CHAPTER THIRTEEN

Global implications of biodiversity loss on pandemic disease: COVID-19

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1. Introduction

The emergence of coronavirus diseases—2019 (COVID-19), an emerging infectious disease (EID) has spread over 215 countries in a short span of 9 months.[1–4] EIDs [i.e., Ebola, H1N1, ZIKA, NIPAH, SARS, MERS, and, most recently, coronavirus (COVID-19)] cause large-scale morbidity and mortality, recession in the economy, and the emergence of poverty.[5–7] The impact on the economy is devastating when localized upsurges lead to regional outbreaks or global pandemics.[6,8] Severe Acute Respiratory Syndrome (SARS) outbreak in 2003,[9] the H1N1 (Influenza A virus subtype) pandemic in 2009,[10] the Ebola outbreak in West Africa during 2013–2016,[5] and the current outbreak of the novel coronavirus[11,12] have caused immeasurable economic damages.[13,14] This recent outbreak of "Novel Coronavirus" has kindled interest in analyzing the relationships between global environmental changes and human health.[15] Despite the clear evidences which clearly link these two phenomena, very little attention has been paid to understand the interactions between environmental changes and the EID.[16,17] It has been observed that around 70% of EIDs and almost all the recent emerging infectious diseases have originated from animals, and their emergence occurs due to complex interactions between animals and humans.[18]

Pandemic disease emergence is driven by anthropogenic factors such as deforestation and conversion of forest into agricultural lands, intensification of livestock production (toward food production), increased hunting and trading of wildlife, and it has an appalling effect on human population density and wildlife diversity.[16,19] For instance, the NIPAH (Nipah Virus encephalitis) virus outbreak in Malaysia in 1998 was due to the increase

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in pig production nearer to the fringes of the tropical forests where the fruit bats (Pteropodidae) live; the sources of SARS and Ebola viruses have also been narrowed down to bats that are hunted for food.[5] The SDG goal 2 aims to increase agricultural productivity to achieve global food security, increasing agrarian lands, increased crop production, and livestock. The SDG goal 3 aims to ensure healthy life of human beings of all ages as referred by WHO. The SDG goal 13 aims at enhancing the resilience and adaptive capacity to climate-related hazards and natural disasters in all countries through national policies and strategies (UNDP). The SDG goal 15 aims at conservation of the world's terrestrial ecosystems as referred by UN. The agricultural land expansion and increased livestock production (SDG 2) lead to biodiversity loss.[20] In their study, Fitzherbert et al.[21] explained how oil palm expansions had caused significant biodiversity losses in South Asia. Similarly, Kehoe et al.[22] investigated the effect of agricultural expansion on the biodiversity in the Amazon and Afrotropics. They found a loss of 30% in species richness and 31% in species abundance because of the agricultural expansions. This suggests that strengthening of SGD2 leads to disturbances in the SDGs 3, 13, and 15. The SDGs 13 and 15 are closely related as climate change affects biodiversity and vice versa. The human developmental activities have triggered highly unfavorable changes in the biodiversity and earth ecosystems. Prevailing uncertainty and stressors like climate change and demographic changes have worsened the situation. In order to develop a secure sustained environment, the decision-makers are reconsidering development and environmental goals toward the achievement of strategic balance.[23–29] With reference to the interrelationship mentioned earlier, the initiatives taken by the various countries to achieve these SDGs interfere with one another. This interference of SDGs 2, 13, and 15 should be dealt with due consideration in framing the strategies to achieve SDG 3 (Human health).

Other drivers, such as livelihood aspects in the affected region, also exert a strong increased effect on the spread of emerging infectious diseases.[30] Initiatives toward drafting policies to decrease the rate of consumption of animal protein show a positive trend in developed countries.[31] These policies may slash down the risk of spreading emerging pathogens due to intensified livestock production.[18] Restoration of degraded natural habitats will help us to retain the original composition and wildlife dynamics, with added advantages such as water conservation, carbon sequestration, and drought management.[32] A measure for the inclusion of emerging infectious risk into sustainable development planning requires an interdisciplinary research approach. EID emergence involves livelihood, attitude of humans toward animals and forest cover, wildlife, livestock, and pathogen dynamics.[33,34]

There is an increased recognition that the United Nations has launched the 2030 agenda for sustainable development based on the following issues: human pressure leading to unprecedented environmental degradation, climate change, social inequality, and other matters which affect planet health. SDGs are interdependent,[34,35] and priorities (i.e., food security, protected ecosystem, and climate change mitigation) cannot be considered separately.[36–38] The objective of this study is to understand the relationship of the causes for the emergence of the pandemic diseases and its relationship with the changes in environment. The study also highlights the interference of one SDG with another and the need for framing the policies considering these interferences.

2. Climate change

Anthropogenic activities have largely impacted global environment that eventually led to the global warming.[39] Global warming of the earth's surface has occurred due to greenhouse gas emissions, especially carbon dioxide, which have exceeded their permissible level of concentration in the atmosphere.[39] Globally, an increase of ~1.0°C in the mean near air surface temperature of the earth is observed from 1850 to 2017.[40] This has led to climate change, which has affected the amount, intensity, and frequency of precipitation, and aggravated the extreme events of climate, e.g., heat waves, droughts, storms, and glacier lake outbursts. For instance, there has been an overall decrease in precipitation over land between 30°N and 10°S during the past few decades of the 20th century, with inevitable impacts on the ecological systems.[41,42] The vulnerability is high in terrestrial ecosystems as the climate change processes play a significant role in these ecosystems. Among the terrestrial ecosystems, forest cover constitutes the central part that influences climate change and, in turn, gets influenced.[43]

Climate change affects the forest and related ecosystems, and additionally more severe impacts are expected.[39] According to the latest report published by the Intergovernmental Panel on Climate Change (IPCC), global near air surface temperature is likely to increase by 1.5°C under a business-as-usual scenario by the end of 2050s; however, under higher emission scenarios, e.g., RCP4.5, RCP6.0, and RCP8.5, the mean temperature is predicted to likely be increased in the range of ~2–5°C by the end of 2100, with an associated increase in the number and frequency of extreme events,[42] with potential severe consequences for forest and ecological resources. Thus climate change may directly affect the ecosystem services provided by forest and will exacerbate the impacts of current natural and anthropogenic stress factors. Occurrence of wildfires, extreme weather changes, precipitation patterns, and nonnative and native invasive species are the deciding factors that make alterations within the forest cover.[44] Decay of certain tree species in North America has been associated with climate change.[45] This continuous process of climate change has the capacity to initiate/alter interacting processes within the forest ecosystem that may affect forest cover.[46]

The possible key drivers of forest cover change related to climate change are discussed as follows: upsurges in temperature, changes in precipitation, and increase in carbon dioxide (CO_2) level and food production.

a) Consequences of warming in the tropics: This gradually shifts the geographical location of some of the tree species toward north or to higher altitudes. Certain species may not be able to survive in the current locations. The species that exist in the higher altitudes may not be able to resist the increase in temperature nor shift to still higher altitudes. A number of biogeographical models demonstrate a polar ward shift of potential vegetation by 500 km or more for boreal zones.[47–49]

b) Consequences of extreme climatic conditions: Due to increased temperature, there is a considerable change in the extent of precipitation and flooding in streams. On the other hand, temperature fluctuation also leads to drought condition increasing the wildfire risk. The drought condition in the forestscape reduces the ability of trees to produce sap, which acts as a shield from destructive insects such as pine beetles. In 2011 due to warm temperature and drought condition in the early summer, more than 8 million acres of forest in the United States succumbed to wildfire. Increased temperature levels enhance the evapotranspiration rate leading to water loss from the forest soil. The soil moisture deficiency for an extended period indicates the onset of drought in a forest ecosystem. The soil moisture deficiency also results in reducing nutrient uptake by the trees, which causes a reduction in forest growth and productivity. The prolonged drought leads to species distribution and composition changes, habitat composition, and net primary productivity in a forest ecosystem.[50]

c) Availability of CO_2: With sufficient water and nutrients, increased atmospheric CO_2 may lead to more tree productivity, which alters the distribution of tree species in the forest.

d) Agricultural Production: It is estimated that the global population will reach to 11 billion people by 2100; accordingly the food production will be much more, accelerating the loss of biodiversity, which acts as a shield from zoonotic diseases. The United Nations Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has projected that 1 million species could become extinct within decades. The report says that the biodiversity loss will be a great threat to climate change pointing toward agriculture as the key factor.

3. Forest cover monitoring

Assessment of impact of climate change on landcover changes in the forest particularly concentrates on modeling and monitoring using remote sensing techniques. Remote sensing techniques are used to monitor the forest cover change, leaf area index (LAI), tree canopy height, and biomass content.[51] The utilization of satellite imageries and remote sensing techniques for the assessment of impact of climate change on forest cover has been gaining importance.[52] The remote sensing techniques allow the quantification of impact of climate change by way of monitoring the climate change-induced incidences, such as extent of degradation due to fire, shifting location of the tree species, and fluctuations in growth and productivity using satellite imageries. Normalized differential vegetation index (NDVI) is one of the key parameters to analyze the spatiotemporal changes in the forest cover.[51] There have been studies to understand the climate change on the phenology of vegetation in a forest cover based on NDVI.[53] LAI which is a vegetation parameter can be used as an indicator to monitor the climate change impacts and allied consequences in a forest cover using remote sensing techniques.[54,55] The rate of tree mortality due to thermal stress and effect of greenhouse gases can be seen as an indicator of climate change and the same can be monitored by color variation in remote sensing studies.[56,57] In recent days, the utilization of unmanned aerial vehicle (UAV) is one of the fruitful emerging technologies[58] that can practically be utilized for monitoring the ecophysiology of the forest cover affected by the climate change.[59] Despite the advantages of monitoring the forest degradation, the extent of shifting cultivation challenges do remain due to spatial limitations and temporal changes and unpredictable impacts on biomass.[60,61]

As per studies, it is observed that different types of forests respond differently to the drivers in forest areas. Therefore it can be concluded that more studies are needed to identify the optimal approach for monitoring forest degradation using remote sensing techniques based on the driver, the forest type, the intensity of impact, and the geographical location.[62]

3.1 Forest cover loss

Changes in land cover and land use from forested to nonforested regions have occurred due to natural causes, such as plant disease, increase in temperature, water stress, and fire; and human causes, such as land conversion for other purposes, timber harvesting, animal hunting, and infrastructure development. Changes from one to other land uses have links to a complex and multifaceted set of underlying driving forces, including population growth, poverty, livelihood changes, government policies, infrastructure development, and population migration.

The forests in humid regions of India such as the Western Ghats, western Himalayas, Eastern Ghats, and northeast India, are predicted to be highly resilient. These forests can be classified under the extremely resilient category to conditions such as large-scale precipitation fluctuations in addition to the shorter drought periods.

As per the studies conducted, it can be inferred that, in 2015, forest cover remained at 3999 M ha globally. The forest cover is approximately 31% of global land cover. Tropical and subtropical forests cover nearly 44% and 8% of the global area, respectively (Fig. 1). Twenty-six percent and twenty-two percent of the global forest area is occupied by temperate and boreal forest covers, respectively. Europe has the largest forest cover at 25% compared with other geographical subregions, followed by South America and North America with 25% and 21%, respectively.

As per Table 1, the changes according to the climatic domain are as follows: Between 1990 and 2015 the tropical forest area has declined by 195 M ha and forest in temperate countries has increased by 67 M ha, at an average of 2.7 M ha/year, but forest in the subtropical and boreal domains showed little change with 0.089 mHa/year (increase) and 0.084 mHa/year (decrease) during the period 2010–2015.

Southeast Asia (SEA) has lost maximum of 30% of its forests in the last 40 years.[64] In Cambodia, agricultural land area has doubled from 15% in the 1980s up to 30% in 2000. Still larger increase in agricultural land was observed in Vietnam with an increase from 20% in 1990 to 35% nowadays. The agricultural land growth rate has increased from 21% in the 1980s to 31.5% in the recent days in Indonesia. For example, in Sumatra region the deforested area has been converted into a growing suburban zone with intensive farming practices.

From Fig. 2, it is observed that annual deforestation rate has declined and increased during 2012 and 2014, showing that zero deforestation has not been adapted in a global manner.

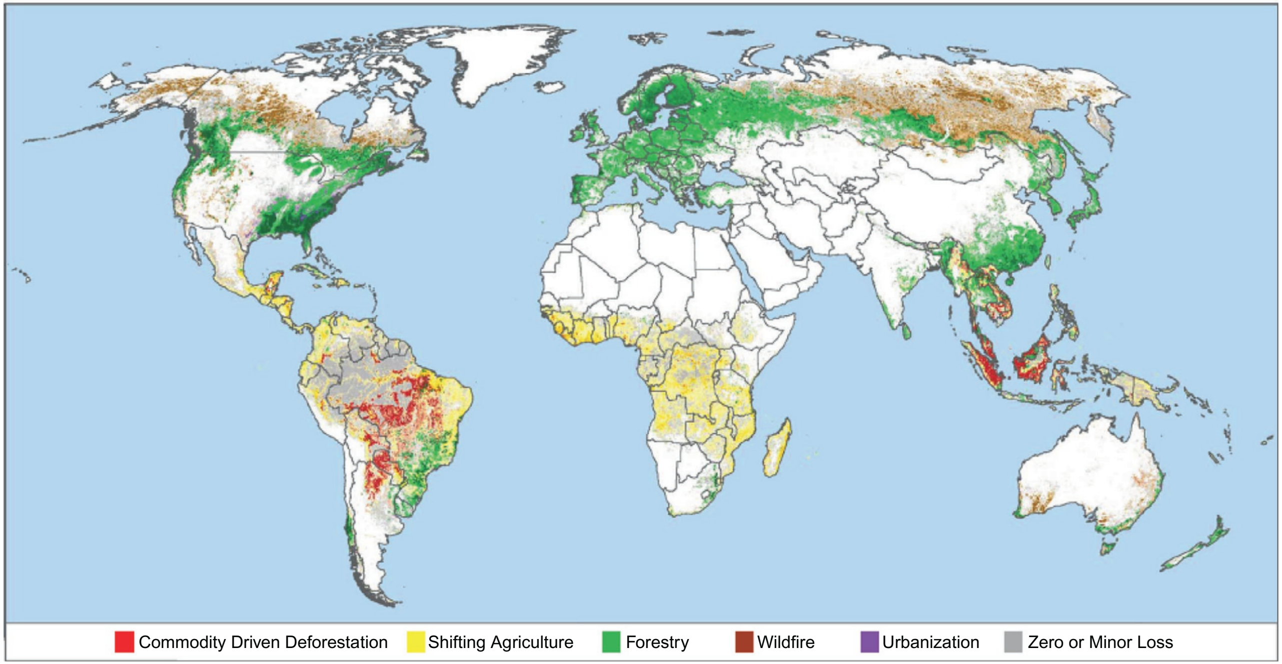

Fig. 1 Forest cover loss during the period 2001–15. Darker color intensity indicates a greater total quantity of forest cover loss.[63] *(Source: Curtis PG, Christy M, et al. Classifying drivers of global forest loss.* Science *2018;***361***:1108–11.)*

Table 1 Rate of change in forest cover.
Net rates of change in the areas of forest and other wooded land from 1990 to 2015 in different global climatic domains (M ha/year) (FAO, 2015)

	1990–00	2000–05	2005–10	2010–15
Forest				
Boreal (Inc. polar)	0.051	−0.193	1.204	−0.084
Temperate	2.290	3.657	2.851	2.208
Subtropical	−0.064	−0.173	−0.860	0.089
Tropical	−9.543	−7.863	−6.608	−5.520
Grand Total	−7.267	−4.572	−3.414	−3.308
Other wooded land				
Boreal (Inc. polar)	−0.348	0.371	0.482	−0.162
Temperate	−0.305	1.007	0.834	0.704
Subtropical	−0.104	1.460	−0.158	49.698
Tropical	1.644	1.989	2.936	4.178
Grand Total	−2.401	−0.151	4.094	46.062

Source: FAO (2015).

In the Western Ghats region of India, there is decrease in forest cover from 50,173 to 45,542.23 Hecs. during the period 2000–11 as shown in Fig. 3. It is projected that it will still decrease to 41,253.94 Hecs due to conversion of forest cover to plantation and built-up land.[65] Land use changes with respect to forest cover are unprecedented in the state of Kerala, India, during the past half century. A substantial increase in coconut and rubber

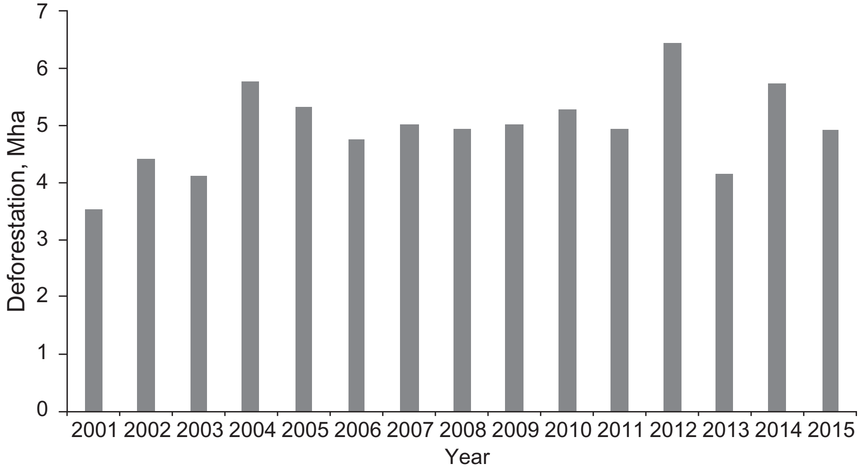

Fig. 2 Annual deforestation rate (2001–15).[63]

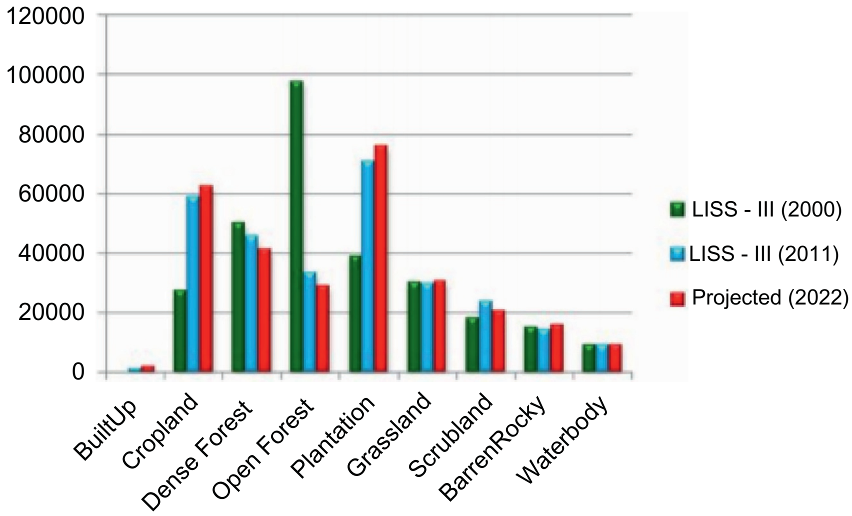

Fig. 3 Graph showing the variations in landcover classes in the Devikulam, Western Ghats, India. *(Source: Binutha C, Somashekar RK. Future prediction of Landcover in Devikulam Taluk, Kerala.* Int J Sci Nat *2014;**5**(4):677–83.)*

cultivation has been experienced in this region.[66] These studies explain the changes in biodiversity due to the expansion of area under food production in SEA.

4. Climate change and EID

The drivers leading to climate change are also causes for the increase of risk of EID. Loss of habitat forces animals to migrate and come in contact with other animals or human beings and transmit pathogens. Increase in production of livestock serves as a source of spillover of infections from animals to people. Decrease in livestock production could decrease the transmission of pathogens and also will lower the greenhouse gas emissions. Besides agricultural encroachment, construction of roads, dams, irrigation structures, mining activities, development of satellite townships, and coastal degradation also act as drivers for forest destruction and indirectly contribute to emerging infectious disease emergence. Unlike natural forest environments which are highly suitable for bat species, these altered forestscapes are more acceptable by a wide range of bat species. The bats find these environmental niches compatible for their resting and hunting needs.

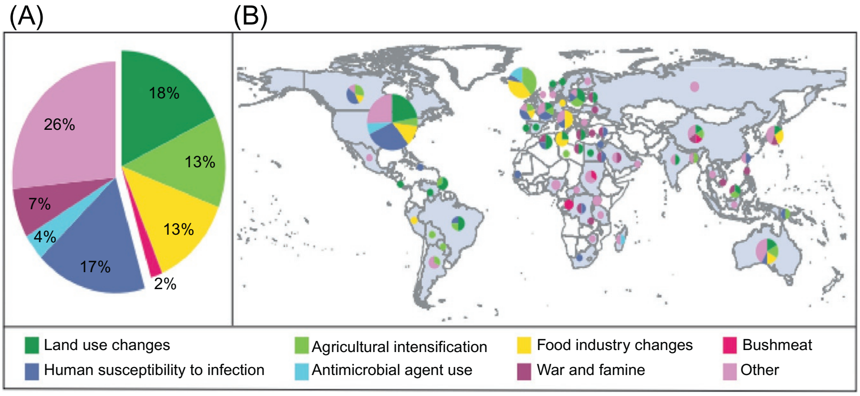

Fig. 4 Drivers and locations of emergence events of zoonotic diseases in humans from 1940 to 2005. *(Source: Keesing F, et al. Impacts of biodiversity on the emergence and transmission of infectious diseases.* Nature *2010;**468**:647–52.)*

Deforestation has increased steadily and is linked to spread of viruses like Ebola, Zika, and Nipah. Fig. 4 shows the distribution of outbreak of zoonotic diseases worldwide from 1940 to 2005. Deforestation pushes wild animals out of their natural habitats and drives them closer to human populations, creating more opportunity for the spread of zoonotic diseases (diseases that spread from animals to humans). There were 12,012 recorded outbreaks from 1980 to 2013. This comprises 44 million individual cases affecting every country globally. A number of factors have contributed to this increase in outbreaks, including globalization of travel, trade and connectivity, and thick populations living nearer to the fringes of devastated forests, but the links to climate change and biodiversity are the most striking. The occurrences of spillover of emerging infectious diseases to people are higher in the tropics, since the diversity of wildlife and pathogens is higher in these forests. For the pathogens to establish in a new species, it needs to cross multiple steps during the emergence process. The steps include initial invasion into the new host ("spillover"), the transmission stage in the new host, and the establishment of the pathogen in the host population in total.[67,68] In these steps, particular species in the biodiversity acts as a source for the initial invasion. Once the pathogen enters into a new host, thickly populated new host species may facilitate pathogen establishment and transmission within the new host habitat.[67] This hypothesis is supported by studies conducted on the jumping of the viruses leading to emerging diseases from animals to humans. Others such as environmental and socioeconomic factors such as clearing of forest for agriculture and wildlife hunting bring humans more into closer contact with new pathogens during the process.[69] In the case of Nipah virus, when it spilled over from wild fruit bats to domestic pigs, the proliferated population of pigs in local farms facilitated the establishment and transmission of the virus from pigs to human beings in Malaysia.[70] The mortality rate was high as 74% in humans due to the infection by Nipah virus. Such availability of high density of domesticated species normally occurs in the regions with low biodiversity conserved regions.

In Australia, the Hendra virus was detected in horses and human beings in 1994. This was reported due to spreading of aerosols from diseased horses which were initially contaminated by Pteropus bats. In the Ugandan forests it was observed that Zika virus infected millions since it could find a host in *Aedes aegypti*, a mosquito that lives in urban areas.

The existence of bat-borne virus like Australian Bat Lyssavirus (ABLV) and Duvenhage, which directly transmit virus to humans, has been studied. CoVs, zoonotic viruses find the wild animals and livestock as carriers for transfer to humans. During more than three decades, four human CoVs (HCoV-HKU1, HCoV-229E, HCoV-NL63, and HCoV-OC43) were identified as responsible for mild to moderate respiratory tract diseases, before the emergences of SARS-CoV and MERS-CoV in human beings.

5. Modeling the movement of pathogens and animals

Development of geographical information systems (GIS) tools and availability of satellite imageries with high spatial and temporal resolution satellites for Earth observation have made a tremendous or spectacular progress in the last three decades. This has made it possible to monitor weather, climate, environmental, and anthropogenic factors that help to forecast the occurrence or reemergence of epidemic diseases. Studies have been carried out to monitor the climatic, planetary health and biodiversity factors with high accuracy based on the techniques like combination of remote sensing data and GIS tools,[71,72] Studies have been carried out to monitor the factors that influence the vector-borne diseases such as malaria,[73,74] visceral leishmaniasis (VL),[75,76] Rift Valley fever,[77,78] schistosomiasis,[79–81] Chagas disease,[82,83] and leptospirosis.[84,85]

Predictive modeling may lead to improved understanding and will lead to planning proactive measures to prevent future epidemic diseases. The critical components to be included in a predictive model are temperature, humidity, chlorophyll content, soil moisture, vegetation indices, pathogen biology and ecology, and human host biology and ecology.[86]

With the availability of high-resolution satellite imageries and data processing techniques, a model has been developed to forecast the movement of forest pathogens using climate variables and real-time data. Support systems have been developed for the detection of movement of wild animals using hyperspectral remote sensing images. One such model has been developed to facilitate detection of moving wild animals (DWA) algorithm.[87] Studies have also been carried out to monitor the movement of wild animals using thermal remote sensing images.[88–91] There is a limitation in thermal remote sensing studies, where it applies only to limited and excellent areas.[89,91] Furthermore, it becomes difficult to differentiate animals from trees in thermal images as it requires a thermal level difference between the target and the background during observation.[88,90] The detection accuracy can be increased by way of developing ideal observation conditions and by processing the images using high-end techniques.

6. Research gaps, challenges, and recommendations for future

Foreseeing the changes shortly will support evidence-led policymaking toward the achievement of sustainability. With increasing uncertainties such as complex and multidimensional scenarios, critical research is needed to ensure balanced development in the life of humans and the sustenance of nature.

Moving forward, the researchers have excellent opportunities to make a definite contribution in facing the grand challenge toward development of sustainable environment without deviating from the SDGs. The responsible research community can take a lead in exploring ways of realizing the full potential of digital technologies toward the formation of a sustainable environment. The integration of SDGs 2, 3 13, and 15 toward achievement of sustainability is a challenging task. The imbalance created while meeting the SDG 2 (Food production) leads to negligence in the SDGs 3, 13, and 15. The clearance of land for agricultural and livestock production has disturbed the biodiversity, consequently the climate and humanitarian health. Suitable studies have to be taken up to reconsidering the targets defined in SDGs and related policy decisions.

7. Conclusions

Degradation of forests, changes in watercourses, and haphazard development toward food security and livelihood are disrupting ecosystems. In this regard, they are vanishing the boundaries between wild and human entities at an unprecedented scale. The studies show that the total forest area has declined by 3% between 1990 and 2015 and the loss of forest area is high in tropics when compared to the temperate. The tropics have lost the forest area by 196 Mha, whereas there is a gain in forest area by 66 Mha in the temperate region during the same period (1990–2015). The vulnerability and ingenuity of the planet toward climate change, degraded landscapes, and damaged ecosystems looks like our future. The emergence of COVID-19 crisis has depicted the relationships between the planetary health, human health, forestscapes, food security and livelihoods, allowing us to see in the real time and take proactive measures. Efforts are to be taken to closely correlate the changes in climatological parameters (like temperature, relative humidity, precipitation), forest cover change and biodiversity loss (endangered species wise), and EID. The efforts for surveillance of EID with related investigations need to be improvised. The surveillance methodology has to be implemented in the emerging disease hotspots especially in the fringes of the tropical forests. This will aid in identifying clusters of emergence in a large scale. This means that establishment of new approaches with explicit utilization of spatial data and computing techniques will lead to informed decisions on forest land cover management and food production. Policies need to be applied/developed to promote research on the interactions between climate change, biodiversity, food production, and EID (i.e., COVID-19) and this approach could provide better insights in integrated SDGs planning.

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