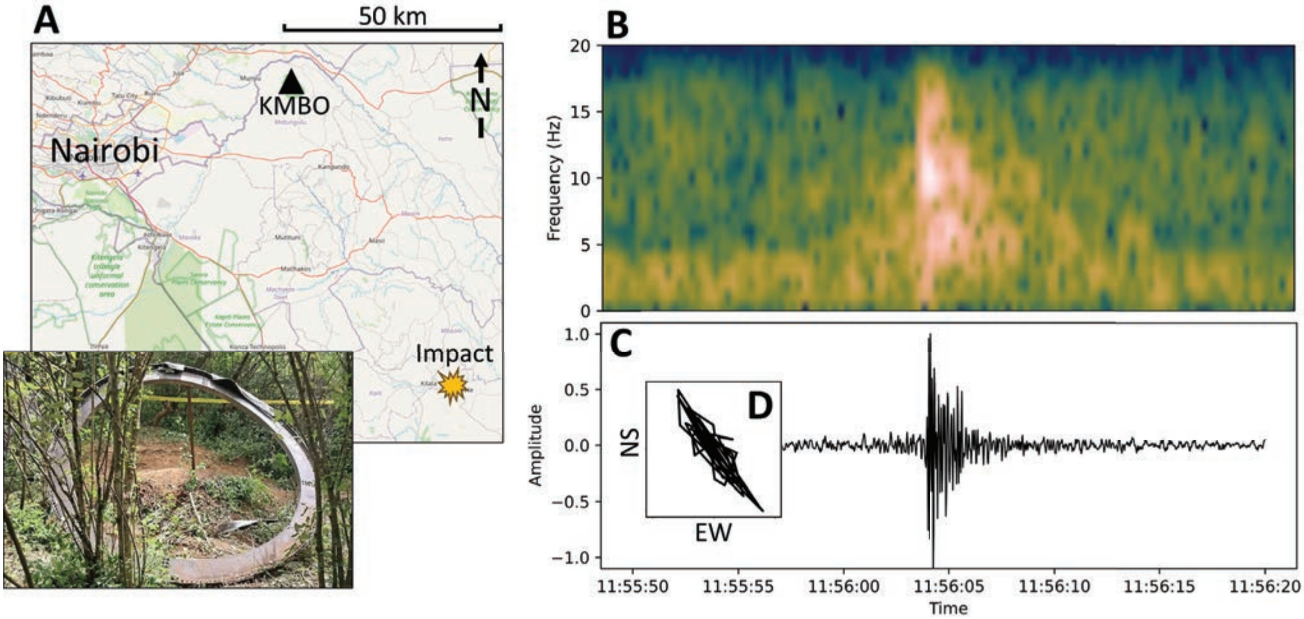

Figure 1. (A) The impact site is ~115 km southeast of Nairobi. The seismic station KMBO (−1.1268S / 37.2523E) is located 80 km from the impact site, deployed in a tunnel dug into a mountain side. The space fragment is shaped like a ring (Photo from Meray, 2025). (B) Spectrogram. (C) Corresponding seismogram (vertical motion component) shows significant increase of amplitudes and spectral energy at 11:56:04 a.m. (UTC). For better visualization I applied a bandpass filter between 1 Hz and 20 Hz. The spectrogram is calculated using a window length of one second and 80% overlap. The sampling frequency of the station's vertical channel (BHZ) is 40 Hz. (D) The horizontal ground motion recorded during the wave onset is clearly directed toward the impact location.

Facing Space Debris Hazards on Earth:

A Groundbreaking Seismic Record of an Impact in Kenya, December 2024

Fabian Limberger[*,1]

On 30 December 2024, a 500 kg fragment of space debris reentered Earth's atmosphere and impacted near Mukunu village, ~115 km southeast of Nairobi, Kenya's highly populated capital. This appears to be the first known instance of such an unpreceded impact being recorded by a seismometer located ~80 km from the impact site. While no injuries or major damages were reported, an impact of similar size in a more densely populated area, like Nairobi, could have caused severe consequences.

The number of space debris in Earth's orbit continues to grow, with more than 40,500 objects larger than 10 cm currently estimated (ESA, 2025). Space debris poses significant risks not only to Earth's orbital environment but also to humans and infrastructures on Earth, due to potential impacts (Bergamini, et al., 2018). Although such uncontrolled impacts are currently rare, their frequency is expected to increase in the coming decades. This highlights the growing need for heightened awareness within the space- and geoscientific communities to enhance the monitoring and detection of debris and to develop strategies for mitigating associated hazards, such as impacts.

IMPACT OBSERVATIONS BY RESIDENTS

The ring-shaped fragment, estimated to weigh 500 kg with a diameter of 2.5 m, entered the atmosphere and struck the Earth's surface on 30 December 2024 at around

* f.limberger@geophysik.uni-frankfurt.de
[1] Institute of Geosciences, Goethe-University Frankfurt, 60438 Frankfurt am Main, Germany
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3 p.m. local time (12 a.m. UTC). The impact generated a loud explosion-like sound, as reported by local residents in the media. Investigations suggest the debris originated from old rocket components, though the exact source remains unclear so far. The object glowed after striking the surface, although such fragments are typically designed to burn up during re-entry (Chutel, 2025).

SEISMIC DETECTION OF THE IMPACT

The seismological station KMBO, located close to Kilimambogo, which is ~80 km northwest of the impact site (Fig. 1A) is part of the global seismological GEOFON network (GEOFON Data Centre, 1993) and I obtained the data from its data center, publicly accessible. The sensor registered a significant sudden increase in ground motion amplitude at 11:56:04 a.m. UTC (Fig. 1B and 1C), confirming the impact time reported by residents. The waveform shows a clear wave onset, probably caused by arriving compressional P-waves that were induced by the object striking Earth's surface. The characteristics are indicative of an impact source, due to no clear S-waves that are usually less emitted than P-waves in case of explosions or impacts (Daubar et al., 2018). The spectral content exhibits the maximum energy at 10 Hz (Fig. 1B); however, the impact causes a broad spectral emission. Signals with similar waveform characteristics are typically recorded in volcanic regions with explosive seismic events (e.g., Fenner et al., 2022; Jousset et al., 2022). The horizontal ground motion in the north-south and east-west directions clearly reveals a motion pointing toward the impact site, consistent with expected wave arrivals originating from that direction. (Fig. 1D). Due to the sparse distribution of seismic stations in the region, no additional recordings were available to, e.g., triangulate the event's precise location. Nevertheless, the data recorded by the station KMBO provide the first evidence of a successful space debris impact detection by a seismometer.

IMPLICATIONS AND FUTURE CONSIDERATIONS

This exceptional incident underscores the significant hazards posed by space debris re-entering Earth's atmosphere, particularly in densely populated areas like Nairobi. The capability to detect such impacts using seismic networks, but also further sensors, e.g., such as infrasound, offer promising technical solutions for real-time monitoring, impact localization and potential early warning, functioning similarly to earthquake monitoring systems (Annesha, 2024). However, the uneven global distribution of seismological stations, with significantly fewer permanent installations in the Global South, must be addressed to establish comprehensive networks capable of ensuring reliable detections across the globe.

With the increasing volume of space debris orbiting Earth, this article seeks to encourage political stakeholders, research organizations, and emerging space companies worldwide to proactively enhance global preparedness and face potential space debris hazards not only in space, but also regarding impacts on Earth.

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