Syndrome, which explains how collisions between space objects can generate additional debris, leading to a cascading chain reaction that may render certain orbital regions unsafe for future space operations. His theory remains one of the most influential scientific foundations for understanding the urgency of international debris mitigation efforts.⁵

Frans G. von der Dunk, a leading scholar in international space law, analyses the legal principles governing outer space under the existing treaty framework. He observes that although the Outer Space Treaty establishes State responsibility for national space activities, it does not specifically regulate the prevention or removal of space debris. He advocates the development of more detailed and enforceable international legal norms capable of addressing contemporary challenges arising from commercialisation and technological advancement.

4. Objectives of the Study

The present study seeks to critically examine the growing problem of space debris from the perspective of international space law and sustainable space governance. The specific objectives of the study are as follows:

1. To examine the concept, nature, and sources of space debris and understand its impact on the safety and sustainability of outer space activities.
2. To analyse the existing international legal framework governing space debris, with particular reference to the Outer Space Treaty (1967), the Liability Convention (1972), the Registration Convention (1975), and other relevant international instruments.
3. To evaluate the effectiveness of international guidelines and institutional mechanisms, including those developed by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and the Inter-Agency Space Debris Coordination Committee (IADC), in mitigating the risks posed by space debris.
4. To identify the legal and practical challenges associated with liability, enforcement, active debris removal, space traffic management, and the regulation of commercial space activities.

5. To examine the adequacy of the existing international legal regime in addressing emerging issues arising from the rapid commercialisation and militarisation of outer space.

These objectives provide the foundation for analysing the existing legal regime, identifying its limitations, and recommending practical measures to ensure the peaceful, safe, and sustainable use of outer space for present and future generations.

5. Methodology and Database Used

5.1 Research Methodology

The present study adopts a doctrinal (library-based) research methodology, which is qualitative in nature. The research primarily involves a systematic analysis of international treaties, conventions, legal principles, judicial decisions, institutional guidelines, and scholarly literature relating to space debris and international space law. The doctrinal approach is appropriate because the study focuses on examining the adequacy of the existing legal framework governing space debris and identifying the legal gaps that hinder effective regulation.

The research critically evaluates the rights, obligations, responsibilities, and liabilities of States under international space law. It also analyses the legal implications of emerging issues such as commercial space activities, mega-constellations, anti-satellite (ASAT) weapon tests, active debris removal, and space traffic management. Comparative and analytical methods have been employed to assess whether the current legal regime is capable of addressing contemporary challenges associated with the increasing accumulation of orbital debris.

5.2 Sources of Data

The study is based entirely on secondary data, collected from reliable and authoritative legal and scientific sources.

Primary Sources

The primary sources include international treaties, conventions, principles, and guidelines governing outer space activities, such as:

- Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty, 1967).
- Convention on International Liability for Damage Caused by Space Objects (Liability Convention, 1972).
- Convention on Registration of Objects Launched into Outer Space (Registration Convention, 1975).
- United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) Space Debris Mitigation Guidelines.
- United Nations General Assembly Resolutions and relevant international principles concerning the peaceful uses of outer space.

Secondary Sources

The secondary sources include:

- Books on international space law.
- Peer-reviewed journal articles.
- Research papers and conference proceedings.
- Publications of the United Nations, NASA, the European Space Agency (ESA), and the Inter-Agency Space Debris Coordination Committee (IADC).
- Government reports, policy documents, and official publications relating to space sustainability.
- Reputed online legal databases, including HeinOnline, JSTOR, and SCC Online.

6. Research Discussion

6.1 Meaning and Concept of Space Debris

Outer space has become an indispensable domain for scientific advancement, communication, navigation, weather forecasting, national security, and commercial activities. However, the rapid increase in space missions has also resulted in the accumulation of space debris, which poses a serious threat to the safety and sustainability of outer space operations. Space debris, commonly referred to as orbital debris or space junk,⁶ consists of all human-made objects in Earth's orbit that no longer serve any useful purpose. These include defunct satellites, spent rocket stages, fragments generated by collisions, discarded mission-related equipment, and debris produced by anti-satellite (ASAT) weapon tests.

Unlike naturally occurring meteoroids, space debris is entirely artificial. These objects continue to orbit the Earth at extremely high speeds, often exceeding 7–8 kilometres per second. Even a fragment measuring only a few millimetres can damage or destroy operational satellites due to the enormous kinetic energy generated by such high velocities. Consequently, space debris has emerged as one of the most significant environmental and legal challenges confronting the international space community.

The growth of the commercial space industry has further intensified this problem. Private companies are launching thousands of satellites to provide global internet connectivity, Earth observation, and communication services. While these developments promote technological innovation and economic growth, they also increase orbital congestion and the likelihood of collisions. Every collision has the potential to generate thousands of additional fragments, thereby escalating the overall debris population.

One of the most significant concerns associated with space debris is the Kessler Syndrome, proposed by NASA scientist Donald J. Kessler in 1978. According to this theory, a collision between orbiting objects can trigger a cascading chain reaction in which newly created

fragments collide with other satellites, producing even more debris. If such a scenario continues unchecked, certain orbital regions may become too hazardous for future space missions, thereby restricting humanity's ability to utilise outer space for peaceful purposes.⁷

The problem of space debris extends beyond scientific and technological concerns. It also raises complex legal questions regarding ownership, liability, responsibility, environmental protection, and international cooperation. Existing international treaties were drafted during an era when space activities were conducted primarily by States. Today, however, the increasing participation of private companies and the emergence of mega-constellations have fundamentally altered the nature of space operations. As a result, the current legal framework is increasingly viewed as inadequate to address contemporary challenges relating to debris prevention, mitigation, and removal.

The growing accumulation of space debris therefore necessitates not only technological innovation but also the development of a comprehensive and binding international legal framework capable of ensuring the long-term sustainability of outer space activities. Effective regulation will require greater cooperation among States, international organisations, and private space operators to preserve outer space as a shared resource for present and future generations.

6.2 Classification and Sources of Space Debris

Space debris exists in various forms and originates from multiple human activities conducted in outer space. Understanding the classification and sources of space debris is essential for developing effective legal and technical strategies for its prevention and mitigation. Different categories of debris present varying degrees of risk depending on their size, location, velocity, and origin. The increasing diversity of space missions and the growing participation of private entities have further contributed to the complexity of the debris environment.

6.2.1 Classification of Space Debris

Space debris may be classified into the following categories:

a) Defunct Satellites

Defunct satellites are spacecraft that have reached the end of their operational life and no longer perform their intended functions. Many of these satellites remain in orbit for years or even decades, occupying valuable orbital slots and increasing the risk of accidental collisions. Since they are no longer controllable, they pose a significant threat to active satellites and future space missions.

b) Spent Rocket Stages

Rocket stages used to launch satellites into orbit often remain in space after completing their mission. These abandoned rocket bodies constitute a substantial proportion of large orbital

debris. Over time, they may explode due to residual fuel or battery failures, generating thousands of additional debris fragments.

c) Fragmentation Debris

Fragmentation debris consists of pieces produced by satellite collisions, accidental explosions, structural failures, or anti-satellite (ASAT) weapon tests. This category represents one of the most dangerous forms of space debris because it includes numerous small fragments travelling at extremely high speeds, making them difficult to detect and track.

d) Mission-Related Objects

During space missions, astronauts and spacecraft occasionally release or discard equipment such as bolts, protective covers, lenses, tools, insulation materials, and other hardware. Although individually small, these objects contribute to the growing debris population and may damage operational spacecraft.

e) Micro-Debris

Micro-debris includes particles measuring less than one centimetre in diameter. Despite their small size, these particles travel at orbital velocities and can penetrate spacecraft surfaces, damage solar panels, and impair sensitive scientific instruments. Detecting and tracking such particles remains a significant technological challenge.

7. Suggestions

Based on the findings of this study, the following recommendations are proposed to strengthen the international legal framework governing space debris and to ensure the long-term sustainability of outer space activities.

7.1 Adoption of a Binding International Treaty on Space Debris

The existing international legal framework is largely based on broad principles and voluntary guidelines. Therefore, there is an urgent need for a comprehensive and legally binding international treaty dedicated specifically to the regulation of space debris. Such a treaty should establish uniform international standards for debris prevention, mitigation, monitoring, removal, and enforcement while clearly defining the rights and obligations of States and private space operators.

7.2 Strengthening the Liability Regime

The liability provisions under the Liability Convention (1972)⁸ should be modernised to address contemporary challenges arising from space debris. The revised framework should:

- Establish clearer rules for attributing responsibility for debris-related damage.
 - Introduce simplified procedures for compensation claims.
 - Develop international mechanisms for resolving disputes arising from orbital collisions.
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- Consider the creation of an international compensation fund for victims of space debris incidents.

A stronger liability regime would enhance accountability and encourage responsible conduct in outer space.

7.3 Mandatory Debris Mitigation Standards

Current debris mitigation guidelines issued by UNCOPUOS and the Inter-Agency Space Debris Coordination Committee (IADC) should gradually be transformed into mandatory international standards. These standards should require satellite operators to:

- Minimise debris generation during launch and operation.
- Safely dispose of satellites at the end of their operational life.
- Prevent explosions caused by residual fuel or batteries.
- Design spacecraft capable of controlled de-orbiting or transfer to designated graveyard orbits.

Making these standards legally binding would promote greater consistency and compliance among all space-faring nations.

7.4 Development of an International Space Traffic Management System

The increasing congestion in Earth's orbit necessitates the establishment of a coordinated International Space Traffic Management (STM) system. Such a system should:

- Monitor satellite movements in real time.
- Improve collision prediction and avoidance.
- Facilitate information sharing among States and private operators.
- Develop internationally accepted operational procedures for safe navigation in outer space.

A globally coordinated STM framework would significantly reduce the risk of accidental collisions and improve the safety of space operations.

8. Conclusion

The rapid expansion of space activities has transformed outer space into an indispensable domain for scientific advancement, economic development, communication, navigation, environmental monitoring, and national security. However, these advancements have also resulted in the unprecedented accumulation of space debris, which poses a serious threat to the safety, sustainability, and peaceful use of the orbital environment. The increasing number of inactive satellites, spent rocket stages, collision fragments, and debris generated by anti-satellite (ASAT) weapon tests has significantly heightened the risk of orbital collisions, thereby endangering both present and future space missions.

This study critically examined the existing international legal framework governing space debris through a doctrinal analysis of international treaties, institutional guidelines, and scholarly literature. The research demonstrates that although the Outer Space Treaty (1967),

the Liability Convention (1972), and the Registration Convention (1975) establish important legal principles concerning State responsibility,⁹ liability, and jurisdiction, these instruments were developed during the early stages of space exploration and do not adequately address the complex challenges posed by modern space activities. Furthermore, the voluntary nature of the UNCOPUOS Space Debris Mitigation Guidelines and the Inter-Agency Space Debris Coordination Committee (IADC) Guidelines limits their effectiveness in ensuring consistent international compliance.

The analysis of major international incidents, including the Cosmos 954 accident, the Fengyun-1C anti-satellite test, the Iridium 33–Cosmos 2251 collision, and the Russian ASAT test, illustrates the growing inadequacy of the current legal regime. These incidents demonstrate that the absence of binding international obligations concerning debris mitigation, active debris removal, and space traffic management creates significant legal uncertainty and increases the risks associated with expanding space activities.

9. References

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