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Article

Space Debris and International Environmental Law: Emerging Legal Challenges

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Abstract: The rapid expansion of space activities has generated substantial socioeconomic benefits through satellite communication; unlimited use of outer space has caused pollution in outer space and, consequently, in the earth's environment. Space debris has become a threat to the security of space activities. Space debris is the most important of these pollutions that not only creates numerous threats and risks for orbiting satellites but also creates environmental, economic and security risks for current and future space activities. Although international space law establishes principles concerning responsibility, liability, registration and the peaceful use of outer space, it does not provide a comprehensive and legally binding environmental regime specifically designed to prevent and remediate orbital pollution. This review examines the relationship between international space law and international environmental law in addressing space debris. It evaluates the Outer Space Treaty, Liability Convention, Registration Convention, United Nations space-debris mitigation guidelines and the Guidelines for the Long-Term Sustainability and examines emerging challenges associated with mega-constellations of outer space activities. The paper finds that the existing international framework provides important principles but remains fragmented and largely dependent on voluntary implementation and concludes that the sustainable use of outer space requires a transition from predominantly voluntary debris mitigation towards a more coherent international environmental governance framework.

Keywords: space debris, international environmental law, space law, orbital environment, satellite, liability, Nigeria, Africa

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1. Introduction

Outer space has become an increasingly important component of modern technological and socioeconomic development. Satellite systems support telecommunications, navigation, and meteorological forecasting. However, almost every aspect of the exploration and use of outer space involves elements that are inherently detrimental to the space environment and to the environment of the Earth. Ulrike, M. B., & Steven, F. [1]. One of the problems of space activities is the increasing pollution of the outer space environment and the environment of the planet Earth due to space

debris. The accumulation of these objects in orbits around the Earth has raised concerns about the safety of astronauts, spacecraft, and orbiting satellites and the risk of them falling to Earth. Some countries are concerned about the effects of increasing space debris on human life on Earth. https://www.unoosa [2]. Space debris has been a growing concern since mankind began launching spacecraft into orbit. With each launch, additional material has been added to the pool of space debris in orbit [3]. As of January 2020, the amount of debris orbiting the Earth exceeded 8,000 metric tons, which is equivalent to the weight of approximately 727 school buses [4]. This debris poses a major threat to spacecraft as well as to terrestrial objects—if this debris falls into the atmosphere. The environmental problem associated with space debris differs from conventional pollution on Earth because the orbital environment is physically distinct, difficult to access, and characterized by extremely high relative velocities. Even relatively small debris particles can cause serious damage to operational spacecraft. A collision between a functioning satellite and a debris object can generate additional fragments, which may subsequently cause further collisions. This cascading process is commonly associated with the Kessler Syndrome, in which the density of objects in certain orbital regions becomes sufficiently high to increase the probability of successive collisions [5]. The legal governance of this problem is complex. International space law was developed primarily during the early period of space exploration and therefore did not anticipate the present scale of commercial space activity. The Outer Space Treaty of 1967, the Liability Convention of 1972, the Registration Convention of 1975, and other international instruments establish important principles concerning state responsibility, liability, and registration. However, they do not constitute a comprehensive environmental law regime for the orbital environment. International environmental law, meanwhile, has developed principles relating to environmental protection, prevention of harm, due diligence, cooperation, and sustainable development. The question therefore arises whether these principles can be applied to the protection of the space environment.

2. Materials and Methods

This study adopts a qualitative systematic-narrative review approach. Relevant academic literature, international treaties, United Nations instruments, policy documents, technical guidelines and institutional publications concerning space debris, international space law, Environmental law and space sustainability were reviewed. Primary legal sources included United Nations space treaties and instruments adopted through the Committee on the Peaceful Uses of Outer Space (COPUOS) and the United States Space Surveillance Network, which monitors more than 23,000 objects larger than 10 cm in Earth's orbit. Secondary sources included scholarly reports addressing space sustainability, orbital congestion, debris mitigation and commercial space activities. And the European Space Agency's Space Debris Office.

International Laws Regulating the Environment of Outer Space

Several international treaties, conventions, agreements, and other legal instruments have been developed to regulate activities in outer space. However, the effectiveness of these instruments in preventing or controlling activities that contribute to the degradation of the space environment remains an important subject of concern. This issue has become increasingly significant because of the rapid expansion of space exploration, satellite deployment, commercial space activities, and the associated growth of space debris.

a. The Partial Test Ban Treaty, 1963

The Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water, commonly known as the Partial Test Ban Treaty (PTBT), was among the earliest international legal instruments to expressly regulate activities associated with outer space. Adopted in the context of the early development of space exploration and nuclear technology, the treaty was motivated largely by concerns over nuclear explosions, radioactive contamination, and the widespread dispersion of radioactive fallout. These concerns became particularly serious following the

development and testing of increasingly powerful thermonuclear weapons by the major nuclear powers during the 1950s and early 1960s [6]. The treaty requires states parties to prohibit, prevent, and refrain from carrying out nuclear weapon test explosions or other nuclear explosions within areas under their jurisdiction or control. Article I prohibits such explosions in the atmosphere; beyond the atmosphere, including outer space; and underwater, including territorial waters and the high seas. It further extends the prohibition to other environments where an explosion could cause radioactive debris to be present beyond the territorial limits of the state exercising jurisdiction or control over the activity. The geographical scope of the PTBT is therefore broader than outer space because it encompasses the atmosphere and underwater environments as well. During the negotiation of the Treaty, consideration was given to prohibiting underground nuclear testing. However, disagreement among the negotiating powers prevented the adoption of a comprehensive prohibition covering underground tests. The possibility of achieving a permanent ban on all nuclear testing, including underground testing, was nevertheless preserved in Article I(b). Despite its historical importance, the PTBT has significant limitations when assessed from the perspective of contemporary space-environmental protection. Its principal prohibition is directed toward nuclear explosions and does not comprehensively regulate other weapons or activities capable of generating space debris. In addition, the Treaty does not establish a detailed system of sanctions for violations by States Parties. A further limitation concerns the treatment of radioactive debris. The treaty focuses on situations in which radioactive debris crosses the territorial boundaries of the state responsible for the explosion, but it does not establish a comprehensive remedial framework for all forms of transboundary environmental harm. Similarly, the treaty does not expressly address non-radioactive debris, including fragments of missiles, spacecraft, or weapons produced by an explosion. These limitations can partly be explained by the historical circumstances in which the treaty was negotiated, when space exploration and nuclear technology were still at relatively early stages of development.

b. The Outer Space Treaty, 1967

Another foundational instrument of international space law is the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, generally referred to as the Outer Space Treaty (OST). The Treaty establishes fundamental principles governing the exploration and use of outer space and recognizes that such activities should be conducted for the benefit and in the interests of all countries, irrespective of their level of economic or scientific development [7]. The environmental and security dimensions of the Outer Space Treaty are particularly evident in Article IV. States Parties undertake not to place in orbit around Earth objects carrying nuclear weapons or other weapons of mass destruction, nor to install such weapons on celestial bodies or station them in outer space in any other manner. The provision therefore establishes an important restriction on the militarization of the space environment. Article IV also provides that the Moon and other celestial bodies shall be used exclusively for peaceful purposes. It prohibits the establishment of military bases, installations, and fortifications; the testing of weapons; and the conduct of military maneuvers on celestial bodies. Nevertheless, the use of military personnel for scientific research or other peaceful purposes is expressly permitted, as is the use of equipment and facilities necessary for peaceful exploration. The provisions of the Outer Space Treaty represented an important development beyond the Partial Test Ban Treaty. Whereas the PTBT principally prohibited nuclear testing in specified environments, Article IV of the OST addresses the placement of nuclear weapons and other weapons of mass destruction in outer space and on celestial bodies. Nevertheless, questions remain concerning the precise scope of the prohibition, particularly regarding temporary deployment, testing activities, and circumstances in which weapons may be used without being permanently stationed in outer space. According to Shaw [8], the interpretation of Article IV has generated debate concerning the precise extent of the prohibition. A narrow interpretation is that the provision specifically prohibits nuclear weapons and other weapons of mass destruction from being placed in orbit around Earth, in outer space, and on celestial bodies. A broader interpretation may, however, draw upon the general

principles of the Treaty, particularly the requirement that outer space be explored and used for the benefit and interests of all countries. From an environmental perspective, the distinction between prohibited and permitted military activities remains important. The treaty does not prohibit all involvement of military personnel in outer-space activities. Instead, military personnel may participate in scientific research and other peaceful activities. Consequently, military activities associated with peaceful exploration and scientific research can be distinguished from activities involving the deployment or use of weapons in outer space. The effectiveness of these provisions is nevertheless affected by several legal uncertainties. The Treaty does not prescribe specific sanctions for every violation of its provisions and does not provide a detailed definition of the expression "peaceful purposes." This ambiguity has contributed to continuing debate concerning the legality of various military and dual-use activities in outer space. The environmental importance of the Outer Space Treaty is further demonstrated by its provisions concerning harmful contamination. States Parties are required to conduct exploration and use of outer space, including the Moon and other celestial bodies, in ways that avoid harmful contamination and adverse changes to the Earth's environment resulting from the introduction of extraterrestrial matter. Where necessary, States are expected to adopt appropriate measures to prevent such contamination.

c. Space weaponization and Environmental Degradation

Despite the principles established under international space law, military activities involving outer space continue to generate environmental and sustainability concerns. A significant example occurred on 11 January 2007, when China conducted an anti-satellite (ASAT) test in which a ground-based missile destroyed a satellite. The event demonstrated the capability to target objects in orbit and generated a substantial quantity of orbital debris, thereby increasing the risks faced by other spacecraft and space-based systems (United Nations Office for Outer Space Affairs [UNOOSA], n.d.). The development of military capabilities associated with outer space has also involved the United States and other major space powers. Although space-based military capabilities may provide important national security and defense functions, their continued expansion raises concerns regarding the peaceful and sustainable use of outer space. The development and deployment of counterspace capabilities can increase the risk of conflict in space and, particularly where destructive ASAT systems are employed, can contribute directly to the creation of long-lived orbital debris. The competing strategic interests of major space powers have consequently complicated attempts to establish comprehensive international restrictions on space weapons. The growing dependence of modern societies on satellites for communications, navigation, Earth observation, and other services makes the protection of the orbital environment increasingly important. Destructive activities in orbit can create debris that remains in space for extended periods and potentially threatens both civilian and governmental space systems.

Other International Legal Instruments Relevant to Space Activities

In addition to the Partial Test Ban Treaty and the Outer Space Treaty, several other international instruments constitute important components of the international legal framework governing space activities. These include the Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space, [9]; the Convention on International Liability for Damage Caused by Space Objects, [10]; and the Convention on Registration of Objects Launched into Outer Space, [11]. The Liability Convention is particularly relevant to environmental governance because it establishes international rules concerning liability for damage caused by space objects. The Registration Convention, on the other hand, supports the identification and registration of space objects launched into outer space. Together with the Outer Space Treaty and other instruments, these conventions contribute to the broader framework for responsible space activities. Nevertheless, a significant limitation of the existing international legal framework is that many of its provisions regulate the conduct of space activities without establishing a comprehensive, legally binding regime specifically dedicated to the prevention, removal, and remediation of space debris. Consequently, governmental and commercial space activities may continue to generate additional orbital debris despite the existence of international principles

concerning the peaceful and responsible use of outer space.

Space Debris Mitigation and International Cooperation

The rapid expansion of space technology and the increasing number of objects launched into orbit have intensified concerns about the long-term sustainability of the space environment. The orbital environment should therefore be regarded as a valuable and finite resource that requires responsible management to ensure continued access and use by present and future generations. International scientific and policy forums have increasingly emphasized the importance of internationally coordinated measures for reducing space debris. Discussions at international conferences on space debris and within governmental institutions have highlighted the need for effective debris-mitigation measures and mechanisms capable of addressing non-compliance. Non-governmental organizations, professional associations, and civil-society institutions also contribute to space-debris mitigation through awareness campaigns, scientific meetings, publications, conferences, and information-sharing initiatives. Such organizations can complement governmental and intergovernmental efforts by promoting responsible space operations and increasing public and institutional awareness of the environmental consequences of orbital debris. At the intergovernmental level, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) has played a central role in facilitating international cooperation concerning outer-space activities. Established in 1958, COPUOS provides a forum for states to exchange information, deliberate on space-related issues, and promote international cooperation in the exploration and use of outer space (UNOOSA, n.d.). One of the important contributions of COPUOS to space environmental governance has been the development of space debris mitigation guidelines. These guidelines encourage states and international organizations to implement appropriate measures through national legislation, regulations, and institutional mechanisms to reduce the generation of space debris to the greatest extent practicable [12]. However, an important limitation of the COPUOS Space Debris Mitigation Guidelines is their non-binding character. The guidelines do not constitute a treaty imposing directly enforceable obligations on States under international law. Their implementation, therefore, depends substantially on states incorporating the recommended practices into their national regulatory systems and on space operators voluntarily adopting responsible debris-mitigation practices.

Active Debris Removal

Active debris removal involves deliberately capturing and removing existing debris from orbit. Technologically, active debris removal could contribute significantly to long-term space sustainability. Legally, however, it raises complicated questions. A state or private company cannot necessarily assume that it may remove another state's inactive satellite simply because the object presents a collision risk. The original space object remains associated with the launching state under international space law, and questions concerning consent, ownership, jurisdiction, and liability arise. Active debris removal, therefore, requires international cooperation and potentially new legal mechanisms establishing procedures for identifying, authorizing, and removing dangerous objects.

Legal Challenges in Space Debris Governance

Space debris governance has become a major legal challenge due to the rapid increase in satellites, spent rocket stages, abandoned spacecraft, and fragments from collisions and explosions. The growing concentration of objects in Earth orbit increases collision risks and threatens the long-term sustainability of outer-space activities [13]. Although international space law establishes general principles for responsible space activities, it does not provide a comprehensive and binding legal regime specifically addressing space debris. A major challenge is the absence of a dedicated international treaty on space debris. The Outer Space Treaty, Liability Convention, and Registration Convention establish rules on state responsibility, liability, and jurisdiction, but they do not provide detailed obligations concerning debris prevention, end-of-life disposal, collision avoidance, or active debris removal. Similarly, the UN Space Debris Mitigation Guidelines provide important recommendations but are largely non-binding, limiting their enforcement and uniform

implementation (United Nations, 2008). Another challenge is the lack of a universally accepted legal definition of space debris. Uncertainty over whether abandoned satellites, spent rocket bodies, and fragments constitute separate categories creates difficulties concerning ownership, registration, liability, and removal. Article VIII of the Outer Space Treaty further provides that space objects remain under the jurisdiction and control of their state of registry. Consequently, the removal or modification of another state's defunct satellite may require consent, creating significant legal difficulties for active debris removal and on-orbit servicing Jakhu [14]. Liability and responsibility for orbital collisions also present significant challenges. The Liability Convention establishes liability rules, but determining the source of debris, proving fault, and establishing causation can be difficult, particularly where small fragments are involved or several operators contribute to a collision. The growing participation of private companies further complicates responsibility because states remain internationally responsible for national space activities, including those conducted by non-governmental entities. The absence of a globally harmonized space traffic management system is another legal gap. Increasing orbital congestion requires effective collision warnings, information sharing, and coordinated maneuvers, yet international law does not establish a single global authority with comprehensive responsibility for orbital traffic management [15]. National regulatory differences may also encourage regulatory arbitrage and produce inconsistent requirements for satellite licensing, debris mitigation, and post-mission disposal. Space debris also raises important environmental and equity concerns. Article IX of the Outer Space Treaty requires States to avoid harmful contamination and adverse environmental effects, but it does not establish detailed standards for orbital pollution or mandatory environmental assessments. Developing countries, including African states, may additionally face financial and technological limitations in monitoring and mitigating debris despite their increasing dependence on space-based services [16]. Overall, the principal legal challenge is the gap between the rapid expansion of space activities and the limited development of binding international rules on orbital debris. Strengthening space debris governance requires clearer legal definitions, mandatory mitigation and end-of-life requirements, improved liability and attribution mechanisms, internationally coordinated space traffic management, clearer rules for active debris removal, and greater technical support for developing countries. Such measures are essential for ensuring the safe, equitable, and sustainable use of outer space.

3. Results and Discussion

The review demonstrates that international space law and international environmental law have complementary roles in addressing space debris. International space law provides the basic legal structure governing state responsibility, authorization, liability, and registration. International environmental law provides broader principles that can support prevention, due diligence, cooperation, precaution, and sustainability. However, neither regime independently provides a complete solution. The Outer Space Treaty was developed when the number of space objects was relatively small and most activities were conducted by governments. The contemporary space environment is substantially different. Commercial companies are deploying large satellite constellations, private actors are developing new launch technologies, and the number of space objects is increasing rapidly. This transformation creates a regulatory mismatch. The legal principles remain relevant, but detailed implementation mechanisms are often insufficient. A particularly important issue is the distinction between environmental harm and compensable damage. Existing liability rules generally become operational when identifiable damage occurs. Space debris, however, may cause significant environmental degradation by increasing collision risks even before direct damage occurs. This suggests the need for a preventive approach to space environmental governance. Rather than waiting for collisions, international and national regulators should require operators to demonstrate that their activities are designed to minimize debris and remain sustainable throughout the mission lifecycle.

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The findings further indicate that the rapid expansion of mega-constellations represents one of the most significant emerging challenges for orbital environmental governance. The deployment of large numbers of satellites can increase the density of objects in frequently used orbital regions and consequently increase the complexity of collision avoidance and space traffic coordination. Although satellite constellations provide significant benefits in communications, navigation, Earth observation, and other services, their environmental implications require greater regulatory attention. Existing international instruments were not specifically designed to regulate the cumulative environmental effects of thousands of individually authorized spacecraft.

This situation demonstrates the importance of adopting a lifecycle-based approach to space activities. Environmental responsibility should begin at the design and launch stage and continue through operation, collision avoidance, end-of-life disposal, and, where appropriate, controlled re-entry. Licensing authorities should therefore consider the cumulative debris contribution of proposed missions rather than evaluating individual spacecraft in isolation. Such an approach would connect the principle of prevention under environmental law with the authorization and supervision responsibilities already recognized under international space law.

Overall, the findings demonstrate that the principal weakness of the current framework is not the complete absence of legal principles but the lack of sufficiently detailed, universally applicable, and enforceable mechanisms. Existing treaties establish important concepts of responsibility, liability, registration, peaceful use, and avoidance of harmful contamination, while the COPUOS guidelines provide practical recommendations for debris mitigation. Nevertheless, the voluntary nature of several important measures limits uniform implementation.

4. Conclusion

The development of international space law has provided an important foundation for regulating activities in outer space and protecting the space environment. The Partial Test Ban Treaty established an early prohibition against nuclear explosions in outer space, while the Outer Space Treaty introduced broader principles concerning peaceful exploration, weapons of mass destruction, harmful contamination, and international cooperation. Subsequent instruments, including the Liability Convention, Registration Convention, and Rescue Agreement, have strengthened the institutional and legal framework governing space activities. Nevertheless, the existing framework contains significant gaps. In particular, international space law does not yet provide a comprehensive and universally binding regime specifically addressing the prevention, active

removal, and remediation of space debris. The non-binding character of the COPUOS Space Debris Mitigation Guidelines further limits the uniformity of implementation. The continued development of commercial space activities, satellite constellations, and military counter-space capabilities, therefore, demonstrates the need for stronger international cooperation and potentially more effective and enforceable rules for the long-term sustainability of the outer-space environment. The international community should progressively develop binding legal standards addressing space debris and orbital environmental protection. Incorporate environmental principles into space law States should make debris mitigation and end-of-life disposal mandatory conditions for satellite authorization. International cooperation should be strengthened to provide accurate information on orbital objects and collision risks. International guidelines should clarify when and how abandoned space objects can be removed by third parties. States should strengthen commitments against intentional debris-generating activities.

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