land

MDPI

Editorial

# Editorial for Special Issue "Socio-Economic Impacts of Carbon Sequestration on Livelihoods and Future Climate"

**Amit Kumar [1,*], Munesh Kumar [2,†] and Marina Cabral Pinto [3,†]**

1 School of Hydrology and Water Resources, Nanjing University of Information Science & Technology, Ningliu Road No. 219, Nanjing 210044, China
2 Department of Forestry and Natural Resources, HNB Garhwal University, Srinagar-Garhwal 249161, Uttarakhand, India; muneshmzu@yahoo.com
3 GeoBioTec, Department of Geosciences, Campus de Santiago, University of Aveiro, 3810-193 Aveiro, Portugal; mcp@uc.pt
* Correspondence: amitkdah@nuist.edu.cn
† Authors contributing an equal share.

check for updates

**Citation:** Kumar, A.; Kumar, M.; Cabral Pinto, M. Editorial for Special Issue "Socio-Economic Impacts of Carbon Sequestration on Livelihoods and Future Climate". *Land* **2022**, *11*, 51. https://doi.org/10.3390/land11010051

Received: 22 December 2021
Accepted: 29 December 2021
Published: 30 December 2021



In the modern era of industrial revolution, urbanization, and deforestation of forest land, carbon (C) sequestration through well-known activities called "land use, land-use change and forestry (LULUCF)" could establish a win–win situation from a climate change and sustainable development perspective [1]. Equally important are the socio-economic co-benefits of C sequestration, given their implications on properly designed policies especially on restoration and/or conservation of forests located in the tropical eco-regions. Further, the huge contribution of C sequestered in the vegetation and its underlain soil helps to protect socio-economic damages from climate change [2]. The literature suggests that a spatial relationship between types of vegetation, C sequestration, and its dynamics are urgently needed to estimate their socio-economic benefits [3]. However, it is crucial to design this activity for environmentalists, foresters, policymakers, etc., due to the inadequate availability of data, the methodologies used to predict the baseline values of C stocks, and the inadequate facilities used to assess the broader environmental and socio-economic effects. These key challenges are robust and need to be integrated with livelihood costs, benefits, and carbon trade-offs [4].

In the past two decades, the Himalayas are vulnerable to LULC change and climate change, from both ecological and socio-economic perspectives [2,5]. In the scientific fraternity, numerous efforts have been carried out to increase the C storage, particularly in the Himalayan range. However, the presence of vegetation biomass and its underlying soils is beneficial for ecosystem functions and services, assisting in the provision of adaptation and maintenance of natural resource-based livelihoods [6]. The planned adaptation can reduce the impacts of climate change and further overcome the risk of key vulnerability but is found to be scarce or costly [7]. Mitigation measures to reduce greenhouse gas (GHG; particularly $CO_2$, $N_2O$, and $CH_4$) emissions in advance will diminish the potential risk associated with most key vulnerabilities [8]. Usually, soil enriched with soil organic carbon (SOC) could help to improve the soil's structure, fertility and ecosystem services, ecological health, and water-holding capacity [9]. The decomposition of organic matter (OM) by microbes (aerobically and/or anaerobically) provides direct benefits through the biogeochemical cycle and maintains the fertility status of the soil [10]. Proper land-use management practices, when adopted in advance, could increase the carbon stock (vegetation and soil) and further help with climate change mitigation. However, a trade-off exists as, to realize the benefits to livelihood and ecosystem services that can be derived from SOC, it must be depleted through extensive crop production resulting from a net release of carbon dioxide [11]. Additionally, the trade-offs between these goals must be identified. These represent key challenges in the modern era [12].

Generally, carbon enters the terrestrial ecosystem by the process of photosynthesis in green plants, which assimilate carbon dioxide ($CO_2$) and fix into organic forms, such as SOC and inorganic carbon (SIC) pools, before subsequently returning to the atmosphere [5]. All these activities depend on the fertility status of the soil, its climate, and its management operations [2,11]. Carbon sequestered in soil systems is determined based on: (i) the input rate of OM and its decomposition rate; (ii) the physical protection of either intra-aggregate and/or organo-mineral complexes; and (iii) the soil depths at which the organic carbon (OC) is placed. The carbon of plants in the SOC pool enters either through above-ground litter or root material and is further consumed by herbivores and their excreta. It then enters into the SOC pool. Further, fragments of plants change into small particulate OM fractions in the soil. The literature revealed that a large proportion of the carbon that enters the soil through various sources returns to the atmosphere through the respiration activities [13] carried out by both microbes and root systems ($CO_2$ efflux falling in the range of from 16 to 95%). Trumbore [14] stated that assessments of autotrophic and/or heterotrophic respiration in the soil system are difficult. Apart from this, Ghosh and Maiti [15] carried out work on coal mining and its vicinity and suggested that open-cast coal mining usually caused a complete loss of C-sink potential due to the destruction of vegetation and soil systems, and thus increased C sequestration potential by restoring the mine spoils area. The mechanism of afforestation activities is widely accepted.

In general, global carbon (C) is categorized into five large pools, where biotic carbon (550 Pg; Pg denotes petagram = $10^{15}$ g) contributes the minimum share [16], followed by atmospheric (800 Pg), soil-based (950 Pg in SIC and 2,460 Pg in SOC), geologic carbon (5000 Pg), and maximum by oceanic carbon (38,000 Pg) [17]. It is estimated that annually 9 Pg of carbon is released into the atmosphere due to industrial activity and the burning of fossil fuels. Similarly, about 1.5 Pg C was released due to changes in land use and deforestation [18]. However, each year, 60 Pg C is exchanged between terrestrial ecosystems and the atmosphere, which will become important in the next few decades, allowing one to buy time while new C-saving, -capture, and -sequestration technologies are being developed [19]. In the global context, soils contain 1500 Pg of SOC at depths of up to 1 m, which is two times that of atmospheric carbon. It is also estimated that 160 Pg of OC is stored in the soils of agricultural croplands worldwide [20]. In a meta-analysis, the long-term use of native forest and pastureland for agricultural productions usually reduced SOC stocks to 42% and 59%, respectively. It is also suggested that if improved agricultural management practices are adopted, world agricultural soils have the potential to sequester C from 0.4–0.8 Pg per year. These improved management practices in agriculture, such as a conversion to permanent pasture, crop rotation, and fertilizer application, usually increase C in soil [21]. The soil organic matter (SOM) retained by grassland is usually influenced by various management practices, which further impacted the rate of carbon sequestration. Guo and Gifford [22], in their meta-analysis study, suggested that the conversion of cropland to pasture increases 30% of the soil carbon. Conversely, the conversion of arable land through grassland decreases the soil C amount by close to 60% [22]. Other management practices, such as increased forage production, irrigation, the use of fertilization, the sowing of grasses and legumes, and introducing earthworms, also drastically increase SOM and change the environmental chemistry [21].

The $CO_2$ concentration in the atmosphere exceeded the pre-industrial period by ~40%, and forests, agricultural crops, soil, and water bodies play an important role in reducing its level, behaving as major carbon sinks [2,8,11]. Furthermore, numerous innovative approaches have been implemented, proposed, and formulated in the recent past to mitigate the effects of excessive GHG emissions on global climate change. Reforestation through the conversion of non-forest lands to forest land is undoubtedly an important dimension of C sequestration. Recently, C sequestration in the terrestrial ecosystems is an important clean development mechanism (CDM) and a long-lasting solution to the mitigation and management of GHG emissions. The impact of socio-economic factors, such as a rapid increase in population and economic growth, changing lifestyle, a change in

LULC, and various environmental policies, are important driving forces for future climate change [23,24]. Reducing $CO_2$ in particular and other major GHG is considered the most pressing environmental challenge [17]. As the United States is a signatory of the United Nations Framework Convention on Climate Change (UNFCCC), it is actively involved in finding the key solutions to the problems created by climate change.

It is evident from the literature that very few studies have been conducted on the carbon dynamics, rate of C sequestration in the terrestrial ecosystem, and its medium-/long-term impact on socio-economics and livelihoods. Although filling these gaps in the research is an urgent task for sustainable environmental management, further state-of-the-art studies on C sequestration and its dynamics (sink and/or source) combining soil sciences, forestry, agriculture and their impact on socio-economics are missing. The present Special Issue explores the C sequestration of vegetation and its underlying soil, deforestation, as well as its impact on climate change, a vulnerability risk assessment for the climate, socio-economic impacts, and the mitigation of future climate impact strategies. The theme of the Special Issue extends across environmental policy (e.g., the Paris Agreement and REDD+), C sequestration in the terrestrial ecosystems, the applicability of land use, and the C credit generated at regional and global scales. This Special Issue is highly useful for environmentalists, hydrologists, soil scientists, and policymakers to understand the C sequestration potential of the vegetation and underlying soil in the terrestrial ecosystems at the regional, national and global scale to further study the long-term impacts on socio-economic development resulting from its implementation via climate change modeling.

**Author Contributions:** Conceptualization, A.K. and M.K.; writing—original draft preparation, A.K. and M.K.; writing—review and editing, A.K., M.K. and M.C.P. All authors have read and agreed to the published version of the manuscript.

**Acknowledgments:** We thank all the reviewers for their feedback on earlier versions of the manuscripts in this Special Issue.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Ji, Y.; Guo, X.; Zhong, S.; Wu, L. Financialization, Uncoordinated Development of Population Urbanization and Land Urbanization, and Economic Growth: Evidence from China. *Land* **2020**, *9*, 481. [CrossRef]
2. Kumar, A.; Kumar, M.; Pandey, R.; ZhiGuo, Y.; Cabral-Pinto, M. Forest soil nutrient stocks along altitudinal range of Uttarakhand Himalayas: An aid to Nature Based Climate Solutions. *CATENA* **2021**, *207*, 105667. [CrossRef]
3. Magnani, M.C.; Azofeifa, A.S.; Metternicht, G.; Laakso, K. Integration of remote-sensing based metrics and econometric models to assess the socio-economic contributions of carbon sequestration in unmanaged tropical dry forests. *Environ. Sustain. Indic.* **2021**, *9*, 100100. [CrossRef]
4. Stringer, L.C.; Dougill, A.J.; Thomas, A.D.; Spracklen, D.; Chesterman, S.; Speranza, C.I.; Rueff, H.; Riddell, M.; Williams, M.; Beedy, T.; et al. Challenges and opportunities in linking carbon sequestration, livelihoods and ecosystem service provision in drylands. *Environ. Sci. Policy* **2012**, *19*, 121–135. [CrossRef]
5. Tamang, M.; Chettri, R.; Vineeta; Shukla, G.; Bhat, J.A.; Kumar, A.; Kumar, M.; Suryawanshi, A.; Cabral-Pinto, M.; Chakravarty, S. Stand Structure, Biomass and Carbon Storage in *Gmelina arborea* Plantation at Agricultural Landscape in Foothills of Eastern Himalayas. *Land* **2021**, *10*, 387. [CrossRef]
6. Huo, C.; Chen, L. Research on the Impact of Land Circulation on the Income Gap of Rural Households: Evidence from CHIP. *Land* **2021**, *10*, 781. [CrossRef]
7. Nor Diana, M.I.; Muhamad, N.; Taha, M.R.; Osman, A.; Alam, M.M. Social Vulnerability Assessment for Landslide Hazards in Malaysia: A Systematic Review Study. *Land* **2021**, *10*, 315. [CrossRef]
8. Kumar, A.; Yu, Z.G.; Klemeš, J.J.; Bokhari, A. A state-of-the-art review of greenhouse gas emissions from Indian hydropower reservoirs. *J. Clean. Prod.* **2021**, *320*, 128806. [CrossRef]
9. Holm, A.M.; Watson, I.W.; Loneragan, W.A.; Adams, M.A. Loss of patch-scale heterogeneity on primary productivity and rainfall-use efficiency in Western Australia. *Basic Appl. Ecol.* **2003**, *4*, 569–578. [CrossRef]
10. Scholes, R.J.; Monteiro, P.M.S.; Sabine, C.L.; Canadell, J.G. Systematic long-term observations of the global carbon cycle. *Trends Ecol. Evol.* **2009**, *24*, 427–430. [CrossRef]
11. Kumar, A.; Bhatia, A.; Sehgal, V.K.; Tomer, R.; Jain, N.; Pathak, H. Net Ecosystem Exchange of Carbon Dioxide in Rice-Spring Wheat System of Northwestern Indo-Gangetic Plains. *Land* **2021**, *10*, 701. [CrossRef]

12. Powlson, D.S.; Whitmore, A.P.; Goulding, K.W.T. Soil carbon sequestration to mitigate climate change: A critical re-examination to identify the true and the false. *Eur. J. Soil Sci.* **2011**, *62*, 42–55. [CrossRef]
13. Darrah, P.R. Rhizodeposition under ambient and elevated $CO_2$ levels. *Plant Soil* **1996**, *187*, 265–275. [CrossRef]
14. Trumbore, S. Age of soil organic matter and soil respiration: Radiocarbon constraints on belowground dynamics. *Ecol. Appl.* **2000**, *10*, 399–411. [CrossRef]
15. Ghosh, D.; Maiti, S.K. Eco-Restoration of Coal Mine Spoil: Biochar Application and Carbon Sequestration for Achieving UN Sustainable Development Goals 13 and 15. *Land* **2021**, *10*, 1112. [CrossRef]
16. Houghton, R.A. Balancing the global carbon budget. *Annu. Rev. Earth Planet. Sci.* **2007**, *35*, 313–347. [CrossRef]
17. IPCC (Intergovernmental Panel on Climate Change). *Climate Change 2007: Mitigation of Climate Change. Working Group III*; Cambridge University Press: Cambridge, UK, 2007.
18. Global Carbon Project. Carbon Budget 2008: An Annual Update of the Global Carbon Budget and Trends. Available online: http://www.globalcarbonproject.org/carbonbudget/index.htm (accessed on 1 December 2021).
19. Morgan, J.A.; Follett, R.F.; Allen, L.H.; Del Grosso, S.; Derner, J.D.; Dijkstra, F.; Franzluebbers, A.; Fry, R.; Paustian, K.; Schoeneberger, M.M. Carbon sequestration in agricultural lands of the United States. *J. Soil Water Conserv.* **2010**, *65*, 6A–13A. [CrossRef]
20. Stockmann, U.; Adams, M.A.; Crawford, J.W.; Field, D.J.; Henakaarchchi, N.; Jenkins, M.; Minasny, B.; McBratney, A.B.; de Courcelles, V.d.R.; Singh, K.; et al. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. *Agric. Ecosyst. Environ.* **2013**, *164*, 80–99. [CrossRef]
21. Lam, S.; Chen, D.; Mosier, A.; Roush, R. The potential for carbon sequestration in Australian agricultural soils is technically and economically limited. *Sci. Rep.* **2013**, *3*, 2179. [CrossRef]
22. Guo, L.B.; Gifford, R.M. Soil carbon stocks and land use change: A meta analysis. *Glob. Change Biol.* **2002**, *8*, 345–360. [CrossRef]
23. Chen, L.; Ye, W.; Huo, C.; James, K. Environmental Regulations, the Industrial Structure, and High-Quality Regional Economic Development: Evidence from China. *Land* **2020**, *9*, 517. [CrossRef]
24. Bhardwaj, D.R.; Tahiry, H.; Sharma, P.; Pala, N.A.; Kumar, D.; Kumar, A. Influence of Aspect and Elevational Gradient on Vegetation Pattern, Tree Characteristics and Ecosystem Carbon Density in Northwestern Himalayas. *Land* **2021**, *10*, 1109. [CrossRef]