Food-System and Water–Energy–Biodiversity in Nepal

Subjects: Agriculture, Dairy & Animal Science

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We reviewed Nepal's food system through the lens of food–water–energy–biodiversity (FWEB) nexus to develop a more robust food system framework. From this approach, food system foresight can benefit from different nature-based solutions such as agro-ecosystem-based adaptation and mitigation and climate-resilient agro-ecological production systems. We proposed a modified framework of food system foresight for developing resilience in a food system, which can be achieved with an integrated and resilient nexus that gives more emphasis to agro-ecological system-based solutions to make the food system more climate resilient. This framework can be useful in addressing the Sustainable Development Goals (SDGs) numbers 1, 2, 3, 6, 13, and 15 and can also be used as a tool for food system planning based on a broader nexus.

biodiversity energy food system agro-ecological system Nepal water nexus COVID-19 agriculture small-holder farmers

1. Introduction

A food system enabled with a large amount of agronomical research in the past led to an almost three-folds increase in productivity of major cereals, coarse grains, root crops, livestock, and fisheries to feed the growing population [1][2][3]. These achievements in advancement of food production, however, had been made possible at large environmental costs that resulted in loss of biodiversity and agro-biodiversity and depletion of essential natural resources such as water, land, and native agriculture gene pools including their wild relatives in nature [1][4][5]. Today about 820 million people are suffering from hunger and malnutrition deficiency [6]. The rising population will reach 9 billion in the next three decades, putting additional pressure on these resources [7]. The scarcity of natural resources necessary to produce additional food will lead to a rise in world food prices, consequences of which may leave a significant amount of the population undernourished [8]. The disparity in food security is seen present today, like Sub-Saharan Africa and South Asia, which are severely affected by hunger problems compared to the other regions and post-COVID-19 situation looks even bleaker [9]. The Global Hunger Index 2019 for South Asia and Africa South of the Sahara shows a higher proportion of population undernourished as well as high prevalence of stunting and wasting among children [10]. A South Asian country, Nepal ranks at 79th position among 113 countries on food security index and has been struggling with food insecurity for a long time [11]. Since food security is the outcome of a food system [12], this factor points to a need for interdisciplinary thinking on food system planning as already postulated in recent Global Environmental Change reports and Food System concept [13][14]. Simpson and Jewitt [15] highlighted the importance of resource security to gain sustainability in all the four

dimensions of food security, i.e., food availability, accessibility, utilization, and stability in a situation of vast growing population and climate change.

Water–energy–food nexus, an integrated solution to sustainable development, was proposed during the Bonn conference in 2011, emphasized the interconnection and interdependencies among the resources [16]. Today, the concept has gained attention of international agencies not only because of its holistic approach to resource utilization but because the modern world is also facing the challenges of climate change impacts on water, energy, and food resources [17]. Nexus is considered highly effective in managing natural and modified resources like land, water, energy, and biodiversity, thereby supporting developing countries to reduce risk of disasters and adapt to and mitigate the impact of climate change [18][19]. Recently, the International Union for Conservation of Nature (IUCN) has released global standards for nature-based solutions, which, among other things, highlights ecosystem-based adaptation [20].

Nepal, a mountainous country, has been facing the impacts of climate change in various sectors including, agriculture, forestry, livestock, health, and livelihood [21]. The country has witnessed a rise in mean annual temperature by 0.06 °C with an increase in maximum temperature, warm nights, and erratic rainfall pattern [22][23][24], which is predicted to be observed until the end of this century [21]. Bhattacharjee et al. [25] reported that the Himalayan regions and surroundings in Nepal are more vulnerable to climate change, which also makes vulnerable the livelihood of tens of millions of people who rely on its ecosystem services. The impact of climate change in water availability is predicted to impact multiple sectors such as the access of people to drinking water, irrigation during dry periods for agriculture production, and electricity generation [26]. To reduce vulnerability and increase resilience to climate change, the government of Nepal has prepared a climate change policy [27].

A sustainable and more holistic approach becomes essential to address growing water, energy, and food demand that is also environmentally sound. Such an integrated system should be possible by applying food–water–energy–biodiversity (FWEB) nexus that can link together the vital food system sectors, especially food production, surface and groundwater-based irrigation, hydropower-based energy, and natural biodiversity in an integrated and embedded system framework wherein these sectors interact positively by creating synergy and minimizing trade-offs among each other. This system of thinking and adaptive management of nexus has as its main objective to optimize the use of resources while simultaneously addressing inequity and conflicts as production grows much better in small and marginal farms that are more dependent on nature for nutrition and food [28][29].

2. Understanding the Food System in Nepal

Geographically, Nepal is a landlocked country in the Hindu-Kush Himalayan region. However, it is well known for its richness of natural resources and biodiversity [30]. Nepal also contains a great diversity of food value plant species (n = 790) and forage species (n = 577) grown in the major three agro-ecological zones, namely, high hill (>2000 meter above sea level or masl), mid hill (1000–2000 masl), and Terai (69–1000 masl) [31]. The economy of Nepal is struggling to graduate the country from least-developed to a developing one but has failed to gain the

desired growth rate. For example, it lags in per capita income and other indicators among the regional countries [32]. Agriculture contributes about a third of the country's gross domestic product (GDP) and employs about two-thirds of the population, primarily dominated by women's participation [33]. However, more than half of the households (52%) in Nepal are still food-insecure and 10% of them are severely food-insecure [34].

Nepalese agriculture is dominated by smallholders who occupy less than 0.5 ha land and have limited access to basic inputs like irrigation [35]. Land fragmentation has been one of the major bottlenecks for agriculture development due to high cost in production in lack of mechanization, which is often difficult in small parcels. Most of the farming is subsistence, grown in small plots, while very few are emerging as commercial or have adopted modern technologies. Most of them are confined to market areas with road access [36]. Farmers rely mostly on traditional knowledge and practice low-input agriculture systems such as farmyard manure, mulching, crop rotation, legume, etc., for soil, water, weed, and insect-pest management [37]. Besides, agriculture production is also constrained due to land degradation. According to IUCN [38], almost all types of land degradation exist in Nepal; among them, soil erosion, landslides, and flooding are the major types that contribute to land degradation processes. Human interventions due to increasing rural poverty are related to cultivation of marginal lands, excessive livestock grazing, and loss of biomass, resulting in continued land degradation. Most of the marginal agricultural practices have been carried out on sloping, fragile, mountain ecosystems without adopting proper conservation measures. There are both direct and indirect drivers that are contributing to land degradation in Nepal. Also, there exist some economic drivers that are directly and indirectly associated with degradation of agricultural lands, degradation of forest lands, and degradation of watershed areas, and other factors responsible for water stress, landslides, and flash floods, such as introduction of invasive alien species, etc. [38]. Similarly, haphazard urbanization and infrastructure development, rapid expansion of riverbed/conversion of fertile land, and climate change are also responsible factors for land degradation [38].

Cereals dominate other crops in Nepal, with a 49.4% share in agriculture GDP [39]. Rice (also known as paddy) is a principal crop among other major cereals because of its area of cultivation and yield (Figure 1). It shares 42.5% in total cereal cropped area, 51.6% in cereal food production, and contributes 20% in agriculture GDP. Maize, wheat, millet, barley, and buckwheat are other cereal crops grown mostly in rainfed conditions and in the mid-hill regions where irrigation development is lower [40][41]. Cereal production in Nepal is among the lowest in South Asia [39]. It has a lower yield than Bhutan, India, and other South Asian countries except for Afghanistan and Maldives [42]. Production of food crops is mainly dependent on timely and adequate monsoons, as only one-third of cultivated land has assured irrigation facilities [43]. Therefore, Nepal has been a major importer of rice a staple food crop. Nepal imported 531,000 tons of rice, amounting to $210 million in 2015 [44]. However, in the recent decade (2007–2018), the yield of major cereals has shown an increasing trend while the area of rice and wheat cultivation shows decreasing. In contrast, maize cultivation area has increased in recent days [45]. Adoption of improved and hybrid varieties and better inputs (chemical fertilizer and irrigation) and technical know-how among growers have contributed to increased production of cereals [46].

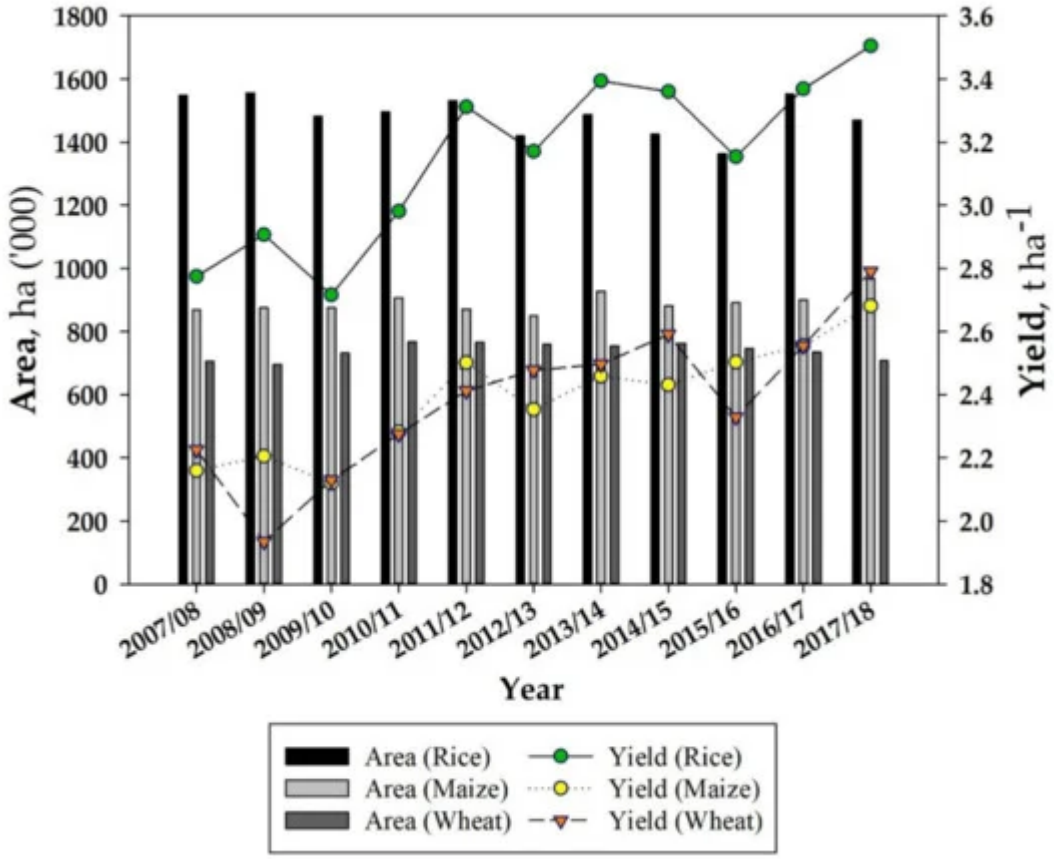

Figure 1. Trends of rice, maize, and wheat production and area covered in Nepal from 2007/08 to 2017/18.

On the other hand, food systems in Nepal have huge potentials to improve if opportunities bestowed by the rich bio-geographical and agro-ecological diversity are harnessed. Farmers grow large numbers of crops and rear livestock breeds. About 12 agro-ecosystems exist in Nepal that include 1026 species of crops and 35 livestock [47]. Besides crops, livestock is an important commodity in the food production system in Nepal and contributes about 26% in agriculture GDP [39]. Moreover, there are a large number of plant species such as buckwheat, millets, sorghum, soybean, etc., which are considered nutritionally important and underutilized species (NUS), are energy efficient, and can withstand adverse environment condition for which they are recognized as future smart foods [48]. If these locally grown future smart foods are prioritized for production, there is ample opportunity to feed all those people isolated due to geographical remoteness [49]. The NUS has huge prospects to reduce food insecurity in the future; they are resilient to climate change and can grow in degraded land where main food crops are found unsuitable [50]. In Nepal, NUS is grown in marginal land, in low soil moisture regime, and slopes [31]

3. Food System Linking with Water–Energy–Biodiversity Nexus

Food–water–energy–biodiversity systems are intimately connected and, among them, biodiversity provides various ecosystem services, a crucial component to make water–food–energy nexus work [19]. Healthy ecosystems, such as forest, grasslands, and wetlands, provide clean and adequate water to grow crops and produce energy. Without river catchments producing water in all seasons, energy to lift and store water is not possible, at least in the context of mountainous and hilly country Nepal [41]. Food, water, and energy are equally dependent upon each other, and biodiversity links and energizes them all. The connection among these systems is known as the FWEB nexus.

While the FWE nexus is well recognized and discussed in the international discourse on food and environment security, biodiversity is the unrecognized and undervalued fourth dimension of the nexus (most commonly seen in food–water–energy nexus literature) [16][51]. However, ecosystem services derived from biodiversity and ecosystem level underpin each of the three securities of FWE. Nature (most prominently expressed in terms of biodiversity) helps mediate the FWE nexus links by storing, moving, cleaning, and buffering flows of water, making drought and flood less severe and food and energy production more reliable [19]. Without healthy biodiversity and ecosystems in well-functioning watersheds, river catchments, basins, and mosaic landscapes, the infrastructure built for irrigation, hydropower, or municipal water supply may not function sustainably and is unlikely to ensure healthy food and nutrition security [52].

Similarly, unmanaged and unsustainably managed watersheds and water catchments will reduce the energy outputs generated by hydropower dams [53]. In a mountainous country like Nepal, nature's geological and geographical buffering role is critical to keep the FWEB nexus operational. Without a sustained flow of quality water and clean and affordable energy, food production cannot be maintained as per the demand and food security is impossible to assure. So, it is clear biodiversity and its extension nature is part of the resources or infrastructure needed to manage the FWEB nexus and ensure sustainability and resilience of critical livelihood components and human well-being agenda.

Understanding the role of nature in the nexus changes the picture of what investment is needed to ensure food, water, energy, and health security. In the food systems' research, the role of nature and ecosystem services should be the focus for policy, institutions, and governance reforms and investment priority for strengthening the nexus and for improving the food, water, energy, and human security. This will be possible through equitable and inclusive social, economic development and environment conservation. The failure of the conventional development model to push economic growth without ensuring the sustained supply of ecosystem services is now well accepted as not being a sustainable solution. Reframing the development or food security problem as the nexus framing alone will not change the fundamental folly of ignoring the integral role of nature's contributions in human well-being and good quality of life [14].

The above information has clearly shown the complementary and synergistic relationship among FWEB that can be harnessed to do local, subnational, and national food systems in Nepal. Food for maintenance of the human body, clean drinking water for health and sanitation, energy for cooking, lighting, cooling, and heating, and biodiversity as basic infrastructure to link them with each and among themselves are important components to

human survival. The rising population with changing demographics and cultural characteristics is putting more demand on these components. Thus, there is a need to strengthen this nexus to ensure resilient food systems. We need to restructure institutions, markets, and governance to manage this nexus to achieve safe, healthy, inclusive and sustainable food systems that will help achieve sustainable development goals [54]. Nexus thinking is, thus, a system thinking approach that considers all the related components together rather than in isolation to maintain the appropriate balance among them [55].

4. Nexus Solution to the Food System Challenges in Nepal

Food–water–energy–biodiversity nexus has never been as important and urgent in Nepal than today. Nepal's population is projected to be 36.2 million in 2050 [56]. With one of the lowest per capita amounts of agricultural lands in the world, the food system scenarios in Nepal are challenging. According to a study conducted by Feed the Future program of the USAID [57], Nepal is a severely food-deficient country. Declining agricultural production has depressed rural economies and increased widespread hunger and urban migration in Nepal. This situation is compounded by a population growth rate of 1.8% per year and a high ratio of population to arable land. "The main underlying causes of hunger, poverty and under nutrition in Nepal include low agricultural productivity, limited livelihood opportunities, weak market linkages, and inadequate production and consumption of nutritious, locally-available foods" according to the USAID study. The economy of Nepal and the livelihoods of its people are highly dependent on the monsoon weather and, therefore, high climate variability is likely to affect food systems adversely. A recent report assessing the possible impact of climate change on Nepal's GDP found that the effects of climate change on water-induced disasters at the national level might cause additional average annual direct cost equivalent to 0.6–1.1% of current yearly GDP by mid-century with an upper estimate of almost 3% per year [58]. Damage to agriculture output is expected to be high.

The solutions to the current challenges of food system in Nepal can be found in an enormous amount of literature that provides nature-based solutions providing holistic management of nexus component. As stated by Rasul and Sharma [18], solutions to food system based on the silo approach may lead to negative consequences on the resources and can be maladaptation. The proposed modified nexus framework that integrates FWEB components recognizes the prime role of biodiversity as a naturally and human-modified infrastructure to enhance the supply of food, water, and energy that can be utilized and adaptively managed according to the local and national situation prevailing in Nepal (Figure 2).

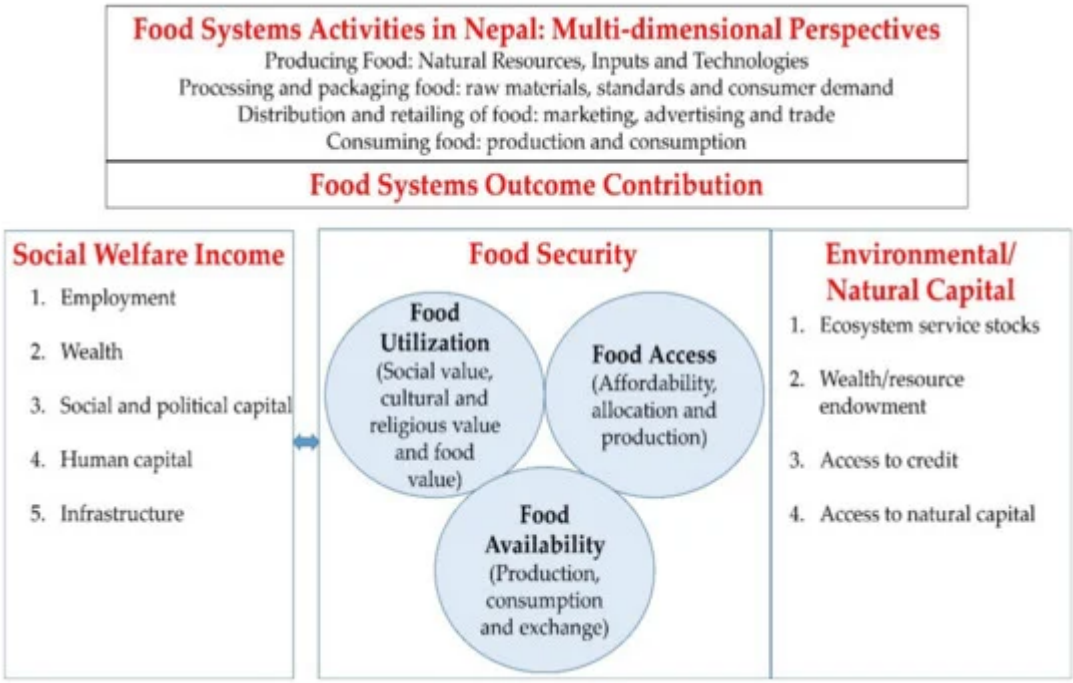

Figure 2. A modified nexus framework of food system in Nepal (adopted from Ericksen [12] as reported by Immaculate [59])

Sustainable and inclusive intensification and an innovative and sustainable farming system approach can increase agriculture production by improving the system efficiency, which also includes synergizing opportunities for poor farmers who traditionally rely on ecosystem services for their livelihood [16]. The water resource challenges can be addressed through investing in irrigation infrastructure. Investing in solar-based groundwater irrigation systems that will allow post-monsoon cultivation in Terai region can foster productivity while breeding drought-tolerant varieties, such as *Sukhadhan* of rice for drought and *Suwarna-Sub* for flood-prone areas. However, conservation of water resources should be prioritized to rejuvenate spring sources by various means of water-conserving technologies, such as digging water-recharge ponds at hilltops [41].

Transformation of subsistence agriculture to commercial, large-scale farming requires land consolidation, which also reduces the risk of fragmented land being used for non-agriculture purpose [60]. Volunteer mechanisms for land consolidation can be nonconflicting measure [61] that, once implemented, will open an avenue for agriculture mechanization that is scale appropriate and socially and environmentally responsible [62]. Incentivizing in high-value agriculture production enabled with sound agro-advisory services and investing in marketing of products [63] can increase return from agriculture. Similarly, for landlocked mountainous countries like Nepal, combinations of cereals, vegetables, and integrated aquaculture systems can be one of the beneficial FWEB solutions to the agriculture system [29].

Food system in recent days needs to be transformed from a more energy-content diet to a balanced and nutritious diet. Biodiversity in agriculture can make year-round availability of nutrition-rich foods [62] and Nepal needs to promote nutritionally rich and underutilized crops found abundantly in the country. Agriculture system that

produces nutrient-rich food and considers human health can benefit the food system [64]. Nexus-based solutions are also acknowledged for their effectiveness in adaptation to climate change [18]. A complete paradigm shift in food system is envisioned through a diversified and agro-ecological system that addresses the issues of subsistence farming as well as industrial agriculture [65]. The promotion of technologies that reduce carbon footprint in agriculture can efficiently produce crops [58]. Adaptation to climate change is a priority of the government of Nepal. In the agriculture sector, climate-smart villages, climate-smart agriculture, and conservation agriculture system and innovation (CASI) models have been tested and proposed [66][67]. However, strategies for adaptation are limited to an agriculture sector-based approach. Yet, climate risk can be minimized by mainstreaming climate action in agriculture [68]. The food system to be resilient requires a sound and efficient food distribution system. Shively and Thapa [69] correlated food prices with roads and bridges in Nepal and suggested the regional and local markets need to be connected. Hence, food system resilience can only be assured when the investment in warehouse, transport facility, or aggregation centers is prioritized in geographically isolated areas [70].

5. Conclusions

A proper and dynamic understanding of the role of biodiversity in the traditional food–water–energy nexus changes the scope of what research, extension, and investment interventions are needed to ensure water, food, and health security or a resilient food system in Nepal. Nature and ecosystem services should be the focus of policy, institutions, and governance reforms in agriculture transformation in Nepal. Updating investment priority based on this broader nexus can help Nepalese policymakers to abandon a silo approach in agriculture plans and seek solution in water, forestry, and energy sectors to achieve the cherished goal of food and nutrition security through equitable and inclusive social means, economic development, and environment conservation. The failure of the conventional agriculture development model to push economic growth without ensuring the sustained supply of ecosystem goods and services is now well accepted. Reframing the food security problem and using foresight thinking with this broader nexus framing of the food system paradigm may change the fundamental folly of ignoring the integral role of nature’s contributions in food and nutrition security in developing countries. The modified nexus framework for assessment of the food system in Nepal is based on this more integrated and resilient nexus approach that adds nature to energize the food–water–energy system sustainably. This broader and holistic thinking is highly relevant in addressing the intractable challenges Nepal faces to achieve Sustainable Development Goals (SDG) number 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well Being), 6 (Clean Water and Sanitation), 13 (Climate Action), and 15 (Life on Land).

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