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Effects of Soot in Third Pole

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The Hindu Kush-Himalaya, often called the "Third Pole," holds more frozen water than anywhere on Earth outside the Arctic and Antarctic, and its meltwater supports over 1.9 billion people across Asia. The region is warming faster than the global average. Soot also known as black carbon, is making things worse. Soot comes from burning wood, dung, coal, crop residue, and diesel, mostly on the Indo-Gangetic Plains. Seasonal winds and thermal updrafts carry it up the mountains, where it settles on snow and glaciers. Soot darkens the surface, so the snow absorbs sunlight instead of reflecting it. Melting of the snow grains, which lowers reflectivity even more and speeds up the melt. Soot in the air also heats the atmosphere, which can turn snowfall into rain and disrupt the monsoon. Downstream, it causes early floods, glacial lake outburst floods, landslides, and eventually serious water shortages once the glaciers shrink. Soot stays in the air for only days to weeks, so cutting emissions can help quickly. Clean cooking fuels, better brick kilns, smarter crop residue management, and stricter diesel standards offer practical ways to protect both the air people breathe and the water they depend on.

Keywords: Third Pole, black carbon, soot, glacier melt, albedo, water security

Introduction

The Hindu Kush-Himalayan is a mountainous region located in the west and south of the Tibetan Plateau. Part of High-mountain Asia, it spreads over an area of more than 4.2 million square kilometres (1.6 million square miles) across nine countries, i.e. Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Pakistan and Tajikistan, bordering ten countries. It is called as the "Third Pole" because its mountain glaciers and snowfields store more frozen water than anywhere else in the world after the Arctic and Antarctic polar caps.

Climate change is now a key concern in the Third Pole. The rate of warming in the Third Pole is considerably greater than the global average, and the rate is increased at an elevated altitude, indicating an acute susceptibility of the cryosphere environment to atmospheric warming (Kang et al., 2020). Climate change projections suggest that all areas of South Asia are likely to warm by at least 1 °C by the turn of the century, while in some areas the warming could be as much as 3.5 to 4 °C. The lives and livelihoods of those living in the Third Pole region are challenged by climate change, and the security and development of the downstream areas are in peril. This will have ramifications for the entire continent, and indeed the effects will be felt worldwide. However, there is insufficient awareness of this risk and its potential knock-on effects outside of the impacted region; a special effort is required to increase the attention given to the fragility of the mountain social-ecological system.

Holding the largest reservoir of permanent ice and perennial snow outside Antarctica and the Arctic, this frozen empire is the Asia's primary water tower. Its seasonal meltwaters feed ten of the continent's mightiest river networks including the Indus, Ganges, Brahmaputra, Yangtze, and Mekong - sustaining over 1.9 billion people downstream with fresh drinking water, agricultural irrigation, and hydroelectric power. Yet, a silent, microscopic intruder is rapidly accelerating the thaw of these high-altitude sentinels: soot,

which is also known as black carbon. The accumulation of soot (Black carbon) on the Hindu Kush-Himalayan (HKH) region commonly referred to as Earth's Third Pole which represents one of the most critical environmental crises in modern geography (Gertler et al., 2016). Soot acts as a powerful short-lived climate pollutant (SLCP). While it remains in the atmosphere for only days to weeks, its localized impact on glaciers is catastrophic (Kang et al., 2020).

Soot and Its Atmospheric Transport

Soot is an aerosol produced by the incomplete combustion of carbon-rich fuels like fossil fuels, biofuels, and biomass (Li et al., 2021). Unlike long-lived greenhouse gases like carbon dioxide (CO_2), soot is particulate matter. A tiny dark speck suspended in the atmosphere. The Tibetan Plateau is bordered by some of the most densely populated and rapidly developing industrial regions on Earth: the Indo-Gangetic Plains to the south and southwest, and eastern China and Central Asia to the east and north.

Sources of Soot

Millions of sources emit black carbon into the lower troposphere every day (Li et al., 2016);

- **Traditional biomass cookstoves** burning wood, dung cakes, and agricultural leftovers in rural households.
- **Brick kilns** operating with coal and low-grade heavy fuel oil.
- **Crop residue fires** flaring seasonally after autumn harvests across northwestern India and Pakistan.
- **Diesel exhaust** from aging truck fleets and decentralized power generators.

During the pre-monsoon and winter months, regional weather patterns create deep thermal inversions and convective updrafts (Yasunari et al., 2013). Powerful atmospheric winds and valley-breeze systems funnel plumes of brown haze up the Himalayan slopes (Gertler et al., 2016; Gul et al., 2021). Carried across and passes higher than 5,000 meters, this soot settles on to the glaciers that were once thought to be insulated from human reach (Li et al., 2016).

The Heat Lamp Effect

When fresh snow blankets a glacier, it possesses an albedo - the capacity to reflect incoming solar radiation. Pristine snow reflects up to 85% to 90% of sunlight straight back into space, functioning as the planet's natural sunblock. When soot particles settle on that pristine crust, the physics changes entirely:

Incoming Solar Radiation

↓

Clean Snow: 85-90% Reflected Vs Sooted Snow: Darkened Surface Absorbs Heat

↓

Accelerated Surface Thaw & Grain Coarsening

↓

Positive Feedback (Lower Albedo, More Melt)

- **Direct Snow Darkening (Albedo Reduction):** Even minute amounts of dark carbon particles - measured in parts per billion drastically darken the snowpack (Gul et al., 2024; Yasunari et al., 2013). Absorbing shortwave radiation instead of bouncing it back, the snow warms and melts much faster (Ren et al., 2024).
- **Grain Coarsening Feedback:** As snow begins to thaw, fine crystalline flakes morph into rounded, coarser grains. Coarse grains naturally reflect less light than fresh powder, creating a dangerous warming loop: more melt causes coarser ice, which absorbs more heat, driving even faster melt (Kang et al., 2020).
- **Atmospheric Solar Heating:** Before soot even touches the ground, airborne soot layers absorb solar energy mid-air. This "atmospheric heating" warms high-altitude air masses and disrupts local cloud formation, shifting precipitation from snow to rain (Gertler et al., 2016).
- Recent field observations and ice-core analyses from the Tibetan Plateau demonstrate that surface temperatures on heavily contaminated snowpacks have spiked significantly,

accelerating ablation rates and leaving glaciers coated in a dull, gritty grey crust (Li et al., 2021a; Gul et al., 2021).

Crisis Dimension	Short-Term Manifestation (Current–Next Decade)	Long-Term Projection (2040–2100)
River Runoff &Water Security	Surges in spring discharge; early-season floods in the Indus, Ganga, and Brahmaputra basins.	Severe water deficits once glacial mass peaks; drying irrigation canals during crucial dry seasons.
Hazard Risks	Outburst floods from unstable moraine dams (Glacial Lake Outburst Floods/GLOFs); devastating mudslides.	Destabilized mountain slopes, recurring landslides, and loss of alpine infrastructure.
Monsoon Disruption	Atmospheric heating from soot alters the land-sea thermal gradient, triggering erratic monsoon onsets.	Unpredictable agricultural seasons, shifting rainfall bands, and frequent flash droughts.

Cascading Downstream Consequences

The rapid loss of Third Pole ice is far more than an ecological curiosity; it triggers severe hydrological, economic, and humanitarian effects across Asia (Kang et al., 2020; Ren et al., 2024). When high-altitude snow vanishes prematurely in spring, downstream farmers miss out on the steady, natural flow of meltwater right when summer crops need planting. Later in the year, when glaciers have exhausted their melt surplus, river basins face permanent shrinkage.

Fast-Track Climate Solution

While long-lived greenhouse gases like carbon dioxide linger in the atmosphere for centuries, black carbon is a Short-Lived Climate Pollutant (SLCP). It survives in the atmosphere for only days to a few weeks before removal by dry and wet deposition (Kang et al., 2020; Yasunari et al., 2013). Mitigating soot emissions produces near-immediate atmospheric clearance, allowing new snow deposits on the Third Pole to remain pristine and reflective.

Targeted, regional interventions can yield dramatic returns within years rather than centuries:

- **Clean Cooking Access:** Expanding reliable electricity, LPG, and solar-induction cooking to replace open-fire biomass stoves across rural South Asia. (Li et al., 2016).
- **Kiln Modernization:** Enforcing cleaner brick-making technologies (such as Zig-Zag kilns) and transitioning heavy industrial boilers to cleaner fuels.
- **Managing Crop Residue:** Incentivizing in-situ mulching machinery (like the Happy Seeder) and converting bio-waste into biochar or localized biogas.
- **Tougher Diesel Standards:** Mandating stringent vehicle emission standards and particulate filters (DPFs) across commercial transport corridors.

Conclusion

The fate of the Third Pole is intimately tied to daily life on the plains below. The cooking fires of the Terai, the coal kilns of Punjab, and the highways of South and Central Asia cast a literal shadow on the glaciers of Everest and K2 (Li et al., 2016; Gul et al., 2021). By addressing soot as an immediate, solvable driver of cryospheric decline, nations sharing the Himalayan watershed have an actionable opportunity: clearing the air above their communities while safeguarding the freshwater lifeline that sustains over a billion people.

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