Climate Footprint of Space Exploration

For Prelims: Paris Agreement, Black carbon, Space Debris, Low Earth orbit (LEO), Outer Space Treaty, 1967, Indian National Space Promotion and Authorization Centre, Network for Space Objects Tracking and Analysis

For Mains: Environmental impact of space exploration, India's role in space sustainability, Intersection of technology and environmental policy

Source: TH

Why in News?

Space exploration is expanding rapidly, but its **environmental impact from rocket emissions** to satellite debris is largely ignored by global sustainability frameworks like the **Paris Agreement.** Urgent action is needed to address these growing concerns.

How are Space Activities Affecting the Environment?

- **Rocket Emissions:** Rocket launches emit **carbon dioxide (CO_2), black carbon**, and water vapor. Black carbon absorbs sunlight 500 times more effectively than CO_2, exacerbating **global warming.**
    - Additionally, **chlorine-based rocket propellants** deplete the **ozone layer,** increasing **ultraviolet (UV)** exposure and disrupting atmospheric circulation.
- **Space Debris:** As of September 2024, 19,590 satellites have been launched, with 13,230 still in orbit, of which 10,200 are operational.
    - The total mass of space objects exceeds 13,000 tonnes, contributing to pollution by **Space Debris** due to overcrowding in **low Earth orbit (LEO).**
        - Non-functional satellites and debris from collisions add to the growing problem of space junk and making **space increasingly inaccessible.**
    - This debris can disrupt radio waves and sensor accuracy, affecting critical systems for **disaster tracking, climate monitoring, and communication.**
- **Satellite Manufacturing:** The production of satellites involves energy-intensive processes that contribute significantly to their **carbon footprint,** particularly through the use of metals and composites.
    - Satellite propulsion systems also release additional emissions during orbital adjustments. Furthermore, satellites **burn up during re-entry,** releasing **metallic "satellite ash"** that could alter atmospheric dynamics and harm the climate.
- **Emerging Threats:** **Space mining,** although not yet operational, poses a potential **threat to both Earth and space environments**.
    - Increased industrial activity in orbit could intensify environmental impacts, compounding the challenges posed by current space operations.

What are the Barriers to Sustainable Space Exploration?

- **Lack of Regulations:** Space activities are not covered by agreements like the **Paris Accord,** leaving emissions and debris largely unregulated.
    - Without clear guidelines, the **rapid increase in satellites and debris led to overcrowded orbits,** making future missions more costly and riskier.
    - While the **Outer Space Treaty, 1967** **emphasizes responsible use,** it lacks binding provisions for environmental sustainability.
    - In 2019, **the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)** adopted 21 voluntary guidelines for the long-term sustainability of space activities.
        - However, the **lack of binding regulations** and **conflicting national and commercial priorities** hinder the implementation of these guidelines, making it challenging to achieve a **unified approach to space sustainability.**
- **Commercial Exploitation of Space:** It involves generating revenue through space-related technologies and services, such as **space resource recovery from asteroids, developing commercial space stations**, and offering space tourism, driven by profit-focused companies, may undermine sustainability efforts.
- **High Costs:** Developing and implementing **sustainable technologies for space exploration is expensive.**
    - This includes **costs related to debris mitigation,** sustainable fuel alternatives, and long-term missions, all of which require significant investment.
    - Achieving sustainability in space requires advanced technologies for debris removal, efficient propulsion systems, and life support systems for long-duration missions.
        - **Many of these technologies are still in development** and demand substantial investment.
- **Data-Sharing Issues:** Security and commercial interests often **hinder real-time satellite and debris tracking,** which is essential for coordinated space traffic management.

Where Does India Stand on Space Sustainability?

- **Private Sector Engagement**: The formal establishment of the **Indian National Space Promotion and Authorization Centre (In-SPACe)** is expected to boost the role of private companies.
    - Startups like **Agnikul, Skyroot, and Dhruva Space** are developing sustainable satellite launch vehicles and technologies.
    - Manastu Space Technologies has delivered the **iBooster Green Propulsion System** to the **Defence Research and Development Organisation**.
        - The system uses a **hydrogen peroxide-based fuel for safer, cost-effective satellite** operations like orbit raising and deorbiting.
- **Space Debris Management**: **Indian Space Research Organisation (ISRO) Network for Space Objects Tracking and Analysis (NETRA) project** aims to track space debris, providing critical data to protect space assets and help manage risks.
    - This initiative helps manage risks and **prevent Kessler Syndrome,** where collisions create more debris.
    - India has also collaborated with the US on space object monitoring under a pact signed in 2022.
- **In-Orbit Servicing**: ISRO is developing the **SPADEX (Space Docking Experiment)** to dock satellites for refueling and other services, which will enhance satellite longevity and mission flexibility.

United Nations Committee on the Peaceful Uses of Outer Space

- COPUOS was established in 1958, following the launch of the **first artificial satellite, Sputnik I, in 1957**. Initially created as an ad hoc intergovernmental committee, it was later made a **permanent body by the UN General Assembly** in 1959. **India was one of the 18 founding members.**
- COPUOS oversees the exploration and use of space for humanity's benefit, focusing on peace, security, and development.
    - It reviews international cooperation, encourages space research, and addresses legal issues related to outer space.

- **India and COPUOS:**
  - **Dr. Vikram K. Sarabhai,** the **Father of Indian Space Program**, served as Vice-President and Scientific Chairman of the **United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE-I) in 1968.**
  - In 2021, India was elected as Chair of the new Working Group on the Long-term Sustainability of Outer Space Activities.

Way Forward

- **Technological Innovations: Reusable rockets,** like those developed by **Elon Musk's SpaceX**, reduce waste and costs. **Green hydrogen and biofuels** can lower emissions in launches.
  - Electric propulsion is efficient for low-thrust missions but not suitable for heavy-lift operations.
  - **Nuclear propulsion** presents a potential option, but it carries the risk of nuclear radiation pollution in the event of an accident within Earth's atmosphere.
- **Mitigating Orbital Debris:** Biodegradable satellites such as **Japan's LignoSat,** where components could disintegrate on re-entry, reducing space debris accumulation.
  - Investment in **Autonomous Debris Removal (ADR)** technologies such as **robotic arms and lasers** is essential for **cleaning up existing debris.**
  - Deorbiting satellites from LEO to **Geostationary Orbit (GEO)** or higher orbits can reduce the risk of re-entry into Earth's atmosphere and minimize debris accumulation in LEO.
- **Global Traffic Management:** A global system to monitor satellite movements in real-time would reduce collision risks and ensure safer orbital use.
  - Overcoming **data-sharing resistance and building trust** with security protocols are key for effective space traffic management.
- **Policy and Governance:** Aligning sustainability goals with the Outer Space Treaty and introducing binding agreements under COPUOS is essential for enforcing environmental responsibility in space.
  - Governments can **enforce emission caps, debris mitigation, and offer incentives for green technologies** through subsidies and penalties to promote a sustainable space industry.
- **Public-Private Partnerships:** Collaboration between governments and private entities is key to funding sustainable technologies. Shared accountability frameworks ensure mutual responsibility for sustainability in space.

Drishti Mains Question:

Examine the environmental impact of space exploration. Suggest sustainability measures.

UPSC Civil Services Examination, Previous Year Question (PYQ)

Mains

Q.1 What is India’s plan to have its own space station and how will it benefit our space programme? **(2019)**

Q.2 Discuss India’s achievements in the field of Space Science and Technology. How the application of this technology helped India in its socio-economic development? **(2016)**

Q.3 What is the main task of India’s third mood mission which could not be achieved in its earlier mission? List the countries that have achieved this task. Introduce the subsystems in the spacecraft launched and explain the role of the ‘Virtual Launch Control Centre’ at the Vikram Sarabhai Space Centre which contributed to the successful launch from Sriharikota. **(2023)**