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Examining policy−institution−program (PIP) responses against the drivers of ecosystem dynamics. A chronological review (1960–2020) from Nepal

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ABSTRACT

Ecosystems are dynamic forms of nature, intuitively affected by natural processes and human interventions, depending on various drivers of changes and management responses. Understanding the ecosystem dynamics (ED) from the perspective of both the drivers of changes and the effectiveness of policy−institution−program (PIP) responses is crucial for nature sustainability. PIP response to a management problem, as a sectoral intervention, has been analysed in the past; however, national-level assessment of drivers of ecosystem dynamics and its PIP responses has not been done so far. This paper is aimed at cyclical assessment and chronological analysis (1960–2020) of the appropriateness and effectiveness of the PIP responses to the drivers of ED, taking the case of Nepal. Using a driver-pressure-state-impact-response (DPSIR) framework, we have assessed 38 drivers of ED on a decadal basis and analysed > 30 policy instruments as well as 15 periodic development plans (i.e., five-year plans and three-year plans) that have been developed yet. Moreover, we have carried out 300 household surveys to understand local people's demand for ecosystem management. Based on various qualitative and quantitative analyses, we have portrayed pressure, state, and impact of various economic, demographic, technological, governance, globalization, and other drivers, including PIP response to address the drivers of changes. We found that the drivers of ED are non-linear and multifaceted, but the PIP responses are sectoral and incremental (i.e., piecemeal gradation to the previous efforts). Instead of characterization of drivers of ED and public demand, domestic PIP responses are largely influenced by global environmental discourse. Our findings are critical in understanding dynamic drivers of ecosystems and pathways of PIP responses, which might support policymakers and scholars in Nepal and other developing countries in the Himalayas to recalibrate PIP measures for sustainable resource management by suitably addressing the drivers of ED.

1. Introduction

Ecosystems are characterized by a complex set of interactions among biophysical and social processes, functioning at various spatial and temporal scales (Díaz et al., 2015; Schindler and Hilborn, 2015; Thierry et al., 2021). Ecosystems are dynamic, but the variations in ecosystem functioning are largely unknown because of the limited understanding of the impact of environmental variabilities, climatic uncertainties, and anthropogenic disturbances on ecosystem assets and attributes (Migliavacca et al., 2021). Ecosystem dynamics (ED) is characterised by spatial and temporal changes in ecosystem assets (i.e., forestland, grassland, wetlands, and other land use types) as well as due to the alteration in the supply of various ecosystem services (i.e., provisioning, regulating, cultural, and supporting services) (Aryal et al., 2022b; Bradshaw and Sykes, 2014). ED is intrinsic to the succession and natural selection, physio-chemical processes, responses to disturbance, and resilience of ecosystems over time and space (Caparros-Santiago et al., 2021; Grotzer et al., 2013). In human-dominated landscapes, understanding the ED is important to identify the drivers of ED and to respond to the drivers to sustain ecological integrity and human well-being. Scientific communities have been engaged in ascertaining direct and indirect drivers of ED, quantifying the state of ecosystem assets, measuring the impact on ecosystem services, and postulating policy−institution−program (PIP) responses to address the drivers of the

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changes in need social demand (Atkins et al., 2011; Gregory et al., 2013; Kelble et al., 2013; Zhao et al., 2021).

Biophysical constituents (i.e., land cover patterns, the interaction of plant and animals, belowground and aboveground environmental components) and environmental gradients (i.e., changes in abiotic factors through time and space) of landscapes or ecosystem assets are linked to and influenced by socio-demographic and economic drivers of change (Koval et al., 2020; Migliavacca et al., 2021). Indirect drivers of ED include demographic, economic, socio-political, science and technology, and cultural and religious factors (MEA, 2005; Quevedo et al., 2021; Xue et al., 2015). Whereas direct drivers, also known as pressures, include changes in land use and species composition, climate change, technological adaptation, management interventions, and resource consumption patterns (MEA, 2005; Meacham et al., 2016; Shen et al., 2021). The drivers of changes characterize the state and impact on ecosystem assets which ultimately determine the status of biophysical supply potentials of ecosystem services against socio-economic demand. The gaps between the supply and the demand of ecosystem services provide an avenue for the identification of various PIP interventions that are essential for sustainable landscape management.

Ecosystem management policies and programs in many countries are blamed to be inconsiderate of the drivers of change in ecosystem service (Asah et al., 2014; Patrício et al., 2016). Instead, most of the conservation programs are designed and launched based on precautionary principles rather than an evidence-based approach (Alam and Mohammad, 2018; Cooney and Dickson, 2012). Further, academia is drowning down in estimating and predicting ecosystem services based on regional and global datasets rather than focusing on empirical observations and locally based assessments for understanding and recommending ecosystem management (Acharya et al., 2019; Kubiszewski et al., 2020). Ill-defined ED might fail to detect the non-linear functioning of ecosystem components, forward and backward linkages of management interventions, socio-ecological interlinkages and feedback mechanisms, and local people's dependency on the transaction of ecosystem services. Consequently, policies and institutions for ecosystem management might not be able to duly address the drivers of change in ecosystem services in time and space.

There has been plenty of research about ecosystem services, especially after the Millennium Ecosystem Assessment 2005 (Aryal et al., 2022b, 2023a; Dang et al., 2021). Such studies have focused on general assessment, quantification and valuation, spatial and temporal changes, biophysical supply potentials across various landscape and environmental gradients, spatial association and interaction, and scenario analysis and simulation (Aryal et al., 2022b). Socioecological configurations, including livelihood connection of ecosystems, biophysical interactions, and multi-fold relationships among ES have been studied in Hindu-Kush Himalayas, African mountains, and European Alps (Egarter Vigl et al., 2016; Finch et al., 2017). Most of the studies were blamed to be a snapshot approach, sectoral based, derived from global datasets of coarse resolution, and inspired from western-based knowledge system (Mengist et al., 2020; Obiang Ndong et al., 2020). Policy research on ecosystem services is very few that includes economic implications and payment schemes (Hausknost et al., 2017; Wunder, 2015), principles of conservation and development (Douglas and Alie, 2014; Sayer et al., 2017), system framework for ecosystem and biodiversity conservation (Acharya et al., 2020; Martín-López et al., 2019), ecosystem-based adaptation (Mills et al., 2020), and various institutional arrangements for ecosystem management (Mann et al., 2015). Literature about comprehensive assessment and analysis of drivers of ED, the impact of those drivers in ecosystem assets and attributes, and PIP response to address the drivers of change are scarce. Although few research has been done on the identification of drivers of ED, feedback on ecosystems, and PIP responses to manage ecosystems (Chacón Abarca et al., 2021; Quevedo et al., 2021; Xue et al., 2015; Yang and Gratton, 2014; Zhao et al., 2021), those are not adequate to elaborate temporal dynamics of changes in the drivers and historical perspectives of management paradigms perspective. Further, the scale and scope of the previous studies were not enough to embrace the multifunctionality wavelength of Himalayan landscapes, including those from the Hindu-Kush Himalayas, African mountains, and the European Alps. Besides, national-level assessment of drivers of changes and PIP responses which is crucial in a comprehensive understanding of the conservation and development pathways (i.e., at the policy scale) is very limited in previous literature.

Taking the case of Nepal, we aim to study the cyclical assessment of the drivers of ED and accordingly the PIP responses at different time periods (1960–2020) from the historical perspective. This study has assessed whether the contemporary PIP measures were adequate to respond to the drivers of ED. Further, by analysing the trends of ecosystem drivers and successive PIP responses, as well as their links over 60 years, this paper serves as a reference to understand the effectiveness of past policies and programs. In addition, it helps guiding future policies for ecosystem management to satisfy various conservation initiatives including UN Sustainable Development Goals, UN Convention on Biological Diversity, Paris Agreement, and UN Decade of Ecosystem Restoration.

2. Analytical framework and methods

2.1. Framework of analysis

After the uptake of the concept of ES in global policy discourse in the late 20th century, a growing number of studies have analysed the linkages of social and ecological factors (Costanza et al., 2017). Various frameworks for analysing coupled social and ecological systems have been applied to understand complex and emerging environmental problems (Agarwala et al., 2014; Binder et al., 2013; Nelson et al., 2009), including but not limited to, earth system analysis, human environmental system framework, management and transition framework, social-ecological system framework, and driver−pressure−state−impact− response (DPSIR) framework. Most of those frameworks are applied to understand the interaction of social and environmental factors, such as earth system analysis focuses on socio-ecological interaction at the global scale (Schellnhuber et al., 2005), human environmental system framework analyses human actions at different scales of the social system and its environmental feedback (Scholz and Binder, 2004), management and transition framework is related to rational choice and social learning processes (Pahl-Wostl et al., 2010), and social-ecological system framework believes on governing institutions to redefine the interactions between social and ecological systems (Ostrom, 2009). Likewise, DPSIR develops an understanding of dynamic drivers of changes in socio-ecological systems and appropriate responses to address the impacts of the drivers of the change (Carr et al., 2007; Svarstad et al., 2008). In addition, DPSIR framework further examines causal chains of interactions both at horizontal and longitudinal scales as well as it supports decision-making and policy directives to sustain socio-ecological interaction (Binder et al., 2013; Liu and Yin, 2022).

After the adoption of DPSIR framework by the European Environment Agency (Smeets and Weterings, 1999), it has been a popular framework of analysis in ES policy research because of its simplicity and transparency in analysis (Yee et al., 2012), as well as the visualization of causal interactions among various social and ecological factors regarding plausible policy alternatives (Xue et al., 2015). In DPSIR, drivers are the major factors that urge changes in the environment and natural resources. In this regard, drivers of ED can be socio-demographic, economic, political, and other that affect resource use and consumption pattern. Those underlying drivers create pressure on ecosystems such as land use change, human-induced disasters, over-exploitation of resources, environmental pollution, and waste. The state of ecosystems and landscape characteristics are altered by those pressures, which eventually impact both environment and society. The impact can be understood as the changes in the supply of ecosystem services and accordingly human well-being (Vidal-Abarca et al., 2014). Responses are the policy feedback, institutional arrangements, and program interventions to address the drivers of ED. In this regard, DPSIR is an important framework for policy-making through establishing and organizing sustainable ecosystem management measures (Quevedo et al., 2021).

Temporal dynamics of change are important in ascertaining the framework of DPSIR in studying ED (Jaligot et al., 2019; Rau et al., 2018). For example, some drivers of change might show their impact immediately while others might take time. To illustrate, the effect of overpopulation can be immediately seen in land use practices (Arfanuzzaman and Dahiya, 2019; Marques et al., 2019), while the effect of technological advancement might take time to realise its impact on the environment and society at the national scale. In this regard, the study of the links between all facets of DPSIR should be considered on a temporal basis. Considering this, we have visualized the drivers of ED and PIP responses on a cyclical basis. It is because the intensity of some drivers, as well as the effectiveness of PIP measures, can change over time. Likewise, some drivers might have coupled effects on others, and it might exert tele-coupling effects over various spatial scales. Considering this spill over phenomenon over the spatial scale, we have considered characterizing the DPSIR framework at the national scale. A national-level assessment of ED from the DPSIR approach is aimed at macro-analysis of the drivers of ED and scrutinizing PIP responses.

2.2. Methods

We have collected and analysed national-level data to visualize the link between drivers of ED and PIP responses. Nepal was selected for this study because: (1) it lies at the centre of Hindu-Kush Himalayan region, representing typical Himalayas landscape for understanding of ecosystems, (2) it contains multifunctional landscapes because of the high altitudinal variations (i.e., 60 m above mean sea level to the Mt. Everest) within a short north-south stretch of about 150–200 km, (3) it is rich in biodiversity yet highly sensitive to climate change, (4) it is an emerging and ambitious country (i.e., aiming to graduate from the category of least developed countries by 2026) which is transitioning to economic development while considering ecological integrity and social inclusion, (5) aid agencies have remained important partners in Nepal's conservation and development trajectory, their influence in shaping PIP would be an important lesson for other similar countries, and (6) due to its remarkable changes in political regimes (from monarch autocracy to democratic republican) and development modalities (from centralized top-down to federal bottom-up) in the last 60 years, DPSIR framework can best be visualised for ecosystem management at the national level.

Our methodological approach (Fig. 1) was inspired by Santos-Martín et al. (2013) and Vidal-Abarca et al. (2014); however, the selection of the attributes for analysis of drivers of ED was based on MEA (2005). Literature review and expert consultation were the main methods to characterize various drivers of ED. Afterward, data collection was based on the review of government reports and 15 periodic development plan documents (i.e., five-year plans and three-year interim plans), information extraction from the Central Bureau of Statistics, annual economic survey reports, the reports from various national and international organizations, including The World Bank, and many others, as currently available in their institutional repositories.

Our study focused on six ES that are important in the case of Nepal (MOFE Nepal, 2014; WWF Nepal, 2016), namely, crop production, timber production, carbon sequestration, water yield, soil retention, and habitat quality which corresponds to the MEA (2005) classification of food, fibre, climate regulation, water regulation, erosion control, and biodiversity conservation, respectively. The details of why only those six ES were considered are explained in Aryal et al. (2023b). Cyclical assessments of the drivers of ED and PIP responses to the changes were carried out since 1960. We selected 1960–2020 as the timeline for this study for three reasons: (1) the government of Nepal adopted a planned development approach since about 1960, (2) various drivers of ED were not documented until then, and (3) most of the PIP responses for biodiversity and environment conservation were not employed and/or documented until 1960. Therefore, a decadal assessment of drivers of ED and PIP responses was done over the last six decades to trace whether the PIP responses were appropriate and adequate to address the drivers of change. Although the PIP was considered after 1960, the quantitative assessment of drivers of ED was considered for 1970 and afterward because of the availability of national-level data. For example, data on governance drivers were available only after 1996, so we considered the data after that period.

As a complementary approach to the existing DPSIR framework of analysis, we carried out a household survey to understand local people's perspective on the response framework. A total of random 300 households residing in the central region (Chitwan Annapurna Landscape area) of Nepal were asked to identify what policies, programs, or institutions are needed to fulfil their ES demand. The questionnaire survey has been approved by the Human Research Ethics Committee of a

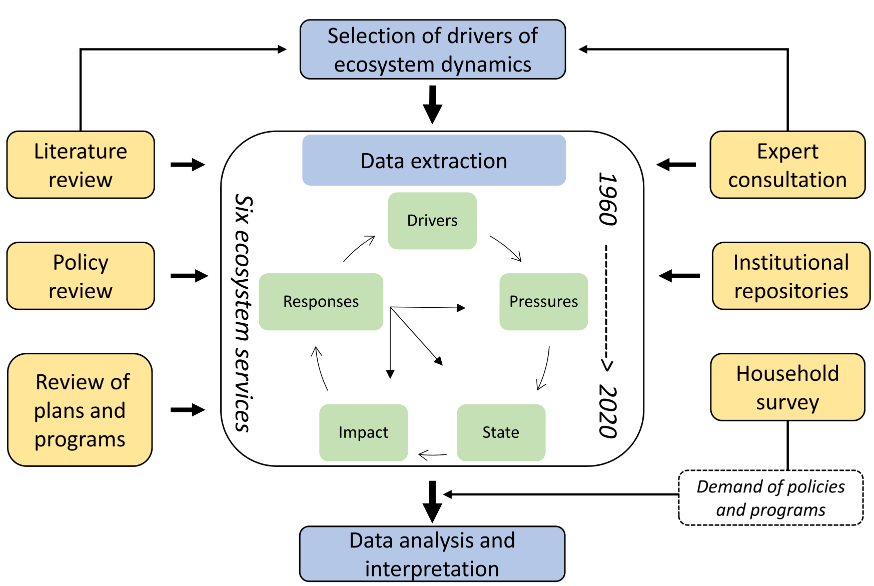


Fig. 1. Methodological overview of the research.

prestigious university (*the name of the university has been withheld for the review process*). The selection of households was random within five categories of people living near (i.e., within a periphery of 1 km from the land cover types) to different land cover types (i.e., 60 households each from forestlands, croplands, wetlands, grassland/shrublands, and urban settlements). Two settlements for each land cover type were selected and 30 households from each settlement were considered for the survey. The purpose of the household survey was not to infer any statistical inference but to depict the general understanding and demand of local people regarding the changes in the availability of ES. The question we asked to the household was "Based on your knowledge, what sorts of policies, institutions, and programs are required to manage ecosystem services in your area (up to five points in a priority order)?". Professed demand programs were then aggregated and grouped through the inductive approach until the specific requirements of the programs were not lost from the name of the program itself. Data analysis was done through various qualitative and quantitative measures such as, trend analysis was done through R software, while thematic analysis of qualitative data was carried out to interpret the link of PIP response to the drivers of ED.

3. Results

3.1. Drivers and pressures of ecosystem dynamics

Fig. 2 presents the trends of various direct and indirect drivers of ED, from 1970 to 2020. Yet, some of the drivers (i.e., governance drivers) were assessed only for later dates because of the unavailability of data from those older times. Altogether, 38 drivers of changes were assessed in our study. Economic drivers are considered the powerful drivers which put unprecedented pressure on ED. Regarding the trends of economic drivers, the per capita GDP was increasing slowly until 2015 and then sharply increased, reaching > $1100 USD in 2020. Similarly, > 40% of the total population was below the poverty line until 1990 which was reduced to < 20% in 2020. Similarly, the economic growth rate has increased from 2.58 in 1970–6.7 in 2020, except in 2005 (due to armed conflict) and 2015 (impact of earthquake) where the economic growth rate has slowed down between 3% and 4%. The human development index has steadily increased from 0.24 in 1980–0.6 in 2020. The rate of unemployment was decreasing between the period of 1970–2005 but it has been increasing since then. Remarkably, the contribution of the agriculture and forestry sector to the national GDP has sharply decreased from 66% in 1970 to only 23% in 2020.

Among the demographic drivers, population density as well as total population, the proportion of the urban population, and life expectancy has been ever-increasing since 1970. However, the rate of population growth has been decreasing from 2.62% in 1980 to 0.93% in 2020. Similarly, technological drivers such as science and technology-related institutions, human resource in science and technology, and access to electricity and alternative energy have been increasing throughout the period of 1970–2020. Investment in research and development, however, has not been increased much (i.e., 0.28% of the GDP in 1990 to that of 0.3% in 2020). Further, there has been a huge cut in investment in transport and communication, such as, about 35% of the GDP was invested in that sector in 1970 which was reduced to just about 7% in 2020.

Regarding Nepal's socio-economic exposure to the international communities, it has been increasingly reliant on imported goods and services (i.e., only 8.3% of the GDP used to be imported in 1970 which has increased to about 34% in 2020). Similarly, the ratio of export to import has decreased from about 66% in 1990 to only 9% in 2020. Overall, the globalization index has increased from 17% in 1970 to about 45% in 2020. Similarly, Nepal's participation in international agreements has also reached more than 192 in 2020 which was just about 50 in 1970. Besides, although the number of industries has increased from about 3000 in 2000 to > 8000 in 2020, the GDP contribution of the industry sector has decreased from about 21–12% in the period between 2000 and 2020. Nepal has also been characterized as a country having very unstable governments, as there have been at least four governments a decade from 1970 to 2020. For instance, 10 different governments were recorded in the decade from 1990 to 2000, and eight governments in the last decade from 2010 to 2020. Regarding the governance indicator, none of the governance indicators ever achieved a score of over 50, except 'rule of law' which was higher in value (i.e., 51.3) in 1996. Most of the governance indicators dropped to their lowest value in 2005, during the peak of armed conflict in Nepal.

Those various drivers put pressure on ecosystem assets as well as the supply of ecosystem services, such as land use change and overexploitation, invasive alien species, climate change and pollution, and natural disasters. Land use change put dominant pressure on ED. For example, the deforestation rate was 2.7% in the period of 1947–1980, which slowed down to 1.8% between 1980 and 2000 (Chaudhary et al., 2016). In a period of just 13 years (1986–1999), > 150,000 ha of forestland was converted to farmland, settlements, building, and roads (Chaudhary et al., 2016). About 100,000 ha of forestland was reported to be encroached by the fiscal year 2015/2016 alone (Bhusal et al., 2018). Regarding the pressures on wildlife, illegal poaching and killing of wildlife has been pertinent issue. Heinen (1995) documented that more than six dozen open shops existed in 1990/1991 for buying and selling of wildlife parts. Likewise, 830 wildlife-related arrest cases were reported within a five-year period from 2011 to 2015, and the wildlife trade of even protected wildlife species is widespread in 67% of the districts of Nepal (Paudel et al., 2020). Pressure on habitat quality exerted by the invasion of invasive alien species is even more devastating. To illustrate, 29 invasive aliens and 184 naturalized species were reported in Nepal in 2021 (Shrestha, 2021). Another study by Shrestha (2016) reported that at least 219 alien species of flowering plants and 64 species of animals are naturalized in Nepal. The pressure of invasive species is so immense, such that a community forestry user group in the lowland of Nepal spent > $13,000 USD to remove a single species, *Aarakande* (scientific name: *Mimosa diplotricha*) from their forest area (Shrestha, 2021). Similarly, almost half of the habitat of endangered one-horned rhinoceros in one of the world heritage sites of Nepal, i.e., Chitwan National Park, has been negatively affected by *Mikania micrantha* (local name: *Banmara*) (Murphy et al., 2013). According to the literature of the past century, infrastructure development and settlements used to impact large chunks of agricultural land areas due to fragmentation (Gautam et al., 2003). Further, the Himalayas were also characterised by high-altitude fire hazards which alter the ecosystem functioning in the Himalayan landscapes (Agee, 1991). Likewise, livestock husbandry used to be an important driver in ecological underpinning in the Himalayan landscapes (Thomas-Slayter and Bhatt, 1994).

Climate change is an emerging pressure on the ecosystem. In the Himalayas, climate data cannot be generalized because of the changes in climatic parameters with a small change in elevation. Yet, the mean annual temperature (5-year smooth) of Nepal has increased from 12.62^0 C in 1970–13.25^0 C in 2020 (Harris et al., 2020). Temperature has increased by between 0.15^0 C and 0.6^0 C per decade from 1971 to 1994 (Paudel et al., 2016). Temperature rise of 0.18^0 C per decade has been reported since 2000, the decade of 2010–2019 was the warmest decade in history (Chandio et al., 2023). Historical warming in Nepal in the last century was estimated at between 1.0^0 C – 1.3^0 C and is projected to warm by 1.2^0 C – 4.2^0 C by 2080 s (Harris et al., 2020). The record of mean annual precipitation is erratic (i.e., a 5-year smooth record of 1356.41 mm in 1970, 1557.16 mm in 2000, and 1401.12 mm in 2020), yet increased at a rate of 6.5 mm per year between 1982 and 2006 (Harris et al., 2020). Regarding climate-induced disasters, approximately 2000 people died and 250,000 families were affected by floods and landslides between 2000 and 2009 (The World Bank Group and the Asian Development, 2021). According to a government report, each year 300 people died of landslides and floods, and more than 33,000 people died due to climate-induced disasters between 1983 and 2015 (GON and UNDP Nepal, 2017). In Nepal, 350 people died and > 100 people were

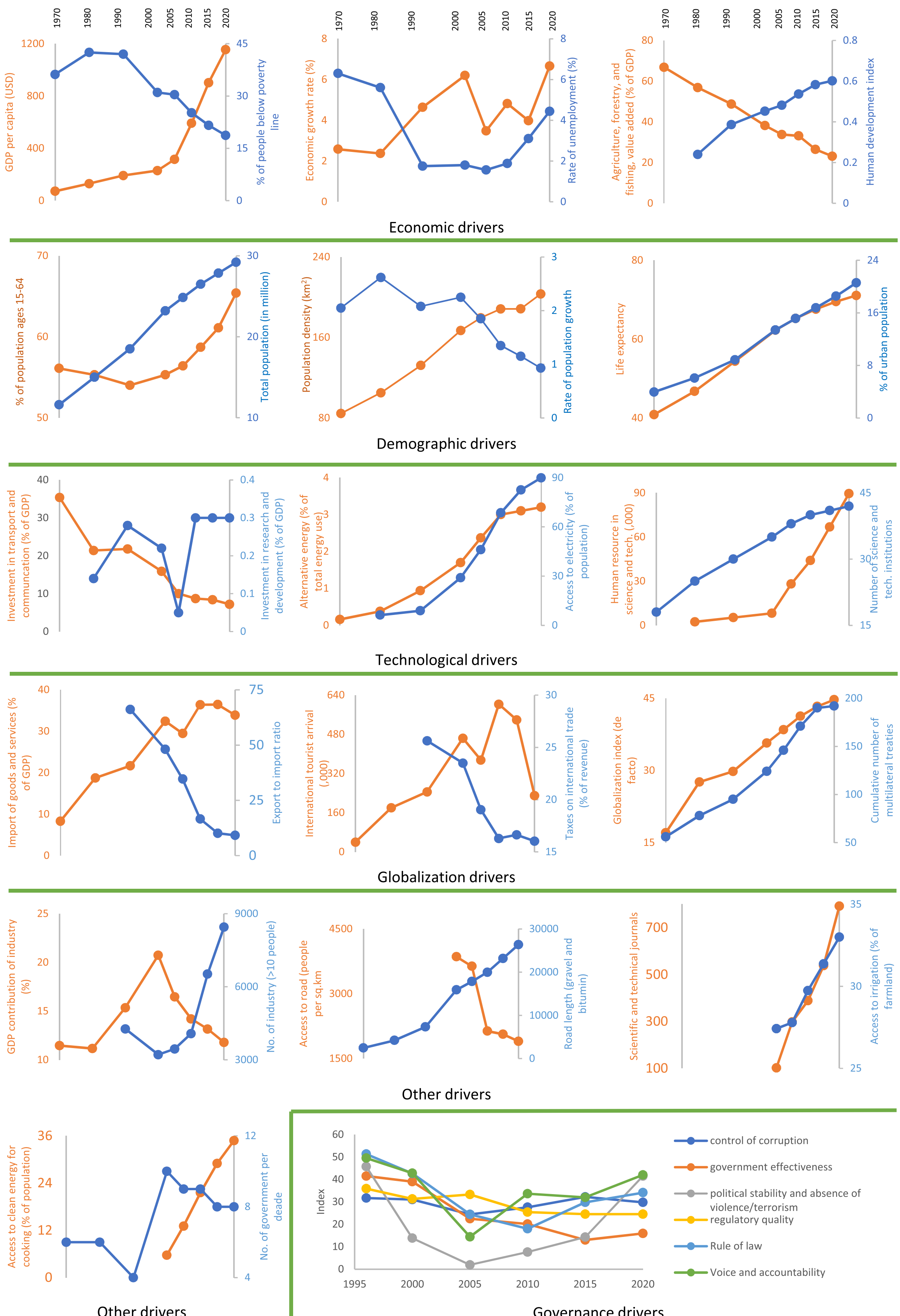


Fig. 2. Trends of drivers of ecosystem dynamics.
[Source: World Development Indicators (retrieved from https://databank.worldbank.org/source/world-development-indicators), annual economic survey reports (retrieved from https://www.mof.gov.np/site/publication-category/21), periodic development plan (retrieved from https://npc.gov.np/en/category/periodic_plans), data from central bureau of statistics (retrieved from https://cbs.gov.np), and others].

missing in a single year (2020) due to climate induced hazards (GON, 2022). Harris et al. (2020) estimated that annually 157,000 people are affected by river flooding with an impact on GDP of about 218 million USD. The government has further estimated that disasters cost about 6% of the annual development expenditure of Nepal (GON, 2022). Moreover, a report (The World Bank Group and the Asian Development, 2021) estimated the loss of ice mass in high mountains by 36–64% by the end of the 21st century, which will put a severe impact on Nepal's Himalayas which have > 2300 glacial lakes covering > 75 sq.km in Nepal (Mool et al., 2001).

Other pressures on the ecosystems include increased fire incidence and greenhouse gas emissions. About 40,000 active forest fires were recorded from 2001 to 2019 (Bajracharya et al., 2021). A study by Khanal (2015) found that an average of 372,000 ha area was burnt annually between the period 2001–2014. The incidence of forest fires is believed to be increased in recent years. For example, in 2016, more than 5000 forest fires were reported impacting 50 districts of Nepal, damaging 12,000 community forests, along with the death of 15 people (Gurung, 2016). Likewise, total greenhouse gas emission has increased twofold (i.e., 21,360 kt of CO_2 equivalent in 1990 to that of 44,220 kt of CO_2 in 2019) in just less than 30 years (The World Bank Group, 2021). Similarly, the noticeable impact of climate change on forest composition (i.e., species alteration, shifting of tree lines, changes in flowering and fruiting time), soil erosion, and drought can be depicted in recent decades.

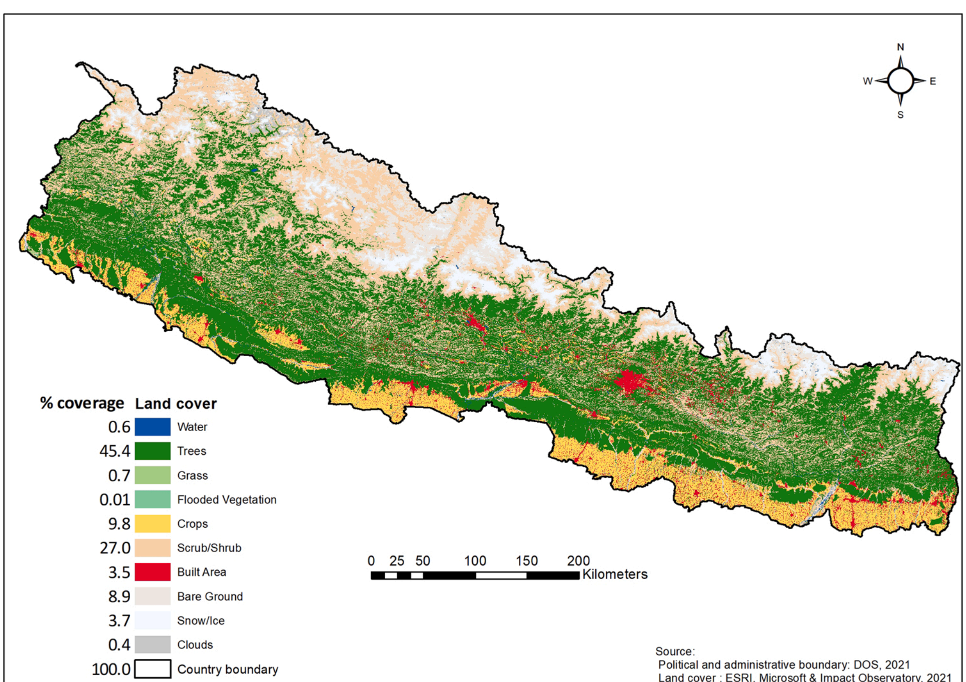
3.2. State and impact on ecosystem assets

Direct and indirect drivers of ED have substantially altered the state of ecosystem assets and accordingly the impact on the supply of ecosystem services for human society. Changes in areas of cropland, built areas, and forestland are the major determinants of ED. Regarding crop production, there has been a very small increase in croplands, such as 26% in 1970 to 29% in 2015, out of which half of that area is arable land (The World Bank Group, 2021). Another estimate by Paudel et al. (2016) showed that cropland increased by 13% between 1961 and 2001. Built area and urban settlement occupied only 122 sq.km in 1978, which increased by four-fold by 2010 by occupying an area of 469 sq.km (Paudel et al., 2016). But, according to recent estimates by ESRI, Microsoft and Impact Observatory (2021), built areas of Nepal occupy more than 5000 sq.km in 2020. As opposed to the rocket-rise of built area, forestland shows the irregular pattern of change over time, such as 43.5% (1964), 38.01% (1978), 29% (1994), 39.1% (2010), and 45.4% (2020) (DFRS, 2015; ESRI, Microsoft and Impact Observatory, 2021; Paudel et al., 2016). Nevertheless, variations in assessment methods and characterisation of forestland by different institutions at different times must be considered while comparing the proportion of forestland. In any case, Paudel et al. (2016) claimed that 14% decline in forestland in 30 years (1964–1994), but increased to about 45% in 2020.

Map 1 shows the land cover map of Nepal for the year 2020 based on ESRI land cover classification (DOS, 2021; ESRI, Microsoft and Impact Observatory, 2021), which visualizes the current state of ecosystem assets in Nepal. Forestland is the dominant land cover in Nepal (i.e., 45.4%), followed by shrublands (27%) and cropland (9.8%). The land cover assessment might differ based on the different approaches to assessment by various institutions, for example, DFRS (2015) reported 44.47% of the country's area as forestlands; however, it did not consider the revised map of Nepal done by DOS (2021). A large proportion of bare ground, especially in the northern part of Nepal, impeded the supply of multiple ecosystem services. Similarly, the co-occurrence of croplands and build areas in and around the large chunk of forestland in the southern lowland of Nepal have largely contributed to habitat fragmentation, deforestation, and carbon emissions. For example, per capita CO_2 emission has increased five-fold in 25 years, from 0.05 mt in 1990–0.24 mt in 2015 (The World Bank Group, 2021). Although the percentage of arable land has been said to increase by 8% in the period of 1970–2020, the total production of cereal crops has increased by 160% in that period of time (The World Bank Group, 2021).

3.3. Responses to the changes in supply of ecosystem services

Various PIP responses have been attempted to address the drivers of ED over time. Fig. 3 shows the detailed chronological overview of responses to various drivers of ED including pressure, state, and impact of varying ecosystem assets. Nepal has enacted legislative measures since the very beginning of the periodic development plan in Nepal. For



Map 1. Land cover map of Nepal, indicating the states of ecosystem assets.

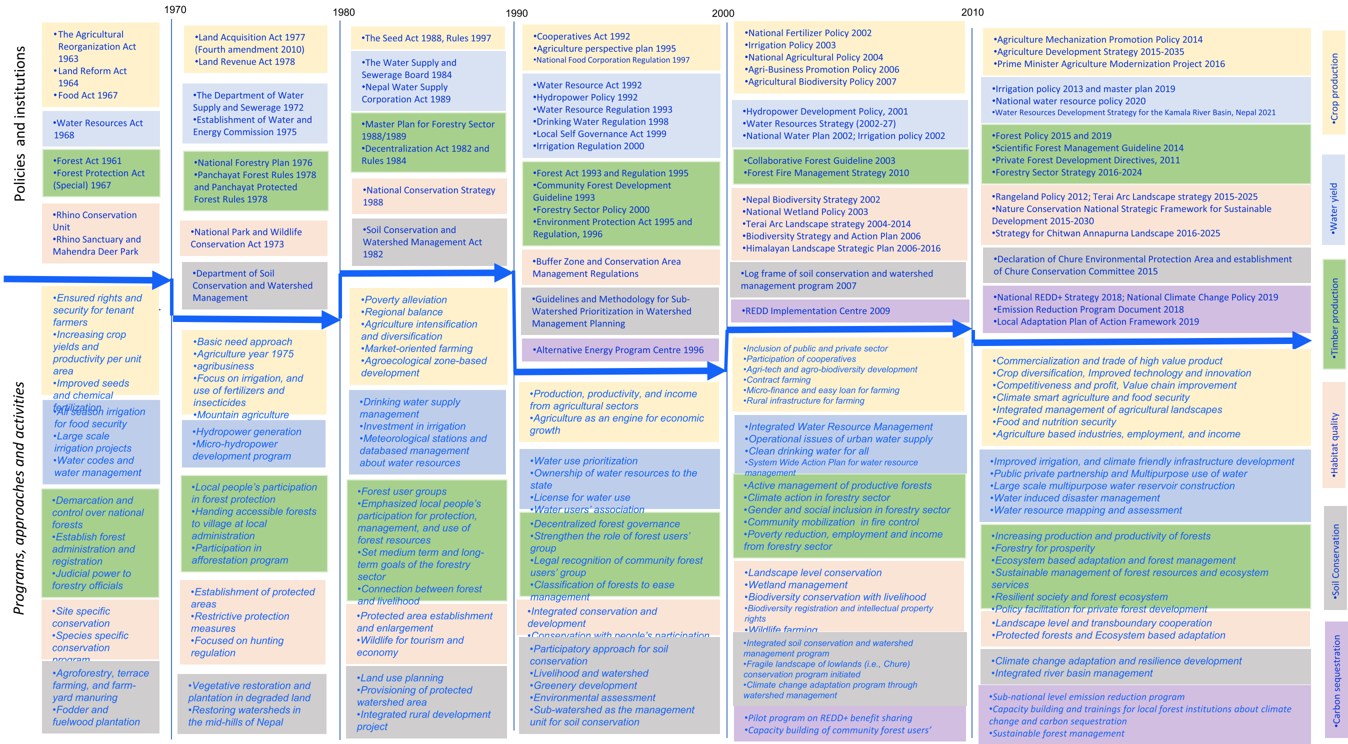


Fig. 3. Chronological overview of policy-institution-program responses to ecosystem services. Upper part of the diagram shows policies, legislations and institutional interventions, whereas the lower part shows programs and approaches. Difference in color of the boxes relates to different ecosystem services, i.e., right side of the diagram.

instance, three Acts related to crop production were promulgated between 1960 and 1970, focusing on food security, increasing yield, and land productivity. Land reform and revenue were the policy priority until the 1980 s which transitioned to quality seed, land productivity and fertilization, agricultural institutions, and capacity building of the farmers. Programs related to crop production were concentrated towards basic need fulfillment and poverty alleviation until 1990 which was broadened afterward to embrace agriculture as a means for economic growth and prosperity through commercialization, modernization, and integrated management of farmlands. Although Water Resource Act was endorsed in 1968 with the aim of regulating large-scale irrigation and hydropower, the integrated water resource management plan was not focused until the 2000 s which was mainstreamed through National Water Plan and Water Resource Strategy.

Regarding timber production, restrictive and centralized forest management was adopted until the mid of 1980 s, through the promulgation of the Private Forest Nationalization Act 1957 and the Forest Act 1961. However, decentralized and participatory forest management was practiced afterward, with the popular management paradigm of community forestry. In the last decade, forest policies have been put forward to address multi-faceted forestry-related issues, such as carbon, biodiversity, and timber production, as well as social consideration of gender and social inclusion in the forestry sector. Programs related to timber production were also directed towards achieving forestry for prosperity through active management of forest resources, social inclusion and community mobilization, increasing production and productivity of forests, ecosystem-based adaptation, and climate actions, amongst others. Although the establishment of the Alternative Energy Promotion Centre in 1996 started working on clean energy and reducing environmental pollution, emission reduction, and carbon sequestration-specific policies were explicit only after 2009 with the establishment of the REDD+ Implementation Centre. Since then, various pilot programs about emission reduction have been implemented and a national strategy for carbon sequestration has been put forward for implementation.

The establishment of Soil Conservation and Watershed Management in 1974 and the governing Act in 1982 have mainstreamed the issues of soil conservation in national development discourse. Afterward, integrated watershed management based on log frame planning and focused protection of dynamic landscape in the southern lowlands of Nepal (i.e., Chure region) has been put forward to respond to soil erosion, land degradation, and desertification. PIP response to habitat quality has been transformative. Until 1990, restrictive policies and enclosure-based wildlife and habitat management programs were implemented to respond to the declining biodiversity and habitat quality. However, there was a paradigm shift in conservation after bringing the concept of the buffer zone and conservation area management approach, which embraced integrated conservation and development in participation with local people. After the 2000 s, the conservation approach has been broadened towards landscape level and transboundary conservation for biodiversity and habitat quality improvement to address dynamic drivers of changes in ecosystem services.

3.4. Public demand of policy responses to tackle with the changes in ecosystem services

A total of 58 different programs were collected from the household survey which were considered as important for ecosystem management from local people's perspective. Fig. 4 shows the top 10 program demands for ecosystem management. Soil conservation was the most preferred program which was demanded by about 23% of the total respondents, followed by the demand for capacity building programs and river training works (21% each), access to clean water (18%), and modernization of the agricultural sector (16%). Greenery development, plantation, and afforestation program were also among the top ten preferred programs along with the conservation of wetland and water resource protection program. Remarkably, the management of problem animals (i.e., monkey, deer, porcupine, and others), which recurrently and negatively affects crop production as well as creates human

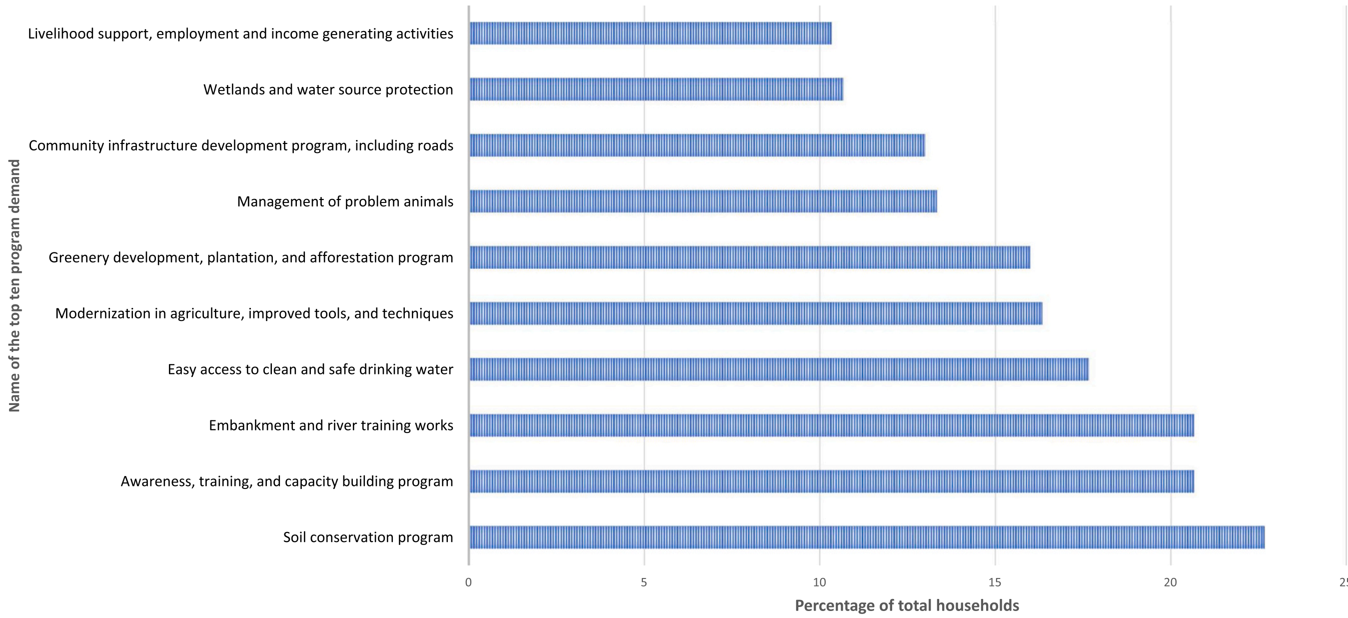


Fig. 4. Local people's demand of ecosystem management programs.

casualties, was among the top ten demanded programs for sustaining the co-existence of wildlife and human being. Local people's demands reflected the need for policy responses that address conservation and development programs in a holistic and integrated way. For example, the demand touches upon soil and watershed conservation, ecosystem restoration and management of human-wildlife conflicts, community infrastructure, and improved agriculture, as well as capacity building and economic activities for the overall development of the area.

4. Discussion

There has been substantial progress in economic drivers and indicators of development in Nepal; however, its environmental impacts and effects in ED are not evenly accounted. The increase in economic growth rate and global share of economy and ecosystem services have complicated environmental implications in the socio-ecological framework of conservation and development. Nepal has attempted successive policy, institution, and program measures to deal with the changes in drivers of ED and its environmental impacts. Yet, the success of the response measures is not evident as such. Further, there has been a gap in local preference for ecosystem management programs with the response from various government and non-government organizations at subnational and national levels. The details of the reflection on the drivers of ED, its impact on ecosystem services, and responses are discussed in this section, followed by some take-home messages for policy implications in sustainable ecosystem management.

4.1. Reflection on drivers of ecosystem dynamics and its impact on ecosystem supply

Nepal has witnessed a vibrant socio-economic and political trajectory since the mid of twentieth century. The country which was isolated from the rest of the world until the 1950 s, has gradually opened to the neo-liberal global economy, including a meaningful share of natural resources and ecosystem services. Per capita GDP, human development index, life expectancy, and urban population, access to road and electricity, use of alternative and clean energy, trends of research and scientific activities, and globalization index have been increasing; however, the rate of increase is not consistent (Fig. 2). The economic growth rate has also been increasing from 1980 to 2020, except in 2005 probably due to the impact of armed conflict and in 2015 due to earthquakes. On the other hand, the contribution of the agricultural and forestry sectors to the national economy, investment in transport and communication, export-to-import ratio, and taxes on international trade have shown declining trends in the last half-century. Various indicators of good governance have also not shown any promising trend of improvement as compared to that of 1996, although the declining trend was slightly reversed after 2005.

Direct and indirect drivers of ecosystem assets have a substantial negative impact on the supply of ecosystem services. Increased economic activities in Nepal, as explained through GDP, economic growth, and increased trade activities have contributed to the declining trends in forest resources of Nepal. Not only in Nepal but globally, the growth in GDP is incurred with the cost of environmental damages as explained by Ward et al. (2016). Further, Kleemann and Abdulai (2013) claimed that international trade has a negative impact on environmental resources, especially in developing countries. Zu Ermgassen et al. (2020) mentioned that commodity production and trade have contributed to the loss of one-third of the global forest area, contributing to over 20% of emissions and a high decline in global biodiversity. For instance, soy and beef export from Brazil to European Union is believed to be largely contributed to environmental degradation and illegal deforestation (Rajão et al., 2020). Besides, de facto globalization was also found to be crucial in affecting the supply of ecosystem services, as evident in Ghana where globalization has shown differing impacts on carbon emissions (Acheampong, 2022). Economic growth might deteriorate the environment and ecosystem functioning as observed in Malaysia (Raihan and Tuspekova, 2022). Likewise, urbanization has been considered one of the major drivers of land cover change, and accordingly, the supply of ecosystem services, which has been confirmed by numerous previous literature (Komugabe-Dixson et al., 2019; Liu et al., 2019; Theodorou, 2022). Infrastructure development activities, including increased access to roads, have a substantial negative effect on forest ecosystem and habitat quality (Ghent, 2018; Tian et al., 2020). In this regard, economic growth and development are more prone to exert a negative impact on the environment and ecosystem services.

Nevertheless, proper planning and a sustainable approach to development might exert a positive impact on ecosystem services. Increased access to electricity and alternative energy reduces the dependency of local people on forest resource extraction for cooking and energy purposes, thereby, support in low carbon economy and biodiversity conservation (Fahlbusch et al., 2018; Poggi et al., 2018; Raihan and

Tuspekova, 2022). Although the trends of investment in research and development are not quite satisfactory (Fig. 2), we can see increasing human resources in science and technology as well as growing research activities in Nepal, which might lead to outlays in a sustainable development pathway. In this regard, Coccia (2019) believed that science and technological advancement support nations to deal with various environmental threats. Likewise, Zhao et al. (2019) claimed that research and development are crucial to cope with environmental stress and to accelerate the green economy. Although political instability has always been a significant problem in Nepal (i.e., on an average of >7 governments per decade over the last six decades) which can be related to the failure of various policy instruments (Laudari et al., 2019), growing involvement in international conservation measures and commitments (i.e., party/signatory to >190 multilateral treaties) has been instrumental in materializing conservation efforts such as inclusive democracy, biodiversity conservation, and sustainable development goals (Aryal et al., 2019a, 2020, 2021; Nepal et al., 2020). There has not been a linear trend in drivers of ED and accordingly, the impacts of those drivers on ecosystems cannot be generalized as such; however, any PIP response to address the impacts must scrutinize the characteristics and intensity of those direct and indirect drivers of ED.

4.2. Calibrating policy responses against the drivers of ecosystem dynamics

Since the beginning of the periodic development plan in the 1960 s, Nepal has endorsed a holistic development approach to address the growing demand for food security, poverty reduction, and economic growth which are closely associated with the bio-physical supply potentials of ecosystem assets (Bhatt et al., 2021; Laudari et al., 2019; Upadhyaya, 2019). Before the 1970 s, an increase in crop yield productivity by securing the rights of tenant farmers was the priority program. Growing population and increasing food demand for the population corresponded to the Himalayan environmental degradation, albeit a controversial theory (Guthman, 1997), but profound incidences of deforestation, soil erosion, and flooding were reported (Ives, 1987; Laudari et al., 2019). Even after the realization of the irreversible environmental impacts, population growth, urbanization, and intensive farming in marginal lands, the agricultural sector barely focused on environmental considerations but concentrated on the redistribution of farmlands (Nepal et al., 2020). Perhaps, the environmental concern was delimited as a sectoral approach, and allocated to the solo responsibility of forest and environmental policy sphere (Aryal et al., 2021; Laudari et al., 2021). It was only after 1995 when Agricultural Perspective Plan was endorsed which considered farming as a cross-sectoral strategic approach with due consideration of land capability as well as suitable and scientific land use practices. Later, Agriculture Development Strategy (2015–2030) embraced a sustainable farming system while graduating from subsistence farming to commercialization (Khanal et al., 2020). Yet, the substantial population under the poverty line, prominent food deficit, and moderate global hunger index reaffirm that agricultural policies and programs have largely failed to address the drivers of Nepal's farming system, production and productivity of agricultural landscapes, and environmental consequences of the farming practices.

We can witness a sequential paradigm shift in conservation policy in Nepal, including that of forest conservation and timber production, wildlife and habitat conservation, and carbon sequestration. Enclosure-based site-specific conservation of forest and natural habitat, such as demarcation of forestland, centralized management of forest resources, and establishment of restrictive protected areas were the major conservation and development approaches until the late 1980 s (Gautam et al., 2020; Laudari et al., 2019). However, those policies and programs were inadequate to embrace the multi-functional service requirement of natural resources for the resource-dependent communities and accordingly failed to meet the desired need for conservation with development (Aryal et al., 2020; Laudari et al., 2019; Sunam et al., 2015). Restrictive conservation policies were not effective in conservation but were counter-productive not only in Nepal but also in other countries, such as, for biodiversity conservation in Mexico (García-Frapolli et al., 2009), bio-prospecting in Costa Rica (Isla, 2005), wild bird conservation in UK uplands (Redpath et al., 2013), reserves and protected forest management in India (Dutta, 2020), and human-elephant co-existence in Sri Lanka (de Silva and Srinivasan, 2019). Historical observation of changes in ecosystems was found to be crucial in building informed and effective ecosystem management policies in African mountains (Finch et al., 2017).

By learning lessons from the weaknesses of the isolated conservation and management approach, the government of Nepal adopted participatory and decentralized conservation and management approach in forest management (i.e., community-based forest management) as well as in wildlife and habitat conservation (i.e., conservation area and buffer zone management) in the 1990 s. Accordingly, the Master Plan for Forestry Sector (1988/89), Forest Act (1993), and 4th amendment in 1993 to the National Park and Wildlife Conservation Act-1973 have institutionalized participatory conservation and management of forest and wildlife habitat (Aryal et al., 2020; Bhattarai et al., 2017). Yet, the improvisation in conservation approaches, such as landscape level and transboundary approach to wildlife and habitat conservation, has been an ongoing effort (MOFE Nepal, 2015), but the interconnectedness of livelihood support and local development from the conservation has not been fully justified (Godar Chhetri, 2012). Similarly, policy turmoil in the forest management approach (Aryal et al., 2022a) and the large sum of annual timber import (Adhikari et al., 2022) provides ample space to question the appropriateness and responsiveness of the forest management policy of Nepal. Carbon sequestration, a newcomer in conservation science, has been gaining momentum in the policy sphere through the establishment of the REDD Implementation Centre, a pilot program on benefit sharing mechanism, and through the endorsement of the national REDD+ strategy (Laudari et al., 2021; Maraseni et al., 2020, 2014). However, it is too early to conclude about the effectiveness of the policy response to deal with emission reduction, climate change mitigation and adaptation programs.

Being a mountainous country with harsh topography and unsustainable land use practices, soil erosion and watershed degradation are the prominent environmental concerns of Nepal, which have been highlighted since the Himalayan environmental degradation theory (Aryal et al., 2019b; Laudari et al., 2019). The government of Nepal lately responded to the watershed problems with Soil Conservation and Watershed Management Act (1982), but the Act has not been implemented until the declaration of a protected watershed in 2022. Nevertheless, various soil conservation and watershed management activities were implemented through departmental guidelines and a log-frame of conservation programs and activities (Aryal et al., 2019b). The declaration of an environment protection area for a sensitive lowland belt of Nepal (i.e., Chure area) can be considered a milestone in sensitive watershed conservation, but current programs, activities, and institutional arrangements are not adequate to respond to the drivers and impacts of Chure area degradation. Similarly, programs related to water yield are being concentrated on water supply, irrigation arrangement, and hydropower generation (Bhattarai et al., 2022; Uprety et al., 2019). Integrated management of water resources, water yield and storage, and wise and multiple use of water resources are not mainstreamed in conservation and development PIP. Although the government has incorporated those concepts in the water resource plan (2002), strategy (2002–27), and policy (2020) as shown in Fig. 3, institutional deliberation of those policy contents is far behind from its ambitions.

PIP responses in Nepal can also be portrayed based on the changes in the political systems of the country. For example, centralized policy measures, isolated approach to conservation, the people as a problem from ecosystems were popular notions in the Panchayat regime until 1990. After the introduction of multi-party democracy in the 1990 s, participatory conservation and development approaches were introduced in managing ecosystems and natural resources. Legal recognition of community-based forest management, the concept of buffer zones in protected areas, and the introduction of integrated conservation and development programs are a few examples of this approach (Laudari et al., 2019). After the federal restructuring of the country and the promulgation of the new constitution in 2015, the country has been adopting a multi-tier government approach in dealing with ecosystem management by specifying the roles and responsibilities of local, provincial, and central governments. As the country progressed towards practicing deliberative democracy, decentralization, and local governance (Ojha et al., 2019), it has also been increasingly influenced by the global discourse of conservation and development. To illustrate, the Brundtland Commission report (1987), Rio Conference (1992), Agenda 21, Millennium Development Goals, and Sustainable Development Goals have triggered substantial changes in national and local policies for ecosystem management.

Against the fancy web of expert-based policy architecture and program framework, local people's demand is straightforward and lively (Fig. 4). As opposed to the conventional belief that people are antagonists to natural resource conservation (Hoyte, 2021; Kaimowitz and Sheil, 2007; Schwartzman et al., 2000), we found that local people demand soil conservation programs as their top priority program demand. Similar to our findings, European Alps have also witnessed a shift in focus of ES supply from provisioning to regulating ES in the last one and a half century (Egarter Vigl et al., 2016). Further, local people believe that they need awareness, training, and capacity-building program. The demand of local people (i.e., top ten programs) seems to be the core part of ecosystem management and is the pillar of integrated conservation and development programs. For example, riverbank protection, proper management and distribution of clean water, modernization in agriculture, and greenery development are the major attributes of rural livelihood that further aid in the sustainable management of ecosystem assets. Along with the improvement in habitat quality, the management of problem animals must be the priority program as reflected in our assessment. Human-wildlife conflict has been a major issue in species conservation and habitat management (Baral et al., 2021; Silwal, 2019); however, current policies and program measures are not adequate to respond to the prominent conservation issue. Likewise, livelihood support, employment, and income generation from the ecosystem management programs must be a pre-requisite condition in developing countries like Nepal, but most of the conservation modalities are devised by western-knowledge based experts (Aryal et al., 2021) which have failed to cater local context and ground truth of the conservation and development demand.

4.3. Lessons learnt and policy implications

Understanding the ED, at the national level, is a very challenging field of study. Inter-connectedness of various social, economic, ecological, and institutional factors, as well as temporal and spatial variations in the functions and processes further complicate the assessment of linkages between drivers of changes and PIP responses (Cavender-Bares et al., 2015; Shrestha et al., 2018; Turkelboom et al., 2018; Xue et al., 2015). Yet, the DPSIR framework was found to be a suitable approach to visualize a holistic overview of the temporal assessment of ED. Although the deliberate presentation of the contribution and/or linkage of each driver and pressure to the state of ecosystem assets and impact might need further detailed assessment, DPSIR posits a reasonable framework to understand the linkage of drivers of ED and PIP response at the country level. Nevertheless, the DPSIR framework should not be understood as a linear causal framework from drivers to responses because a state of ES or an impact might not be triggered only by a few drivers or pressures of ES but due to the holistic chain of interactions among numerous drivers of ED, including their forward and backward linkages and feedback mechanisms. Yet, we depicted that various economic, demographic, technological, governance, globalization, and other drivers of ED have defined the current state of ecosystem assets In Nepal and its associated impact on the biophysical supply (potentials) of ecosystem services.

Based on the detailed assessment of drivers of ED and PIP responses to address the drivers (including their pressure, state, and impact), we can identify a few lessons that can support decision-making for future policy entrepreneurship and program implementation, not only applicable for Nepal but other countries with similar socio-economic conditions and geographical settings. First, the country has undergone a substantial economic transformation (i.e., per capita GDP, economic growth rate, and human development index) but the contribution of agriculture and forestry to the GDP has been consistently declining. Just one-fifth contribution to GDP (Fig. 2) from the resource with 80% land cover (i.e., >45% forestland, 27% scrub/shrubland, and about 10% cropland as shown in Map 1) shows that Nepal has not improvised its policy instruments and programs to optimize the economic potentials of existing natural resources. For a developing country, having about 18% of people below the absolute poverty line, the sustainable management of the natural resources and optimization of associated ecosystem services must be the prime concern for sustainable development.

Second, although the percentage cover of forests has increased at the national level, forest quality and supply of ecosystem services from the forest areas have not been improved as such. Acharya et al. (2011) also believed that there has been a significant decline in forest quality, composition, and structure. Increasing urbanization (Fig. 2) and sky-rocketing labour migration over the last two decades (Bossavie and Denisova, 2018; Sharma et al., 2021), especially from the rural areas of Nepal, might be associated with the increased forest cover back in the rural areas (Oldekop et al., 2018). In this regard, endorsement of a participatory approach to forest management (i.e., community-based forest management) was found to be successful in reducing deforestation, reversing forest encroachment, and increasing greenery in open and bare ground. But the problem of forest degradation has not been addressed and yet, more suitable policy instruments and institutional arrangements are required for sustainable management of forest resources to meet the growing demand for forest products while maintaining the ecological integrity of the landscapes.

Third, we can depict numerous policies for the conservation and management of natural resources (see Fig. 3 in detail), but there has been a significant gap in cross-sectoral coordination and collaborations. Sectoral efforts to address multifaced and dynamic drivers of ED are inadequate (Aryal et al., 2023a; Laudari et al., 2022). For example, the Agriculture Development Strategy 2015–2035 (i.e., Output # 2.13: Forestry development) was not compatible with the Forestry Sector Strategy 2016–2025, and alternatively, the Forestry Sector Strategy barely recognizes the policy content of the Agriculture Development Strategy. Besides, there is significant overlap and confusion among various policies such as the National Forest Policy 2019, National Environment Policy 2019, and National Climate Change Policy 2019. Such policy fragmentation and sectoral approach are not adequate to address the drivers of ED, and therefore, we argue for integrated policy entrepreneurship for adaptive management and synergistic policy outcomes.

Fourth, policymaking in Nepal is highly ambitious, but the institutional arrangement and means of implementation have always been challenging which put the risk of sick policy or policy failure (Aryal et al., 2021; Khanal et al., 2020). For instance, to reverse alarming trends of soil erosion in the mountains and flooding in the lowlands, the government promulgated the Soil and Watershed Conservation Act 1982 with the aim to adopt land use planning for all types of land cover (including private farmlands) in a protected watershed area, but the Act did not become effective because of the complications in implementation and institutional arrangements after designating protected watershed area. Likewise, the Forestry Sector Strategy aimed at scientific management of 50% of lowland forests and 25% of mountain forests by 2025 (MFSC, 2016), but it is barely implemented in < 5% of Nepal's forest area until 2022 (Aryal et al., 2022a). Considering those evidence, rather than incorporating theoretically possible all sets of ambitious targets, PIP responses must be considerate of the practical perspective of governance structure, institutional efficiency, and socio-economic context while dealing with the dynamic drivers of change.

Fifth, policymaking in Nepal is blamed to be a copying process from other countries or largely dictated by multilateral agreements but does not thoroughly look back on what has worked and what did not, based on the characterization of drivers of ED. For example, the soil conservation program has been a central issue in the mountainous country, which is evident through the annual loss of lives and properties due to water-induced disasters (GON, 2022), and also supported by our results (Fig. 4). But soil conservation and watershed management program is one of the least preferred programs as evidenced by the collapse of the Department of Soil Conservation and Watershed Management in 2019. One reason might be the lack of focused international governing mechanisms for soil conservation, which are available for others, such as biodiversity conservation (i.e., UN Convention on Biological Diversity) and climate change (i.e., UN Framework Convention on Climate Change). PIP responses should therefore consider internal factors of change, socio-economic context, and characteristics of local drivers of ED rather than be largely inspired by a blueprint ecosystem management framework.

While discussing the lessons learned for policy implications, we acknowledge that we have limited our study by focusing on six ecosystem services. Further, we have illustrated a national-level picture of the six ecosystem services which give a general overview of the DPSIR, but a focused analysis of individual ecosystem assets (i.e., forestland only or cropland only, or water resource only) would support understanding detailed phenomena through the comprehensive process-based models at a finer scale of attributes of the DPSIR framework. Moreover, we admit that there might be other drivers of ED than what we have considered in this study. In this regard, we would suggest consideration of all the possible direct and indirect drivers of changes in future studies. The findings would be more robust if we could have quantitative data for all the drivers of ED since 1960. Periodic assessment of PIP responses based on changes in national political systems (i.e., Panchayat, multi-party democracy, and Federal restructuring of Republic Nepal) as well as global policy milestones of World Conservation Strategy, Brundtland Commission, Agenda 21, and Sustainable Development Goals would be more insightful for analysing paradigm shifts in ecosystem management. Besides, we believe that assigning the weight of each driver and/or pressure to the state of ecosystem assets and the impact on ecosystem services would be helpful in a clear understanding of the linkages among DPSIR framework, so future studies should consider prioritization of drivers and pressures based on its impact on ecosystem services would ease in devising PIP responses. Notwithstanding, based on our findings we argue that the current provisioning of PIP responses is incremental and sectoral which is inadequate to respond to the dynamic drivers of ecosystems. Further, peace meal PIP responses that are considerate of a single element of DPSIR (i.e., either driver, pressure, state, or impact alone) are not sufficient in the dynamic socio-ecological framework. In this regard, PIP responses in the future should be considerate of the holistic system framework of drivers to pressure, and pressure to state and impact on ecosystem functioning. Overall, drivers of ES in the Himalayas are dynamics that cannot be effectively addressed by the static (or incremental) PIP responses. In this regard, Himalayan landscapes throughout the world (including those from Hindu-Kush Himalayas, African mountains, and European Alps) should consider dynamic and adaptive PIP to respond to the changes in drivers of ED.

5. Conclusions

Ecosystem functioning is a dynamic process which is affected by various natural and human induced disturbances. Drivers of the changes in ecosystem functioning are being managed by appropriate policy−institution−program (PIP) responses. The question is whether the responses appropriately and adequately address the drivers of changes and associated pressure, state, and impact. We assessed and analysed national-level direct and indirect drivers of ecosystem functioning and its impact on ecosystems along with PIP responses to address the drivers for the last 60 years.

Economic drivers of changes were prominent in impacting ecosystem functioning mostly negatively, but the shift in management approach from centralized to participatory was found to be successful in reversing loss of forest and natural resources. Substantial changes in globalization drivers and involvement in multilateral environmental agreements were found to be impactful in designing policy feedbacks and accordingly managing ecosystems. Nepal has shown a substantial progress in policy making and periodic planning since the mid of 20th century. Periodic plans were mostly incremental, and policy responses were mostly sectoral. We have revealed that the drivers of ED were not linear but dynamic in its nature, but PIP responses were structured as linear, sectoral, and incremental. Nevertheless, we see a silver lining in sustainable ecosystem management by assigning priority and relative weightage to various drivers of ecosystem dynamics and adoption of comprehensive process-based models of DPSIR framework.

In conclusion, although the current PIP responses are not adequate to respond to the dynamic drivers of ED, there is an ample opportunities to address the drivers with a few improvements in policy entrepreneurship such as (1) optimization of ecosystem services to meet the basic need of the broader population, (2) sustainable management of forest resources to enrich multiple ES from forest areas, ranging from provisioning and non-provisioning ES, (3) integrated and coordinated policymaking approach for synergistic policy outcomes, (4) consideration of the ground reality of governance structure, and institutional capacity while addressing multifaceted dynamic drivers of change, and (5) embracing local socio-economic context and development phenomena while planning rather than adopting blueprint management framework.

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CRediT authorship contribution statement

Maraseni Tek: Supervision, Writing – review & editing. **Aryal Kishor:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Apan Armando:** Supervision, Writing – review & editing.

Declaration of Competing Interest

Authors declare no conflict of interest.

Data Availability

Data will be made available on request.

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