Chapter 2
Drivers and Pressure on the State of Environment in Bhutan

Background

Conceptually, *drivers* are normally causative factors that enact change, while *pressures* are the more immediate factors that affect the environment. The *Global Sustainable Development Report (2019)* announced that inequalities, climate change, biodiversity loss, and increasing waste generation caused by human activities would inflict irreversible impacts upon the earth’s life-fostering systems if urgent actions were not taken [1]. The principle drivers of environmental degradation, namely, climate change, population growth, and the vast aggregate of human activities, have direct and indirect effects, obviously, on every ecosystem and on the biodiversity therein, through the pressures that they unleash. Those same driving forces amount to the sum total of human development, such activities as transportation, consumption, chemical emissions, the dissemination of synthetic biological and chemical materials, manufacturing, human usurpation of habitats, outright predation on other species, freshwater abstraction and the diversion of riparian systems, the ruination of previously wild biomes through a combination of impacts, the warming of the entire planet, with its accelerating redistribution of chemicals throughout the biosphere (e.g., the climate crisis), and such other human activities that singly or in concert exert adverse pressures on the environment. The core and edge effects of all these human-induced catalysts are resulting in the sixth extinction spasm in the 4 + billion years of life on Earth [2]. The nuts and bolts of such depredations have now reached epic proportions, as translated into the geological language of an actual epoch, namely, the Anthropocene, or, as E.O. Wilson proposed, the Eremozoic, that era describing a world gone barren, a time of great loneliness. The question on everyone’s mind who follows these developments is; thinking, caring, feeling, and the hope for sufficient policy measures that might yet be implemented in order to stave off the worst of these rapid trends; to mitigating the adverse impacts on the “lonely planet” [3] and to engender smart resilience from nation to nation.
In this context, the logical consequences within the DPSIR framework (DPSIR = driver, pressure, state, impact, and response model of intervention) poses the most complex and challenging range of policy response measures in human history. Nothing less than the survival of the biosphere is at stake (Table 2.1).

The diversity of species plays a key role in ecosystems and their provisioning, regulating, and supporting services. However, as pointed out in the 2019 Global Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), species and genetic resources are disappearing at unprecedented rates. Some 25% of the species in assessed animal and plant groups are threatened, suggesting that nearly 1 million species already face extinction – many within decades, unless appropriate action is taken to reduce biodiversity loss. This chapter analyzes various combinations of ecological driving forces and pressures within Bhutan and attempts to provide responses with recommendations and policy measures, with due recognition and review of assessments made in NAP-DD (2014) [3] and NBSAP (2014) [4]. Notwithstanding its Bhutanese regional focus, the DPSIR framework model could be a very useful tool for the preparation of a “bigger picture” periodical report for the state of the environment in Bhutan.

### Table 2.1 Driver-pressure-state-impact-response (DPSIR) framework

| Driver | Pressure | State | Impact | Response |
|--------|----------|-------|--------|----------|
| Land use; population; transport; energy use; power plants; industry; refineries/mining; agriculture and livestock; landfills; sewage systems; non-industrial sectors | Resources use; emissions; production of waste; production of noise; radiation; vibration; hazards (risks) | Air quality; water quality; soil quality; ecosystems; biodiversity; humans (health); soil use | Environmental or economic “impacts” on ecosystems and biodiversity; life-supporting abilities, human health; economic and social performance of society | Response by policy makers; example of a response to driving forces is a policy change on mode of transportation, e.g., from private (cars) to public (trains). While an example of a response to pressures is a regulation concerning permissible SO2 levels in flue gases |

Source: Kirstein, 2004 [3]

Illegal Activities

Illegal activities such as unauthorized use of timber and non-wood forest products, misuse of rural timber permits, land encroachment in forest, and poaching have been increasing over the years in Bhutan. About 1,423 number of offenses related to forest and wildlife species have been reported, of which 924 cases of illegal timber extraction and 40 cases of poaching activities have been recorded in 2018 alone [5]. According to the Department of Forest and Park Services of Bhutan, illicit harvesting
of timber, fuelwood, and stones is a major concern with many more offenses most likely occurring undetected. In the forest areas bordering India, illegal extraction of fuelwood and timber is reportedly common because of the exhaustion of forest resources and burgeoning human population across the border. A porous international border and shortage of forest law enforcement personnel make it very difficult to regulate cross-border illegal forest harvesting.

Globally, the illegal wildlife trade now stands at the value exceeding US$ 19 billion per year (as of 2016; counting for inflation and further data, that number could be well in excess of that). Currently, some 25,000 elephants are being killed each year across Africa (WWF), and 668 rhinos were reported killed in 2012 [6], [7], [8]. The illegal wildlife trade is accelerating the loss or near loss of endangered species (the Javanese rhino a case in point); and these atrocities will directly affect the ecosystems where the animals live. The loss of top predators can lead to an abundance of wild prey that introduce new competitive levels of stress and risk into long stable systems while triggering imbalances that occur in trophic cascades, seriously undermining both the natural environment and human occupants of those same regions. In Southeast Asia and China alone, authorities seized 32 tons of pangolin scales and 563 live pangolins in 2017 [6] (Fig. 2.1). The pangolin trade has been implicated in Covid-19.

Bhutan’s strategic location in between China, Nepal, and India poses a picture-imperfect state of high vulnerability to poachers. Indeed, as Brown analyzes, poaching and militarism from Nepal, to Nagaland to Myanmar, have gone hand in hand [8]. Major occurrences of poaching have already occurred along Bhutan’s borders. Such crimes have been detected and seized at hotels, airports, along high-altitude border areas, check posts, etc. [9]. Body parts of wildlife species that are trafficked include Himalayan black bear, musk deer, common leopard, elephants, tiger, pheasants, hornets/wasps, Asiatic golden cat, clouded leopard, red sanders (a sandalwood, Pterocarpus santalinus), rhinos, and pangolin [5]. Between 2013 and 2014 in Bhutan, about 270 poaching cases were apprehended that amounted to a total fine of Nu.14.51million (USD 223,784.91). Given the practical inaccessibility of many of Bhutan’s border areas, and resource constraints in monitoring, it is likely that many more wildlife crimes occur than can be effectively pursued and prosecuted.

*Fig. 2.1* Chinese pangolin found in Bhutan (commonly poached in many countries for traditional medicine © NCD, DOFPS)
Bhutan has ratified the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and joined 12 other tiger range countries (TRCs) that aim to eliminate poaching in all key sites for tigers, elephants, and rhinos by 2020 [10] [9]. Although poaching and other illegal activities relating to forest habitats occur all over Bhutan, such crimes have been commonly taking place along the international borders that share the common landscapes and protected areas. To this geographic point, the Transboundary Manas Conservation Area cooperation (TRAMCA) between India and Bhutan needs to be strengthened in terms of patrolling capacity along the border areas of both these countries. There is a definitive need to improve patrolling routes, particularly in SMART (Spatial Monitoring And Reporting Tool) patrolling, and training on handling weapons, improving the intelligence network system, crime investigation, and prosecution. Major incidences of hunting, killing, and collecting terrestrial animals, wildlife poaching, and the disappearance of keystone species have also been reported as major threats in Bumdeling Wildlife Sanctuary and Jigme Dorji Wangchuck National Park, while illegal timber felling and the disappearance of keystone species were some of the threats in Jomotshangkha Wildlife Sanctuary (Bhutan’s smallest wildlife sanctuary) along the border with India [11].

In consideration of the controlling of the illegal activities, Bhutan has developed a zero poaching strategy focusing on the assessment of the current situation, adopting best available tools and technologies, strengthening institutional capacity, improving community participation, strengthening prosecution, strengthening partnerships, and improving regional coordination [9]. To strengthen vigilance and tracking of illegal activities, WWF has developed an innovative camera and software system with new thermal and infrared capacities that can identify poachers from afar and alert park rangers of their presence [12].

**Land Use**

With rapid socio-economic development progress, Bhutan’s forest area is increasingly converted for various developmental activities across the country. As per the Section 308 and 310 of the Land Act of Bhutan [13], the state reserved forests can be leased without any ceiling for the purposes of economic activity, including grazing land and collection of leaf litter for a maximum of 30 years on a renewable basis of the lease. During a period of 4 years (2013–2017), some 113,378.02 hectares of Bhutanese forest were exploited for various purposes such as the establishment of schools, hospitals, agriculture, roads, hydropower projects, transmission lines, etc., as indicated in Table 2.2 [14].

Anthropocentric interferences and infrastructure development in forest habitat obviously can and usually does lead to the extirpation of biodiversity and the compromise or all-out destruction of natural habitat for a multitude of wildlife species. However, forest land allotment within Bhutan does not specify the type or category of forest allotted to the government agencies or private parties, as such loss of
biodiversity cannot be measured. This represents a huge gap in our understanding of how current Bhutanese industrial development is ensuring the national primary forest canopy protective legislation established under the Fourth King. The annual average deforestation predicted to occur in year 2030 owing to RGoB allotments of SRF for various purposes is roughly 28,800 ha [14].

### Hydropower Projects

The economy of the country is mainly reliant on the development of hydropower generation, and Bhutan has significantly increased such electricity for export to India. With the potential capacity of 27,000 MW, Bhutanese hydropower development is widely viewed as the country’s main thrust for economic development through export revenue, as envisioned in the Hydropower Development Master Plan of Bhutan (2008) [15]. Until 2017, Bhutan had six large hydroelectric plants with a total installed capacity of 1606 MW [16] with an additional plant currently installed with a capacity of 720 MW in 2019 making a total installed capacity of 2326 MW [17].

The national policy of universal electrification “to provide electricity for all by 2013” has accelerated rural electrification in remote corners of Bhutan. 94% of that target was, in fact, achieved in 2013 [18]. It is envisaged that forest area conversion for hydropower projects and transmission lines will be increasing in the coming years, all detrimental to various life forms and targeted biomes. The present hydropower projects have affected 2,276 ha, with an average of approximately 272 ha of forest required for each hydropower project and an average of 2 hectares of forest per megawatt (MW) generation capacity [14]. Given that “The typical American home uses about 7,200 kilowatt-hours (7.2MW) each year” [19], this data translates into a most disturbing vision: approximately 35 acres of Bhutanese forest being converted each year for electricity per Western-style consumerist-aspiring household. That scenario hits up against an even more complicating picture when we recognize that household debt, in Bhutan, is responsible for the fifth highest

### Table 2.2 State reserved forest land allotted in hectares for different purposes (2013–2017; See [15])

| Purpose                | 2013–2014 | 2014–2015 | 2016    | 2017    |
|------------------------|-----------|-----------|---------|---------|
| Govt. establishment    | 80.40     | 0         | 0       | 0       |
| Kidu land (Grant)      | 11.31     | 23.55     | 2.39    | 3.87    |
| Land lease             | 452.08    | 1325.09   | 665.49  | 3782.33 |
| Road                   | 774.06    | 311.20    | 383.86  | 10989.48|
| Transmission line      | 6253.11   | 183.16    | 79.72   | 83420.34|
| Land substitute        | 2166.25   | 122.67    | 92.85   | 56.41   |
| Land exchange          | 0         | 0         | 5.05    | 28.15   |
| Others                 | 494.90    | 0         | 0       | 1670.30 |
| **Total land allotted**| **10,232.11** | **1965.67** | **1229.36** | **99,950.88** |
government debt to GDP ratios in the world [20]. Paradoxically, such diminutive, seemingly ecologically successful nations like Bhutan – Suriname, Andorra, Lichtenstein, San Marino, Sao Tome and Principe, the Mauritius, Iceland, and Gabon – all suffer inordinately (and unfairly given the shadow of globalized trade and transboundary pollutants and downstream effects) from the Netherlands fallacy [21] (Fig. 2.2).

Future trends indicate an estimated 39,760 hectares of forest conversion for the generation of 18,380 MW hydropower projects [14]. In addition, installation of transmission lines with a total number of 3,295 transmission towers usurped approximately 89,936.33 hectares of forest land between 2013 and 2017 [22]. As most of the rural electrification has now been achieved, further installation of low voltage transmission lines should not be required, indicating that the future demand for forest should occur only for the installation of high-voltage transmission lines. The “plow-back” mechanism of depositing 2% of the total revenue of the electricity for support of the conservation programs of the Ministry of Agriculture and Forest could be effectively utilized [23], while the government should take a concerted effort in the UNFCCC Clean Development Mechanism (“CDM”) process of trading clean energy for mitigation measures with its global partners.
Farm Roads

In the pursuit of achieving rapid socio-economic developmental progress through improved road networks and accessibility, construction of farm roads in the remote areas of the country have been accorded tremendous priority during the last decade (2008–2017) [16]. Anyone who has driven Bhutan’s back-country roads will quickly appreciate the country’s earnest struggle with rendering remote villages accessible. If this fundamental premise of national infrastructure is at odds with the basics of conservation, then it is clear that among all countries in the world, Bhutan has the greatest challenges. Perhaps Denmark’s autonomous territory of the Faroe Islands competes, in that sense, with Bhutan: an archipelago where some children on some of the more remote islands must go by helicopter – everyday, round trip – to adjoining islands to get to school, because the North Atlantic waters can be too treacherous [24].

The total length of farm road construction increased quite significantly over the years from 1,657.74 km in 2008 to 4,175.71 km in 2013 to 5,362.79 km in 2017, with abrupt and fourfold increases in road network constructed mainly through the wilderness and forest areas. [25]. Such accelerated development plans have intensified the pressure on environment and biomes causing heavy landslides and instability, erosion, degradation, disturbances, and displacement of species, as most of the new farm road construction took place in remote Dzongkhags (districts, of which there are 20 in Bhutan) through remote forests and oftentimes over navigably challenging mountain areas. However, thorough environmental impact assessments and analysis on the broader composite impacts are incomplete. Normally, the impacts from roads and utility passages like power tiller roads can include habitat loss, disturbance of edge effects in natural areas, and seclusion of populations (Fig. 2.3).

Barrier effects, road mortality, and increased human access are not uncommon [26] because of open spaces created by humans in otherwise closed forests. The major impacts of roads relating to edge effects, which can be characterized as antithetical to integral habitat quality, have been abundantly studied elsewhere, particularly across the Amazon [27]. Edge effects can cause habitat loss by changing

Fig. 2.3 Farm road construction in Bhutan. (Data Source: DOA, MOAF)
species composition, temperature, moisture, light availability, and wind speed and, most importantly, altering original biodiversity systematics [28]. Vehicular traffic on such roads increases the risk of collisions with wildlife and the stress on breeding individuals affecting the long-term viability of biodiversity and a range of vulnerable taxa and ecosystems. There have been reports that the effect of infrastructure like roads on bird populations can stretch over distances up to about 1 km; while the mammal populations avoid infrastructures up to about 5 km [29]. However, they reported that some raptors (particularly turkey vultures) can be more abundant in the proximity of infrastructure (as with corvids attracted to road kill); whereas other bird taxa tend to avoid it [30]. Botanically, edge effects on plant diversity can occur up to 30 m from the road or even beyond [31]. Most recent Bhutanese farm road construction has been reportedly of poor construction quality, under conditions that exacerbated the construction costs and the ecological impact (often visible to the layperson). From lessons learned, or beginning to be comprehensively studied, recommendations for minimizing environmental impacts associated with road building have been legally codified in terms of various EIAs (environmental impact assessments). [32]. The arsenal of mitigation tools include the obvious ones: sufficient advance studies, adequate resource allocation for timely maintenance, professional engineering services and quality constructions, and effective monitoring mechanisms (Fig. 2.4).

![Fig. 2.4 Farm road construction in Dzongkhags (2008–2017). Data Source: DOA, MOAF](image-url)
Mining activities have been steadily growing and becoming a valuable industry in Bhutan over the last decade because of the growing domestic needs of its products, with 4.22% GDP contribution to the overall economy as of 2017 [33] and a growth rate of 7.01% in 2017 [34]. But from Bhutan to Chile, from China to India, from Montana to West Virginia, and from Papua New Guinea to Indonesia, mining has the potential for wide-ranging adverse impacts on biodiversity and the well-being of people and environment. Bhutanese exports of the products of mineral extraction have increased rapidly over the recent years because of enormous demand from Bangladesh. As such, there has been an unprecedented surge in proposals for operation of mines in the recent years; around 3,800 hectares of land were leased for mining and extraction of minerals between 2008 and 2014 [14]. A total of 45.94 million metric tons of minerals were extracted in Bhutan within a period of 8 years (2010–2017). The minerals included coal, dolomite, lime, stone, gypsum, quartzite, stone, talc, iron, and ore [22]. Extraction occurred at various sites and ecological zones in the non-protected areas following environmental regulation and impact assessments. Dolomite mining and stone quarries in particular are increasing – with production more than doubling. Export of stone to Bangladesh has triggered massive extraction of stones. Taken together, there is pronounced and worrying escalation of Bhutanese trends favoring said exports, with a demonstrable supply-and-demand cybernetic easily quantifiable for the 8-year period between 2010 and 2017, as indicated in Fig. 2.5. It is very much expected that mining will continue to exert an increasing pressure on Bhutanese biomes for years to come. Coal reserves as of 2017 have been estimated at 0.18 million metric tons (mmt); dolomite at 14,527.32 mmt; limestone at 157.47 mmt; gypsum at 132.70 mmt; quartzite at 4.45 mmt; talc at 0.03 mmt; and iron ore at 2.54 mmt. In terms of remaining mineral reserves from Bhutan’s known sources, the balance of remaining (unexploited in situ) coal reserves as of 2017 is about 17%, talc 26%, dolomite 99%,

![Fig. 2.5 Export of various minerals (million tons)](image-url)
Gypsum 99%, limestone 96%, iron ore 97%, and quartzite 86%. The growth rate of GDP in the mining sector is 7.01%, while the GDP contribution is 4.22% in 2017. Due to improper planning and a very real negligence in the realm of strict regulations, mining activities in Bhutan have resulted in appreciable damage, degradation, and deterioration of habitat, with accompanying documented losses in biodiversity and medicinal plants and ecological damage to water, air, and soils [22].

There is thus an urgent need for enhanced legal codes within the country mandating holistic strategic environment impact assessments at every stage of extraction design and infliction. The hard questions must be levied at would-be exploitation, fundamental questions that go to the core of exploitation of nature in a Buddhist country. Are the profits worth it in the most ethical and ecological perspectives? Can the trade-offs be justified? Are there no alternatives? Ultimately, such investigations must turn upon the very carrying capacity of any given ecological zone. Inherent to those EIAs must emerge questions that might not even have emerged a generation ago, when the full revelations of the damage of the Anthropocene were yet to be revealed. It is no secret to the scientific and policy communities worldwide that the acceleration of collective damage has outpaced any of the projections and models of two decades ago. The very indicators of carrying capacity, and the signs of stress in the “commons,” have been dramatically altered. No one, for example, could have predicted in 1920 that within a mere decade most of the large vertebrates of Nigeria would have been driven to extinction; that DDT, mercury poisoning, heavy particulate matter, O3, and methane would become global environmental crises; that the vast majority of wetlands from New Zealand to California and coral reefs from Australia to the Mozambique Channel to the Bahamas and Cuba would be vastly compromised within just a few human generations, not to mention the accelerated destruction of neotropics from Brazil to Borneo; that Bhopal disaster, the Exxon disaster in Alaska, the Three Mile Island accident, the Chernobyl disaster, the BP Deepwater Horizon oil spill, and Fukushima Daiichi nuclear disaster would come to define just a few of the “highlights” of the twentieth and twenty-first century introduction to the Anthropocene; or that the USA would become a nation with over 1,300 Superfund sites of high toxicity, a situation mirrored in country after country.

Historically, rehabilitation of mine sites has focused on site stabilization and the formation of vegetation cover, but now with stringent regulations, such measures represent only just the initial process of rehabilitation and ecosystem restoration [35]. In certain countries, restorative practices require the reintroduction of both plant and animal species and the effective functioning of ecological processes such as nutrient cycling and the build-up of leaf litter, resilient to invasive species and fire. Such full-spectrum eco-restoration has, to-date, rarely been effectively applied. For example, US pit mining and large-scale clear cutting has yet to demonstrate successful reforestation in model plots where damage is so extreme as to have impeded full-ecosystem post-trauma resiliency, taking into account the complexities of biological interdependencies. Humanity, and all of its restorative sciences, has failed in its half-hearted attempts to heal a wounded world. The scars everywhere remind us of the planet’s biological fragility, just as a human footprint in the fragile tundra can remain for a century.
**Land Use for Agriculture**

Spatial analysis conducted by the Department of Forest and Park Services showed conversion of 36,298 ha of forest to agricultural lands between 2000 and 2015, to be used as Chuzhing (wet land agriculture), 8,303 ha; Kamzhing (dry land), 25,690 ha; and Orchards, 2,304 ha, in the subtropical and temperate agro-ecological zones of Bhutan [36]. At the same time, rural-to-urban migration of certain farming communities resulted in the abandonment of 24,631 ha of agricultural land which transformed itself back to second- and third-generation forest growth. Such new developments increased the forest area, and the actual conversion of forest to agriculture was 11,667 ha. This trend is expected to increase over the coming years as the 62.2% of population currently living in rural areas will be reduced to 43.2% by 2047 as per the population project report of NSB [33] (Fig. 2.6).

Over the recent past, there has been a new trend of leasing government forest land for orchard development like cardamom, as a low-cost farming cash crop, creating an additional human interference into natural ecosystems, while the rural-to-urban migration rush has forced the government to change prime agricultural lands to urban towns which in turn becomes a compelling factor for encroachment into forest land for agricultural farming. Unsustainable agricultural practices such as farming on steep slopes (with about 31% cultivated land located in 50% slope) [3],

![Aerial view of paddy field terrace in Paro Valley](https://example.com/paro_valley_aerial_view.jpg)
increasing use of pesticides and chemical fertilizer (explained in a different section), and only about 2.93% of the total land area being suitable for cultivation [37] taken together pose serious challenges in the near future that can have either direct or indirect pressure on the environment and forest habitats particularly. Such reversibilities, so called, are by no means the answer to ecological restoration, given the underlying, long-term soil, water, and biodiversity disruptions these human-induced vacillations create.

**Chemical Pesticides and Fertilizer**

Pesticides application has been a key feature of agricultural intensification in all countries, and this is closely linked to changes in farming practices and wildlife habitat destruction or loss. Therefore, data and information on pesticide use is important as it is generally perceived as the most expedient means of controlling insects, pests, and weeds in agriculture farming. Given the immense health and environmental benefits of organics, as demonstrated from France to New Zealand, Bhutan has pledged to become totally organic by 2020 [25]. However, reality at ground zero tells a very different story. Quantified over many years, the trends across Bhutan have yielded evidence of an increase in the use of pesticides as per the import figures indicated in Fig. 2.7, although there was slight decrease in 2017. An all-organic Bhutan remains an ecological elixir for the country. That said, the country is certainly mindful of the harmful effects of chemical pesticides, and as such, stringent measures have been enacted to try and control the import and use of inorganic farming chemicals and dispersion. In Bhutan, an integrated pest management practice is being followed, limiting the use of pesticides as the last resort by ensuring that only appropriate types and quality of pesticides are introduced and that pesticides are used on the basis of authorized application and in accordance with best practices.

![Fig. 2.7 Pesticides imported in metric tons (environmental accounts)](image)
No private parties are allowed to import chemical pesticides due to the concerns that hazardous or inferior quality chemical pesticides may be imported for distribution to farmers [38]. The import and distribution of plant protection chemicals is mandated by the National Plant Protection Centre (NPPC), an agency under the Department of Agriculture. Most used pesticide in the country has been butachlor (a selective, pre-emergent herbicide of the acetanilide class). The fate of butachlor in most environments is largely considered nonhazardous [39], while lesser quantities of other pesticides have been used as indicated in Figs. 2.7 and 2.8. Application of pesticides does not seem to be uniform across the country, with less pesticide application in remote Dzongkhags and high-altitude areas where the targeted import and application of such pesticides have fallen sharply after 2016 (Fig. 2.7).

Studies on pesticide use from other countries, like the UK, have shown population declines among those farmlands studied of roughly half of all plants, a third of all insects, and 80% of bird species [40]: most alarming results. In Canada, intensive agriculture practices like aerial spraying have led to an increase of endangered species [41]. There are reports that almost 97.5% of pesticides used in Bhutan are butachlor, while 2.5% of pesticides are considered hazardous [42]. The extent of impact of pesticides on the environment and biodiversity of Bhutan needs urgently to be assessed to ensure proper planning and precautionary measures. Customarily, Bhutanese farmers have been dependent on farmyard manure for fertilizing agricultural farm soils, a practice that remains widely practiced in many parts of the country.

With the introduction of high-yielding crop varieties and cash crops in the 1960s, inorganic fertilizers have been used in certain parts of the country, those areas accessible by motor roads. The expansion of road network has facilitated the promotion of inorganic fertilizers through subsidies and extension services in increasing farming of high-yielding crop varieties and cash crops. The use of chemical fertilizers is highly regulated and its import and distribution is mandated to the National Seed Centre (NSC) of the Department of Agriculture. Imported fertilizers are distributed to the farmers in the Dzongkhags through the NSC-designated commission agents.

![Fig. 2.8 Insecticides distributed to Dzongkhags (in 2017). (Data source: RNR Statistics 2017)](image)
The challenges using inorganic fertilizer is balancing the ratio of N (nitrogen), P (phosphorus), and K (potassium) which is 6:1:1 by the national standard; imbalance of these ratios have led to lumping of soils [42]. Too much nitrogen fertilizer results in significant nitrogen losses mainly through leaching and runoff that contribute to groundwater contamination, atmospheric pollution, soil acidification, and degradation [1]. Therefore, balancing the application of fertilizer sufficient to meet the demand for food and ensuring environmental sustainability for future generations will require effective management. Most critical in terms of biodiversity, “agroecosystem resilience and sustainability” however will be the necessary shift – in keeping with the most responsible systems throughout the world – to a strictly organic future in Bhutan.

Waste Management

Associated with socio-economic development progress in the country, the quantity of waste generation increased by more than 50% in a space of 4 years (2014 and 2017), while the nominal GDP grew by almost 12% during the same period of time [22]. If such trend is characteristic of the socio-economic progress of the country, this indicates that the economy is becoming more waste intensive. Without accounting for the waste generated in rural areas of Bhutan, the annual quantity of waste in four major cities amount to 14,490.5 tons, while the collection and disposal of waste at the landfills figures an annual expenditure of Nu. 53.61 million; the cost of managing waste was estimated at Nu.4 per kg of waste [22].

Rapid urbanization, enhanced manufacturing and production, changing consumption patterns, lack of understanding in waste management facilities, and appropriate technology are some of the key factors that have led to increased generation and improper disposal of soil waste. Due to increasingly larger human populations and enhanced economic activities in urban towns such as Thimphu, Paro, Phuntsholing (Chukha), Gelephu (Sarbhang), and Tashigang, the amount of waste generated and the associated challenges are much greater in these towns when compared with the other parts of Bhutan (Fig. 2.9). However, it could also mean that there is a pronounced absence of state-of-the-art information on waste generation in most of the Dzongkhags. The composition of waste in the urban towns of Bhutan mostly contains medical waste, e-waste, municipal solid waste, organic waste, and plastic waste [22]. Currently, there is no proper system of waste segregation at source, and the landfills are poorly managed without any scientific management systems in place. In addition, there are no effective measures to control pollutant emissions, leaching, and other adverse impacts on environment, human, and other animal and plant health. This leads to overfilling, adverse odors, and the troubling contamination of land and water through leachate. Needless to say, landfill sites constitute most unpleasant realities [43].

Bhutan’s environmental policies related with waste management seem to be sound but not effectively implemented. Many in the country are working to improve
the situation. But, writes one commentator, “the amount of waste gathered by volunteers is both impressive and saddening” [44]. Several waste treatment and mitigation policies, laws, and strategies have been put in place, that include the National Environment Protection Act, 2007 [45]; National Integrated Solid Waste Management Strategy (NISWMS), 2014 [46]; Waste Management and Prevention Act, 2009 [47]; Waste Management and Prevention Regulation, 2012 and 2016 (Amendment) [48]; Zero Waste by 2030; and several localized management strategies like Integrated Solid Waste Management for Bajothang (pilot project); Public–Private Partnership for ISWM (Thimphu Thromde); Zero Waste (Mongar); Youth Action for 4 R’s (waste clubs in 10 schools in Thimphu); and Samdrup Jongkhar Initiative on Zero Waste [49]. The National Environment Commission, Bhutan, has the mandate to coordinate the implementation of policies and laws.

But despite having specific Acts, regulations, and responsible authorities specified by law, waste management measures remain to be effectively implemented, a reality that (philosophically, in any case) goes to the quintessential truth of human nature and its societal implications. Even in an essentially nonviolent oriented, mostly Buddhist society, the pile-up of human nature(s) manifests itself at large. Throughout human history, waste has always backfired, at almost any scale. According to the National Integrated Solid Waste Management Strategy (NISWMS), Bhutan’s current gaps in what ideally would be deemed a Zero Waste Society (ZWS – equivalent to a carbon neutral or negative society) failure seems to be due to limited workforce and budget, lack of implementing capacity in Thromdes and Dzongkhags, and largely minimal awareness of the overall problems by the public [50]. Serious concern regarding waste management has even led to observing a Zero Waste Hour (ZWH) on the second day of every month through the involvement of business offices and institutions, led by the National Environment Commission with a vision to achieve a Bhutanese Zero Waste Society by 2030. However, apart from those few recycling units for plastics, bottles, metal wires, and organic waste, there does not yet exist proper waste processing facilities for biomedical waste, e-waste, and other hazardous liquid or solid waste in the country. Sewage from domestic and

Fig. 2.9 Waste generated (tons/day), Dzongkhag-wise. (Data source: MOWHS)
hotel industries, waste oil, and effluents from automobile and other mechanical industries also remain a major source of water pollution, apart from the solid waste. Virtually none of the landfills are scientifically managed, as described earlier. There seem to be about 19 waste entrepreneurs, excluding those (variously designated) who spend at least part of their time sifting through and removing various waste articles whose primary objective is to recycle and market.

The Waste Management Strategy (WMS) of 2019 needs to itemize and analyze waste management plan systems in every Thromdes and Dzongkhags including the proper collections systems and segregation systems that feed different categories of waste processing facilities. Additionally, the Strategy needs to implement various requirements and mandated levels for effective processing technologies for biomedical and hazardous waste, including e-waste and hazardous waste, followed by proper disposal systems into the landfills. In addition, liquid waste such as automobile waste needs to be properly processed for disposal. As advocated by the National Environment Commission Secretariat “My Waste My Responsibility,” there could be a nominal waste collection fee for each household levied to make the waste management service sustainable. Zero plastic waste in Santa Monica, California, and ten cents per bag at every store throughout the states of California and New Mexico are just two of the examples now in place throughout much of the world. In Germany, Austria, South Korea, and Wales, more than 50% of all municipal waste is recycled. Switzerland is nearly at 50%.

**Fuel Wood Consumption**

About 62.5% of the country’s population live in rural areas of Bhutan [33], and fuel wood is still the main source of energy for cooking and space heating. Although collection of dry fuel wood is commonly done in the form of fallen twigs and driftwood, a far more substantial portion of the fuel wood needs are met from natural forests; removal of trees as firewood occurs within and outside of forest management units (“FMU”) [14]. Fuel wood accounts for 21% of total household energy consumption, second only to electricity (69%) at the national level. But 94% of rural household energy consumption is met by fuel wood, while it is only 6% in urban areas [51]. Apart from domestic use in rural areas, fuel wood is heavily used for industrial production, forest products processing, and road construction and in hospitals, schools, military encampments, and monasteries. As per the environmental audits/accounts [22], the amount of firewood extracted and supplied between 2010 and 2017 amounted to 892,072.85 cubic feet of wood (“CFT”) including 404,138.75 CFT for household consumption and 487,934.08 CFT for industrial purpose or an annual average consumption of 111,509.106 CFT, or an increase by 60% consumption in 2017 (132,195.62 CFT) when compared with that of 2010 (80,036.00 CFT) as indicated in Fig. 2.10. The per capita consumption of firewood in 2017 for a population size of 727,145 [33] was 0.1818 CFT or 1818 kg which is much lower than the world capita consumption of 0.40 m3 [52]. However, informal
collection of fuel wood in the rural settlement areas of Bhutan are not accounted for in this assessment which could mean larger per capita consumption of fuel wood. In consideration that firewood extraction is degrading the forests, RGOB has begun to promote fuel-efficient cook stoves, use of biogas, electric bulb cookers, 100 units free electricity to rural areas, and tax subsidy on appliances such as boilers and rice cookers to reduce forest degradation. Such alternative strategies to reduce fuel wood consumption need to be strengthened as the demand has been progressively increasing over the years in Bhutan, as indicated in Fig. 2.10.

Timber Production

In the Bhutanese construction industry, timber is commonly used mostly with traditional architecture technical specifications which are mandatory for the real state and private builders. Such standards entail precise wood works and huge quantities of timber. Almost all traditional housing structures – floor, roof, staircase, windows and doors, and beams and pillars – are made of wooden structures. Added to these requirements, demand of timber for new constructions is rising because of population growth, fragmentation of families, and frequent house fires; and construction of infrastructures such as Dzongs, hospitals, basic health units, outreach clinics, schools, agriculture research and extension centers, and geog administrative offices has surged in the recent years. There has been a steady increase of timber demand over the past many years. Indeed, within the period 2012–2017, a total amount of 45,579,220.86 CFT (45.5 million CFT) was supplied for a multitude of construction projects, as indicated in the Fig. 2.11. [22]. Timber is supplied at highly subsidized rates for rural settlements, as permitted by the Forest and Nature Conservation Act of Bhutan [53], and the commercial rate applies only for other, non-rural endeavors.

The sum total of all this is conceptually abetted by Bhutan’s stellar primary forest canopy conservation stature, as well as the fact that within the Buddhist pantheon, forests are largely sacred. For example, Gomju Drake in the Shelling village
located in Central Bhutan, a very old and enormous oak is considered an important meditation site. The low-biodiversity input of second, or third growth, or fast-growing plantations is not in sync with the picture of a conservation-driven Bhutan. Yet, the trends of growing demand are irrefutable: 62.5% of rural Bhutanese are driving up the demands on free timber. Moreover, demand for construction timber surged exceedingly high during 2015 after the removal of major of bank loan suspensions in 2012 and 2013 [33]. The demand dropped slightly in 2017.

With an average annual extraction of 7,596,536.8 CFT (7.5 million CFT) (without accounting for unauthorized/illegal extraction), the per capita timber requirement is 10.44 CFT in the country. For comparison sake, between 1988 and 2011, US per capita consumption was roughly 38 CFT [54]. The timber requirement is equivalent to about 19% of the estimated sustainable annual yield in the country, while just 14% (including community forests) of forest area in Bhutan is estimated to be suitable for commercial timber production for a sustainable forest management [14].

The most commonly mentioned impact of the timber industry is forest degradation. Felling trees for timber in any forest worldwide alters the tree age structure, composition of tree species, and vertical stratification, thereby affecting local temperature, light, moisture, soil, and litter conditions [55]. This results in changes or complete removal of microhabitats (such as dead wood, cavities, root plates, or mature trees) that host forest biodiversity. On the other hand, species dependent on forest cover, deadwood, and large trees such as bryophytes, lichens, fungi, saproxyllic beetles, and carabids seem to be negatively affected by forest management, while many vascular plant species may in fact benefit, at least in the short term, from some management [56]. But there are a host of other major concerns related to forest logging operations. These include adverse impacts on water availability for downstream communities as a result of disturbances and felling of trees in catchment areas, soil erosion, and the destruction of the very regenerative capacity of soils and tree species diversity resulting from the destruction of boles and mature tree species. How trees are felled varies, and those uprooted without biology/professional consultation will invariably exact tremendous damage all around.

Fig. 2.11 Total timber supply in cubic feet. (Data source: NSB 2018)
The Department of Forest operates several forest management units (FMUs) across the country for sustainable timber harvesting, guided by the forest management plans which determine the available growing stock and annual allowable cut. However, it has been reported that a significant amount of timber needs required for rural construction, renovation of Dzongs, and monasteries are not necessarily enacted as per the forest management plan [14]. As previously stated, such gaps in timber harvesting practices could lead to forest degradation because of unplanned removal of trees. Although, there are community forestry programs, local area forest management plans, etc. outside the FMUs, there is a need for holistic management strategies that encompass contingency planning for all the forest areas in Bhutan.

Bhutan is endowed with one of the world’s richest diversities of tree species, given its enormous altitudinal differentiation [57]. Fortunately, only a few species are normally used for timber. In this regard, there is a need to diversify the use of timber species by promoting lesser known and useful timber species, as mentioned in Chap. 7. In order to reduce the massive exploitation of forest resources, regulatory mechanisms need to be strengthened to curb illegal extraction of timber and non-wood forest products by making local governments and communities accountable for their actions.

In addition to timber and fuel wood extraction from the forest, extraction of non-wood forest products such as leaf litter, barks and pulps, mushroom, medicinal plants, ornamental plants, ferns, wild vegetables, bamboo, cane, animal fodder, etc. are some of the very common products collected for consumption as a customary practice. Unless effective monitoring and management strategies are implemented, indiscriminate collection and utilization of non-wood forest products will invariably lead to the severe degradation of these natural resources.

The magnitude of impact on species diversity due to forestry activities is obviously predicated upon several factors. As forestry operations are carried out in different climatic zones and regions that differ in biodiversity, food web structures, and ecosystem properties, the impacts can be largely variable depending on geographical locations. Although forest management units follow certain scientific operation guidelines, some effective harvesting techniques like reduced impact logging (RIL) could be a useful introduced technique to minimize the impact on species diversity and degradation of remaining forest.

**Forest Fires**

Each year, significant forest areas of Bhutan are burnt due to various causes including deliberate burning for regeneration of grazing areas, the attempts to prevent wild animals from attacking crops, and climate change. Between 2013 and 2017, there were 234 fire events recorded in the country, affecting 93,705.3 acres of forest areas, with an annual average of 18,741.06 acres of forest areas affected [14]. This is a huge concern that represents an irrereplaceable loss in the face of so much intense...
conservation efforts invested for so many years by the Royal Government of Bhutan. Forest fire outbreaks generally occur during windy and dry weather conditions and in pine and oak forests, while the incidents also differ from region to region – occurring between November and May in western areas of the country and between January and June in the eastern regions. Incidents of forest fire are low in the high altitudes because of cooler conditions, while most of the incidents occurred in Dzongkhags that have subtropical and dry weather conditions as indicated in Fig. 2.12. Management of forest fires in Bhutan is extraordinarily challenging because of rugged and steep terrains inaccessible to most conventional fire-fighting controls. Nonetheless, the Department of Forest and Park Services has been making tremendous efforts to reduce the incidents of forest fires in Bhutan. Forest fires can easily inflict adverse impacts on biodiversity and threaten endangered species and reverse the conservation success of many years. For example, in Russia it has been reported that the number of the rare and critically endangered Siberian tigers (Panthera tigris altaica) and wild boar (Sus scrofa) decreased by 20–50% due to forest fire, while mortality of squirrels and weasel populations reached 70–80%, boar 15–25%, and rodents 90% [58]. If a forest fire is followed by rain in steep areas, the rainwater washes away topsoil and ash, exposing the area without any nutrients to support natural regeneration and becoming barren and prone to erosion and degradation. It is normally accepted that a regular occurrence of fires can reduce the amount of fuel build-up thereby lowering the likelihood of a potentially large fire incident that could indiscriminately wipe out the diversity of species. It is also believed that fires often remove alien plants that compete with native species for nutrients and space and can clear undergrowth allowing sunlight to reach the basal growth area thereby supporting the growth of native species. However, such
benefits of forest fire can occur only under controlled fire management. Scientific study on the impact of fire in Bhutan’s forest is required as controlled burning of low intensity appears to bring benefits to the natural environment and biodiversity; concerted effort for fire prevention and control could be prioritized in those Dzongkhags very much prone to fire outbreaks (Figs. 2.13, 2.14).

Other operational protocols that have become standardized in many other countries could greatly benefit Bhutan, which so prides herself on the protection of forests as a key indicator of the conservation health of the country. Clearly, Bhutan requires advanced forest fire detection technologies, such as airborne optical and thermal remote sensing [59]. In addition, water and chemical drops from various aircraft – standard procedures in many other countries – would be welcome components in an overall Bhutanese emphasis on a national strategy for ensuring, particularly in an age of escalating climate crisis, that major fires do not ever succeed in reversing decades of enormous conservation success. Such considerations should be viewed with maximum urgency.

Livestock Grazing

Traditionally, livestock rearing is an important economic activity among Bhutanese rural communities (Fig. 2.15). In fact, nomads in the northern regions of Bhutan are mostly dependent on livestock for their sole livelihood. The impact of livestock grazing on forest degradation can be a localized effect that varies from place to place depending on the forest types and grazing intensities. In accordance with the
Land Act of Bhutan, 2007, Sections 235–236 [13], livestock-dependent beneficiaries have the *Tsamdro* (native pasture) usufruct rights, and the GOB offers legal provisions on livestock grazing depending on herd size and the *Tsamdro Management Plan* proposal to be submitted by the beneficiary.

Overgrazing is understood to result in forest degradation; however, definitive research study needs to be conducted to accurately assess its impact. Cattle are owned by almost all of the rural households in the temperate and subtropical regions of the country. In the alpine and sub-alpine regions, such as *Merak-Sakteng, Laya,* and *Lingshi* yaks and sheep are commonly herded, and the economy is solely based on yak products. With the livestock population (excluding pigs and poultry) of
4,25,980 heads (little less than half a million) [25], livestock grazing density in Bhutan is about 1 cattle for every 5 hectares of forest, posing challenges with respect to the degradation of forests, overgrazing of rangeland pastures, and possible deterioration of plant species (Fig. 2.16).

Free-range and migratory grazing is the most common practice as it is far less labor-intensive compared to stall-feeding. In this regard, some of the pastures and forest lands in the temperate region are subjected to continuous grazing – by yaks in winter and cattle in summer – leading to overgrazing. However, overgrazing can be caused by wildlife herbivores and extreme weather events especially in the northern frontiers. If livestock grazing in the forest is to be a continued practice in Bhutan, detailed scientific assessments of impact of such grazing on rangeland pastures and other grazing areas are required for proper planning and sustainable management of the resources.

Over the last many years, the government implemented various strategies like the introduction of improved breeds to replace native animals, sterilization of unproductive native cattle breeds, and pasture development programs to decrease livestock population and forest degradation through overgrazing. Nonetheless, livestock populations have been increasing every year which could be attributed to the religious sentiments against culling and killing in some of the parts of Bhutan. The only clear and present ethical solution to this would and could easily be accomplished through various forms of immunocontraception. In addition to the breed improvement program for the replacement of unproductive livestock breeds, rangeland management and rotational grazing could be some of the alternatives to prevent overgrazing and forest degradation.
Fig. 2.16  Hometown of yak herders in Sakten – Bhutan @ M. C. Tobias

Fig. 2.17  Yaks perform multipurpose jobs (food, cloth, transportation), Sakten © M. C. Tobias
Air Pollution and Fossil Fuels

Bhutan has long been recognized for its pristine air quality. Conversely, air pollution is increasingly becoming one of the emerging challenges posing threats to both human and environmental health, glaciers, and agriculture throughout the nation [60]. Rapid socio-economic development is causing local sources of air pollution through emissions of GHG from vehicles, industries, and space heating using firewood; burning of biomass, debris, garbage, construction waste, and agricultural residue; forest fire; and suspended dust and soil particles from roads and construction site (Fig. 2.18).

In addition, transboundary air UNESCAP pollution under the regional phenomenon of “Atmospheric Brown Cloud” (ABC), triggered by burning of biomass and fossil fuels in South Asia, is an issue of concern for local air quality [61].

As of 31 December 2017, the number of vehicles in Bhutan rose to 92,008 units, and the import of vehicles has increased over the years as indicated in Fig. 2.19; with the maximum number of light vehicles followed by heavy vehicles such as trucks and busses; other vehicles include taxis, two-wheelers, earth mover machines, power tillers, tractors, medium vehicles, and a few electric vehicles [61]. Thus far, there has been a cumulative increase in the pollution levels through vehicle emission. Fossil fuels such as diesel, petrol, and LPG gas are imported from the neighboring country India. Of the total 61,348.5 KL of fossil fuel imported, about 78% is diesel and 21.69% petrol. These amounts were used for vehicles, agriculture machineries, industries, and other uses. Such import of diesel grew by 10% in 2017 as compared with 4% in 2016, while petrol imports grew by 8% in 2017 compared to 6% in 2016 [22]. In a business-as-usual scenario, such trends will continue to deteriorate the environmental quality of Bhutan unless cleaner technology such as electric vehicles and mass transportation systems can replace the fossil fuel-powered transportation systems. Bhutan’s vehicular realities, within the lucid context of a

Fig. 2.18 Fossil fuel consumption in Bhutan. (Data source: Environment accounting, 2018)
nation that prides herself on being an environmental leader worldwide, could embark upon entirely new prototype programs that thwart air pollution with carbon-neutral vehicles that include all of the hybrid, electric, and hydrogen fuel-cell options. Bhutan represents a fertile testing ground for those corporations that are branding dependent in today’s climate crisis environment. There is no reason that Bhutan could not, in coming years but starting now, become the first all-electric vehicle nation on Earth.

It appears the percentage of polluting vehicle imports have been decreasing in general with increased import tax and loan sanctions. But such measures cannot be a systemic solution and are certainly not the alternative to a truly alternative emissions paradigm for the country. Additional fossil fuels such as LPG and kerosene are also imported for cooking and heating purposes in most of the houses that only add up to air pollution, and these, as well, should be phased out as part of an enlightened new carbon-neutral grid for the nation.

As highlighted in the “Middle Path – Vision 2020,” the industrial sector is one of the key strategies of economic development in Bhutan. But the invoking of “middle path” and “vision” are clearly complicated with regard to any kind of specular, ecologically, and ethically sustainable frontier for a nation like a Bhutan. Thus far, there have been just a few large manufacturing industries, such as the Penden Cement Authority Ltd., the Bhutan Board Products Ltd., Bhutan Carbide and Chemicals Ltd., the Bhutan Ferro Alloys Ltd., and Bhutan Agro Industries Ltd., all located in the border areas with India [22]. Cement, it should be pointed out, has one of the largest carbon footprints known. Hence, as with all industry, the scrutiny upon which its origins and distribution are conducted must necessarily be intensively documented. Industrial production is primarily of the cottage industry type in Bhutan because of the reason rugged mountainous terrain makes the construction of roads and other infrastructure difficult and expensive. However, with a 5.50% GDP growth rate and a GDP contribution of 7.25% in the manufacturing sector [22] that is expected to grow, it is likely that pollution through manufacturing industries will keep worsening as the government has planned four additional industrial states.
mostly along the Indian border [62] (12th 5-Year Plan). There has been a steady increase in the number of production and manufacturing industries over the years, sharply increasing from 1648 in 2015 to 2539 in 2018. Manufacturing industries have been one of the major sources of pollution. The question must necessarily devolve: Would nations like New Zealand or Switzerland, largely enjoying low-pollution economies because their economic prosperity derives from tourism and agriculture sectors, not serve as fitting exemplars for Bhutan, whose two largest income-generating modalities are agriculture and tourism? Why risk ecological despoliation under the banner of a “middle path vision” for short-term economic gain, at a time when the climate crisis is unprecedented and nations everywhere are scrambling to get their industrial houses in order (up to new ecological standards in sync with a whole new global reality of environmental consciousness)?

As a result of increased human activities, the capital city, Thimphu, is experiencing an observed trend of high-level particulate matter (“PM”)10 concentrations, especially during the dry winter months as indicated in Fig. 2.20. While the levels are still within the national permissible limits for mixed area, the levels exceed WHO guidelines and EU directives for annual average levels of PM10 emissions (i.e., 20 μg/m3 and 30 μg/m3, respectively) (see Table 2.3). At the industrial area in the southern region of Bhutan, the PM10 levels at the Pasakha industrial estate between 2011 and 2015 exceeded the national permissible annual average PM 10 limits for industrial areas [61].

During the UNFCCC 15th Session of Conference of Parties (COP15) in Copenhagen, the Royal Government of Bhutan committed to remain carbon neutral to strengthen environmental well-being that is core to the GNH philosophy – ensuring that the country’s greenhouse gas (GHG) emissions do not exceed the sequestration capacity of its forests [63]. “Carbon” here refers to the greenhouse gases CO2, CH4, and N2O and is measured in CO2 equivalents (CO2e). The National Environment Commission (NEC) is charged with the responsibility to make recommendations to the Royal Government of Bhutan on options for pursuing green growth so that the goal of remaining carbon neutral is achieved (wwwnec.gov.bt).

![Air pollution in Thimphu area. (Data Source: NEC)](image)
The national strategy for low carbon comprises various scenarios of development paths while maintaining carbon neutral and green growth until the year 2040. NEC has estimated the 2009 carbon emission level to have been approximately 2.1 million tCO2e, which is about one-third of the estimated sequestrated 6.3 million tCO2e. Emissions from industry count for a quarter of Bhutan’s estimated carbon emissions of approximately 2.1 million tCO2e, which is one-third of the estimated sequestrated 6.3 million tCO2e [64]. Using the expected population increase and GDP forecasts, the industrial emissions are expected to increase by four times the emissions in 2010 while still maintaining carbon neutrality in the year 2040.

The baseline projection shows that in 2040, the emissions will be 4.7 million t CO2e or more than double the level in 2010 but still below the expected sequestration of 6.3 million t CO2e [63].

Many of the pollution control measures can be enforced through relevant provisions of existing legislations such as the Environmental Assessment Act (for control of development activities), Waste Prevention and Management Act (for management of wastes and debris), and the Local Government Act (for activities within municipal boundaries and local jurisdictions). All of these legislation mandates decentralized action to manage and control environmental standards at local levels or across sectors. As such local-level authorities and line agencies need to be supported to implement the various measures. In this regard, several of these measures are already underway, such as introduction of mass transport, promotion of electric vehicles, revision of vehicle emission standards, forest fire management, improved wood stoves, and greening of urban centers. However, these measures will need to be scaled up to generate visible impacts on air quality in the country. Needless to say, scaling remains an imprecise science in which the viability of politically achieved policies vie with verifiable, environmental goals.

### Table 2.3 Ambient air quality standard of Bhutan (maximum permissible limits in μg/m3)

| Parameter                           | Industrial area | Mixed area | Sensitive area |
|-------------------------------------|-----------------|------------|---------------|
| Respirable particulate matter (PM10) |                 |            |               |
| 24 hour average                     | 200             | 100        | 75            |
| Yearly average                      | 120             | 60         | 50            |
| Sulfur dioxide                      |                 |            |               |
| 24 hour average                     | 120             | 80         | 30            |
| Yearly average                      | 80              | 60         | 15            |
| Nitrogen dioxide                    |                 |            |               |
| 4-hour average yearly average       | 120             | 80         | 30            |
|                                      |                 | 80         | 15            |
| Carbon monoxide                     |                 |            |               |
| 8-hour average                      | 5000            | 2000       | 1000          |
| 1-hour average                      | 10,000          | 4000       | 2000          |

Data Source: NECS

*mixed area: where residential, commercial, or both activities takes place

*Sensitive area: where there are sensitive targets such as hospitals, schools, and sensitive ecosystem
Measures to manage transboundary air pollution include improving national monitoring of such pollutants and engaging in regional agreements and programs such as the Malé Declaration on Control and Prevention of Air Pollution and its likely Transboundary Effects for South Asia of 1998 under the auspices of the South Asian Cooperative Environment Program (SACEP). Other climate change actions in South Asia can also potentially improve this issue of regional air pollution.

Strategic policy measures to control and manage pollution will include enforcement of vehicle emission and industrial discharge standards of 2004 to control air and water pollution, including the enforcement of Environmental Assessment Act 2000, the Waste Management Strategy (2019), and Waste Prevention and Management Regulation (2012) that address pollution from all kinds of waste. The Green Tax levied since 2012 on the import of vehicles has been an effective initiative of the government to control the veritable explosion of the number of vehicles [65], [50], [48].

For effective monitoring of air pollution, spatial mapping of the major sources of pollution countrywide could provide important information for the enforcement of regulations on emissions, as well as the application of the polluter pays principle [66]. Such GIS mapping would also provide data to help measure compliance on the ground. Additionally, creating green jobs for the people in polluted areas could contribute towards public awareness and mitigation of the pollution problems while demonstrating the economic benefits of such awareness. The government could also facilitate the switch to cleaner energy sources in households in order to decrease the problem of indoor air pollution (the source of numerous respiratory and other ailments, particularly for children) that invariably add to the overall burden of pollution.

Demographic and Poverty Factors

Bhutan’s population grew to 727,145 people in 2017 as per the Population and Housing Census of Bhutan [16], while the Population Projection Report for 2017 to 2047 reveals that Bhutan’s population will reach 883,866 in 2047 [67], indicating that the population size will remain well below the 1 million mark even 30 years from now. While the population figure seemingly presents one of the lowest in the world, with an average population density of 19 /km² as opposed to 300/ km² in South Asia [68], the inhabitants and settlements are very much concentrated in the deep valleys and along gentle slopes, the country being predominantly characterized by steep terrains and rugged mountains not suitable for human settlement. Such landscapes and high concentrations of denizens in the deep valleys could possibly pose immense pressure on the environment and natural resources. In addition, the population density is very much lop-sided and skewed towards the urban towns and cities, owing to the systematic pursuit for a better life, higher-paying jobs, and prosperity within cities – a trend mirrored worldwide which accounts for the fact for several years now the global urban human population has exceeded 50% of the entire human population (Fig. 2.21).
A Bhutanese case in point: Thimphu Dzongkhag and the capital city harbor a density of 67/km², while the density is just 1/km² in Gasa Dzongkhag located in the northern most part of the country. The concentration of people in the narrow valleys of cities and towns is persistently getting overcrowded due to migration of people from the rural areas. The World Bank Group reported that growth rate of Bhutan’s urban population was the highest among the eight South Asian countries at 5.7% per year from 2000 to 2010 [69] with 37.8% of the population living in urban towns of Bhutan as of 2017, an increase by 6.8% when compared with that of 2005 [67]. This certainly indicates the pressure on the environment is continuously mounting with an acute demand of land use, housing, and natural resources like timber and water; construction of schools, hospitals, and service centers; generation of waste; transport; etc. Thus demographic pressure on land and natural resources can be severe than the average population density verges towards 19%/km². With 62.2% of Bhutan’s population currently living in rural areas, the myriad pressures on the environment can only escalate. Such pressure is expected to continue as some 43.2% of that rural population will continue to be alive in 2047. The scientific assessment and monitoring of the associated pressure on the environment and exploitive trend upon natural resources are yet to be determined.

One of the qualifying factors that has yet to receive systematic analysis anywhere in the world is the de-escalation effect that rural-to-urban migration might provide (in the most positive sense) for ecological rehabilitation in those areas depopulated by migrants. One of the few intensively studied areas under this demographic sce-
nario has been at Chernobyl in Ukraine, where, since the nuclear tragedy, in the absence of all the former human residents, there has been an extraordinary renaissance of biodiversity that the scientific community did not anticipate.

Because of the visionary leadership and guidance from His Majesty The King, Bhutan has made significant progress in socio-economic development. The overall poverty rate in the country declined from 23.2% in 2007 to 12% in 2012 and further declined to 8.2% in 2017 [33]. Rural Bhutanese poverty is still much higher than urban poverty. It was reduced from 30.9% in 2007 to 16.7% in 2012 and 11.9% in 2017, signifying income gaps and inequalities. However, in general the proportion of urban poor significantly reduced to 0.7% in 2017. Under such a scenario, rural poverty still persists and will have a significant impact on the utilization of natural resources. For example, poverty stimulates extraction of timber for commercialization. It all easily prompts the overexploitation of non-wood forest products and other illegal activities such as poaching of endangered and charismatic species. Much against the Bhutanese culture and tradition, there are indications of paradigm shifts from a joint family system to nuclear families, as the Bhutanese population moves increasingly towards the fragmentation of farm lands and properties resulting in the changes in land use such as construction of infrastructures on agricultural lands. Under such scenarios, Bhutan’s challenges with urbanization need effective implementation of urban development strategies that promote regional balance (2008) and relieve the related environmental pressures.

Many scientific reports reveal that inequality is bad for the environment. It has been reported that the average pollution rates across a suite of chemical adulterants is lower in more equitable and affluent countries, like South Korea and Japan, than those less equitable affluent countries like the USA and Canada, indicating that countries with a bigger gap between rich and poor do more harm to the planet and its climate [70]. Climate change is intricately related to economic inequality. The catastrophic consequences of greenhouse gas emissions produced by the wealthy (including nearly 20% of those emissions produced in the USA alone) hit the poor of the world the hardest. Inequalities are also considered to be one of the critical tipping points that could create irreversible damage to the Earth’s systems [1]. Inequalities can worsen the environmental impact in poorer nations as wealthier countries, with their economic and geopolitical power, can contract out polluting and resource demanding production practices to poorer nations [71]. As such, economically disadvantaged people are often very vulnerable and excessively exposed to the risks of climate change impacts because of low capacity to cope with environmental hazards, inadequate access to infrastructure for protection, or absence or low level of prevention services to combat environmental hazards [71].

In Bhutan, there have been social media reports that income gaps have widened between the rich and poor in the period of the 11th Plan (during the period 2013–2017) [72]. The National Statistics Bureau of Bhutan revealed, despite the achievement in reducing overall poverty, that income inequality has widened since 2007, after the nation introduced a democratically elected government [73]. The Gini coefficient/index, representing the income or wealth distribution of a nation,
measures statistical dispersion between the rich and poor. Applied to Bhutan, it is seen that national inequalities declined from 0.42 in 2003 to 0.35 in 2012 but increased to 0.38 by 2017. In this context, as a firm resolution to reduce inequality, the current democratically elected government made pledges with the mission to “narrow the gap” between the rich and poor through various fiscal policy reforms, development strategies, and allocation of resources targeting the poor and disadvantaged groups in the country. Uplifting the poor and reducing the gap between the “haves” and “have-nots” are understandably not just the solution to economic prosperity but to reducing the pressure on environment and depletion of natural resources.

As indicated, many scientific reports reveal that inequality is bad for the environment. Therefore, countries with a bigger gap between rich and poor do more harm to the planet and its climate [70]. Unquestionably, climate change is intricately related to economic inequality, as it is a catastrophe much determined by the greenhouse gas emissions of the rich that hits the poor the hardest.

**Invasive Alien Plant Species**

Invasive plant species, defined as exotic (alien) species, today represent serious ecological effects on in situ (native) biodiversity. “Invasives” (in every Kingdom of life) have the capacity to overtake entire biomes, often outcompeting native species as they colonize their new habitats because of their reproductive and dispersal abilities and high survival rates, which are normally supported by the absence of co-emerging, co-evolving predators [74]. While there have been some sound arguments in favor of certain non-native species, particularly in light of the net gain in biodiversity (e.g., more than half of all plant species in the USA and New Zealand are non-natives), the majority of said “invasives,” at least with the current ecological data at hand, and the lenses through which the scientific communities have viewed gains versus losses, appear to pose unambiguous and significant threats. Such invasions are being facilitated by increased land degradation, especially through over-grazing and deforestation, and also by climate change [75]. Most of the invasive species found in Bhutan have been introduced for agriculture, horticulture, floriculture, or fodder purposes or accidentally through travel, trade, and tourism [76]. According to the World Conservation Union, invasive species are generally considered to be the second greatest threat to biodiversity after habitat destruction [77]. Invasive alien species are characterized by strong vegetative growth, abundant seed production capacity, high seed germination rate, long-lived seeds, rapid maturation of a sexually reproductive stage, and an often devastating ability to establish over large areas [77] (Fig. 2.22).

Many species are capable of vegetative reproduction via stolons (*Alternanthera philoxeroides*, *Eichhornia crassipes*), rhizomes, bulbs (*Oxalis latifolia*), and rooting at the tips of stem (*Ipomoea carnea*, *Mikania micrantha*) and root fragments
(Ageratina adenophora). They are very adaptive for wind and insect pollinations, and their seeds get extensively dispersed by wind, water, and birds enabling them to colonize in new areas far from their original habitat [76]. The Global Invasive Species Database records indicate 46 Invasive Species in Bhutan of which 11 species are alien [76]. Although there has been no socio-economic and environmental impacts assessment of IAS in Bhutan, Trifolium repens (white clover), Ageratina adenophora, Chromolaena odorata, and Eichhornia crassipes are widespread in the local landscape and water bodies. In addition, climate change has led to native plant species such as Potamogeton distinctus becoming invasive, reducing rice yield by 35 percent [78]. The IAS can threaten species diversity, alter soil properties, degrade wildlife forage, alter fire regimes, threaten endangered species, or change land use and decrease crop yield. Of 300 species of exotic plants in Bhutan, 17 species are found to be invasive species, while 34 plant species are found to be established and naturalized in the country, as indicated in Annexure 2.1 [76]. As such, success in the eradication or control of widespread growth of invasive species requires proper planning, swift removal, and the prevention of reinvasion. Biological control, practiced widely in other countries, is found to be safe and cost-effective, with the introduction of highly specific natural enemies or diseases from the invader’s native range [76]. To enable effective removal of IAS from the country, it would be strategic to classify the intensity of invasion by these plants, as high, moderate, and low [79]; [80]; [81]: (i) high, these species have severe ecological impacts on the physical processes, plant and animal communities, and vegetation structure, with high rates of growth and dispersal; (ii) moderate, these species have substantial impact (not severe) on the ecosystem and apparent with moderate to high rates of dispersal; and (iii) limited, species that have minor ecological impacts with low to moderate rates of invasiveness but can be locally persistent and problematic (Figs. 2.23).
Climate Change in Bhutan

The climatic regions of Bhutan are typically divided into the following categories: the Southern foothills (with subtropical, high humidity, and heavy rainfall – 100–1500 masl), inner Himalayas (with cool winter, hot summers, moderate rainfall – 1500–3000 meters above sea level, “masl”), and higher Himalayas (with alpine, cool summer, cold winter – 3000–7550 masl) [82]. Although Bhutan has a relatively pristine environment with clean air and water, impacts of climate change will not only cause environmental problems but pose a serious threat to the livelihood of people and sustainable development owing to the fragile ecosystems in the Eastern Himalayas.

Bhutan is a small, landlocked country. Around 70 percent of the country is forested (much of it primary forests), and approximately 62 percent of the country’s population depends on subsistence farming for their livelihoods [33]. Bhutan’s hydropower production – much of which it exports to India – is described as the backbone of the country’s economy, and there are early concerns that this resource may be adversely impacted by climate change [15].

With high growth rates in population, unchecked rural to urban migration, increased population density in the towns and cities, rapid increases in imports of cars, and rising demand for fuel wood, roads, and building construction, the future suggests many negative effects on environmental assets, which can further expose the population to climate change vulnerabilities. These syncretistic, cumulative stressors are at the core of the Anthropocene and readily palpable in the microenvironments of a country like Bhutan.
Even as a carbon-negative country with more than 70% of the country under forest cover, Bhutan is experiencing the increasingly problematic and potentially catastrophic impacts of climate change. [64]. A simple analysis of over two decades of temperature records indicates that maximum temperatures increased by 1.3 °C during a period of 22 years (1996–2018), while the minimum temperature decreased, indicating warmer days and cooler nights (see Fig. 2.24, 2.25, and 2.26). During the similar period of time, there was a marginal decrease in rainfall trends, largely variable, with the summer season and winter season being the wettest and the driest seasons, respectively [83]. In a similar study, it has been reported that the temperature rise is higher in the Himalayas when compared with the lowlands and other regions [84]. Rising temperatures in the Himalayas accounted for an average temperature increase from 0.6 to 1.3 °C between 1975 and 2006, at altitudes ranging from 2192 masl and 3250 masl in the Western Himalayas. Popular media rightly seized upon such data. In the pages of the National Geographic, for example, it was reported, “Climate change is roasting the Himalaya region threatening the survival of millions of people and the scientists forecast a hot future for the high mountains of Asia” [85].
The future climate scenarios for Bhutan under two socio-economic conditions for RCP ("a representative concentration pathway) 4.5 and RCP 8.45 (5th IPCC Report), during 2021–2100, have been projected as 0.8 °C–2.8 °C and 3.2 °C–5.6 °C (under the worst-case scenario), respectively, larger warming being forecasted during the spring and winter months and in higher altitude areas of Bhutan as indicated in Figs. 2.27 and 2.28; [83]. Bhutan is also likely to experience increasing trends in rainfall during 2021–2050, with a marginal decrease towards the end of the century (2070–2099) with respect to the baseline of 1975–2005 [83].

Bhutan’s economy is heavily dependent on climate sensitive sectors such as agriculture, forestry, tourism, and hydropower. And, its vulnerability to impacts of climate change, exacerbated by its fragile ecosystems and mountainous terrain, has been characterized by cyclone-induced storms, heavy and erratic rainfall, early monsoon, landslides, glacial lake outburst floods (GLOF), drought, etc. [86]. Heavy monsoon rains and glacial melt have been occurring more and more frequently, leading to flash floods and landslides throughout the country.

Risk and vulnerabilities to climate change could become much more severe as majority of the human settlements are located along the main drainage basins. With just about 2.9% of the land being suitable for agriculture, such as farming typically occurring along the deep valleys and mountain slopes, there is an eminent danger of losing lives, properties, and infrastructures because of flooding. As a result of glacial meltdown due to global warming, successive GLOF events in 1957, 1960, 1968, and 1994 have resulted in tremendous impact on the lives and properties of the downstream settlement areas of the country [83]. For example, the 1994 GLOF (supra-glacial lake outburst) event originated from Luggye Tsho (lake) killing 21 people, damaging 91 houses, and 1781 acres of land, (Fig. 2.29 and 2.30).
Fig. 2.27  RCP 4.5: Difference in seasonal temperature (°C) between future- and present-day climates: 2070–2099. (Source: NCHM/RGOB)

Fig. 2.28  RCP 8.5: Difference in annual mean temperature (°C) between future- and present-day climates (a) 2021–2050 and (b) 2070–2099. (Source: NCHM/RGOB)

Other weather event such as the heavy rainfall resulting from Cyclone Aila in 2009 severely impacted Bhutan’s small economy with an estimated loss of US$ 17 million in damages relating to crops, livestock, biodiversity, and other properties [83]. Torrential rainfall during monsoons that trigger flash floods and landslides have become a common occurrence, signaling uncertainties and great risks in Bhutan. For example, the southern part of the country was “pounded” by a flash flood, in July 2016, dislodging more than 100 families and damaging bridges, infrastructures, environment, and road blocks due to landslides. Frequent landslides and road blocks during monsoon seasons have become a challenge for travelers who need to regularly commute. Much riskier events take place when artificial lake
Fig. 2.29  Mitigation of GLOF, Thorthormi Lake at an altitude of 4400 m © Karma Toeb, DGM

Fig. 2.30  Mitigation works to prevent GLOF of Thorthormi Lake © Karma Toeb, DGM, RGOB
formation resulting from the blockade of narrow rivers due to landslides pose tremendous risks of outburst flood to the settlements downstream. Despite the flash floods and torrential rainfall, the country is also increasingly experiencing extended dry periods in some parts of the country, that pose threats such as biodiversity loss, forest fires, reduction of crop yield, and agricultural productivity [64]. Bhutan normally receives snowfall every winter, but most of winter seasons in the last few years have been marked by a dry and snowless periods that have triggered a record number of forest fire incidents; similar events could invariably happen in the coming years as the temperature is expected to rise significantly. It has been also foreseen that Bhutan’s extensive forest cover, rich biodiversity, and water resources will be affected by climate change resulting in degradation of ecosystems and loss of wildlife species; reduction of alpine range lands; and possible increase in vector-borne disease in wildlife due to warming. The policy arrangements to address the climate aspects are not yet clearly defined. As a member to the UNFCCC, the National Environment Commission of Bhutan which is the highest decision-making body of environment [45] submits its priorities of climate change actions to the UNFCCC through national communication reports. Thus far, Bhutan has submitted two national communications reports (1st and 2nd National Communications) prioritizing the National Adaptation Plan of Actions including the mitigation plans of GLOF events and artificial lowering of lake. Some of Bhutan’s climate adaptation programs include a disaster management strategy, a weather forecasting system, landslide management, flood prevention, and community-based forest fire management and prevention [87].

The INDC (Intended Nationally Determined Contribution) submitted to the UNFCCC notes that the priority mitigation and adaptation actions within the INDC will be incorporated in the 12th 5-Year Development Plan of the government (2018–2023) [88]. Among numerous scientists and policy formulators within Bhutan, voice has been wisely given to the belief that mitigation and adaptation actions for ecosystems and biodiversity species must be considered in the National Adaptation Plans, which thus far has been less than ideal. There is also a need to deliver on the enrichment of knowledge and capacity development on climate impacts, mitigation, and adaptation all the way to the communities at the village level. Future climate scenarios for many countries appear to be very long term. But it would be much more relevant and pragmatic to the present-day life of Bhutanese residents, if medium-term projections and adaptive actions at more finely honed scales could be projected. The Intergovernmental Panel on Climate Change (“IPPC”) projections of 0.8 to 1 °C rise in temperature may not be accurate for many mountainous regions of the world, as earlier indicated. Indeed, temperature gradients have already reached 1.3 °C for Bhutan and other Himalayan regions. That said, the IPCC has confirmed that the current global average temperature rise, even at a level less than 1 °C above pre-industrial levels (1992), has significantly impacted the Earth’s climate system [89], disturbing ecosystems and threatening a multitude of species with extinction [90]. Thus, conserving and restoring ecosystems and species should be recognized as a crucial component of climate change mitigation and adaptation.
policy. In this regard, Bhutan needs a Climate Change Policy that embraces the mitigation and adaptation measures, including the carbon-neutral policy (that has been declared at the COP meeting of UNFCCC in Copenhagen, 2009)[63]. Essentially, the anthropogenic activities associated with pressure on the environment will need to be embraced with various mitigation and adaptation measures such as improvement in transport sector and replacement of fossil fuels, etc. or reduction in timber and fuel wood consumption through strategic measures. Such mitigation and adaptation measures need empowerment of local communities and civil societies, allocation of financial resources to local communities, creation of “green” jobs, etc. Strengthening the institutions and climate network will enhance the mechanism and capacity to fight climate change impacts. For example, the Strengthening National Center for Hydrometeorology will also go a long way towards providing robust data and information on climate change for mitigation and adaptation plans.

**Annexure 2.1: List of Invasive Species in Bhutan**

| Scientific and vernacular name | Origin, habitat, and management |
|-------------------------------|--------------------------------|
| Ageratina adenophora; (Crofton weed, locally known as Kalo char) | Native to Mexico, introduced through seed contamination, found in forest roadsides, crop fields (altitude 750–2500 m), very resilient species, colonizes the area with abundant seed production, major weed in some parts of Bhutan, a profuse seeder [91]. To be managed by uprooting and slashing, removal of crowns |
| Ageratum conyzoides L. (Billygoat weed, locally known as Rogpu-ngon) | Native to Southeast North America and Central America; introduced travel and trade; found in forest roadsides; cultivated sites (altitude 100–1900 m); very fast-growing species and adverse ecological and agricultural impact and highly resistant species [92]; manual uprooting, cutting, or burning can be used as control measures |
| Cannabis sativa L. (hemp/bhang, locally known as Kenha or ganja) | Native to Central Asia; found in road sides and settlement areas, cultivated fields, and peripheries of forest (altitude 300–3000 m); quite invasive and used for fiber, paper production, food, oil seeds, and intoxication. Can be uprooted, slashed, and burnt [93] |
| Cassia occidentalis (ant bush, coffee senna) | Native to South America and reported by [94]; found in river banks, roadsides, waste ground, fallow land, drainage ditches, woodland edges/gaps, savannah, riparian vegetation, and gullies; causes loss of crop yield, degradation of seed quality; competitive displacement of native species [93]; altitude 200–1450 m; managed by uprooting or using herbicide; can be toxic |
| Chromolaena odorata (Siam weed, locally known as Nayra-ngon, Achame) | Native to South and Central America; found in roadsides and cultivated sites, 200–1450 m. One of the world’s 100 worst invasive species (Rinchen et al., 2018); produces hairy seeds and dispersed by winds and water, very invasive and strong competitor, can impact animal and plant communities and the aquatic life (Tellez et al.; 2008); manual or mechanical removal; can be used for vermicomposting [76] |
| Scientific and vernacular name | Origin, habitat, and management |
|-------------------------------|--------------------------------|
| **Eichhornia crassipes**    | Native to South America; found in ponds, lakes, and marshy rice fields at altitude 300–1800 m; one of the worst aquatic weeds and impact the aquatic life systems [93]. Can be removed manually or mechanically |
| **Lantana camara**           | Native to South America; introduced to Bhutan through cultivation as ornamental plant; found at 250–600 m altitude; can alter ecosystem and suppress growth of native species, reduces diversity of plants, alters fire regimes, can threaten the rare and endangered species with continued existence in thickets [93]. Controlled fire can be effective for removal |
| **Leucaena leucocephala**   | Native to Central America; found at altitude of 500 m and below in subtropical areas; fast-growing and introduced to Bhutan as fodder species and for reforestation and land management; disrupts the ecosystem by releasing allelopathic chemicals like mimosine [95]; very deep-rooted and larger trees can be debarked, while small seedlings can be manually removed; herbicides can used |
| **Mikania micrantha**       | Native to Central and South America; found commonly in citrus orchards and cultivated land at altitude of 200–500 m; known for rampant growth thus known as mile-a-minute weed; introduced to India during the Second World War to camouflage airfields; spread into Bhutan through Indian borders; produces massive seeds that can be spread through wind, water, or other carriers; can be removed by digging and uprooting before flowering [93] |
| **Mimosa pudica**           | Native to South America; found at low altitudes along roadsides, cultivated fields; forms a dense ground cover and prevents the growth of other plants; very prickly and can be removed by digging, controlled fire, overgrazing, etc. [76] |
| **Opuntia vulgaris**        | Native to South America; found in altitude of 250–1500 m; one of the worst invasive species; the cactus grows into shrub and invades the hillsides in dry valleys; the cactus was formally used as a host for cochineal insect in Bhutan and used as fodder for pigs, hedges, fences, and ornamental plants. Can be removed by controlled fire [76] |
| **Parthenium hysterophorus**| Native to Central and South America, found at altitude of 200–1700 m in roadsides and fallow lands in subtropical areas, competitive and colonizes aggressively displacing native species, can be problematic in cultivated fields and rangelands, causes hay fever and dermatitis in humans. Careful removal is required due to risk of disease transmission [96]; common uses include insecticidal, nematicidal, and herbicidal properties; vermicomposting [97] |
| **Pennisetum clandestinum** | Originally from East Africa, introduced to Bhutan as fodder and lawn grass; found at altitude of 500–2600 m. Difficult to remove once established; solarization by covering with plastic sheets for 8–12 weeks in summer can be an effective control; growing legumes could be planted in infested areas to suppress the species [92] |
| **Robinia pseudoacacia**    | Native to Southeastern USA, found at altitude of 1200–2500 m mostly in Thimphu and Punakha areas at livestock farms, used as fodders species, invades forest edges and disturbed dry slopes, reproduces vigorously by root suckering and stump sprouting; mechanical control such as hand-pulling and slashing may be applied during the seedling stage, intolerant to shade and thus competitive exclusion can be followed [91] |
### Scientific and vernacular name

| Name            | Origin, habitat, and management                                                                                                                                 |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| *Sida acuta*    | Native to central America; very hardy species; found in subtropical and temperate forests in waste places, roadsides, and open habitats, competes with native flora and displaces them, deep taproot helps the plant to withstand drought. Foliage of *S. acuta* has been observed to cause poisoning in cattle [98]. For removal, a combination of manual removal, competitive exclusion and grazing control, can be up rooted, slashed, or mowed before flowering [99] |
| (Malvaceae, locally known as Jaharu, Khareto) | Native to Central America and found at an altitude of 350–1200 m, probably introduced to Bhutan as an ornamental plant and escaped into the wild; herbaceous perennial forms thicket, invades roadsides and disturbed lands preventing growth of native plant species, digging or uprooting prior to flowering, grazing and competitive expulsion using native grass and legumes as it is shade intolerant [100] |

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