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FEATURE

The flood-drought syndrome and ecological degradation of the Indo-Gangetic Plains of South Asia

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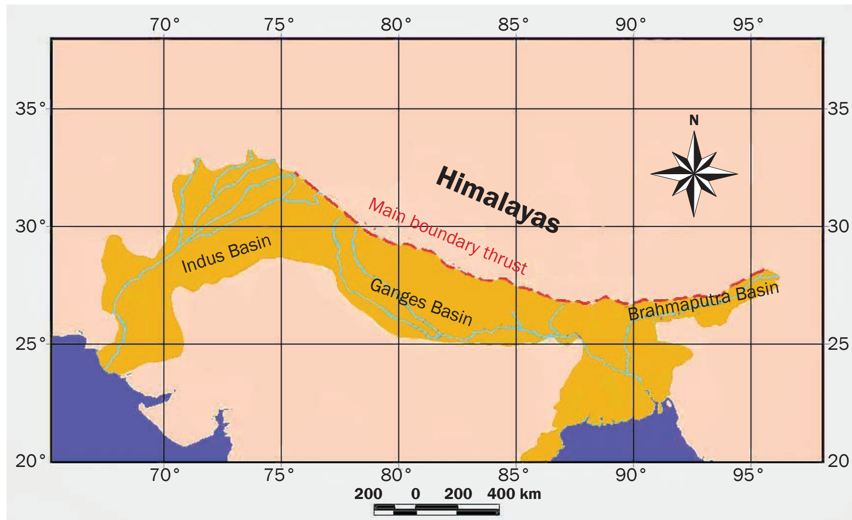
THE INDO-GANGETIC PLAINS

The Indo-Gangetic Plains (IGPs), covering 70 million ha (172 million ac), span from the Indus River in Pakistan to the Punjab Plains in India and Pakistan, to the Haryana Plains and Ganges Delta in Bangladesh (figure 1). The IGPs are among the world's most fertile lands, comprising the densely populated region of the Indian subcontinent (Mani 1974). The IGPs include two drainage basins: the western region drains to the Indus and the eastern part to the Ganges-Brahmaputra drainage system. Major rivers of the IGPs are Indus with its five tributaries (Sutlej, Ravi, Beas, Chenab, and Jhelum), Ganges (along with Yamuna), and Brahmaputra. The IGPs are the world's most extensive alluvial formations, intensively farmed areas, and the seat of the Green Revolution of the 1960s and 1970s. Annual rainfall increases from west to east, and the climate ranges from arid to humid. The total population of the IGPs is over 900 million people (Biemans 2019), who also raise the world's largest livestock population (Teufel et al. 2010).

Figure 1
The geographical extent of the Indo-Gangetic Plains of South Asia (adapted from IIT [2022]).



The Green Revolution and the attendant agricultural intensification have addressed the issues of food and nutritional security (Davis et al. 2018; von der Goltz et al. 2020) but aggravated the ecological degradation. Among numerous examples of ecological degradation are air pollution from the burning of rice (*Oryza sativa* L.) straw in October through November (Shyamsundar et al. 2019), severe soil degradation because of land misuse and soil mismanagement (Bhattacharyya et al. 2015), eutrophication and contamination of water by agricultural chemicals (Sarker et al. 2021; Sunam and Mahat 2020), and the flood/drought syndrome due to denudation of lower Himalayas (Ahmad et al. 2022) along with related loss of biodiversity (Pandit et al. 2007). There is a strong need for adopting nature-based solutions to address the drought/flood syndrome and other issues of ecological degradation. Some examples of innovative approaches include (1) use of crop residues for bioenergy production rather than in-field burning, (2) adoption of conservation agriculture with residue mulch rather than plowing, (3) implementation of drip subfertigation rather than flood irrigation, (4) cultivation of direct-seeded aerobic rice rather than puddled and flooded paddies, and (5) reforestation of the lower Himalayas to conserve soil and water and reduce the incidence and severity of the flood/drought syndrome.

The IGPs are prone to extreme flood/drought events. Six floods devastated India in 2019 (Tiwari 2019), and an unprecedented flood crippled the Assam state of India in 2022 (Guha 2022). Similarly, there is a long history of floods in Pakistan with casualties of 484 in 2003, 967 in 2007, >2,000 in 2010, 361 in 2011, 100 in 2012, 80 in 2013, 78 in 2014, 39 in 2015 (Faiza et al. 2017), and 1,678 in 2022 (ABC News 2022; NDMA 2022). The 2022 flood tragedy in Pakistan has affected 33 million people and inundated one-third of the nation's land area (ABC News 2022; NDMA 2022).

The recurring floods in Pakistan (figure 2) necessitate an objective and effective action plan to address this issue on a long-term basis. A strategy is to establish the cause-effect relationship and develop an international plan of action based on scientific principles and practical approaches with due consideration of biophysical environments and socioeconomic and political issues. Soil and environmental degradation are biophysical processes but driven by social, economic, and political forces. Thus, objectives of this article are to deliberate the cause-effect relationship leading to the recurring cycles of the flood-drought syndrome in the IGPs and identify a cooperative action plan to address this menace by implementing

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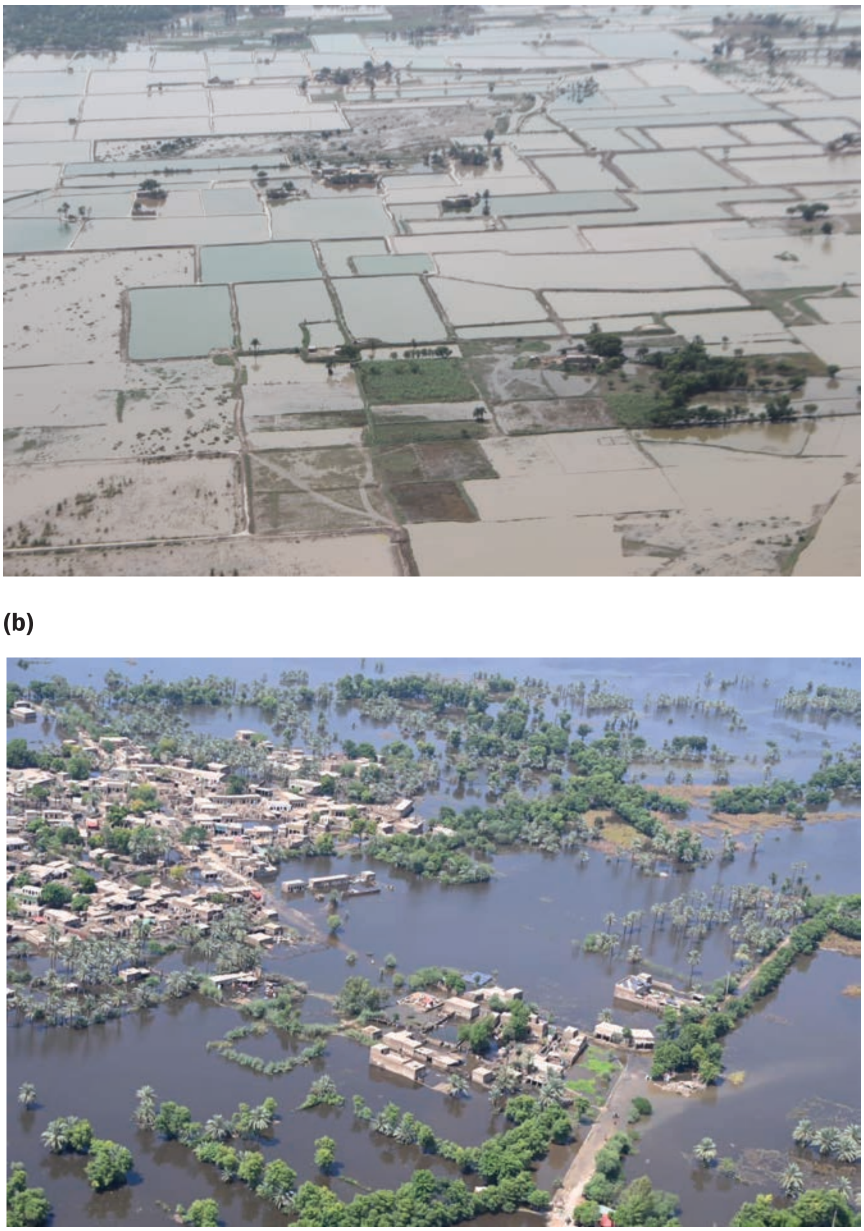
Figure 2

Aerial views of the floods in Pakistan in (a) 2010 (photo courtesy of Australian Government) and (b) 2022 (photo by Ali Hyder Junejo).

(a)

(b)



site-specific nature-based or nature-positive solutions.

THE FLOOD-DROUGHT DILEMMA OF THE INDO-GANGETIC PLAINS

The devastating flood in Pakistan since mid-June of 2022 is the most recent tragedy that has plagued South Asia with severe floods during monsoon season (June through September) and droughts (March through June) during the dry period. The flood/drought tragedy reflects two sides of the same coin, often set in motion by long-term land misuse and soil mismanagement in the upper reaches of the watershed that reduce the ability of the land to retain water on the surface and store it in soil and deep aquifers.

In addition to climate change and geological factors, it may be the excessive water runoff that causes flash floods and inundation during the monsoons; runoff is increased by the denudation of hills caused by indiscriminate and excessive deforestation of the lower Himalayas from Afghanistan through Pakistan, India, Nepal, Bangladesh, Bhutan, and beyond.

In the context of floods in the IGPs, the term “land misuse” implies deforestation of hills (steep lands) resulting in a minimal protective cover of the aboveground vegetation and belowground root biomass that hold the soil together and retain water. An unprotected and bare soil surface is highly vulnerable to kinetic energy of impacting raindrops, velocity of runoff water, and interaction among them. The hydropedological processes, occurring over vast denuded and unprotected hills, lead to cascading effects resulting in runoff, erosion, eutrophication, sedimentation, siltation of waterways and reservoirs, and inundation of vast regions in the plains. The same regions that are prone to accelerated runoff, erosion, landslides, and sedimentation during the rains are also prone to drought during the dry season because water did not infiltrate into the soil and little, if any, was stored in the root zone for availability to crops.

BIOPHYSICAL ATTRIBUTES OF THE INDO-GANGETIC PLAINS OF THE HIMALAYAS

The Himalayas are the world’s youngest mountains and constitute extremely fragile ecosystems. These mountain ranges are prone to frequent seismic activities and earthquakes, leading to shifts in river courses and floods (Molnar 1986; Mahmoud and Rogers 1987), and are a major source of sediments (Sinha et al. 2009). The IGPs are composed of older (>120,000 years) and younger (<13,500 years) alluvia (Pal et al. 2009). Predominant soils of IGPs include Entisols, Inceptisols, Alfisols, Mollisols, and Aridisols (Pal et al. 2009). The rice–wheat (*Triticum* spp.) rotation, the predominant cropping system of the IGPs since the 1960s, has a potential yield of 7.7 to 10.7 Mg ha^{-1} (3.4 to 4.8 tn ac^{-1}) for rice and 5.2 to 7.9 Mg ha^{-1} (2.3 to 3.5 tn ac^{-1}) for wheat (Pathak et al. 2003). Snow and glacier meltwater are important determinants of the agricultural potential of the IGPs (Biemans et al. 2019). In the pre-monsoon season, up to 60% of the total irrigation withdrawal is based on mountain snow and glacier melt, which contribute to an additional 11% to total crop production (Biemans et al. 2019). In total, 129 million farmers in the Indus and Ganges basins considerably depend on snow and glacier melt for their agricultural activities. The current and projected climate change, receding glaciers, and decline in snow cover are impacting and will significantly impact the livelihood of a large population in the IGPs. Rather than rice-based systems, alternative cereals can improve water use and also enhance nutrient supply in the region (Davis et al. 2018).

CLIMATE CHANGE IN THE INDO-GANGETIC PLAINS AND THE HIMALAYAS

The Himalayan region is undergoing a rapid climate change, as are also the IGPs. Singh and Sontakke (2002) observed that summer monsoon rainfall shows an increasing trend (170 mm [6.7 in] per 100 years) over the western IGPs from 1900, a decreasing trend (5 mm [0.2 in] per 100 years) over the central IGPs from 1939, a decreasing trend (50 mm [2.0 in] per 100 years) over the eastern IGPs during 1900 to 1984, and an increasing trend (480 mm [18.9 in] per 100 years) over the eastern IGPs from 1984 to 1999. In general, there is a westward shift to rainfall and extreme events over the IGPs. Basistha et al. (2009) assessed change in rainfall patterns in the Indian Himalayas during the twentieth century using 80-year data from rain gauge stations. They observed an increasing trend up to 1964 followed by a decreasing trend in 1965 to 1980. In the entire region, changes were more obvious over the Shivaliks and southern part of the western Himalayas.

Observed increases in temperature in the Himalayas are found to be higher than the global average (Dimri et al. 2021). The surface air temperature over the IGPs shows an increasing trend (0.53°C [0.95°F] per 100 years) during 1875 and 1958 and decreasing trend (–0.93°C [–1.67°F] per 100 years) during 1958 and 1997. The latter may be due to expansion of agriculture and use of irrigation (Singh and Sontakke 2002). In the western Himalayas of India, Jaswal et al. (2016) observed a decrease in the average seasonal diurnal temperature range. Large-scale deforestation in the Himalayas has also increased the diurnal temperature range. On the contrary to general observations, Yadav et al. (2004) observed a rapid decrease of temperatures at about a three times higher rate as compared to increases in the maximum temperature.

There is also a notable lateral shift in the river course, which has serious environmental consequences, such as flooding. Snow cover has declined since the 1960s with an enhanced decreasing trend since the 1990s. Consequently, glaciers are losing mass and retreating. Thus, extreme flood events, such as that in Pakistan in 2022, are frequent. Climate change has adverse effects on traditional subsistence agriculture and food systems (Dimri et al. 2021).

DEFORESTATION IN THE HIMALAYAS AND AGRICULTURAL EXPANSION

Coping with floods (Dhawan 1993) remains a major issue for the South Asia region in general and IGPs in particular. Establishing the cause-effect relationship of the flood/drought tragedy requires understanding of natural environments and anthropogenic factors. There are two views about the flood/drought syndrome in the Himalayas. One is that extensive deforestation is the cause of catastrophic floods (Ives 1989; Hamilton 1987; Myers 1986), such as those experienced in Pakistan in 2022. The second states that deforestation is not the only cause of floods in the plains of the sub-Himalayan regions. The fragile ecosystem of the Himalayan region is another critical factor that cannot be ignored. These regions have high seismic activity, and soils on the hilly terrains are highly erodible. Under these conditions, deforestation and climate change aggravate floods that occur because of the physiography, landscape attributes, and highly fragile environment.

Forests in the Himalayas are among the most depleted (Schickhoff 1995). Deforestation in the Himalayas is a complex process, and there are numerous drivers, including increase in human population (Myers 1986). Forests are a source of critical ecosystem services for the Himalayas and are being drastically altered. In addition to water and energy balance, deforestation also adversely affects biodiversity that is unique for the region, such as pheasants of the Himalayas (Jameel et al. 2022). Continuous grazing pressure and soil erosion, along with deforestation, are leading to drastic perturbations of ecosystems (Shaheen et al. 2011, 2016, 2017). For example, forest cover in Pakistan is less than 5% of the total land area and is rapidly declining in the hilly regions (IUCN 2002). The rate of deforestation is estimated at 1.5% or an annual loss of 270 km^2 (104 mi^2), corresponding with 4% to 6% decline in wood biomass (IUCN 2002). The rate of deforestation is aggravated with growing demands for fuelwood, timber, and agricultural land. Fuelwood consumption in Pakistan's Himalayas may have been increasing at the rate of 3% per year (IUCN 2002; Ahmed et al. 2015). Fuelwood consumption per household in Pakistan Kashmir is 16.2 Mg y^{-1} (17.9 tn yr^{-1}), which is equivalent to 5.9 kg $person^{-1}$ d^{-1} (13 lb $person^{-1}$ day^{-1}, with a range of 3.9 to 6.6 kg [8.6 to 14.6 lb]).

However, deforestation in the Himalayas is not only due to fuelwood consumption and timber extraction but also due to commercial harvesting (Ali and Benjaminsen 2004). There are divergent views regarding the environmental impacts of commercial harvesting. One view is that commercial harvesting during the 1970s and 1980s, such as that in the Basho Valley in northern Pakistan, has caused environmental degradation. The second view is that effects of commercial harvesting have been exaggerated and overestimated (Ives and Messerli 1989). The third view is that deforestation is a long-term process caused by changes in the socioeconomic environment in the early years of British rule, rather than being caused by the recent process of population growth (Schickhoff 1995). The fourth view is that construction of new roads in rural areas is aggravating deforestation and may have implications to local forest conservation (Charley et al. 2016). In Basho Valley, Pakistan, Ali and Benjaminsen (2004) and Ali et al. (2005) observed that construction of a link road in 1968 reduced the forest cover by 50%

due to an increase in legal and illegal logging for fuelwood and timber.

Deforestation is also a serious problem in the Indian Himalayas. Prabhakar et al. (2006) observed that 61% (48% to 73%) of the forested area has less than 40% crown cover in the Himalayan forests. They concluded that forest surveys of India usually understate the degree of forest degradation.

Verma et al. (2021) synthesized reports between 1984 and 2020 to identify drivers and mechanisms of forest change across the entirety of Himalayan mountain range in India. Verma and colleagues argued the forest change dynamics is "dominated by widespread smallholder agriculture, extensive non-timber forest product extraction, widespread commercial and non-commercial timber extraction, and high rates of agricultural abandonment. Underlying drivers of these practices include population growth, poor agricultural productivity, international support for development projects," and more. In the central Himalayas of India, Ranjan (2018) explored the impact of excessive harvesting of forests for fuelwood and fodder on a shift in the species composition from oak (*Quercus* spp.) to pine (*Pinus* spp.) trees. This shift is leading to adverse effects and exacerbating the ecological and socioeconomic feedback effects (Ranjan 2018). Prasad et al. (2001) outlined energy conservation measures and renewable energy technologies for conserving fuelwood in Himachal Pradesh, India. Transition from wood fuel to liquefied petroleum gas can also have a strong and positive impact on air quality and human health (Nautiyal 2013). There is a need to identify alternate feed sources by identifying native fodder tree species (Schreier et al. 1994) through integration of trees with livestock and crops.

In the Sikkim Himalayas, Prokop and Ploskonka (2014) tracked land use change over 150 years, with special emphasis on the period of 1930 to 2010. The replacement of natural forest by monoculture tea (*Camellia* spp.) and rice cultivation drastically altered soil properties such as decline in soil organic carbon (SOC) content by 76%. Change in land use also affects the area under waterbodies and wetlands (Romshoo and Rashid 2014) and causes changes in soil moisture reserves (Tyagi et al. 2013).

Forest cover is also changing in Nepal. Uddin et al. (2015) evaluated change in land cover and fragmentation of forest between 1990 and 2009. They observed a decrease in forest cover by 9% and increase in crop cover by 12%. Further, an additional decline in forest cover by 4% and increase in crop cover by 5% may occur between 2009 and 2030.

DEFORESTATION AND SOIL DEGRADATION IN THE HIMALAYAS

There is a close relationship between the occurrence of floods and soil quality in the watersheds comprising denuded hills and fragile soils. Deforestation also leads to declines in soil quality through decreases in SOC stock, and the attendant degradation of soil physical, chemical, biological, and ecological properties. In the southern region of Indian Kashmir, Wani et al. (2014) observed low SOC stocks because of anthropogenic activities and pressure on the natural resources since the 1990s. Wani and colleagues argued that there is the potential of increasing SOC stock with the adoption of better management for reversing the degradation trend. Sharma et al. (2014) observed that SOC stocks decreased in agricultural and degraded lands of the Himalayan foothills by 25%, corresponding with the loss of 12 Mg C ha^{-1} (5.4 tn C ac^{-1}) in the top 50 cm (20 in) layer. Therefore, attention must be given to strategies and approaches that protect soil against anthropogenic activities, restore degraded soils, and return agriculturally marginal lands back to nature.

THE NEED FOR COOPERATION AMONG NATIONS

The devastating flood of 2022 in Pakistan is a wake-up call for South Asian countries to work together and develop an action plan to reforest the lower Himalayas. Ecologically fragile, economically underdeveloped, and geopolitically volatile Himalayan regions are in urgent and strong need for sustainable land use and restorative soil management, both for prosperity and peace. Cooperation among nations of the Himalayan region is essential to address the perpetual problem of flood/drought that has plagued countries of South Asia. A nature-based solution involves reforestation of the denuded hills across the entire Himalayan range, which is the source of all major rivers that flow through the IGPs. Deforestation and expansion of agriculture (cropland and grazing land) must be reduced in the fragile and ecologically sensitive Himalayas. Verma et al. (2021) outlined five thematic focus areas to stop forest loss and accelerate recovery: "(1) decreasing the population pressure, (2) sustainable increase of agricultural productivity, (3) strengthening of forest management institutions, (4) leveraging tourism growth and sustainable infrastructure expansion, and (5) fuel transition and establishing firewood plantations on degraded land." The irrational land use and soil mismanagement must be transformed through groundwater recharge, soil and water conservation, and economic development (Tiwari 2000).

Clean fuel sources for cooking and heating are needed so that biomass can be recycled and forests protected against harvesting for fuelwood. Renewable energy technology is essential to protecting fragile ecosystems, reversing the process of soil degradation, conserving water, and minimizing risks of devastating floods followed by drought and heat waves.

Reforestation of the denuded hills is required in the entire Himalayan range from Afghanistan in the west through Pakistan, India, Nepal, Bhutan, and Bangladesh in the east and beyond to Cambodia. International cooperation is critical to protecting the fragile ecosystems and minimizing the risks of the flood/drought syndrome that has plagued the IGPs. Reforestation of the denuded and degraded hills is the long-term and nature-positive solution and is also critical to advancing Sustainable Development Goals of the Agenda 2030 of the United Nations. Addressing this recurring tragedy will promote cooperation, peace, and economic development in South Asia. This cooperation among nations will be the foundation stone for establishing a South Asian union in which the countries will prosper together while learning how to live in harmony with nature.

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