Chapter 7
Wetlands as a Carbon Sink: Insight into the Himalayan Region

Awais Iqbal and Zhanhuan Shang

Abstract The Hindu-Kush Himalaya region's land cover is comprised of 54% rangeland, 25% agricultural land, 14% forest, 5% permanent snow and 1% water bodies. The Himalayans contain some of the largest water reservoirs, which are critical for HKH countries. Amidst these, wetlands have remained important to ecosystem services and the overall water cycle of the basins. Beside their cultural and provisioning amenities, wetlands are important carbon reservoirs, accounting for 20–30% of the global carbon pool. They act as a sink for atmospheric carbon, thus can influence GHG emissions, especially CH_4, and, thus, should be managed properly. However, substantial data gaps remain in quantifying carbon sequestration and the potential of CH_4 emission. Furthermore, studies on CH_4 fluxes in high-altitude wetlands, particularly in remote areas, remain inconclusive. Hence, more research is required to understand the role of wetlands in term of GHG emissions and carbon sequestration.

Keywords Wetland · Methane · Hindu-Kush Himalaya · Carbon sink

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7.1 Introduction

Wetlands are considered to be one of the oldest territories of the planet. Initially they posed a hindrance to human exploration, however once people learnt the art of boat building, what was once a hindrance became a convenient means for travel and exploration. Subsequently, wetlands became prolific habitats, and a vital food resource. In general, wetlands may seem as abrasive and threatening, with shallow standing water, strong odors, infinite swarms of mosquitoes and deep mud. The word wetland might seem simply as an area that is wet; nevertheless, describing a wetland is more challenging than one would anticipate. Wetlands comprise all regions where shallow water, both salty or fresh, moves or stands. Overall, oceans, seas and deep lakes are usually omitted from the definition of a wetland, yet the shallow boundaries of seas and lakes are considered as wetlands (Moore and Garratt 2006).

Wetlands are occasionally termed as “the kidneys of the landscape” since they play an important role as the downstream receivers of waste and water from human and natural resources. Given this background, wetlands consume CO_2, filter pollutants, protect against flooding, hold and gradually release storm water runoff and generate much oxygen. In addition, wetlands have been called “ecological supermarkets” because of their rich biodiversity and vast food chain. Relating to its importance, wetlands are now valued worldwide and have led to wetland regulations, conservation, management plans and protection laws. The Ramsar Convention on ‘Wetlands of International Importance’ (Ramsar Convention Secretariat 2013) endorsed a definition of wetlands that embrace all types of aquatic habitats: “Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six meters.” The convention in its second article further stated that wetlands “may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands.”

Wetlands have championed the cause *célebre* for administrations across the world, because of the disappearance of water resources in natural habitats and loss of economy. To overcome these problems, scientists, engineers, lawyers and government officials are studying wetland ecology and wetland management to comprehend, preserve, and recreate these vulnerable ecosystems (Mitsch et al. 2009). Development of wetlands entails the interaction between living (animals and plants) and non-living components of the habitat (water, chemical, particles and rock). Collectively, the living and non-living elements co-exist as an integrated ecosystem (Fig. 7.1).

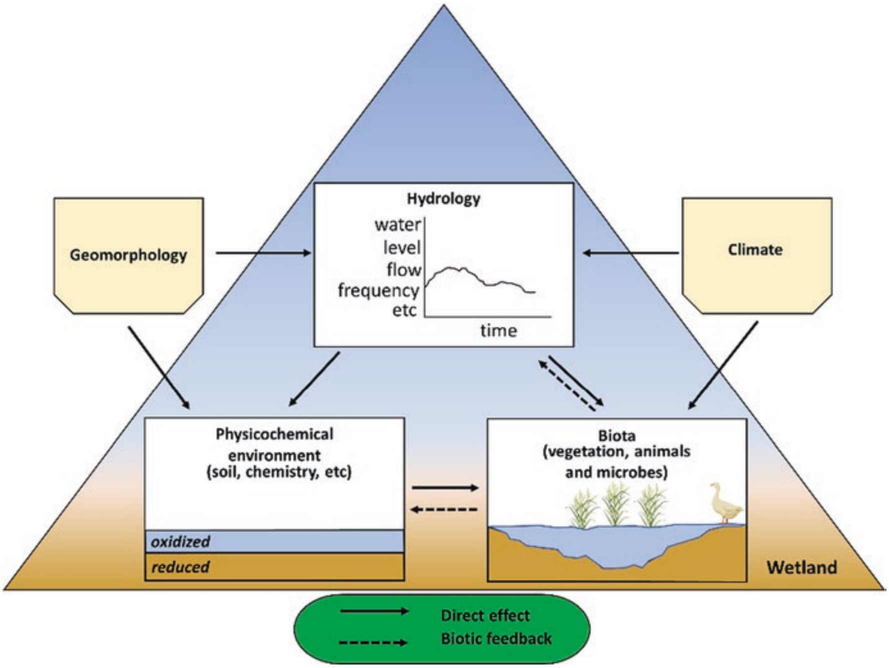

Fig. 7.1 Living and non-living components of an ecosystem working together to form a wetland (Mitsch et al. 2009)

7.2 Hindu Kush-Himalaya

The Hindu Kush-Himalayan (HKH) region covers an area greater than four million km^2 (Gurung et al. in preparation), approximately 18% of the global mountain areas and almost 2.9% of the global land area. These gigantic mountain ranges contain the world's largest peaks, including K2, Mount Everest, Lhotse, Kangchenjunga, Makalu, Cho Oyu, Annapurna and Dhaulagiri, and the headwaters of the ten foremost river systems, including Brahmaputra, Amu Darya, Ganges, Indus, Irrawaddy, Mekong, Yangtze, Yellow, Salween, and Tarim. In addition, these mountain regions support the livelihood of 210 million inhabitants while providing services and goods for 1.3 billion people residing downstream. Collectively, around three billion people benefit from food and energy yielded by the river basin. The HKH region includes China, Pakistan, India, Bangladesh, Myanmar, Afghanistan and all of Nepal and Bhutan (Fig. 7.2).

The land cover throughout the HKH region comprises 54% rangeland and scrubland, 25% agricultural land (including areas with a mixture of natural vegetation), 14% forest, 5% permanent snow and 1% water bodies. The water bodies of the Himalaya consist of rivers, lakes and wetlands of various shapes and sizes, making

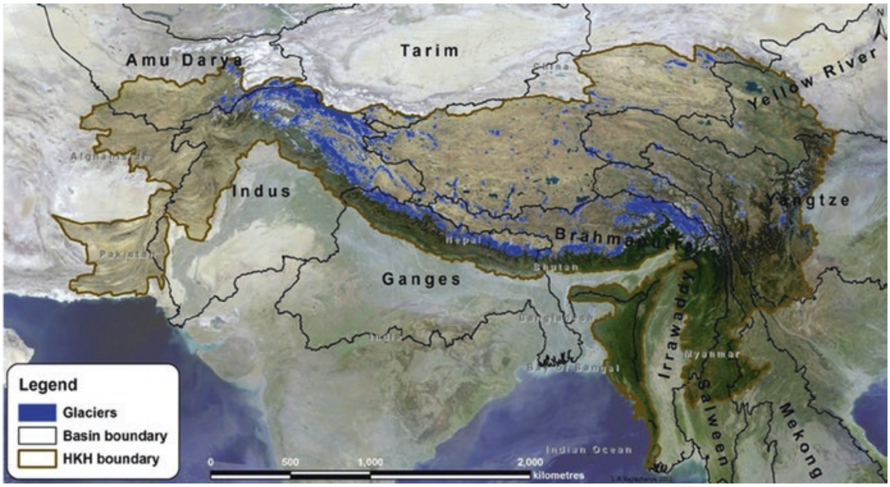

Fig. 7.2 Regions included in the HKH and Major river basins

it an ecosystem that fulfils a crucial function in the overall water cycle of the basins. Wetlands and lakes have received little attention in terms of water management and conservation; however, they are receiving more attention owing to their importance due to the probable consequences of global climate change. Table 7.1 shows some of the international important wetlands/regions, including those in the HKH.

7.3 Wetland Types

Wetlands differ among themselves in chemical, biological, hydrological and sedimentation characteristics, as well as in in size and shape. Table 7.2 represents all types of wetlands that exist among the HKH countries. Numerous classification schemes have been employed in distinct regions (Finlayson and Van der Valk 1995). US Fish and Wildlife Service divide wetlands into two basic groups: freshwater and saltwater. Freshwater wetlands include marshes (prairie potholes, wet meadows, playa lakes, vernal pools), swamps (mangrove, shrub, forested), and bogs (common, fen, pocosin), while saltwater wetlands include tidal marshes and mangrove swamps. Estuarine/coastal wetlands account for 10% of the global wetlands, whereas freshwater wetlands make up the remaining 90%. The Ramsar convention primarily implemented a simple classification that identified 22 wetland types (Table 7.3) but was revised later to recognize more groups.

Table 7.1 Some internationally important Wetlands/regions of the Hindu Kush-Himalaya (Boere et al. 2006; Gujja 2007; Jha 2009; Byomkesh et al. 2009; Gopal et al. 2010; Sherab et al. 2011; Tan et al. 2011; Li et al. 2014; Khan and Arshad 2014; Uddin et al. 2015; Zhu et al. 2015; Meng et al. 2017; Paudel et al. 2017; Qamer et al. 2008)

Afghanistan	
Himalayan regions	1. Pamir-i-Buzurg (wakhan) 2. Imam Sahib (kunduz) 3. Khulm, Ajar (Baghlan) 4. Nursitan, band-i-amir (Bamiyan) 5. Ab-i-Estada (Ghazni) 6. Ab-i-nawar (Dasht-i-nawar)
Ramsar sites	N.A.
Altitude	2000–4800 m
Total area/total number of wetlands	N.A.
Bangladesh	
Himalayan regions	1. Sundarbans mangrove wetlands 2. Chandabill-baghiar bill 3. Bildakatia, Atadanga Boar 4. Marijat Baor (Ganges Delta)
Ramsar sites	2
Wetlands type	Mangrove wetlands, Oxbow lakes
Total wetlands/total area	Number: NA Area: 7–8 million (ha)
Bhutan	
Himalayan regions	1. Torsa (Amo Chu) 2. Raidak (Wong Chu) 3. Sankosh (Mo Chu) 4. Manas (Gangri) 5. Phobjikha 6. Khalong Chu 7. Jigme Darji wildlife sanctuary
Ramsar sites	3
Total area/total number of wetlands	Number: 3027 Area: 10,200 ha Glacial lakes: 2674 (2000–4500 m) and 60 (3500 m)
China	
Himalayan regions	1. Tibet autonomous region {Pumqu (Arun) 2. Poiqu (Bhote-Sun Koshi) 3. Rangxer (Tama Koshi) 4. jilongcanbu (Humla karnali)} 5. Yunnan region (Bitahai and Napahai wetland) 6. Zoige 7. Sichuan 8. Yangzte 9. Mekong 10. Salween 11. Namucuo lake 12. Yanzongyongcuo lake 13. Lhasa
Ramsar sites	57
Average altitude	4500
Total area/total number of wetlands	Number: NA Area: 53.42×10^6 ha Glacial lakes: 824

(continued)

Table 7.1 (continued)

India	
Himalayan regions	1. Tripura 2. Meghalaya 3. Assam 4. Arunachal 5. Nagaland 6. Manipur 7. Mizoram 8. Darjeeling 9. Jalpaiguri 10. Coochbehar 11. Sikkim 12. Ladakh 13. Hokar Sar wetland
Ramsar sites	26
Total wetlands/total area	Natural: 67,429 (lakes, marsh, ponds, reservoirs and oxbow lakes, tanks) Area: 4.1 million (ha)
Myanmar	
Himalayan regions	1. Irrawaddy-Chindwin 2. Sittaurg 3. Salween
Ramsar sites	5
Total wetlands/total area	Numbers: 99 (lakes, marsh, ponds, reservoirs and paddy fields) Area: N.A.
Nepal	
Himalayan regions	1. Terai region (Koshi Tappu Wildlife Reserve) 2. Shey Phoksundo 3. Lake Rara 4. Lake Tilicho 5. Khumbu Himal region 6. Gokyo lake 7. Phuksundo 8. Gosaikunda lakes 9. Dhaap lake 10. Beeshazar lakes 11. Pokhara (8 lakes)
Ramsar sites	10
Total wetlands/total area	Number: 242 Area: 7,43,563 ha Glacial lakes: 2323 lakes (above 3000 m) and 90 lakes (4, 500 and 5645 m)

(continued)

Table 7.1 (continued)

Pakistan	
Himalayan regions	1. Sheosar lake (4250 m) (deosai) 2. Saucher lake 3. Karumbar lake (deosai, 4150–4250 m) 4. Rupal (shaigiri) 5. Mankial lake 6. Swat, jabba (falak sher) 7. Lulusar wetland complex 8. Uttar lake 9. Handrap
Ramsar sites	19
Altitude	4200
Wetland types	Inland, delta marshes, mangroves, lakes, reservoir, paddies
Total area/total wetlands	Number: 225 Area: 189,089.4 (ha)

7.4 Value of Wetlands

The wetlands are characterized by huge biodiversity and beautiful landscapes. Regardless of any importance, everyone wants to know "what use it provides?" However, there is no difficulty in demonstrating the worth of wetlands. People ascribe 'value' to many ecosystem functions, where functions are the product of the relations among the biological, chemical and physical elements of the wetlands. Instant, primary or secondary functions are important since they provide products such as fiber, food, fuel, timber and fodder. The Ramsar Convention stated that these functions and values are "products, functions and attributes" while the Millennium Ecosystem Assessment (MEA) mentioned "the assistance people gain from ecosystems" or simply "ecosystem services" (MEA 2005) and divided them into four categories: (a) providing services such as food and water; (b) controlling services such as regulations of land degradation, disease, flood and drought; (c) assisting services such as nutrient cycling and soil formation; and (d) social services such as spiritual, recreational, religious and additional non-material benefits (Table 7.4). In general, the value of Himalayan wetlands relies on their characteristics, location and the economic and socio-cultural status of the peoples nearby. Many glacial lakes at these high altitudes are considered to be a rich source of water along with headwaters of various rivers. Moreover, wetlands, the rivers to be precise, in the Himalayan region are important for their hydropower potential (Agrawal et al. 2010). Most of the glacial lakes and accompanying marshes and additional high-altitude wetlands are principal habitats of many wildlife species such as migratory waterfowl and cold-water fish. Some of these lakes, e.g. Lake Tsomgo and Lake Guru Dongmar in Sikkim, are also sacred according to local communities (Gopal et al. 2008). However, at middle and lower altitudes, wetlands are usually valued for their provisioning services—forage for wildlife and domestic animals and fish for human

Table 7.2 Types of wetlands in the Hindu Kush-Himalaya

Country	Types of wetlands	Reference
Afghanistan	HAW, Lakes, Rivers and Marshes	Bridge et al. (2006)
Bangladesh	HAW, Lakes, Mangroves, Back-swamp (Haor), Oxbow (Baors), Paddy fields and rivers etc.	Islam and Gnauck (2008), Byomkesh et al. (2009)
Bhutan	HAW, Alpine wetlands, Paddy terraces, water bodies, Alpine marshes, Bogs, Riverbeds, Perpetual Snow cover, Rivers (chu) etc.	Sherab et al. (2011)
China	HAW, Alpine wetlands, Mires, Lakes, Paddy fields, Inland Marshes/Swamps, Snow Covers, Glacial lakes, Peat lands etc.	Zhao and He (n.d.), Meng et al. (2017)
India	HAW, Glacial lakes, Mangroves, Swamps, Peat lands, Coastal lagoons etc.	SAC (2013), Bassi et al. (2014)
Nepal	HAW, Lakes, Ponds, Marshes, Swampy lands, Paddy fields etc.	Jha (2009), Bhandari (2009)
Pakistan	HAW, Lakes, Paddy fields, Mangroves, Delta marshes etc.	Qamer et al. (2008), Asad and Sana (2014)
Myanmar	HAW, Lakes, River Basin, Marshes, Mangroves, Paddy fields etc.	"Ye Htut Deputy Director Nature and wildlife Conservation Division I. Water is Life: Too Much or Too Little, Every Drop Counts," (2013)

HAW high altitude wetlands

consumption. It is believed that most of the local communities depend on these wetlands (Barik and Katiha 2003). The efficient output of swamps, marshes, and streams are evident that these wetlands harbor huge amount of nutrients and act as significant systems for household waste discharged into the rivers prior to treatment.

7.5 Wetland Losses and Consequences

Globally, 1052 sites in Europe; 359 sites in Africa; 289 sites in Asia; 211 sites in North America; 175 sites in South America; and 79 sites in the Oceana region have been recognized as Ramsar sites or wetlands of International prominence (Ramsar Convention Secretariat 2013). Wetlands are vital to the livelihoods of almost 250 million people residing on the valley floors and plateau areas of the Himalayas (Trisal and Manihar 2004). The environmental meanings and amenities of the Himalayan wetlands in controlling river drifts and maintaining grasslands are indispensable for more than 10 countries in Asia. Furthermore, these countries have about 140 million people residing in high-altitude areas and 1.3 billion people downstream of the river basins (Xu et al. 2009).

Table 7.3 Ramsar classification system for natural and artificial wetlands (Ramsar 2006)

Types	Examples
Inland wetlands	
Permanent inland deltas	N.A.
Permanent rivers/streams/creeks	waterfalls
Seasonal/intermittent/irregular rivers/streams/creeks	N.A.
Permanent freshwater lakes (over 8 ha)	Large oxbow lakes
Seasonal/intermittent freshwater lakes	Floodplain lakes
Permanent saline/brackish/alkaline lakes	N.A.
Seasonal/intermittent saline/brackish/alkaline lakes and flats	N.A.
Permanent saline/brackish/alkaline marshes/pools	N.A.
Seasonal/intermittent saline/brackish/alkaline marshes/pools	N.A.
Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent, vegetation water-logged for at least most of the growing season	N.A.
Seasonal/intermittent freshwater marshes/pools on inorganic soils	Sloughs, potholes, seasonally flooded, meadows, sedge marshes
Non-forested peatlands	Shrub or open bogs, swamps, fens
Alpine wetlands	Alpine meadows, temporary waters from snowmelt
Tundra wetlands	Tundra pools, temporary waters from snowmelt
Shrub-dominated wetlands	Shrub swamps, shrub-dominated freshwater marshes, shrub, alder thicket on inorganic soils
Freshwater, tree-dominated wetlands	Freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils
Forested peatlands	Peat swamp forests
Freshwater springs	Oases
Geothermal wetlands	
Karst and other subterranean hydrological systems	Inland
Human-made wetlands	
Aquaculture	Fish/shrimp ponds
Ponds	Farm ponds, stock ponds, small tanks (generally less than 8 ha)
Irrigated land	Irrigation channels and rice fields
Seasonally flooded agricultural land	Intensively managed or grazed wet meadow or pasture
Salt exploitation sites	Salt pans, saline
Water storage areas	Reservoirs/barrages/dams/ impoundments (generally greater than 8 ha)
Excavations	Gravel/brick/clay pits; borrow pits, mining pools
Wastewater treatment areas	Sewage farms, settling ponds, oxidation basins
Canals and drainage channels, ditches	N.A.
Karst and other subterranean hydrological systems	Human-made

Table 7.4 Value and services of wetlands (Millennium Ecosystem Assessment 2005)

Services	Examples
Provisioning	
Food	Fish, wild game, fruit, and grain
Freshwater	Storage and retention of water for domestic, industrial, and agricultural use
Fibre and fuel	Production of logs, fuelwood, peat, and fodder
Biochemical	Extraction of medicines and other materials from biota
Genetic materials	Genes for resistance to plant pathogens, ornamental species, and so on
Regulating	
Climate regulation	Source of and sink for greenhouse gases; influence on local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows)	Groundwater recharge and discharge
Water purification and waste treatment	Retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	Retention of soils and sediments
Natural hazard regulation	Flood control and storm protection
Pollination	Habitat for pollinators
Cultural	
Spiritual and inspirational aspects of wetlands	Source of inspiration; many religions attach spiritual and religious value to wetlands
Recreational	Opportunities for recreational activities
Aesthetic	Many people find beauty or aesthetic value in wetland ecosystems
Educational	Opportunities for formal and informal education and training
Supporting	
Soil formation	Sediment retention and accumulation of organic matter
Nutrient cycling	Storage, recycling, processing, and acquisition of nutrients

Human activities and climate change have resulted in degradation of many wetland environments in the Himalayas (Erwin 2009). As a consequence, loss of vegetation cover and degradation of wetlands expose the soil surface which ultimately increases CH_4 emission into the atmosphere (Melton et al. 2013), hence influencing global climate. Studies over the past 50 years attributed people for changing ecosystems more rapidly than in any parallel period. Summary of a recent conclusion of Working Group II of the Intergovernmental Panel on Climate Change forecasted that "if existing warming rates are continued, Himalayan glaciers possibly decay at very prompt rates, decreasing from the current 500,000 square kilometers to 100,000 square kilometers by 2030s." Shrinking of glaciers, reducing water flow in rivers, gradual rain failure during monsoons, hefty and unpredictable rain in shorelines and climate fluctuations are some examples of the climate change predicted under the Indian Prospective (Thomas et al. 2007). Amidst the innumerable factors cited as influencing the changes in wetland, land use has been categorized as the sole factor accounting for their degradation in the western Himalayas. In addition, serious loss has also been related to unplanned urban sprawl, unregulated agricultural development and inflow of fertilizers, silt, solid waste and pesticides into the wetland.

Hokar Sar is in the Doodhganga watershed of the western Himalayas in the extreme northern part of Indian occupied Kashmir, where it plays a significant role in the overall water cycle of the basin. This wetland is also a wildlife reserve and was named as a Ramsar site in 2005. Current studies have suggested that this wetland is under serious threats regarding land cover use and climate change. Based on the China National Land Cover Database, from 1990 to 2010, China lost 2883 km^2 of wetlands to urbanization, of which approximately 2394 km^2 were in the eastern regions (North China, Northeast China, South China, and Southeast China). Overall, four urbanization-induced wetland losses in China were recognized, including the Qinghai Tibetan plateau, Yangtze river delta, one of the important Himalayan regions of China (Mao et al. 2018). Similarly, threats to Nepal's wetlands can be broadly classified as habitat degradation and destruction, loss of environmental integrity and reduction of species abundance and diversity.

With a population of nearly 30 million people, Nepal has a growth rate of 2.5% per year. About 81% of the population depends on agriculture, and consequently the conversion of wetlands to agricultural land, specifically to paddy fields, will continue to rise, exerting more pressure on wetlands. Various other factors such as disposal of untreated industrial effluents, use of agro-chemicals for high value crops, construction of dams thus inundating important habitats; disturbance of nutrient dynamics, reduction of downstream water flow and alteration of local microclimates are some the issues which need to be addressed by Nepal.

7.6 Insight into Wetlands

A group of individuals of the same species collaborating is called a population while organisms interacting with other living organisms belonging to different species, is called a community. A community interacting with the non-living world is called an ecosystem**.** Generally, all ecosystems have a pattern of energy flowing through them. Sunlight, which is utilized mostly by plants for photosynthesis, is the basic source of energy for most ecosystems. However, there are certain microorganisms which photosynthesize, while others acquire energy from non-solar sources by reacting with inorganic materials, for example the oxidation of iron.

Based on this energy flow, we can identify groups of organisms which have distinct roles. Plants, being the primary producers, fix solar energy into organic matter; and are autotrophic, which means they can make their own food. Herbivores are primary consumers; depending on plants for energy. Predators are categorized in the heterotrophic group as they rely on plants indirectly, feeding on herbivores or animals that consume herbivores. They are referred to as secondary and tertiary consumers. They are listed in different spots in a hierarchy of feeding, occasionally regarded as a food web in the ecosystem. The waste products of living organisms and dead parts/left-overs which remain unconsumed by predators are utilized by decomposers. Decomposers of the ecosystem are mostly bacteria and fungi, which consume all the energy-rich materials that remain. Energy remains constant—nothing is wasted, nothing is lost. Energy entering the ecosystem is consumed and is released as heat during respiration. Chemical elements are recycled as the energy flows through the ecosystem.

At a glance, the carbon atoms (gaseous form CO_2) that are taken up by plants are fixed either into carbohydrates or fats or converted into other compounds by incorporating elemental nitrogen (soil), or possibly modified into other forms by the addition of phosphorus to synthesize phospholipids. Animals in turn consume the biomass stored in plants and eliminate a proportion as waste. Respiration releases carbon back into the atmosphere as CO_2 gas, whereas nitrogen and phosphorus along with other elements are returned to the soil through the process of decomposition. Hence, they are recycled and can be utilized again. This rotating wheel of element motion is known as a nutrient cycle.

Many different types of wetlands exist, each of which can be regarded as an ecosystem, with its own pattern of energy flow and nutrient cycle. Wetlands have many features in common which make them different from other ecosystems. The most evident feature is their water, which influences the pattern of energy flow and storage. The foremost barrier posed by the water is the low availability of oxygen. Every organism, except for some fungi and bacteria, requires oxygen to respire. The energy trapped in the organic compound upon which they feed can only be retrieved if oxygen is available, as they convert sugars into CO_2.

The supply of oxygen is abundant in air (~21%) while it decreases under water, as it dissolves. Therefore, fast flowing streams might be rich in dissolved oxygen, whereas in still water, oxygen relies on the course of diffusion where the molecules flow from high density to regions of low density. Diffusion of oxygen molecules follows from the surface layers, where water interacts with air, descending deeper, where oxygen is utilized by the decomposers at the bottom layer of wetlands. However, oxygen diffuses about 10,000 times more slowly in water as in air, thus oxygen consumed by the respiration of organisms in still water is replaced very slowly. The slow diffusion of dissolved oxygen results in the incomplete decomposition of dead organic matter. Generally, all residual matter of the ecosystem that enters the soil is ultimately decomposed and is lost, but in the case of wetlands, the slow decomposition may create an imbalance in the flow of energy, hence developing a layer of energy-rich organic matter deposited in the sediments of the ecosystem.

Due to this imbalance, wetlands appear as a "sink" for atmospheric carbon and as an aid in the assimilation of carbon released by the combustion of fossils fuels. Considering that wetlands form through the process of succession, the energy pool within the sediments increases, and this is the foundation of the growing mass of peat in bogs. It is important to mention that most of the energy does not recycle, but often follows a complicated route through an ecosystem, which ecologists have termed food webs instead of food chains. It must also be noted that energy is reduced as it travels through the ecosystem, as some of the energy is absorbed, hence only 10% of the energy (in aquatic environment) present at one feeding level (known as trophic level) is passed to the next level. The remainder is handled by detritivores and decomposers.

Decomposition occurs mostly in the surface layers of peat and sediments, where oxygen diffuses easily. The upper, loosely compacted layer of the peat deposit, where movement of water and decomposition occur rapidly, is termed as acrotelm, while the deeper layer, where decomposition and movement of water is comparatively slow, is termed as catotelm. Poor oxygen diffusion under water and waterlogging are, apparently, the key factors in regulating the rate of decomposition; however, some materials are less palatable to fungi and bacteria then other materials. In summary, the atmosphere is common to all terrestrial ecosystems, thus offering a medium through which elements can shift from one ecosystem to another.

Looking at elemental shifts, carbon is one element that is obtained from the atmosphere by plants for building biomass. Importantly, it is said to be the critical element for all living organisms, as almost all energy transfer and storage encompass compounds built utilizing carbon atoms. Wetlands and carbon are discussed in synchrony, as wetlands act as “sinks” for atmospheric carbon. Moreover, it also enters the ecosystem in a dissolved form in rainfall and rivers or streams. This dissolved CO_2 is made available for photosynthesis by phytoplankton and submerged aquatic plants. Other means of carbon entry into the wetlands is via hydrogen carbonate ions, HCO_3^-. This may have originated from carbonic acid, by the chemical reaction of CO_2 with water, or from lime (calcium carbonate) dissolving in water. Aquatic plants of the wetlands can once more utilize this hydrogen carbonate ion for photosynthesis. Most of the carbon fixed by photosynthesis is lost in respiration, while some is deposited in the sediments that accumulate, particularly in the peat deposits of the temperate bogs.

Current dilemma concerns the entry of carbon into the atmosphere in that about 5.5 billion tons of carbon enters the atmosphere every year due to human combustion, of which over half remains in the atmosphere, increasing every year and causing climate change. Eventually, some is recruited by forests and some is dissolved in oceans. There is a “missing sink” for carbon that has yet to be identified. The absorption of carbon by peat land is probably a portion of this sink for atmospheric carbon. Peat deposits grow slowly, so the total carbon taken up is limited, yet every carbon sink is the key in precluding the buildup of CO_2 in the atmosphere.

7.7 Carbon Sink and Gaseous Emissions

Predominant biogeochemical processes aid wetlands to be one of the most important carbon reservoirs, accumulating approximately 20–30% of the global carbon pool. Carbon deposits in the wetland sediments are very sensitive to environmental changes such as in temperature, flood, microbial activity and nutrient regime. The wetlands provide a major source of carbon. Especially greenhouse gasses (GHG) such as CH_4, CO_2 and nitrous oxide (N_2O) (Mitra et al. 2005).

From 1750 to 2011, the amount of CO_2 increased from 278 to 390.5 ppm, N_2O from 271 to 324.2 ppb and CH_4 from 722 to 1803 ppb (IPCC 2013). "Wetlands contain 12% of the global carbon reservoir with a carbon density of 723 t ha^{-1} (Mitra et al. 2005), storing nearly 2500 Pg 1 Pg = 10^{15} g) of the earth's carbon pool" (Mitsch et al. 2013). The main carbon pool of wetlands includes: (a) particulate organic carbon; (b) plant biomass carbon; (c) dissolved organic carbon; (d) gaseous end products such as CO_2 and CH_4; and (e) microbial biomass carbon. Plant remnants are the major organic matter in the wetlands, comprising 45–50% of carbon (Kayranli et al. 2010), where it goes through a series of complex aerobic and anaerobic processes. The main aerobic processes entail respiration while the main anaerobic processes undergo fermentation, methanogenesis and sulfate, iron and nitrate reduction.

The wetlands function as a carbon sink, but they also contribute substantial GHG emissions (Mander et al. 2014). Among all GHGs, CH_4 is considered the most prominent and potent gas in terms of global warming. Methane is the product of methanogenesis in anoxic environments and low redox potential of ≤150 mv by transmethylation or decarboxylation of acetic acid and by the reduction of CO_2 (Segers 1998; Singh et al. 2000), whereas, N_2O is the net result of: (a) nitrate or nitrite-reducing processes of denitrification; (b) nitrate ammonification; (c) ammonia oxidation; and (d) nitrifier denitrification (Baggs 2011). The escalation of the GHGs is possibly the main cause of the rise in ocean and land surface temperatures.

Being one of the most significant GHGs exchanged amidst terrestrial ecosystems and the atmosphere, CH_4 as compared to CO_2 has 28 times more global warming potential on a 100-year time horizon (IPCC 2013). Therefore, any change in atmospheric CH_4 concentration can contribute to significant climate impacts because of strong greenhouse effects (Bridgham et al. 2013). Currently, worldwide atmospheric CH_4 concentration is about 1810 parts per billion (ppb), a rise of over 1000 ppb since pre-industrial level (Myhre et al. 2013). Hence, increases in atmospheric concentration of CH_4 have prompted significant interest in calculating CH_4 emission from various sources.

Studies have revealed that CH_4 fluctuations are associated to biological (plant life cycle related with microbes) and physical (wind, temperature and water table) variables at various temporal and spatial scales (Song et al. 2015). However, there remain large uncertainties while estimating future and current CH_4 emission from wetlands for many reasons. Until now, many studies on CH_4 fluxes have focused largely on high-latitude wetlands, since these wetlands store vast amounts of carbon in waterlogged sediments.

The HKH contain most of the high-altitude wetlands, and there is a paucity of research on these wetlands, especially in remote areas. Most of the studies on Himalayan wetlands were carried out by Chinese and Nepalese researchers. Hirota et al. (2004) measured CH_4 emission from the Luanhaizi alpine wetlands in four vegetation zones on the Qinghai-Tibetan Plateau: three emergent plant zones, including *Hippuris*-dominated, *Scirpus*-dominated and *Carex*-dominated zones and one submerged zone, *Potamogeton*-dominated. The study revealed that the lowest

CH_4 flux (seasonal mean was 33.1 mg CH_4 m^{-2} day^{-1}) was observed in the *Potamogeton*-dominated zone while the highest CH_4 flux (seasonal mean was 214 mg CH_4 m^{-2} day^{-1}) was in the *Hippuris*-dominated zone (Hirota et al. 2004). Similarly, CH_4 fluxes were also calculated in regions such as Maduo (Qinghai), Hongyuan (Sichuan) and Zoige (Qinghai) (Table 7.5).

Changes in CH_4 emission were mostly due to variation in vegetation, seasons and type of wetlands. A recent study compared Beeshazar and Dhaap, two wetlands located in the southern slopes of Himalayan Nepal, for day-time based CH_4 emission (Zhu et al. 2015). The authors correlated plant community height, standing water depth and soil temperature to CH_4 emission from these wetlands. They suggested that their findings could be valuable in filling the gap and in generating the emission pattern of CH_4 at regional and global scales. Sundarbans mangroves are the largest biosphere reserves in the world, which stretches over 1000 km^2 covering West Bengal, India and Bangladesh. During the summer season, the mean concentration of CH_4 was 1682 ppb while the daily CH_4 flux was 150 mg m^{-2} day^{-1}. Many studies have suggested that the global warming status of Himalayan wetlands and the specific quantification of CH_4 from these regions are not fully understood and need more research data.

7.8 Conclusion and Recommendations

The HKH region is home to various types of wetlands and the services they provide are essential for people as well as the environment. They also act as reservoirs for carbon in their biomass, peat, sediment and litter. They pose a serious threat to the environment by emitting GHGs, especially CH_4. Wetland loss due to commercial development, extraction of minerals and peat, intensive agriculture, drainage schemes, pollution, construction of dams, over-fishing and tourism are causing serious damage to the wetland ecosystem. These threats have affected the overall biogeochemical cycle and biodiversity and have caused rising floods and droughts, nutrient runoff, water pollution and mounting global warming.

To maintain the wetlands, several organizations are focusing to conserve and manage these water bodies and relieve the environmental pressure. In this regard, the WWF (World Wildlife Fund) has initiated projects such as the conservation of high-altitude wetlands. The project has produced socio-economic, technical, scientific and biodiversity related information which is being utilized to protect and conserve these unique places in the interest of local communities and biodiversity. The organization is also working with Ramsar for collecting scientific information essential for wetland management. ICIMOD (International Center for Integrated Mountain Development) aims to assist sustainable and resilient mountain development for better livelihoods via knowledge and regional cooperation. However, most of the structural policies have led to the implementation of countrywide plans that were not particularly designed for mountain people.

Table 7.5 Studies on methane emission from wetlands located in the HKH

Location	Wetland type	Measurement period	Season	Vegetation	Methane emission mg CH_4 m^{-2} day^{-1}	Reference
China						
Luanhaizi, Qinghai	Peatland	4 Jul.–15 Sep. 2002	N.A.	Carex allivescer	196	Hirota et al. (2004)
				Scirpus distigmaticus	99.5	
				Hippuris vulgaris	214	
				Potamogeton pectinatus	33.1	
Maduo, Qinghai	Peatland	27 Jul.–8 Aug. 1997	N.A.	Kobresia humilis	1.01–147	Jin et al. (1998)
				Hippuris vulgaris	–4.38 to 2.81	
				Kobresia tibelica	12.9–88.8	
				Kobresia humilis	3.82–10	
				Batrachium trchophyllum	3.58–18.8	
				Kobresia humilis	–6.49 to 75.6	
				Batrachium trchophyllum	–19.4 to 63.3	
				Hippuris vulgaris	–5.76 to 188	
				Carex muliensis	–4.39 to 347	
				Batrachium trchophyllum	0.28–23.9	
Hongyuan, Sichun	Peatland	May–Oct. 2001	N.A.	Carex muliensis	12.2–197	Ding et al. (2004)
				Carex meyeriana	8.64–241	
		May–Oct. 2002		Carex muliensis	3.84–138	
				Carex meyeriana	20.6–214	
Zoige, Qinghai	Alpine	2011	N.A.	Kobresia littledalei	144.3 μg m^{-2} h^{-1}	Wei et al. (2015)
				Carex moorcroftii	67.6 μg m^{-2} h^{-1}	

Zoige, Qinghai	Natural Peatland	2013	N.A.	Potamogton pusittus	19.13 mg m^{-2} h^{-1}	Zhou et al. (2017)
	Drained peatland			Utricularia vulgaris	0.14 mg m^{-2} h^{-1}	
Nepal						
Beeshazar Lake, Chitwan National Park	Freshwater lake	June 10th, 2013	Monsoon season	Kans grass	4.46 ± 4.80	Zhu et al. (2015)
				Water pepper	11.45 ± 6.29	
		December 31st, 2013	Dry season	Kans grass	2.43 ± 5.18	
				Water pepper	1.13 ± 3.68	
Dhaap Lake, Shivapuri-Nagarjun National Park	Freshwater lake	July 23rd, 2013	Monsoon season	Water moss	0.44 ± 0.71	
				Sweet flag	1.60 ± 1.39	
		January 21st, 2014	Dry season	Water moss	0.40 ± 0.90	
				Sweet flag	0.12 ± 0.31	
India (West Bengal)						
Sundarbans	Mangrove	April-May, 2012	NA	NA	150.22 ± 248.87	Jha et al. (2014)

Consequently, the HKH mountain region lags behind in conservation-linked management. Conservation is just not placing fences around areas and keeping people and livestock out. The local people must get involved with organizations and management to conserve biodiversity. Such conservation and management must be based on a combination of literature surveys, workshops, field research and incentive mechanisms to know how these wetlands function and to meet the challenges of climate change, mainly in relation to adaptation, biodiversity conservation and restoration of wetlands as carbon reservoirs in the HKH.

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