THE ECONOMICS OF LAND DEGRADATION

UN environment

The Economics of Land Degradation Neutrality in Asia

Empirical Analyses and Policy Implications for the Sustainable Development Goals

www.eld-initiative.org

Report Director:
Pushpam Kumar, UN Environment

Edited and coordinated by:
Jan Libera (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH)
Naomi Stuart (London School for Hygiene and Tropical Medicine)

Authors:
Mesfin Tilahun (Norwegian University of Life Sciences, Ås & Mekelle University, Mekelle)
Pushpam Kumar (UN Environment)
Ashbindu Singh (Environmental Pulse Institute (EPI), Washington DC)
Eugene Apindi (Environmental Pulse Institute (EPI), Nairobi)
Mark Schauer (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH)
Jan Libera (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH)
Gyde Lund (Environmental Pulse Institute (EPI), Washington DC)

Reviewers:
Dr Lu Qi, Institute for Desertification, Chinese Academy of Sciences, Beijing
Dr Cheng Leilei, Institute for Desertification, Chinese Academy of Sciences, Beijing
Dr Li Changxiao, Southwest University, Chongqing, China
Dr Wang Feng, Institute for Desertification, Chinese Academy of Sciences, Beijing
Prof. Uriel Safriel, University of Hebrew, Israel
Dr Muhammed Murshid Anwar, University of Gujarat, Sialkot, Pakistan
Dr Iskander Abdullaeve, CAREC, Almaty, Kazakhstan
Dr Ida Kubiszewski, Australian National University, Canberra
Prof. Robert Costanza, Australian National University, Canberra
Mr Jian Liu, Chief Scientist, UN Environment

This ELD report was published with the support of the partner organisations of the
ELD Initiative and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).

Photography: Pushpam Kumar/UNEP (pg. 1); GIZ (pg. 22); Louis Putzel/CIFOR (pg. 32);
UN Photo/Kibae Park (pg. 56); GIZ / Michael Kottmeier (pg. 63); UN Photo/Gayle Jann (pg. 73); GIZ (pg. 81);
Mr. Prachanart Viriyaraks (pg. 90); GIZ / Robert Heine (pg. 110)

Visual concept: MediaCompany, Bonn Office

Layout: kippconcept GmbH, Bonn

For further information and feedback please contact:
ELD Secretariat
info@eld-initiative.org
Mark Schauer
c/o Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Friedrich-Ebert-Allee 36
53113 Bonn, Germany

Pushpam Kumar
Senior Economic Advisor
United Nations Environment
P.O.Box 30522
Nairobi 00100

Suggested citation:

Tilahun, M., Singh, A., Kumar, P., Apindi, E., Schauer, M., Libera, J., Lund H.G. (2018). The Economics of Land Degradation Neutrality in Asia: Empirical Analyses and Policy Implications for the Sustainable Development Goals. Available from **www.eld-initiative.org**

The Economics of Land Degradation Neutrality in Asia:

Empirical Analyses and Policy Implications for the Sustainable Development Goals

March 2018

www.eld-initiative.org

Acknowledgments:

We are very grateful for the financial and organizational support of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ). The thanks also goes to **Mark Schauer** (coordinator of the ELD Initiative) and the rest of the ELD team for their organizational support. Furthermore, we would also like to extend our gratitude to **The Regional Environmental Center for Central Asia** (CAREC) for the support in organizing the inception workshop in November 2016 held in Almaty, Kazakhstan. We would also like to thank all the participants of the inception workshop for their valuable comments on the draft proposal for this report presented at the inception workshop. Additionally, we would like to thank the Institute for Desertification of the Chinese Academy of Sciences for their contributions. Our gratitude also goes to **Mette Wilkie** (Director, Ecosystems Division), **Ligia Norhona** (Director, Economy Division), **Steven Stone** (Head, Market and Resources Branch), **Maxwell Gomera** (Head, Ecosystems and Biodiversity Branch) and Mr **Jian Liu** (Chief Scientist, UN Environment).

The Economics of Land Degradation Neutrality in Asia

Foreword by Erik Solheim; Executive Director, UN Environment

Unsustainable land use is scarring the Earth for generations. Every minute we lose land the size of 26 football fields. Land degradation and desertification are amongst the biggest environmental challenges we face. This study on land degradation neutrality in Asia finds however that there are enormous economic benefits of implementing a series of sustainable land management practices that protect our land and allow it to thrive.

The study's focus on Asia is timely because the region is home to almost 60 percent of the world's population and a huge number of people live in rural areas, dependant on land and ecosystem services for their livelihoods. The continued and rapid destruction of our land, will severely hit the people of the Asia Pacific region and their access to food and water. Climate change and a lack of investment in sustainable land management will further compound the challenges facing the region.

The Sustainable Development Goals recognize the importance of achieving land degradation neutrality. The good news is that not only is this achievable, it can be economically attractive as well. A few years ago Pongha, a woman farmer from a small village in the Indian state of Nagaland began adopting a series of simple soil and water conservation strategies on a small piece of land. The results have been astounding. She has raised her income by 60 percent and improved soil fertility on her land. Pongha's experience demonstrate that when investments are made in preventing topsoil erosion and improving land quality, communities can immediately benefit through higher incomes, while ensuring that their most important asset i.e. land, remains intact for generations to come.

This study analyses topsoil erosion and crop productivity on 480 million hectares of cropland in 44 Asian countries and 2 provinces of China. By introducing a series of measures to achieve land degradation neutrality, the region can benefit economically, more than three times the cost of implementation. While on average Asia has been producing close to 2.5 billion tons of crops each year, an additional 1.3 billion tons of crops can be produced from the same area of land simply by preventing topsoil loss.

I hope the economic and social benefits reflected in the study will encourage governments, businesses and communities to invest in and adopt sustainable land management practices in Asia and elsewhere in the world, resulting in many more inspiring stories from the field.

Executive summary

1. Land degradation and desertification are some of the world's greatest environmental challenges in the light of a rapidly growing world population and increasing demand for food, fibre, and biomass energy.

2. Asia is the largest and most populated continent in the world, with a total land area of 4.3 billion hectares. Degraded areas on the continent include expanding deserts in mainland China, India, Iran, Mongolia, and Pakistan, the sand dunes of Central Asia, the steeply eroded mountain slopes of Nepal, and the deforested and overgrazed highlands of the Lao People's Democratic Republic.

3. Asia holds almost 60 per cent of the world's population. Of this, nearly 70 per cent live in rural areas depending directly on land and land-based ecosystem services. As a result, Asia is the continent most severely affected by land degradation, desertification and drought in terms of the number of people affected.

4. Within the Sustainable Development Goals, the world set a target (Goal 15) to protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. Target 15.3 in particular states that *"By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral (LDN) world".*

5. The United Nations Convention to Combat Desertification (UNCCD) defines land degradation neutrality *"as a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems".* Progress on the goal is to be measured by an indicator of *"proportion of land that is degraded over total land area",* and several sub-indicators of land cover and land cover change, land productivity, and both above and below ground carbon stocks.

6. Empirical studies integrating biophysical indicators with socioeconomic factors are limited, particularly at the national level. Generating empirical evidence based on biophysical and econometric modelling approaches is crucial to provide a framework in which the costs and benefits of interventions against land degradation can be assessed at different spatial and temporal scales. These types of results are essential tools for policy makers, practitioners, and other stakeholders as it allows for informed decisions to be made towards sustainable land management. Moreover, such studies highlight policy implications and the interdependent nature of achieving a specific Sustainable Development Goal with other goals and targets.

7. The current report aims at assessing the policy implications of achieving sustainable development goal target 15.3, in particular agricultural land degradation neutrality, on achieving economic growth (target 8.1), rural employment (target 8.5), poverty reduction (target 1.1 and 1.2), food security (target 2.3 and 2.4), and for integrating the value of land as a natural capital in social accounting matrices of nations.

8. It provides a continental level empirical analysis, with data from 2002–2013 of arable and permanent cropland area of 487 million hectares cultivated with more than 127 crop types accounting for 87 per cent of Asia's total arable and permanent cropland across 44 countries and two provinces of China over 13 years (2018–2030).

9. The study conducted under this report finds that the aggregate annual soil nitrogen (N), phosphorous (P) and potassium (K) nutrient balance for Asia was -60 million tons, indicating an annual depletion of 52 million tons of nitrogen, phosphorous and potassium from soil nutrient reserves at a depletion rate of 108 kilograms per hectare per year. There is a considerable variation in this annual rate across sub-regions; the highest was in West Asia at 140 kilograms per hectare, and the lowest was in Southern Asia at 82 kilograms per hectare. Total nitrogen, phosphorous and potassium losses increased from 60 million tons in 2002 to 73 million tons in 2013. The average annual rate of nitrogen, phosphorous and potassium loss over the 12 years was 139 kilograms per hectare. The rate of top soil loss from agricultural lands was 12 tons per hectare. From the total harvested area of the 487 million hectares, loss amounted to 5.8 billion tons. Topsoil loss induced soil nitrogen, phosphorous and potassium depletion amounted to about 50 million tons (102 kilograms per hectare per year) with a replacement cost value of about 30.1 billion United States dollars.

10. The estimated topsoil loss has induced nitrogen, phosphorous and potassium loss amounting to 52 million tons (about 107 kilograms per hectare per year). The costs to replace this ecosystem service loss through commercially applied fertiliser at a weighted average price of 0.85 United State dollars per kilogram of nutrients (2013 prices) are about 34.1 billion United States dollars.

11. From 2002-2013, Asia produced close to 2.5 billion tons of crops across the 487 million hectares in the study, with an average annual regional productivity of 5 tons per hectare. Over the same period, on average for every kilogram of soil nitrogen, phosphorous and potassium depletion caused by top soil loss, productivity was declining by 17 kilograms of crop outputs. For every kilogram of nitrogen, phosphorous and potassium loss caused by top soil loss, regional crop yield loss declined by 0.32 kilograms. Total annual aggregate crop production loss due to top soil loss induced soil nitrogen, phosphorous and potassium depletion amounts to about 1.3 billion tons or close to 53 per cent of annual total crop production. The corresponding value of this loss at the weighted average crop prices amounts to 733 billion United States dollars. This implies that avoiding topsoil induced soil nitrogen, phosphorous and potassium depletion in the agricultural lands of Asia would increase regional productivity from 5 to almost 8 tons per hectare per year.

12. The results of the cost benefit analysis indicate that if in the next 13 years (2018-2030) all Asian countries invest and develop sustainable land management technologies on the 487 million hectares of agricultural lands, the present value of the total costs of investing is estimated to be 1,214 billion United States dollars, a cost of 2,494 United States dollars per hectare. The present value of the flows of total benefits from investing in sustainable land management is estimated at about 4,216 billion United States dollars, equal to 8,663 United States dollars per hectare.

13. Asian regions could create a net present value of about 3,008 billion United States dollars, equal to 6,169 United States dollars per hectare with a benefit-cost ratio of about 3.5. Seven countries (Mainland China, Saudi Arabia, Uzbekistan, Iran, Myanmar, Indonesia, and Japan) all together account for 88.34 per cent of the net present value, with the ratio ranging from 3.02 in Japan to 6.75 in mainland China.

14. The study indicates that investing in sustainable land management technologies and achieving agricultural land degradation neutrality would enable countries to reduce the poverty gap to zero by 2030, increase the total per capita domestic food crop production to 858 kilograms across Asia by 2030 and result in economic growth as well as expansion in the agricultural sector.

About the ELD Initiative

The Economics of Land Degradation (ELD) Initiative is an international collaboration initiated in 2012 with the aim of increasing and strengthening awareness of the economics of land degradation and sustainable land management (SLM) in the scientific, political and public discourse. Through research, capacity development, and active knowledge exchange, the Initiative seeks to ensure that the economics of sustainable land management are comprehensibly mediated and appropriately implemented. Therefore, the Initiative highlights the value of land and its services to the society in reports and provides a global approach for the analysis of the economics of land degradation. The aim of ELD is to achieve that economic valuation of ecosystem services becomes an integral part of policy strategies and decision-making. To provide a scientifically robust, politically relevant, and socio-economically considerate approach that is economically viable and rewarding, the Initiative is working with an international team of scientists, practitioners, decision makers from public and private sectors, as well as all interested stakeholders.

Ensuring the implementation of more sustainable land management practices is of critical importance considering the vast environmental and socio-economic challenges we are collectively facing, such as food, water, and energy security, climate change, a reduction in biodiversity, and the deterioration of ecosystems and their services. Understanding the cost of inaction and benefits of action in preserving ecosystem services are important for all stakeholders to be able to make sound, informed decisions about the amount and type of investments in land for sustainable use. Even though numerous techniques for SLM are known, many barriers remain and financial and economic aspects are often put forward as primary obstacles. If stakeholders do not realize the full value of land, it may not be managed sustainably, leaving future generations with diminished choices and options to secure human and environmental well-being. A better understanding of the economic value of land will therefore help in correcting the imbalance that can occur between the financial value of land and its economic value.

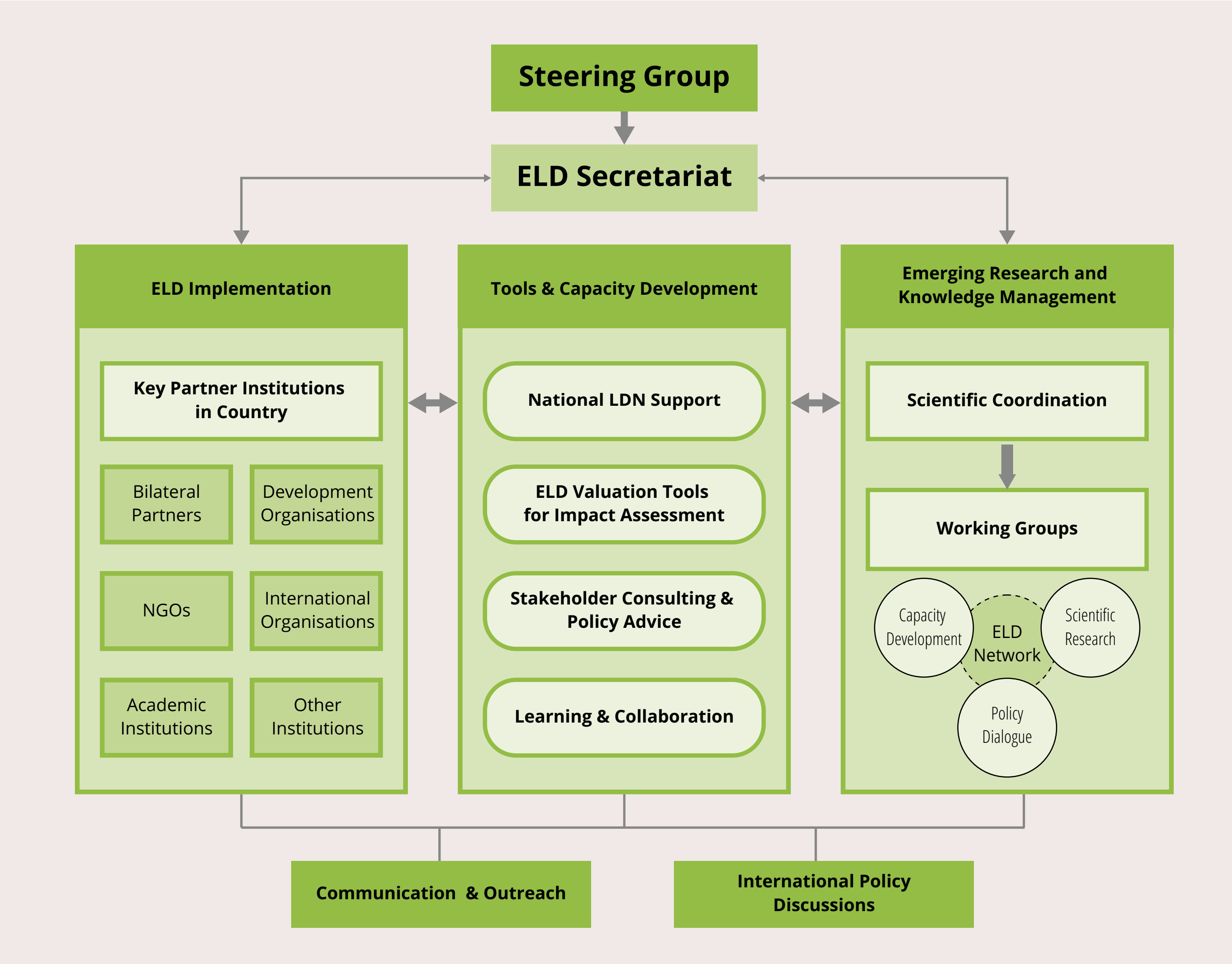
Economic values can provide a common language to help responsible entities decide between alternative land uses, set up new markets related to environmental quality and services, and devise a variety of land management options to reverse and halt land degradation. It should also be noted that the resulting economic incentives must take place within an enabling environment that includes the removal of cultural, environmental, legal, social, and technical barriers, and considers the need for equitable distribution of the benefits of land amongst all stakeholders.

Although there is a wide variety of appropriate methods, valuations, and approaches available, the ELD Initiative promotes the use of the total economic value achieved through cost-benefit analyses, as this approach provides comprehensive information and a broad and cohesive understanding of the economics of land degradation. This method is generally accepted by governments and decision making bodies as a decision-making instrument, and avoids the application of tools that may require a fundamental change of existing systems. To this end, the ELD Initiative operates under the following vision and mission:

Vision

The partners' vision of the ELD Initiative is to transform global understanding of the value of land and create awareness of the economic case for sustainable land management that prevents loss of natural capital, secures livelihoods, preserves ecosystem services, combats climate change, and addresses food, energy, and water security, and to create capacity for the utilisation of economic information for sustainable land management.

Economics of Land Degradation (ELD) Initative Governance Structure



Mission Statement

The central purposes and role of the ELD Initiative is that through an open inter-disciplinary partnership:

- We work on the basis of a holistic framework built upon a recognized methodology to include the economic benefits of sustainable land management in political decision-making;
- We build a compelling economic case for the benefits derived from sustainable land management from the local to the global level while applying/using a multi-level approach;
- We estimate the economic benefits derived from adopting sustainable land management practices and compare them to the costs of these practices;
- We stimulate the development of land uses that provide fulfilling and secure livelihoods to all while growing natural capital, enhancing ecosystem services, boosting resilience and combating climate change;
- We increase the awareness of the total value of land with its related ecosystem services;

- We develop the capacities of decision-makers and land users through innovative formats, and;
- We mainstream the full benefits of land in international and national land use strategies by proposing effective solutions, tailored to country- or region-specific needs, including policies, and activities to reduce land degradation, mitigate climate change and the loss of biodiversity, and deliver food, energy, and water security worldwide
- We will propose effective solutions, policies and activities to reduce land degradation, mitigate climate change and deliver food, energy, and water security worldwide

Acronyms and abbreviations

BCR	Cost Benefit Ratio
BMZ	German Federal Ministry for Economic Cooperation and Development
CBA	Cost Benefit Analysis
CBD	Convention on Biological Diversity
DLDD	Desertification, Land Degradation and Drought
ELD	Economics of Land Degradation
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GLASOD	Global assessment of human-induced soil degradation
GM	Global Mechanism
ha	Hectare
LDD	Land Degradation and Desertification
LDN	Land Degradation Neutrality
NPK	Nitrogen, Phosphorous, Potassium
NPV	Net Present Value
PPP	Purchasing Power Parity
PV	Present Value
SDG	Sustainable Development Goal
SLM	Sustainable Land Management
SRTP	Social Rate of Time Preference
TEV	Total Economic Value
TLU	Tropical Livestock Units
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	UN Environment (United Nations Environment Programme)
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
WOCAT	World Overview on Conservation Approaches and Technologies

Table of contents

01 Land Degradation in Asia

1.1 Background and objectives

It is estimated that with a world population of nine billion people by 2050 it will be required to increase food production on agricultural land globally by 70 per cent or otherwise convert six million hectares (ha) of unused land into agricultural production each year (United Nations Convention to Combat Desertification [UNCCD], 2014c). However, the most recent estimates predict that the world population will reach close to ten billion people by 2050 (United Nations [UN], 2017b). Consequently, food production has to be increased even more drastically while natural resources are on the decline. By 2014 around 60 per cent of all ecosystem services were already degraded and 25 per cent of the world's land area is already highly degraded or under threat (UNCCD, 2014c). Under this assumption the competition for natural resources will further increase in the future, which will have a negative impact on the livelihoods of billions of people as well as the environment if there is no change towards a more sustainable approach of economic activities.

The importance of a sustainable future with a green economy has already been acknowledged at the United Nations Conference on Environment and Development in Rio de Janeiro. On this occasion, the majority of the world leaders had agreed on a commitment to protect the world's environmental resources while engaging in a sustainable economic development. One of the outcomes of the Rio Summit had been the enactment of three legally binding agreements, namely the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (UNCCD).

As the solely legally binding international agreement linking environment and development to sustainable land management (SLM), the UNCCD is the third agreement that has been adopted in the context of the Rio Summit. The UNCCD addresses the problems closely linked with land and land-based ecosystems in the world to "forge a global partnership to reverse and prevent desertification/land degradation and to mitigate the effects of drought in affected areas in order to support poverty reduction and environmental sustainability (UNCCD, n.d. a)."

The importance of addressing desertification, land degradation and drought (DLDD), was highlighted again at the Rio 20+ conference in 2013, by underlining the economic and social significance of good land management practices striving for a land-degradation neutral world. Following the Rio 20+ conference and as a logical progression of the Millennium Development Goals, the SDGs (Sustainable Development Goals) were developed.

In the context of DLDD, SDG 15 "Life on Land" is of particular interest with regard to the work of the ELD Initiative as it aims to *"protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (UN, n.d.)."*

More specifically, SDG 15.3 addresses the need to *"combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world by 2030 (UN, n.d.)"*. Achieving SDG 15.3 is of great importance to realise food security, the eradication of poverty and climate change mitigation as it is closely linked to other SDGs. Therefore, the committed parties have to establish mechanisms for local and national actions and engage in regional and international cooperation as land degradation, desertification and droughts do not follow national borders.

The global impact of land degradation and desertification can be seen, among others, by the increasing number of sand and dust storms. These are occurring globally, particularly in dry areas and can have significant impacts on ecosystems

BOX 1

Definitions

Land

According to the UNCCD, land can be defined as "the terrestrial bio-productive system that comprises soil, vegetation, other biotica, and the ecological and hydrological processes that operate within the system (UNCCD, 2017)". Alternatively it can be defined as: "a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations (biodiversity), the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.) (Commission on Sustainable Development [CSD], 1996)".

Land degradation

UNCCD defines land degradation as "any reduction or loss in the biological or economic productive capacity of the land resource base. It is generally caused by human activities, exacerbated by natural processes, and often magnified by and closely intertwined with climate change and biodiversity loss" or alternatively as "the reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes arising from human activities (UNCCD, 2017, UNCCD, 2014b)."

Sustainable Land Management (SLM)

Sustainable land management practices are the most promising tool to halt and reverse land degradation and desertification and thereby achieve LDN. It can shortly be defined as "people simply looking after the land – for the present and for the future (World Overview of Conservation Approaches and Technologies [WOCAT], n.d.b)". A more detailed definition describes SLM as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions (Liniger, Studer, Hauert, & Gurtner, 2011)."

Soil nutrient loss and nutrient depletion

The term soil nutrient depletion refers to all nutrient losses from a soil through both natural and human-induced processes. It is the process by which the soil nutrient stock is shrinking because of continuous nutrient mining without sufficient replenishment of nutrients harvested in agricultural products, and of nutrient losses by soil erosion and leaching (Tan, Lal, & Wiebe, 2005). The quantity or rate of nutrient depletion is estimated as the difference between the amount of nutrients exported annually from cultivated fields and the amount added or imported annually in the form of fertilizers, manure, fixation, and the physical processes of deposition and sedimentation (Henao & Baanante, 1999). Nutrient loss is the difference between nutrient inputs plus nutrients depleted from the soil, and nutrient outputs in the crop. Nitrogen losses are mainly as leaching of nitrate, volatilization as ammonia, and gaseous loss following denitrification and potassium losses from the soil also result from leaching whereas Phosphorus losses occur by soil fixation and erosion (Sheldrick, Syers, & Lingard, 2002).

Desertification

Desertification is land degradation that occurs in drylands. UNCCD defines it as "land degradation in arid, semi-arid and sub-humid areas resulting from various factors, including climatic variations and human activities. When land degradation happens in the world's drylands, it often creates desert-like conditions (UNCCD, 2012a)." It may also refer to "the irreversible change of the land to such a state it can no longer be recovered for its original use (Food and Agriculture Organization of the United Nations [FAO], n.d.)."

Land degradation neutrality (LDN)

The concept of "zero net land degradation" was proposed at the 2012 UN Conference on Sustainable Development. The UNCCD defines land degradation neutrality (LDN) as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security stable or increase within specified temporal and spatial scales and ecosystems (Orr et al., 2017)."

and their services in the originating country but also in neighbouring areas or even far-off regions. In mainland China, although desertification has only increased slightly in the last years, it has nevertheless created large areas of enhanced dust emissions resulting in up to half of the global production of dust. Dust from mainland China has travelled more than 20,000 km and can be found in the French Alps, but also in Korea, Japan, Hawaii and Alaska (United Nations Environment Program [UNEP], World Meterological Organisation [WMO] & UNCCD, 2016). This example illustrates that land degradation and desertification have to be seen as a global problem that needs a strong international commitment and collaboration within regions and between countries.

This is particularly true, when considering that land degradation, desertification and droughts can also pose a security threat to local, national and international level. Climate change and environmental changes have significant impact on peoples' livelihoods, national economies and the availability of natural resources, which are likely to intensify in the future, leading to an increased competition for natural resources. In this context, under specific circumstances and in certain areas, environmental changes, such as land degradation or desertification, can increase the risk of violent conflicts.

An increasing number of conflicts over food, land and natural resources would consequently lead to an increasing number of temporally or permanently displaced people. However, even without further violent conflicts it is estimated that 135 million people are at risk of being permanently displaced due to desertification and land degradation. By 2050 up to 200 million people could be already permanently displaced, with the majority coming from developing countries (UNCCD, 2014a).

Mainland China has seen an intensification of agricultural production and the expansion of agricultural land over the last decades. In combination with infrastructural projects and urbanization it is estimated that 50 million people were directly displaced (UNCCD, 2017). This migration has been further accelerated by degrading land, deforestation and a state controlled land use and household registration leading to active relocation of pastoralists and the urban population by the government (UNCCD, 2017).

Sustainable land management practices, such as land rehabilitation, reforestation, agroforestry or sustainable pasture management are solutions which can be applied in the context of land degradation and desertification. Thereby, in the overwhelming number of examples the benefits of action towards sustainable management outweigh the costs.

The aim of the ELD Initiative is to provide valid data to highlight the consequences of inaction and the benefits of action by investing in SLM practices. Together with UN Environment, the ELD Initiative already published a regional report titled "Economics of Land Degradation in Africa: Benefit of Action Outweigh the Costs" (Economics of Land Degradation Initiative [ELD] & UNEP, 2015), which provides evidence from 42 countries that benefits of action are on average seven times higher than the costs associated during the next 15 years (2015 to 2030) in 42 African countries.

Following the African report, UN Environment in partnership with the ELD Initiative, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), the European Commission and other partners pursues a similar approach for the Asian continent:

- assess the economics of land degradation neutrality in Asian regions
- design response options for sustainable land management
- attain selected Sustainable Development Goals

It is critical to assess the state of our knowledge about land degradation in Asia to provide a baseline for future assessments, which can be started through a synthesising review of the literature. Therefore, the objectives of this study are to:

1. Assess the extent and severity of land degradation in Asia;
2. Estimate the economic efficiency of measures for the target of LDN in Asia;
3. Suggest LDN options, assess financing options and develop scenarios for the benefits and investment gaps of achieving it by 2030;
4. Map the impact of land degradation on food security, equity, youth unemployment and poverty, gender and health.

1.2 Land degradation and land degradation neutrality

The global land surface covers an estimated 13.3 billion ha and comprises of woodland and grassland (35 per cent), forest (28 per cent), and cropland (12 per cent) while the rest is covered by barren land, settlements, infrastructure or water, whereby 29 per cent of the total land area is already degraded (UNCCD, 2016b). 78 per cent of the land degradation is occurring in humid areas. The other 22 per cent of land degradation can be found in the worlds' dry regions, covering nearly 34 per cent of the land mass (Gomiero, 2016). In the context of drylands, land degradation is mainly referred to as desertification.

Land degradation and desertification can manifest in various ways, generally grouped in three categories. Physical degradation includes the decline in soil structure through compaction, anoxia or crusting, but also the loss of top soil through erosion, mainly by wind and water. Salinization, alkalization, leaching, acidification and illuviation are elements of chemical degradation. Biological degradation leads to a decline in soil biodiversity and the reduction in humus quality and quantity (Eswaran, Lal, & Reich, 2001). In general, it is estimated that each year approximately 24 billion tons of soil are lost (UNCCD, 2017). Water erosion is the most widespread form of land degradation affecting approximately 1094 million ha worldwide, followed by wind erosion with 548 million ha (Bai, Dent, Olsson, & Schaepman, 2008).

All the processes leading to degradation and desertification can be caused by a variety of drivers, either of natural or anthropogenic origin. However, most of the degraded land can be traced back to human actions. According to a report by UNCCD the primary causes are overgrazing

FIGURE 1.1

Global assessment of the four main threats to soil by FAO regions
(Montanarella et al., 2016)

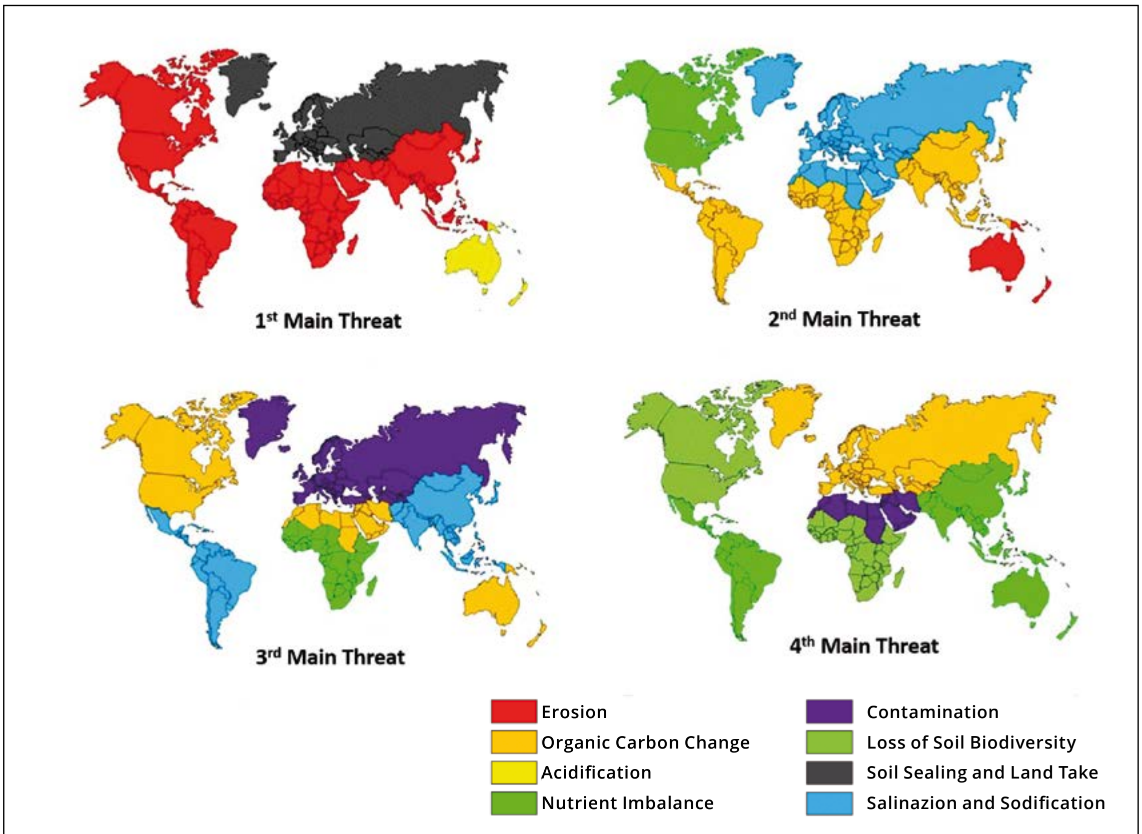


TABLE 1.1

The total economic value (TEV) cost of land degradation in the zones of the world
(Mirzabaev, 2014)

Zone	Cost of land degradation (2001 – 2009), USD billions	Cost of action (30 years) USD billions	Cost of inaction (30 years) USD billions	Ratio
Central Asia	216	53	277	5
East Asia	164	508	2,594	5
East Europe	52	777	4,813	6
Latin America and the Caribbean (LAC)	473	754	2,977	4
North America (NAM)	238	751	4,545	6
Near East and North Africa (NENA)	94	80	504	6
Oceania	125	407	2,442	6
South Asia	87	210	646	3
Southeast Asia	52	135	400	3
Sub-Saharan Africa (SSA)	543	797	3,343	4
West Europe	47	181	926	5
Global	**2,091**	**4,653**	**23,465**	**5**

(35 per cent), crop production and intensive pasture (28 per cent), deforestation (30 per cent), overexploitation to produce firewood (7 per cent) and industrialization (1 per cent) (UNCCD, 2016b).

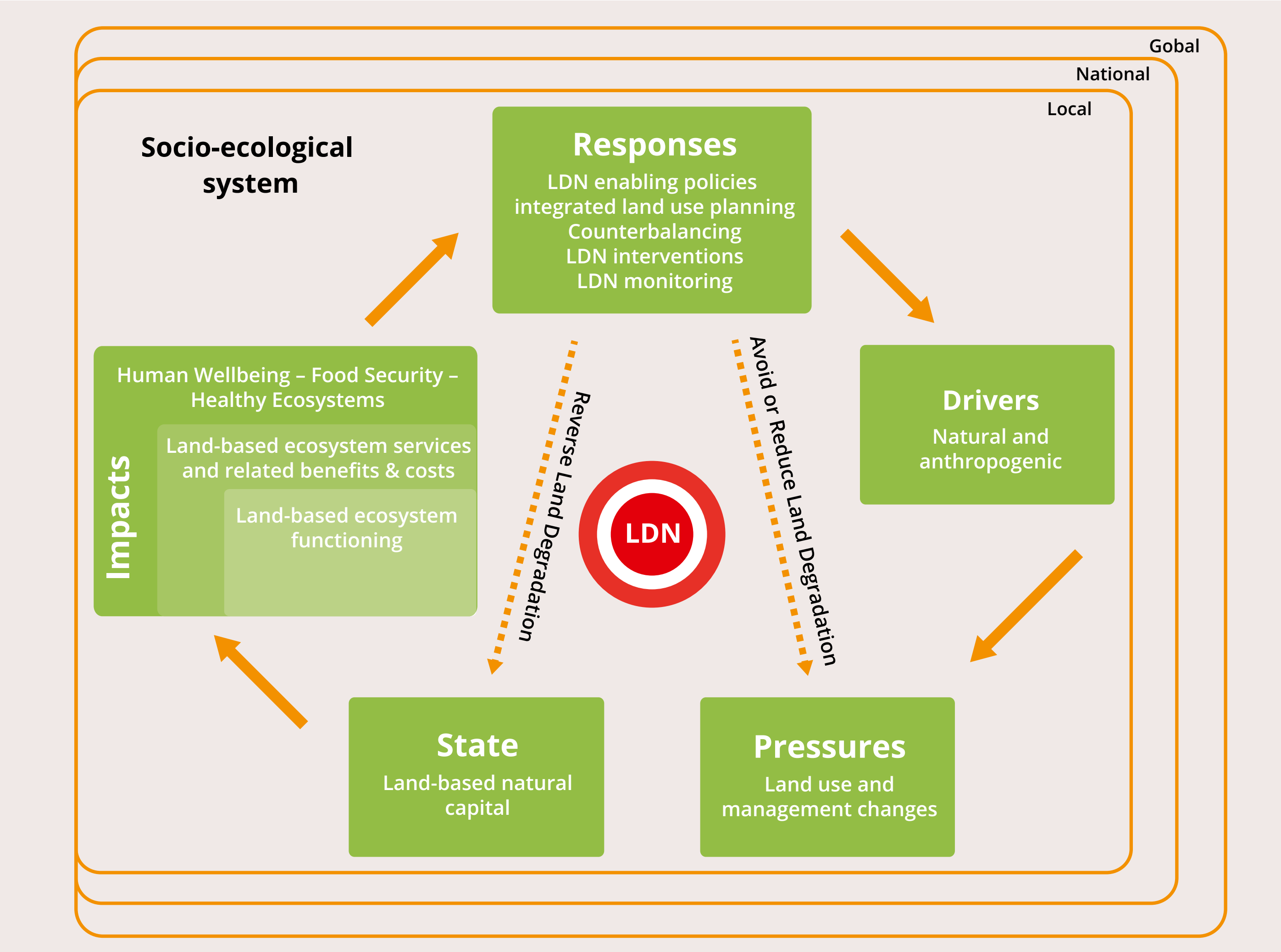
The majority of data on land degradation is provided by site-specific studies. Specific studies of land degradation at the regional level are limited. The 1992 Global assessment of human-induced soil degradation (GLASOD) project produced a world map of human-induced soil degradation, the first of its kind that showed the severity of the problem of soil degradation at a global scale. However, in addition to biophysical assessments of land degradation, few studies have attempted to provide economic cost of land degradation. *Table 1.1* shows the costs of land degradation for various zones of the world (Mirzabaev, 2014).

It is estimated that there are currently over 1.3 billion people living or depending on degraded land and for many more, their culture and values are closely linked to land, including religious, spiritual or recreational aspects. Although it is a global problem, occurring in almost all ecosystems of high, middle, and low-income countries, a disproportionate large number of the worlds' poorest, depending heavily on natural resources, are severely affected. In addition, concurrent environmental shifts like climate change and biodiversity losses all interact in a feedback loop with land degradation. The implementation of SLM practices in the affected areas could result in economic benefits of up to USD 1.4 trillion and restoring natural ecosystems has been proven to be highly cost-effective with benefit/cost ratios ranging from 2 (coastal systems) to 35 (grassland) (ELD, 2015; UNCCD, 2016b). Therefore, it is important to consider the bigger picture to make an impact and achieve the successful implementation of more sustainable land management.

The most promising and in this context appropriate strategy is the concept of "land degradation neutrality" as proposed by the UNCCD and defined as:

FIGURE 1.2

Conceptualizing LDN in a cause and effect model within the socio-ecological system.
(Orr et al., 2017)



Solid arrows indicate cause-effect relationships; dotted arrows indicate response relationships

"a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems (Orr et al., 2017)."

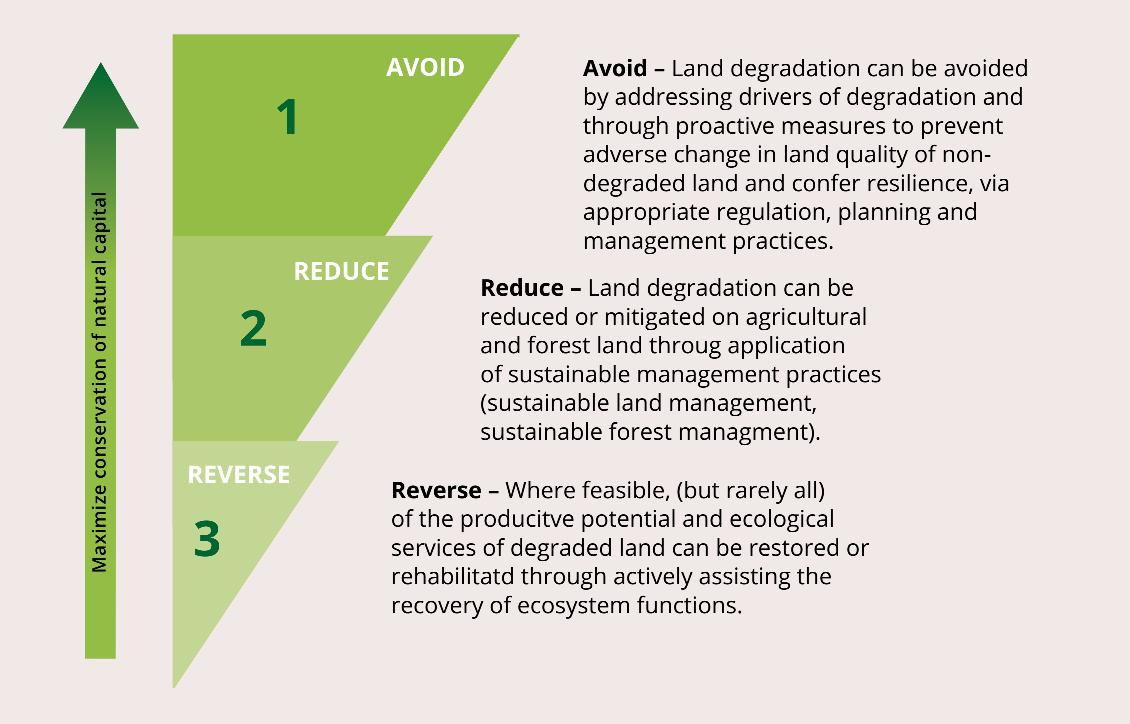
The focus of LDN lies on:

- maintaining or improving the sustainable delivery of ecosystem services,
- maintaining or improving productivity to enhance food security,
- increasing resilience of the land and populations dependent on the land,
- seeking synergies with other social, economic and environmental objectives,
- reinforcing responsible and inclusive governance on land. *(Orr et al., 2017)*

The concept of land degradation neutrality acknowledges that the amount of arable land must be increased, or at least maintained, to ensure the delivery of goods and services provided by it and its interconnected ecosystems. With the vision, as proposed at the end of the 2012 UN Conference on Sustainable Development, to achieve a land degradation neutral world, the signing parties agreed to expedite policy and laws to avoid or reduce land degradation and desertification.

FIGURE 1.3

The LDN response hierarchy.
(Orr et al., 2017)



Furthermore, measures will be taken to reverse already degraded land in order to achieve a net loss of healthy and productive land (Orr et al., 2017). Each country will thereby develop its own national targets for land degradation neutrality based on baseline assessments as well as trends and drivers of land degradation in the respective region with assistance of the LDN Target Setting Programme.

To address the implemented targets, the LDN response hierarchy serves as a guideline for decision-makers in achieving LDN, following the principle of: avoid → reduce → reverse.

Parallel to the planning of LDN processes and setting the targets, UNCCD is establishing a monitoring scheme, which is crucial for the success of LDN. The scheme is based on three land-based indicators and associated metrics (Orr et al., 2017; Viek, Khamzina, & Tamene L., 2017), which are used to monitor the progress of SGD 15.3:

- land cover (metric: land-cover change)
- land productivity (metric: NPP)
- carbon stocks above/below ground (metrics: organic carbon)

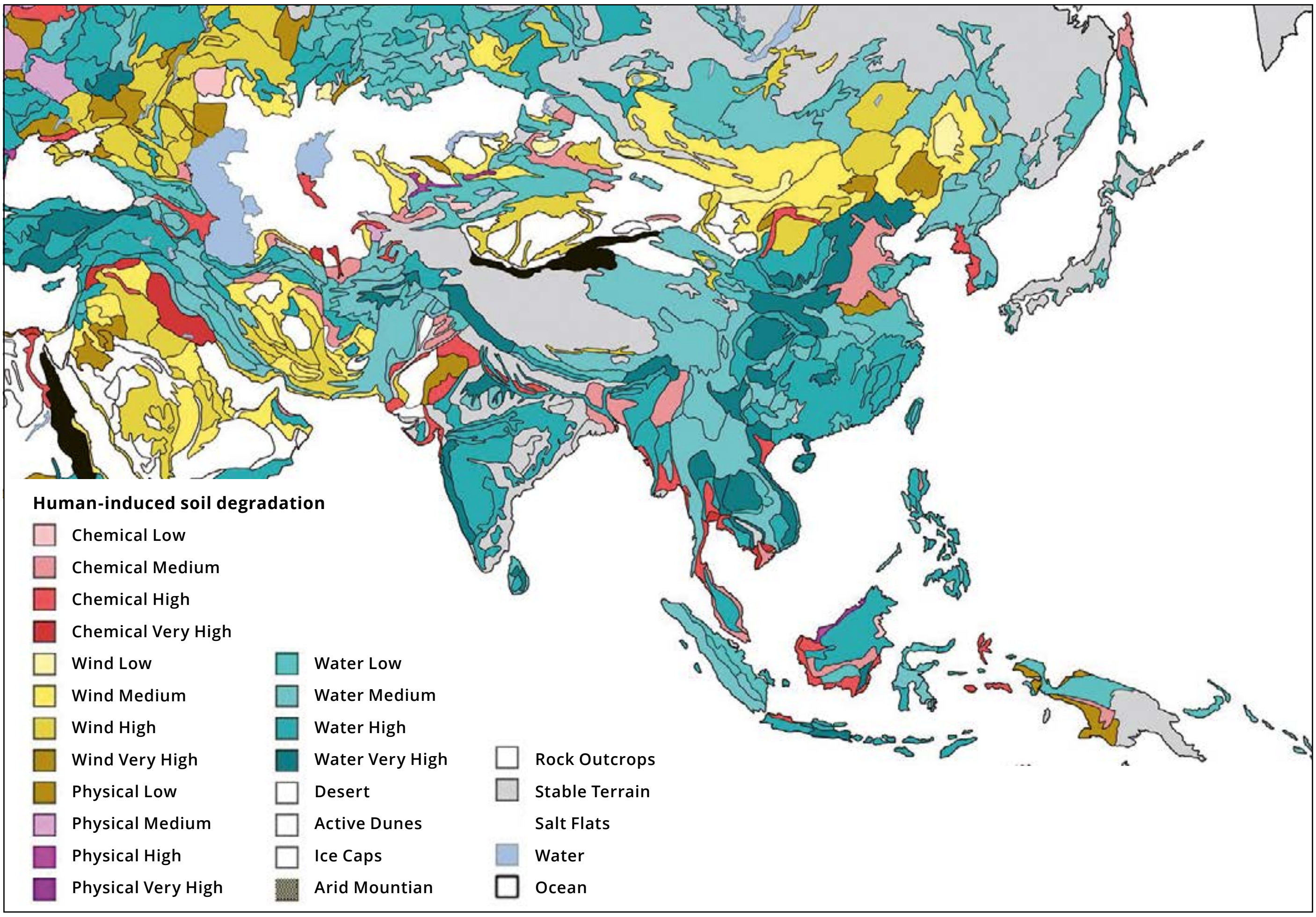
These indicators should be extended by additional national and sub-national indicators. Furthermore, UNCCD strives for synergies with the other conventions of the Rio Summit, namely the UNFCCC and CBD, and their respective commitments and initiatives. “So far, more than 100 countries have expressed interest in participating in the TSP, setting LDN targets, identifying strategies and measures to achieve these targets and establishing a corresponding monitoring scheme (Viek et al., 2017).” The Global Mechanism (GM) of the UNCCD manages these national approaches. Several of these partner countries are located in Asia.

Therefore, it is critical to assess the state of our knowledge about land degradation and land degradation neutrality in Asia by an extensive review of the published literature, which could provide the baseline for future assessments.

FIGURE 1.4

Global assessment of human-induced soil degradation (GLASOD) – Asian section (International Soil Reference and Information Centre)

(ISRIC, 1990)



1.3 Land degradation in Asia

1.3.1 Status and trends

Asia is the largest and most populated continent in the world, covering around 30 per cent of the global land. More than 4 billion people are currently living in Asia, which can be divided into five sub regions, namely Central Asia, East Asia, South Asia, Southeast Asia and Western Asia, often referred to as the Middle East. Due to the size of the continent, it encompasses various climatic conditions, from the arid climates of Western and Central Asia to the tropical, humid climates of the equatorial region. As a result, Asia shows a great biological and cultural diversity. Each region has seen a different social, economic and political development over the centuries. Consequently, each part of Asia faces different challenges regarding climate change, loss of biodiversity and land degradation as addressed by SDG 15.

For this report, we consider the following countries to be part of Asia: Armenia, Afghanistan, Azerbaijan, Bahrain, Bangladesh, Bhutan, Brunei, Myanmar, Cambodia, mainland China and two Special Administrative Regions (SARs), Cyprus, Democratic People's Republic (DPR) of Korea, Georgia, India, Indonesia, Iran, Iraq, Israel, Japan, Jordan, Kazakhstan, Kuwait, Kyeargyzstan, Lao People's Democratic Republic, Lebanon, Malaysia, Maldives, Mongolia, Nepal, Oman, Pakistan, State of Palestine, Philippines, Qatar, Republic of Korea, Saudi Arabia, Singapore, Sri Lanka,

TABLE 1.2

Asia geographical regions, countries and administrative areas

Central Asia (CA)	Eastern Asia (EA)	Southern Asia (SA)	South-East Asia (SE)	Western Asia (WA)
Kazakhstan	China Hong Kong SAR	Afghanistan	Brunei Darussalam	Armenia
Kyeargyzstan	China, Macao SAR	Bangladesh	Cambodia	Azerbaijan
Tajikistan	China, mainland	Bhutan	Indonesia	Bahrain
Turkmenistan	Taiwan Province of China	India	Lao People's Democratic Republic	Cyprus
Uzbekistan	Democratic People’s Republic Korea	Iran (Islamic Republic of)	Malaysia	Georgia
	Japan	Maldives	Myanmar	Iraq
	Mongolia	Nepal	Philippines	Israel
	Republic of Korea	Pakistan	Singapore	Jordan
		Sri Lanka	Thailand	Kuwait
			Timor-Leste	Lebanon
			Viet Nam	State of Palestine
				Oman
				Qatar
				Saudi Arabia
				Syearian Arab Republic
				Turkey
				United Arab Emirates
				Yemen

Syearia, Tajikistan, Thailand, Timor-Leste, Turkey, Turkmenistan, United Arab Emirates, Uzbekistan, Viet Nam and Yemen. They are grouped into following five regions[1] in Table 1.2.

Central Asia – The Tian Shan mountain range, deserts and vast steppes are characteristic for Central Asia. Most of the countries in the region gained independence after the collapse of the Soviet Union in 1991 leaving them with severe challenges for economic and social development. Of the total land area, around two-thirds are drylands with extreme biophysical constraints and only eight per cent arable land. It is estimated that 4-10 per cent of the cropland is already degraded, as well as 27-68 per cent of pastureland and 1-8 per cent of forests (ELD, 2016). Soil degradation is thereby mainly caused by salinization, wind and water erosion and vegetation changes. The underlying causes are anthropogenic, including overgrazing of pasture lands due to increasing livestock, unsustainable cropping practices, deforestation, extensive use of water sources, and expansion of agricultural land onto marginal lands. Soil and land degradation in croplands over the last three decades is estimated to be presently decreasing annual agricultural profits in the region by about 27 per cent (Central Asian Countries Initiative on Land Management [CACILM], 2016). Central Asia has one of the most modified land cover under irrigation influence and related ecological problems (Mirzabaev et al., 2016).

[1] *Not listed or shown is the Northern Asia – Russian Federation as it is not included in this report.*

One of the most well-known consequences of agricultural mismanagement and unsustainable water use in Central Asia is the desertification of the Aral Sea *(Figure 1.5)*.

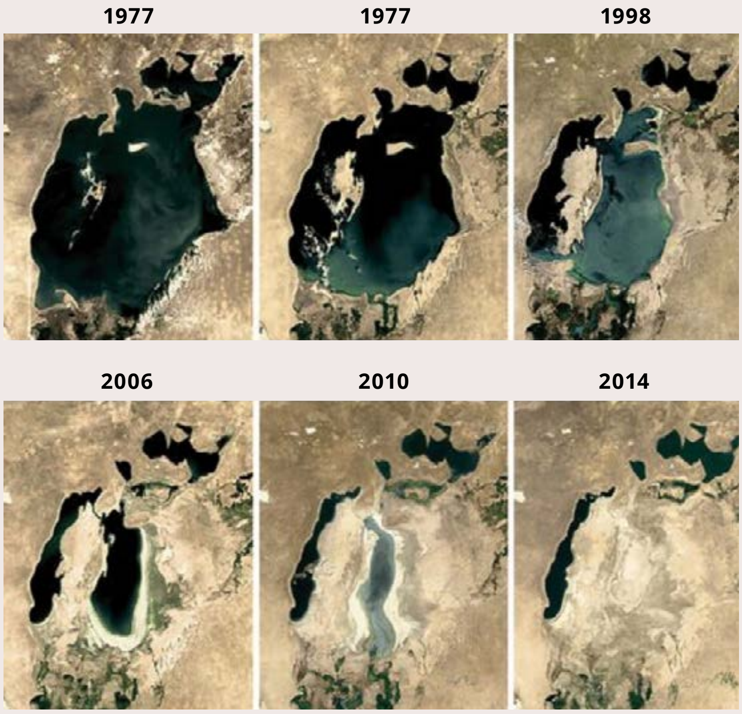
BOX 2

The demise of the Aral Sea

The name "Aral Sea" comes from the Turkic word aral meaning island. The sea's name reflects that it is a vast basin existing as an island amongst waterless deserts. It was once the world's fourth largest inland sea, but problems began in the 1960s and 1970s with the diversion of rivers that fed it to provide for cotton cultivation in Central Asia.
The surface of once measured 66,100 km², but by 1987, about 60 per cent of the volume had been lost, its depth had declined by 14 m, and salt concentration had doubled, killing the commercial fishing trade. Wind storms became toxic, carrying fine grains of clay and salts from the now exposed sea floor, and life expectancies in the districts near the sea became significantly lower than in the surrounding areas.
The sea is now a quarter of the size it was 50 years ago and has broken into several smaller seas. Re-engineering along the Syear Darya River delta in the north has retained water in the North Aral Sea and has helped to partially restore the fishing industry.

FIGURE 1.5

Change of the surface of the Aral Sea from 1977-2014
(Schakirow, 2016; based on data from United States Geological Survey (USGS)/National Aeronautics and Space Administration (NASA))



By 2080, 17 per cent of the area in Central Asia will be unsuitable for agriculture due to unproductive soils. The governments of Central Asia have failed to improve the agricultural infrastructure and address the need for a more sustainable development in the past. Policies and laws holding back the transition, are still in place. A study of the ELD Initiative showed that the implementation of policies and laws supporting SLM practices can result in significant benefits for farmers, livestock breeders and the society. The study highlighted that a yield increase of 0.3 to 0.85 tons per ha is achievable in Turkmenistan, no-till technologies in Tajikistan could profit an additional net benefit of USD 483/ha and in Kyeargyzstan the net present value from SLM could go as high as USD 19.2 million in the Son Kol watershed (ELD, 2016). Similar findings were also obtained for Uzbekistan and Kazakhstan.

Other estimates show that the annual cost of land degradation in the region due to land use change is about USD 6 billion, mostly due to rangeland degradation (USD 4.6 billion), followed by desertification (USD 0.8 billion), deforestation (USD 0.3 billion) and abandonment of croplands (USD 0.1 billion) (Mirzabaev et al., 2016). Thereby, the costs of action against land degradation are significantly lower than the costs of inaction. It is estimated that for each dollar spent on addressing land degradation it is likely to have about 5 dollars of returns. This is a very strong economic justification. In general, the costs of action equals around USD 53 billion over a 30-year horizon, whereby inaction may cost up to USD 288 billion over the same time period (Mirzabaev et al., 2016).

Eastern Asia: East Asia ranges from the sparsely populated high plains of Mongolia to the densely populated coastal lines of China and the islands of Japan and Taiwan Province of China. More than 1.5 billion people or one fifth of the global population live in the countries of East Asia. In China alone the population almost doubled over the last 50 years leading to the expansion of cities and industrial zones and increasing pressure on ecosystems and its services. In this context, pollution is a severe challenge for Chinese land. However, also overgrazing, the expansion of agricultural land and deforestation have led to a decreasing soil quality and the expansion of degraded land.

It is estimated that already 27 per cent of the land in China is already desertified and each year 2,460 additional km² are lost (UNCCD, n.d. b). A large number of the Chinese population lives in the affected area, depending heavily on the land. According to UNCCD, the economic loss can be estimated at around USD 6.5 billion/year (UNCCD, n.d. b). Furthermore, due to degradation and desertification, sand and dust storms occur more regular in China resulting in economic losses and severe impacts on the livelihoods of people, mainly from the north and northeast. For the time period 2010-2013 the total economic losses caused by sand and dust storms in China summed up at USD 964 million (Deng & Li, 2016).

According to one study, the cost of grassland degradation is estimated to equal about USD 0.49 billion due to losses in livestock productivity (Deng & Li, 2016). Moreover, the costs of cropland degradation for three crops: wheat, maize and rice, sums up to about USD 12 billion annually. For the year 2007 it was estimated that the total cost of land degradation in China was USD 37 billion or 1 per cent of China's 2007 GDP. However, the study also shows that the costs of rehabilitating the degraded lands are significantly lower than the costs of inaction over a 30-year period. For each Yuan invested it is expected to get 4.7 Yuan of returns (Deng & Li, 2016).

Mongolia faces similar problems in the region because of a significant livestock increase over the last decades comparable to the development in Central Asia. Desertification and land degradation through overgrazing are the consequences. Further causes are deforestation for the extension of agricultural land and firewood as well as unsustainable irrigation practices and water use for mining activities. Between 2006 and 2009, 7 per cent of the total territory or 110,000 km^2 of land were degraded annually (Khuldorj, Bum-Ayush, Dagva, Myagmar, & Shombodon, 2012). However, the problem of deforestation has been acknowledged by the Mongolian government and is addressed through supportive laws and policies promoting reforestation and the protection of forest areas (Tsogtbaatar, 2004).

Also in North Korea, forest cover has been significantly reduced, from 8.2 million ha (1990) to 5.7 million (2010). A reduction in forest land of 127,000 hectares per year over the past two decades (Lager, 2015).

Deforestation also had severe impacts on the Republic of Korea, resulting in the loss of half its forest cover. As a result, severe erosion, repetitive flood and drought damage could be observed as well as a decrease in agricultural production threatening national food security. Consequently, the government undertook an intensive forest rehabilitation effort. Two Ten-Year Forest Rehabilitation Plans in the 1970s and 1980s not only fully restored the country's forest cover, but also improved the food security level and contributed to national economic development (FAO, 2016).

South Asia: South Asia is the most densely populated region in the world with over 1.749 billion people living in eight different countries

TABLE 1.3

Provisional estimates of the cost of land degradation in the South Asia region
(Young, 1994)

Type of degradation	Cost, USD billion / year	Notes
Water erosion	5.4	On-site effects only
Wind erosion	1.8	Assessed relative to water erosion
Fertility decline	0.6 – 1.2	Tentative estimate
Waterlogging	0.5	
Salinization	1.5	
Lowering of water table		Not assessed
Total	9.8 – 10.4	

and 70 per cent of them in India. The region can roughly be divided into two climatic zones. Bangladesh, Bhutan, Nepal, Maldives and Sri Lanka have predominantly humid climate and arid climates are typical for Afghanistan, Pakistan and Iran, while India lies in between. High mountain ranges, vast alluvial plains and uplands are characteristic for the South Asian region. The most severely degraded countries in South Asia are Iran, Bangladesh and Pakistan. A study by the FAO revealed that land degradation and desertificaiton in all nations of South Asia could cost up to USD 10 billion/year (Young, 1994). However, in this calculation only the on-site effects (erosion, fertility decline, salinization, waterlogging and ground water discharge) are included and it would be significantly higher if also off-site effects (e.g. river silting, floods, and landslides) were accounted for. The underlying causes identified are inappropriate land tenure systems, poverty, population growth in combination with land shortages, agricultural mismanagement, overgrazing, deforestation, but also surface mining and industrial development (Bhattacharyya et al., 2015; Young, 1994).

Altogether 140 million hectares, or 43 per cent of the region's total agricultural land, suffers from one form of degradation or more. Of this, 31 million hectares were strongly degraded and 63 million hectares moderately degraded. The worst country affected was Iran, with 94 per cent of agricultural land degraded, followed by Bangladesh (75 per cent), Pakistan (61 per cent), Sri Lanka (44 per cent), Afghanistan (33 per cent), Nepal (26 per cent), India (25 per cent) and Bhutan (10 per cent) (Khor, 2011). More than 100 million hectares or 59 per cent of forest land in the region are understocked and unproductive and thus in need of some form of rehabilitation (Krishnapillay, Kleine, Rebugio, & Lee, 2007).

South-East Asia: Mainland and maritime South-East Asia is, compared to the other parts of Asia, mainly characterized by tropical and humid climates with a strong monsoon season. South-East Asia is a hotspot of biodiversity. However, severe deforestation is threatening the ecosystems. The ongoing deforestation in almost all countries in the region has one of the highest rates in the world. Between 2000 and 2015, South-East Asia lost around 158,862 km^2 of natural forest area (Squires, 2009). Main causes for deforestation are thereby the export of tropical wood and agricultural expansion, often related to oil palm cultivation. Other unsustainable agricultural practices include the cultivation of slopes in the mountainous regions as well as the extreme overuse of chemical pesticides and fertilizers. Soil erosion by wind and water, nutrient leaching and loss of soil quality are some of the consequence. Soil infertility is a serious problem in the region. Already half of the agricultural land reached the yield maximum due to poor soil quality (United Nations Environment Assembly [UNEA], 2016).

Western Asia – Western Asia is dominated by arid and semi-arid regions, but also contains forests and fertile valleys. The dry areas are particularly susceptible to wind and water erosion, but also salinization. Agricultural mismanagement, an increasing number of livestock combined with population pressure and a changing climate have exacerbated the process of land degradation over the last decades. Several countries in the region also often lack the required governmental structures to address the issue appropriately due to political turmoil and ongoing security threats. As a result, food security in the region will be increasingly at risk, especially in the Mashriq countries and Yemen. Furthermore, overexploitation of groundwater resources has resulted in a deterioration of water quality, seawater intrusion, depletion and salinization of aquifers, and rising pumping costs. Water demand in West Asia has been increasing, resulting in a diminishing per-person availability of water. Only 4 out of 12 countries in West Asia are above the water scarcity limit of 1,000 m^3 per person per year (Svensson, 2008).

1.3.2 Drivers and types of land degradation

Drivers of land degradation

Land degradation is a complex process that involves both the natural ecosystem and the socioeconomic system, among which climate and land use changes are the two predominant driving factors. There are several approaches to evaluate all the variables contributing to land degradation. *Figure 1.6* illustrates a scheme that identifies six "root" or underlying causes of land degradation and four direct causes including agricultural activities, infrastructure, harvesting of wood and fires (European Environment Agency [EEA], 2016).

According to the UN Environment Global Environmental Outlook GEO 6 Regional report: "Asia and Pacific" main human induced drivers include (UNEP, 2016):

A. Population: A key driver of environmental degradation is rapid population growth. Asia and the Pacific's huge population drives significant environmental challenges. The region's population, about 60 per cent of the world's total, reached around 4 billion people in 2012, of which China with 1.36 billion and India with 1.25 billion people account for more than half of the total population of the region. The region's 2014 mid-year population stands at 4.367 billion, and it is projected to rise to 5.08 billion by 2050. By 2014, around 42 per cent of the region's population was urban and 58 per cent rural, but by 2050 the urban population is projected to increase to about 63 per cent of the total. Out of 28 mega-cities with more than 10 million people in the world, 15 are in Asia and the Pacific – Tokyo (37.8 million), Delhi (25 million) and Shanghai (23 million) are the three most populous cities in the world. The demographic transition to urban areas and its environmental consequences will largely determine the sustainable development pathways of the region during the next 25 years and beyond.

B. Globalisation and regional integration: Asia and the Pacific have participated actively in globalisation, with many manufacturing and service sector activities moving to the rapidly developing Asia, providing immense economic opportunities for millions of people. In addition, regional integration has had a strong beginning in the last decade.

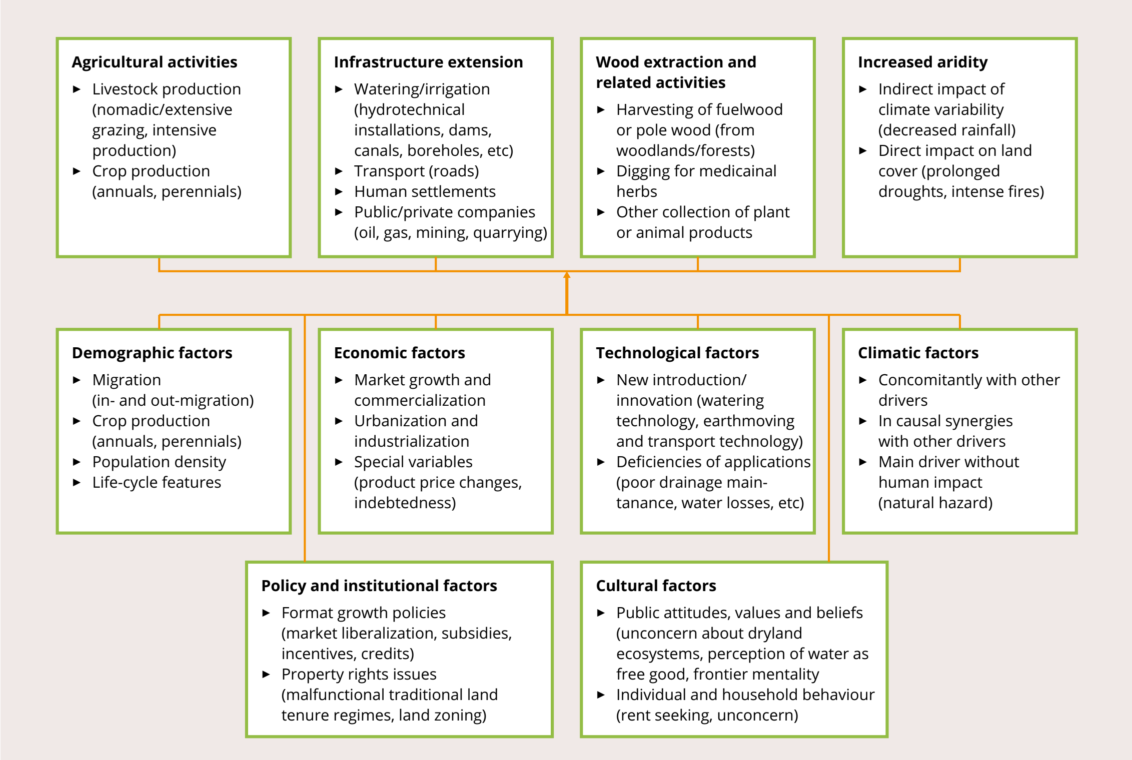
C. Economic growth: countries have introduced policies paving the way for rapid economic development and inclusion of populations in the economic growth of the region. Consequently, there was a significant growth in the proportion of the middle class in most developing Asian countries.

D. Living standards: the region has witnessed poverty reduction, access to healthcare and education, reduction in hunger and malnutrition, better transport and communication facilities and improved access to water and sanitation facilities. Change in people's dietary preferences has influenced the way that food is produced and consumed in the region.

FIGURE 1.6

Causes of land degradation: drivers and pressures

(Svensson, 2008)



E. Changing migration pattern: Asia and the Pacific host more than 30 million migrant workers, amongst whom, in contrast with the past, women make up about half of the total. The regional population movements have local and global environmental consequences such as

- Rural-rural migration produces direct household impacts on natural resources, often through agricultural expansion to critical and vulnerable ecosystems.
- Rural-urban migration and associated livelihood changes are often accompanied by changing patterns of consumption, energy use, and increased pressures on water supply and waste management, which can deteriorate urban environments and intensify land pressures in productive rural areas.
- International migration, with remittances sent home, can have a direct impact through land-use investment or an indirect impact through increased meat, dairy and material consumption.

However, in many parts of Asia agriculture in all its forms, is often still the main driver for land degradation and desertification. In general, the three main causes are overgrazing (35 per cent), unsustainable crop production and intensive pasture (28 per cent) and deforestation (30 per cent) (UNCCD, n.d. b).

Overgrazing

In many Asian countries livestock production is a major part of the agricultural sector and therefore overgrazing is a main contributor to land degradation. According to Jarvis (1991) overgrazing "implies that the stocking rate on a given pasture is too high, i.e., economic resources are used inefficiently and the value of society's output is less than it could be". This means intensive livestock production leads to the extensive removal of vegetation, which in turn decreases soil cover

FIGURE 1.7

Hot spots of land degradation in Central Asia

(Mirzabaev et al., 2016)

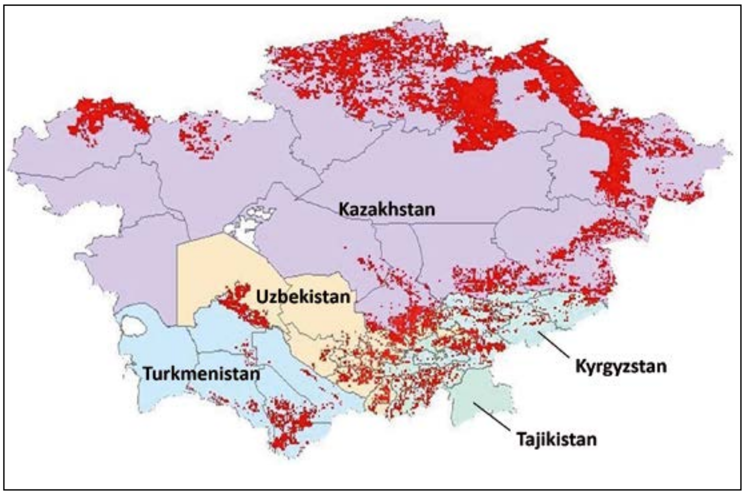
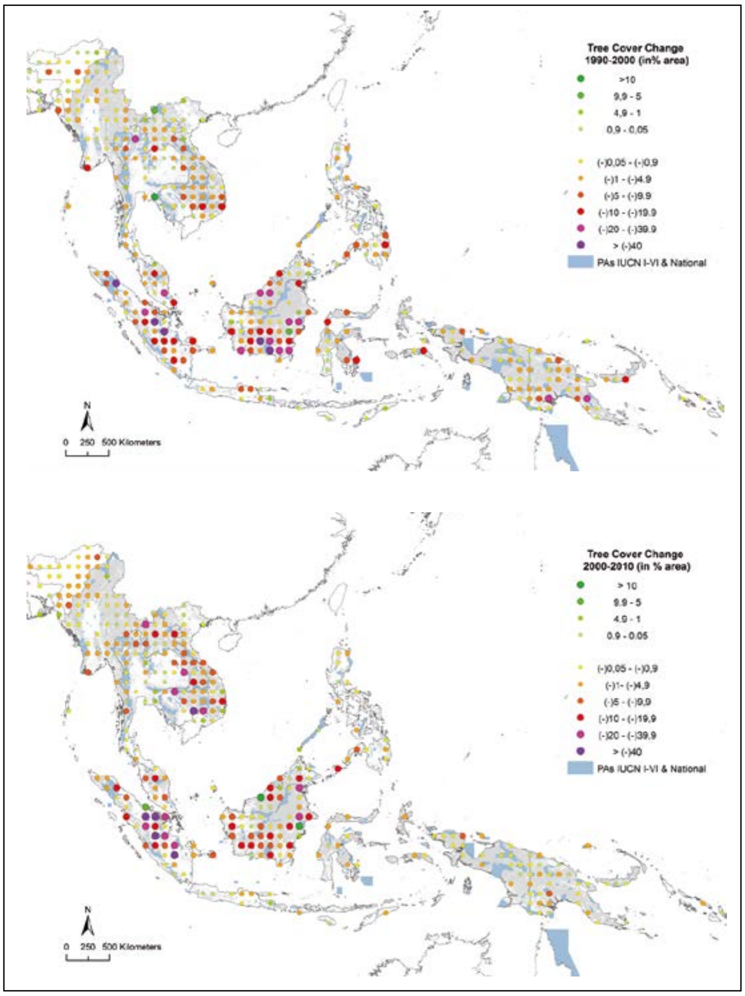


FIGURE 1.8

Tree cover change in SEA between 1990-2000 & 2000-2010

(Stibig et al., 2014)



and leads to soil compaction. Therefore, land becomes particularly susceptible to wind and water erosion. In Central Asia, the ELD Initiative studied how unsustainable livestock farming contributes to land degradation and how a change towards sustainable management practices can benefit the population and entire ecosystems (ELD, 2016). *Figure 1.7* shows that large parts of highland pasture in Central Asia already faces severe land degradation, mainly due to livestock production.

Agricultural mismanagement

Agricultural mismanagement cannot be defined clearly, as it refers to the improper management of agricultural land and includes a wide variety of practices. In general, agricultural mismanagement fails to cultivate land sustainably such as conserving soil quality and protecting soil from erosion, pollution and overexploitation. Contributing factors are the excessive use of fertilizers and pesticides, poor irrigation and shortened fallow periods.

Deforestation

Deforestation, which refers to the "the long-term or permanent loss of forest cover and implies transformation into another land use (Schoene, Killmann, Lüpke, & LoycheWilkie, 2007)" can have different causes. It can be linked to the export of exotic wood, extension of agricultural land for large-scale cultivations, but also to small-scale farmers and their swidden cultivation practices or grazing livestock. The removal of forests significantly affects the water cycle and resources causing a drier climate, reducing flood/drought control and increasing water erosion. The impact on land can be severe once soil is exposed to sun, rain and wind (Chakravarty, K., P., N., & Shukl, 2012). South-East Asia is particularly affected by deforestation, often in the context of legal/illegal logging and agricultural extension for oil palm cultivation. Results show a drop of total forest cover from 268 to 236 million ha in only 20 years (Stibig, Achard, Carboni, Raši, & Miettinen, 2014).

Types of land degradation

Degradation can be categorized into two main process of soil erosion and two minor processes. The displacement of soil by wind and water is

TABLE 1.4

Wind and water erosion in Asia and the world
(Oldeman, 1992)

In Million ha	Light	Moderate	Strong	Total	Percentage of degraded soils	Dryland zone	Humid zone
Water Erosion Asia	124	242	73	441	59	165	276
Water Erosion World	343	526	223	1,094	56	478	615
Wind Erosion Asia	132	75	15	222	30	206	16
Wind Erosion World	269	254	26	548	28	513	36

TABLE 1.5

Chemical deterioration in Asia and the world
(Oldeman, 1992)

In Million ha	Loss of nutrients	Salinization	Pollution	Acidification	Total	Percentage of degraded soils	Dryland zone	Humid zone
Chemical Erosion Asia	15	53	2	4	74	10	54	20
Chemical Erosion World	136	77	21	6	240	12	111	130

responsible of the largest share of degraded land in Asia and worldwide.

Sand and dust storms are one phenomenon caused by wind erosion responsible for severe problems on the environment and humans. Wind erosion mainly occurs in dryland zones where rainfall is below 600 mm, the dry season lasts more than six month and soils have a loose structure. Wind erosion accounts for 30 per cent of the degraded land and affects a total of 222 million ha, mainly in Western, South and Eastern Asia.

Water erosion is more likely to appear in humid zones. It can occur in various forms with different intensities and consequences. Typically, erosion refers to splash, sheet, rill, gully, or tunnel erosion. It can occur naturally but more likely is human-induced by deforestation or agricultural mismanagement, which removes the vegetation cover and therefore destabilises the land. Water erosion can be found all over Asia and is responsible for 59 per cent of the degraded soil on the continent (Oldeman, 1992).

Soil degradation by physical and chemical deterioration only accounts for a small part of the degraded land but can severely affect soil quality.

Only 10 per cent of the degraded soils in Asia are the result of chemical deterioration. This includes loss of nutrients, salinization, pollution and acidification. Salinization affects thereby

TABLE 1.6

Physical deterioration in Asia and the world
(Oldeman, 1992)

In Million ha	Compaction, Sealing, Crusting	Waterlogging	Subsidence of organic Soils	Total	Percentage of degraded soils	Dryland zone	Humid zone
Chemical Erosion Asia	110	+	2	12	2	10	2
Chemical Erosion World	68	11	4	83	4	35	48

the largest are (53 million ha), followed by loss of nutrients (15 million ha). Salinization is often a result of poor irrigation practices causing a significant decline in soil quality and fertility of the land. The loss of nutrients is mainly linked to agricultural practices. Ongoing agricultural production withdraws a substantial part of the soil nutrients. On the one hand, those need to be replaced to maintain the soil quality, on the other hand, can the overuse of fertilizer cause acidification and pollution of soil and water.

The physical deterioration of soil can be caused by compaction, sealing, crusting, water-logging or the subsidence of organic soils. Only 2 per cent of the degraded area in Asia is a result of physical deterioration. Compaction, sealing and crusting are the main parts of physical degradation and are mainly caused by the use of heavy machinery in the agricultural sector and the expansion of urban areas and infrastructure. It affects a total area of 110 million ha in Asia.

1.3.3 Review of key datasets

A review of methods and key data sets in the context of land degradation was conducted by (Gibbs & Salmon, 2015).

The major approaches used to quantify degraded lands can be grouped into four broad categories *(Table 1.7)*:

1) Expert opinion;
2) Satellite- derived net primary productivity;
3) Biophysical models;
4) Mapping abandoned cropland.

Each offers a glimpse into the conditions on the ground but none capture the complete picture.

Expert opinion

Assessment based on experts' opinion remains one of the most common approaches for mapping and quantifying land degradation. This approach is rather subjective and difficult to verify nevertheless it continue to play and important role. GLASOD was the first attempt to map human-induced degradation around the world. Despite its limitations, GLASOD remains the only complete, globally consistent information source on land degradation and has been widely used and interpreted. The expert opinion approach will continue to dominate until satellite-based measurements can provide more comprehensive and detailed information for both vegetation and soils (Gibbs & Salmon, 2015).

Satellite-based approach

Remotely-sensed data is major source of information to improve our knowledge about the locations and distribution of degraded lands in a consistent manner. However, satellite measurements provide an excellent measure of productivity over large areas it is difficult to capture different facets of land degradation as well as the process of degradation. Thus, it is unlikely that remote sensing will be able to map all cases of land degradation unequivocally, but the approach does provide valuable information and identification

TABLE 1.7

Benefits and limitations of major approaches used to map and quantify degraded lands *(Gibbs and Salmon, 2015)*

Approach	Benefits	Limitations
Expert opinion	Captures degradation in the past Measures actual and potential degradation Can consider both soil and vegetation degradation	Not globally consistent Subjective and qualitative Actual and potential degradation sometimes combined The state and process of degradation often combined
Satellite-derived net primary productivity	Globally consistent Quantitative Readily repeatable Measures actual rather than potential changes	Neglects soil degradation Only captures the process of degradation occurring following 1980, rather than complete status of land Can be confounded by other biophysical conditions
Biophysical models	Globally consistent Quantitative	Limited to current croplands Does not include vegetation degradation Measures potential, rather than actual degradation
Abandoned cropland	Globally consistent Quantitative Captures changes 1700 onward	Neglects land and soil degradation outside of abandonment Includes lands not necessarily degraded Measures actual rather than potential changes

of potential hotspots of ongoing degradation. Extensive ground truth data is required to produce reliable estimates of degraded areas from remote sensing at broad scales (Gibbs & Salmon, 2015).

Biophysical models

The biophysical modelling approach to assessing land degradation is a recent development. Generally speaking, biophysical models may indicate land degradation by combining their prediction of the cropping suitability of land with observation of their current productivity. The accuracy of the biophysical approach will be influenced by the quality of the data used for calibration and the suitability of the model selected, which can be especially challenging when trying to manage conditions that vary locally at the global scale (Gibbs & Salmon, 2015).

Abandonment of agricultural lands

One way to identify degraded lands is to identify areas that were once croplands but have since been abandoned because of decreased productivity, or due to political and economic reasons. A severe limitation of this approach is that it excludes degradation other than agricultural abandonment, so provides an extremely biased estimates of degradation. Furthermore, estimates of historical land use on which the agricultural abandonment approach is based are themselves highly uncertain (Gibbs & Salmon, 2015). Hence this approach is of limited value for assessing land degradation

02 Economics of Agricultural Land Degradation Neutrality: underlying assumptions and methodological approaches

2.1. Introduction

This chapter aims to estimate the nutrient balance in soil for agricultural ecosystems in the selected countries, using nutrient auditing and results from a biophysical modelling approach as an input into econometric modelling, alongside an estimation of soil nutrient depletion and total soil nutrient loss. It also aims to develop an econometric model of aggregate crop yield as a function of land degradation and factor inputs.

Based on the empirical model results, the chapter also looks at an estimation and valuation of soil nutrient depletion, nutrient losses, and associated aggregate crop production losses. It discusses economic valuation approaches, conceptual frameworks, biophysical modelling of soil nutrient balances and trends of land degradation in Asia for the period 2002-2013.

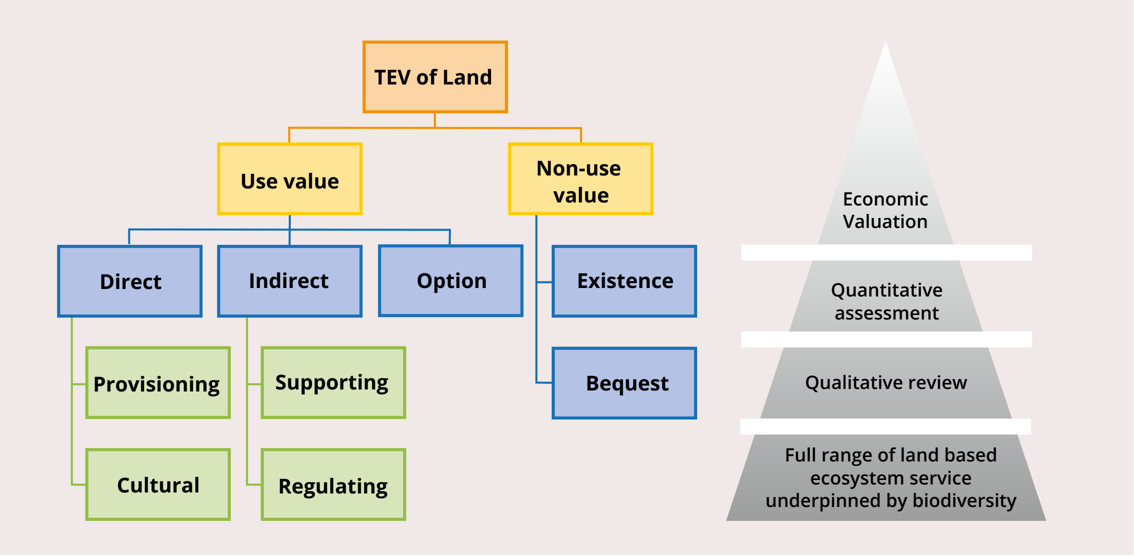
2.2. Total economic value and approaches for assessing the value of land

Economic valuation is an important tool that can aid decision makers in evaluating the trade-offs between losses due to land degradation and net gains of actions taken towards SLM. The concepts of total economic value and ecosystem services are important in the broader context of environmental valuation and the valuation of costs and benefits associated with measures against land degradation at different scales.

FIGURE 2.1

Total economic value

(Adapted from Convention on Biological Diversity [CBD], n.d.; Millenium Ecosystem Assessment [MEA], 2005; Pearce, 1993))



BOX 3

Valuation methods

Market demand based approaches

1. ***Direct market price:*** this involves the valuation of an ecosystem service using its market price. For some of the direct use value elements of forests like timber, fuel wood, and resins there are markets and the prices of these goods can be used directly to value them.

2. ***Hedonic pricing:*** this is based on the consumer theory that every good provides a bundle of characteristics or attributes (Lancaster, 1966). The value of a real estate near a degraded landscape with a possible risk of flooding to another real estate with similar conditions but has a forest in the nearby will be different. The forest as a public good provides different amenities to the nearby real estate. Therefore, the difference in prices of the two real estates can be attributed to the services that the forest provides.

3. ***Travel cost method:*** this method helps estimate the demand or marginal valuation curve for recreation sites. These cultural ecosystem services can be inferred from observing how the number of visits to the sites varies according to the prices of private goods (like transport costs) with the travel distance.

4. ***Contingent valuation:*** this method first describes the ecosystem service to be valued and then asks how much respondents are willing to pay for the specified service. The conventional contingent valuation method values an ecosystem service in its entirety and nothing is revealed about the values of the different attributes of the service.

5. ***Choice experiments:*** in choice experiment valuation, the characteristics of the ecosystem service are explicitly defined; vary over choice cards along with a monetary metric. Then, individuals have to choose different combinations of characteristics of the ecosystem service over other combinations at various prices.

Non-market demand based approaches

6. ***Dose-response and/or production function:*** first requires assessing the relationship between environmental quality variables (example: soil nutrient levels) and the output level of a marketed commodity (say crop output) and, then valuation of the loss or improvement in environmental quality is made in terms of the loss or gain in the commodity with market price (Garrod and Willis, 2001). This approach requires availability of scientific knowledge on the cause effect relationships between for example supporting ecosystem service and an economic activity that it supports (Barbier et al., 2009).

7. ***Preventive expenditure or aversive behavior approach:*** the value of the environment is inferred from what people are prepared to spend on preventing its degradation (Garrod and Willis, 2001). The value of an ecosystem service (say a forest near urban areas for example providing air purification service through absorbing dust particles and pollutants) can be inferred from the expenditure on technologies required to reduce the pollutants.

8. ***The replacement cost approach:*** values an ecosystem service in terms of the cost required to restore the ecosystem service to its original state after it has been damaged. Example, nutrient depletion due to soil erosion can be valued in terms of the cost of commercial fertilizer required to replenish the depleted nutrient to its original state.

9. ***Opportunity cost approach:*** this approach values the benefits of an ecosystem service (for example the benefits of assigning a forest area for nature conservation) in terms of the next best alternative forgone as to achieve it. For example a forest area assigned for nature conservation could have been used for agricultural crop production as second best alternative. Thus, the opportunity cost of conserving the forest is the forgone net income from crop production.

The total economic value of environmental resources, as defined by economists and illustrated in *Figure 2.1*, is the sum of two main sources of value that human beings drive from the environment, namely the 'non-use values' and 'use values' (Pearce, 1993; Perman, Ma, Common, Maddison, & McGilvray, 2011). Non-use values refer to those unrelated to current, future, or potential uses of an environmental resource (Krutilla, 1967). It measures the value or satisfaction that people get from the knowledge of the existence of environmental assets per se (existence value), for the pleasure of others (altruistic value) or for future generations (bequest value) (Plottu & Plottu, 2007). The use values include direct use values and indirect use values. The first refers to the goods and services that directly accrue to the consumers and can be either market or non-market benefits. Whereas indirect use values are special functions of environmental resources that accrue indirectly to either users or non-users. This can include the benefits that forests provide as watershed functions like soil conservation, improved water supply and water quality, flood and storm protection, fisheries protection, and local amenity services. The third component of use value is the option value that refers to the potential future benefits of all use values (Weisbrod, 1964).

The typology of ecosystem services introduced by the Millennium Ecosystem Assessment provides a conceptual structure to identify a comprehensive list of the services that land and land based natural resources provide to society as provisioning, regulating, cultural, and supporting ecosystem services (MEA, 2005; Nkonya, Gerber, Braun, & Pinto, 2011; Noel & Soussan, 2010). Land provides society with **provisioning services** as direct use values, which include food, water, fibre, timber, fuel, minerals, building materials and shelter, and biodiversity and genetic resources. Education, research, aesthetic, and spiritual values that land provides to society are **cultural ecosystem services** which can fall in the categories of direct use value, indirect use values as well as existence value of the total economic value framework. Soils support almost all units of life forms, and land provides soil formation and nutrient cycling as **supporting ecosystem services**. This can be considered as elements of the indirect use values, option values as well as non-use values. Forest resources as land-based ecosystem provide carbon sequestration and stock services as **regulating services**, which are part of the indirect use value (MEA, 2005).

In the valuation of ecosystem services, it is important to distinguish between values of asset or stock values and products or flow values to avoid double counting. A stock is a quantity existing at a point in time and a flow is a quantity per period. Stocks, flows, and their relationship are crucial to the operation of both natural and economic systems (Common & Stagl, 2005). It is important to note also that economic valuation can only capture part of the value of environmental resources and the services it provides. Therefore, it is necessary to complement the economic valuation with quantitative and qualitative assessments and reviews for the ecosystem services for which attaching monetary value is difficult or if possible, the monetary value may not provide the true value of the resource to human welfare. For example, it is difficult to attach monetary value to biodiversity but it is possible to describe quantitatively and qualitatively the importance of biodiversity to human welfare.

BOX 4

Assumptions and caveats of the ELD Asia Study

1. Land degradation influences the society through its on-site and off-site impacts. We have considered only the on-site impact
2. Amongst the on-site impacts, flow of various ecosystem services are impaired. Due to unavailability of data at the appropriate scale for all countries of Asia, we have focused on only on nutrient loss and soil nutrient depletion.
3. Land degradation in arable and permanent croplands has been approximated with the loss of N, P, and K nutrients and soil N, P, and K depletion
4. Change in productivity due to change in nutrients resulting from soil erosion has been captured
5. Water borne top soil loss remains the dominant form of land degradation
6. Data used in the analysis do not explicitly capture and explain spatial variability within a country.

Note that the estimates in this study are very conservative and would fall in the lower bound.

2.3. Conceptual framework and land degradation neutrality

The ELD Asia study covers 44 countries and two provinces of China[2]. The countries cover all the five geographical sub-regions, which are Central Asia (4 countries), East Asia (4 countries and two provinces of China), South Asia (8 countries), South East Asia (11 countries), and West Asia (17 countries). The countries are selected based on availability of data required for undertaking the study. The study is guided by the conceptual framework in *Figure 2.2* and based on the assumptions presented in *Box 4* beside.

FIGURE 2.2

Conceptual Framework

1. Biophysical Modeling of National Level Nutrient Flows and Balances

Inputs
Fertilizer
Nitrogen fixation
Crop residues (recycled)
Sedimentation
Sewage
Animal residues (Manure)

Soil
NPK nutrient reserves

Crop residues

Animal residues

Animals

Outputs
NPK in Arable crops and crop residues

Losses
Gaseous, Leaching, Erosion, immobilization (fixation), crop residues (not recycled), animal residues (not recycled)

Soil
NPK nutrient reserves

Outputs (animal)
NPK in animal products

Nutrient flows in mixed farming. Source (Sheldrick, Syers and Lingard, 2002)

2. Econometric Modeling of Land Degradation and Induced Losses of ESS

Nutrient losses
Biophysical factors (Soil erosion, forest cover ...) and socioeconomic factors (Poverty, equity, gender, GDP per capita, GDP by sectoral composition, livestock population)

Crop yield (food and fibre)
Soil nutrient depletion and factor inputs

Cost of SLM
Socioeconomic factors

3. Estimation & Valuation of Benefits & Costs for Baseline & an LDN Scenario

Avoided Nutrient Loss and Nutrient Depletion

Gains in Crop Productivity and Production

Cost of SLM for LDN

4. Costs Benefit & Sensitivity Analysis of the LDN Scenario

NPV & BCR for achieving LDN by 2030 in Asia, sub regions and each country

Sensitivity of NPVs and BCRs to changes in real discount rate, prices, costs of SLM, efficiency in SLM interventions in achieving LDN

5. Policy Implications

SDG

Other SDGs (1, 2, 8, ...)

[2] **Central Asia** *(Kazakhstan, Kyeargyzstan, Tajikistan, Uzbekistan);* **East Asia** *(Mainland China, China Hong Kong SAR, Japan,Taiwan Province of China, Republic of Korea, Mongolia);* **South Asia** *(Afghanistan, Bangladesh, Bhutan, India, Islamic Republic of Iran, Japan, Nepal, Pakistan, Sri Lanka);* **South East Asia** *(Brunei Darussalam, Myanmar, Indonesia, Cambodia, Lao Peoples's Democratic Republic, Malaysia, Philippines, Timor-Leste, Singapore, Thailand, Viet Nam);* **West Asia** *(Armenia, Azerbaijan, Bahrain, Cyprus, Georgia, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syearian Arab Republic, Turkey, United Arab Emirates, Yemen).*

2.4. Biophysical modelling: National and regional level nutrient auditing in croplands

Depletion of soil nutrients is a major problem in soil degradation and jeopardises long-term resource production, like food and fibre, which are important commodities. National level nutrient balance accounting dates back to the late 19th century in the UK by Johnston and Cameron as referred to by Powlson (1997) and cited in Sheldrick et al. (2002). The first regional level accounting of soil nutrient balances was the study by Stoorvogel and Smaling (1990) which assessed the state of soil nutrient depletion in 35 sub-Saharan African countries in 1983 alongside expected balances for 2000. Earlier studies in Asia were in only a few countries with some focusing on specific sites and at farm levels. Such studies include Mutert (1996) for 10 countries for major crops and rice only, and Dobermann, Santa Cruz, and Cassman (1995) who did site specific nutrient balances for rice farming systems in 10 sites covering some Asian countries. A study by Xianqing, Cunshan, and Dehai (1996) reported nutrient balances in south China based on studies on 71 farms.

The latest regional and global level study on soil nutrient balances available is the work of Sheldrick et al. (2002) that reported aggregated regional level nutrient balances for Africa, Asia (West Asia, South Asia, and East Asia), the former Soviet Union, Americas (North America, Central America, South America), and Oceania. Their study covered the years 1961-1996 and provided a conceptual framework for auditing national and regional level nutrient balances using mainly relevant national level data available in the FAO database. However, the study reported national level nutrient balances only for three countries as an example (Japan, Republic of Korea, and Kenya) and did not provide details on the rest of the countries covered in their study. Moreover, it has now been more than two decades since, and there has not been any study on nutrient balance at global or regional levels that covers as many countries as possible to have data for regional level economic analysis of the impact of soil nutrient depletion. Therefore, it is important to carry out national level soil nutrient accounting indicating the current state in Asian countries. Furthermore, such up-to-date information is important for making economic analysis and derive policy implications for the Sustainable Development Goals.

TABLE 2.1

Average annual NPK nutrient flows and balances in millions of tons from 2002 – 2013 by sub regions and across Asia

	Central Asia		East Asia		Southern Asia		South East Asia		West Asia		Asia	
	Million tons	% Total	Million tons	% Total	Million tons	% Total	Million tons	% Total	Million tons	% Total	Million tons	% Total
NPK Inputs												
Fertiliser	0.66	15.9	41.56	56.8	27.91	45.2	10.02	37.4	3.40	38.1	83.55	47.8
Crop residue	0.04	1.0	0.16	0.2	0.27	0.4	0.05	0.2	0.08	0.9	0.59	0.3
Manure	0.78	18.6	13.02	17.8	11.52	18.6	4.17	15.6	0.79	8.8	30.28	17.3
*N fixation	0.04	1.0	0.95	1.3	1.18	1.9	0.41	1.5	0.17	1.9	2.75	1.6
*N deposition	0.01	0.3	1.42	1.9	1.25	2.0	0.28	1.0	0.10	1.2	3.07	1.8
Sewage	0.01	0.3	0.40	0.6	1.65	2.7	0.13	0.5	0.01	0.1	2.21	1.3
From soil	2.63	63.0	15.61	21.3	17.98	29.1	11.74	43.8	4.38	49.0	52.34	29.9
Total NPK Inputs	4.18	100.0	73.11	100.0	61.77	100.0	26.80	100.0	8.92	100.0	174.78	100.0
NPK Outputs												
Arable crops	2.51	60.1	37.98	51.9	33.05	53.5	18.20	67.9	4.60	51.6	96.34	55.1
Crop residues	0.67	16.1	3.55	4.9	4.50	7.3	0.77	2.9	1.26	14.2	10.75	6.2
Losses	1.00	23.8	31.59	43.2	24.22	39.2	7.83	29.2	3.06	34.3	67.69	38.7
Total NPK Outputs	4.18	100.0	73.11	100.0	61.77	100.0	26.80	100.0	8.92	100.0	174.78	100.0

**refers only to Nitrogen*

Therefore, based on the methods described in Sheldrick et al. (2002) and using mainly data from the FAOSTAT database, we conducted accounting of NPK nutrient balances and evaluated the trends in nutrient depletion in arable and permanent croplands of the 44 Asian countries and two provinces of China for the period 2002 to 2013. Interested readers on the details of the methodology are referred to Sheldrick et al. (2002). The scope of the study covers arable and permanent crop lands cultivated with 127 crop types of which 13 are cereals, 6 root and tuber crops, 10 pulses, 7 nuts, 20 oil crops, 25 vegetables, 37 fruit types, and 9 fibre crops. According to the FAOSTAT database, the land area cultivated with these crops in total was about 487 million hectares over the period 2002-2013 and it accounts for 87.43 per cent of the total arable and permanent cropland of all the countries covered in the study. Land cultivated with cereals accounts for the highest (59.06 per cent) of the 487 million hectares followed by oil crops with 18.22 per cent and pulses accounting for 6.7 per cent. The other crop categories all together cover the remaining 16.03 per cent of the cultivated land.

2.4.1. Results of NPK auditing

NPK flows and balances in croplands

NPK inputs and outputs: Table 2.1 shows the annual flows of NPK inputs and outputs from 2002-13 by sources, sub-regions, and the region of Asia. Country level flows are given in Table 2.2. These indicate the relative importance of NPK inputs and outputs in arable and permanent crop farming across these scales. In the case of input flows, the total regional level annual input was 174.8 million tons. Commercial fertiliser accounts for 47.8 per cent of the inflow followed by nutrients from soil reserves (29.9 per cent) and manure (17.3 per cent). Similar trends in the relative importance of commercial fertiliser, soil reserves, and manure as the first three most important sources were observed in East and Southern Asia sub-regions. In the other three sub-regions nutrient mining from soil reserves was the largest source (accounting for 43 to 63 per cent) with commercial fertiliser in Southeast and West Asia and manure in central Asia as the second NPK input source respectively.

In 13 countries[3] and the two provinces of China, input flow from soil reserves was negative, indicating that these countries achieved surplus in their soil nutrient balances. In nine of these countries and Taiwan Province of China, commercial fertiliser was the major input source ranging from 57.5 per cent in Cyprus to 181.9 per cent in Qatar. Manure was the largest input source in the China Hong Kong SAR (63 per cent), Singapore (81.6 per cent), Kuwait (96.8 per cent), Mongolia (157.7 per cent), and Brunei Darussalam (193 per cent).

In the remaining 31 countries, input flow from soil reserves was positive indicating nutrient mining that accounts from 1.7 per cent of the total input in Malaysia to about 81 per cent in Kazakhstan. NPK nutrient from soil reserves was the largest input in 22 of these countries[4] whereas commercial fertiliser was the largest source in the other nine[5].

NPK nutrient outputs in crops and crop residues: Out of the total nutrient outputs of 174.78 million tons at the regional level, close to 61.3 per cent is as NPK in crop products (crops and crop residues) with crops accounting for the largest share in total output. There was no difference in the relative contribution of NPK output in crops to total output between sub-regions. In each of the sub-regions, the share of NPK output in crops to total output was the largest contributor and accounts for between 51.6 per cent in West Asia to 67.9 per cent in South East Asia.

In 30 countries[6] the proportion of NPK output in crops to total output ranges from 48.8 per cent in Iran to 81.7 per cent in Cambodia, whereas the share of NPK output in crop residues in these group of countries was from 0.5 per cent in Malaysia to 21.8 per cent in Kazakhstan. In the other 14 countries[7] and two provinces of China, the proportion of NPK output in crops to total output was in the range of 1.6 per cent in Singapore to 45.8 per cent in Japan. In these countries, the highest output was in the form of nutrient losses. The contribution of output in crop residues ranged from almost zero in Singapore to 11.9 per cent in Saudi Arabia.

NPK nutrient losses: Nutrient losses account for the losses in the form of gaseous losses, volatilisation as ammonia, immobilisation or soil fixation, leaching, and erosion (Sheldrick et al., 2002). Such losses cannot be estimated directly in the model. Instead, they are estimated indirectly from nutrient inputs from the different sources, nutrient depleted from soil, and nutrient outputs in crops and crop residues.

The annual NPK nutrient losses for the region were 67.69 million tons for the study period, accounting for close to 39 per cent of the total nutrient input or output. At sub regional level, East Asia had the highest proportion of losses, accounting for 43.2 per cent of total output in the sub-region. Central Asia was the lowest at 23.82 per cent. At the country level, the proportion of losses to total national level inputs or outputs ranges from 14.2 per cent in Cambodia to 98.4 per cent in Singapore.

NPK soil balances: The aggregate annual soil nutrient balance for Asia during the study period was -60.42 million tons, indicating an annual depletion of 52.34 million tons of NPK from soil nutrient reserves of arable and permanent croplands, at an annual average depletion rate of 107.5 kg/ha/year (Table 2.3). There was a considerable variation in the rate of nutrient depletion across sub-regions, with the highest depletion rate 139.7 kg/ha in West Asia, and the lowest was 82.4 kg/ha in Southern Asia.

There was also a substantial variation in the rate of nutrient depletion between countries, allowing them to be grouped into two categories. The first group comprises 31 countries[8] with negative annual soil nutrient balances. In this group, the highest depletion rate was 198.6 kg/ha in Uzbekistan and the lowest was 6.3 kg/ha in Malaysia. The second group of countries[9] consists of 13 countries and the two provinces of China. This group showed surplus in annual soil balances, with the largest surplus of 7,119 kg/ha in Singapore and the lowest in Saudi Arabia with 1.27 kg/ha. However, these countries with surplus balances

[3] *Qatar, Jordan, Bahrain, United Arab Emirates, Oman, Taiwan Province of China, Saudi Arabia, Republic of Korea, Japan, Cyprus, China (Hong Kong), Brunei Darussalam, Mongolia, Kuwait, Singapore*

[4] *Indonesia, Bangladesh, Turkey, Georgia, Iran, Uzbekistan, Syearian Arab Republic, Iraq, Philippines, Armenia, Tajikistan, Kazachstan, Kyeargyzstan, Yemen, Azerbaijan, Afghanistan, Bhutan, Cambodia, Nepal, Myanmar, Timor-Leste, Lao PDR.*

[5] *Malaysia, Sir Lanka, Israel, China (mainland), Pakistan, Lebanon, India, Thailand, Viet Nam*

[6] *Iran, Republic of Korea, Yemen, Israel, Malaysia, China(mainland), Afghanistan, Iraq, Armenia, Syearian Arab Republic, Turkey, India, Georgia, Uzbekistan, Azerbaijan, Kazakhstan, Kyeargyzstan, Sir Lanka, Viet Nam, Thailand, Timor-Leste, Bhutan, Nepal, Indonesia, Bangladesh, Myanmar, Philippines, Lao PDR, Cambodia.*

TABLE 2.2

Average annual NPK nutrient flows and balances in 1000s of tons from 2002 – 2013 by country

Country	INPUTS				OUTPUTS		
	Fertiliser+ crop residue+ manure+ sewage	N fixation+ deposition	From soil	Total Input	Crop + crop residues	Losses	Total Output
Afghanistan	333.39	26.90	329.86	690.16	482.77	207.39	690.16
Armenia	31.89	1.06	34.49	67.44	46.89	20.55	67.44
Azerbaijan	71.09	1.35	233.33	305.77	243.43	62.33	305.77
Bahrain	5.43	0.00	-2.52	2.91	0.32	2.59	2.91
Bangladesh	1398.94	74.76	1236.07	2709.76	2050.28	659.48	2709.76
Bhutan	9.12	0.95	10.65	20.72	14.84	5.88	20.72
Brunei Darussalam	8.09	0.01	-4.27	3.84	0.21	3.63	3.84
Cambodia	189.28	10.62	474.61	674.50	578.56	95.94	674.50
China, mainland	51504.29	1787.18	16084.27	69375.75	39758.86	29616.88	69375.75
China Hong Kong SAR	11.23	0.03	-5.25	6.01	0.36	5.65	6.01
Cyprus	27.72	0.18	-2.39	25.52	10.34	15.18	25.52
Georgia	44.14	0.61	39.66	84.41	54.30	30.11	84.41
India	30108.28	2443.94	13803.05	46355.27	28101.64	18253.64	46355.27
Indonesia	5322.21	140.45	4786.33	10248.99	7328.94	2920.04	10248.99
Iran	2143.15	130.93	1284.06	3558.14	2178.69	1379.45	3558.14
Iraq	239.97	5.53	314.27	559.77	392.17	167.60	559.77
Israel	124.60	2.49	18.40	145.49	81.86	63.63	145.49
Japan	2172.27	19.09	-155.00	2036.35	1003.22	1033.13	2036.35
Jordan	167.72	0.78	-73.36	95.14	24.51	70.63	95.14
Kazakhstan	374.96	16.18	1645.26	2036.41	1689.81	346.60	2036.41
Republic of Korea	1128.67	11.04	-50.26	1089.45	565.50	523.95	1089.45
Kuwait	30.86	0.05	-12.93	17.98	3.68	14.30	17.98
Kyeargyzstan	91.56	2.65	157.18	251.40	187.23	64.16	251.40
Lao PDR	92.63	3.82	221.44	317.89	271.70	46.19	317.89
Lebanon	69.83	1.52	11.56	82.90	42.42	40.48	82.90
Malaysia	1791.74	7.41	31.34	1830.49	959.77	870.72	1830.49
Mongolia	179.26	0.82	-73.81	106.27	26.77	79.50	106.27
Myanmar	649.70	140.16	1802.86	2592.71	2022.03	570.69	2592.71
Nepal	214.16	23.29	260.88	498.33	369.67	128.66	498.33
Oman	34.06	0.02	-12.49	21.59	7.86	13.74	21.59
Pakistan	6322.02	189.39	934.71	7446.12	4024.15	3421.97	7446.12
Philippines	1068.27	20.82	1248.32	2337.41	1826.14	511.27	2337.41
Qatar	59.06	0.01	-29.12	29.94	0.81	29.13	29.94
Saudi Arabia	543.44	0.85	-1.05	543.24	242.90	300.34	543.24
Singapore	11.05	0.00	-5.64	5.41	0.09	5.32	5.41
Sri Lanka	350.05	15.38	122.09	487.51	325.16	162.36	487.51
Syearian Arab Republic	419.75	13.14	503.94	936.83	630.04	306.79	936.83
Taiwan Province of China	686.15	5.27	-193.75	497.67	171.42	326.25	497.67
Tajikistan	129.60	2.19	108.45	240.24	167.06	73.18	240.24
Thailand	2946.77	48.52	1662.29	4657.58	3189.49	1468.09	4657.58
Timor-Leste	11.56	0.64	10.62	22.81	15.55	7.27	22.81
Turkey	2421.59	85.43	3302.76	5809.78	3964.73	1845.04	5809.78
United Arab Emirates	59.55	0.11	-21.46	38.20	12.19	26.01	38.20
Uzbekistan	926.00	3.80	719.84	1649.63	1138.45	511.18	1649.63
Viet Nam	2560.86	37.11	1513.09	4111.06	2780.77	1330.29	4111.06
Yemen	80.89	3.81	73.38	158.09	108.50	49.58	158.09

[7] *Japan, Lebanon, Pakistan, Taiwan Province of China, Saudi Arabia, Cyprus, Oman, United Arab Emirates, Jordan, Kuwait, Mongolia, Bahrain, China (Hong Kong), Brunei Darussalam, Qatar, Singapore.*

[8] *Uzbekistan, Azerbaijan, Lao PDR, Turkey, Kyeargyzstan, Indonesia, Viet Nam, Myanmar, Cambodia, Bangladesh, China (mainland), Tajikistan, Armenia, Philippines, Syearian Arab Republic, Nepal, Bhutan, Thailand, Afghanistan, Iraq, Georgia, India, Sri Lanka, Timor-Leste, Yemen, Israel, Pakistan, Lebanon, Malaysia, Bahrain, Iran, Kazachstan.*

[9] *Singapore, Qatar, China(Hong Kong), Kuwait, Brunei Darussalam, Jordan, Mongolia, Taiwan Province of China, Oman, United Arab Emirates, Japan, Republic of Korea, Cyprus, Saudi Arabia.*

TABLE 2.3

Average and total soil NPK balances and rates of NPK losses from 2002 – 2013 by country, sub regions, and across Asia

Country	Area in 1000s ha	NPK soil balance in 1000s tons	NPK soil balance in kg ha	NPK losses in 1000s tons	NPK losses in kg/ha
Afghanistan	3305.2	-329.86	-99.80	207.39	62.75
Armenia	283.9	-34.49	-121.48	20.55	72.39
Azerbaijan	1256.9	-233.33	-185.64	62.33	49.59
Bahrain	3.3	2.52	766.40	2.59	786.84
Bangladesh	8646.4	-1236.07	-142.96	659.48	76.27
Bhutan	101.3	-10.65	-105.11	5.88	58.05
Brunei Darussalam	8.5	4.27	501.76	3.63	426.86
Cambodia	3255.2	-474.61	-145.80	95.94	29.47
China, mainland	123000.0	-16084.27	-130.77	29616.88	240.79
China Hong Kong SAR	2.0	5.25	2664.44	5.65	2867.32
Cyprus	94.7	2.39	25.22	15.18	160.27
Georgia	463.1	-39.66	-85.64	30.11	65.03
India	170000.0	-13803.05	-81.19	18253.64	107.37
Indonesia	29500.0	-4786.33	-162.25	2920.04	98.98
Iran	13000.0	-1284.06	-98.77	1379.45	106.11
Iraq	3304.5	-314.27	-95.10	167.60	50.72
Israel	289.4	-18.40	-63.57	63.63	219.86
Japan	2951.0	155.00	52.53	1033.13	350.09
Jordan	190.9	73.36	384.29	70.63	369.98
Kazakhstan	16600.0	-1645.26	-99.11	346.60	20.88
Republic of Korea	1746.0	50.26	28.79	523.95	300.08
Kuwait	12.0	12.93	1079.81	14.30	1194.01
Kyeargyzstan	919.1	-157.18	-171.01	64.16	69.81
Lao PDR	1198.3	-221.44	-184.80	46.19	38.55
Lebanon	245.3	-11.56	-47.11	40.48	165.05
Malaysia	4961.9	-31.34	-6.32	870.72	175.48
Mongolia	241.1	73.81	306.17	79.50	329.73
Myanmar	11600.0	-1802.86	-155.42	570.69	49.20
Nepal	2377.5	-260.88	-109.73	128.66	54.12
Oman	55.6	12.49	224.69	13.74	247.11
Pakistan	19500.0	-934.71	-47.93	3421.97	175.49
Philippines	10300.0	-1248.32	-121.20	511.27	49.64
Qatar	5.5	29.12	5341.41	29.13	5343.27
Saudi Arabia	827.4	1.05	1.27	300.34	362.98
Singapore	0.8	5.64	7219.26	5.32	6810.54
Sri Lanka	1700.5	-122.09	-71.79	162.36	95.47
Syearian Arab Republic	4518.6	-503.94	-111.52	306.79	67.90
Taiwan Province of China	636.7	193.75	304.28	326.25	512.37
Tajikistan	869.0	-108.45	-124.80	73.18	84.22
Thailand	16300.0	-1662.29	-101.98	1468.09	90.07
Timor-Leste	149.8	-10.62	-70.91	7.27	48.51
Turkey	18600.0	-3302.76	-177.57	1845.04	99.20
United Arab Emirates	163.6	21.46	131.18	26.01	159.00
Uzbekistan	3624.6	-719.84	-198.60	511.18	141.03
Viet Nam	9582.2	-1513.09	-157.91	1330.29	138.83
Yemen	1040.0	-73.38	-70.56	49.58	47.68
Central Asia	22083.3	-2630.73	-119.13	995.12	45.06
East Asia	128333.3	-15606.18	-121.61	31585.36	246.12
Southern Asia	218333.3	-17981.36	-82.36	24218.83	110.93
South East Asia	86666.7	-11740.98	-135.47	7829.45	90.34
West Asia	31333.3	-4376.44	-139.67	3058.04	97.60
ASIA	486666.7	-52335.69	-107.54	67686.81	139.08

also have the high rates of nutrient losses (Table 2.2 and 2.3). The annual rate of nutrient losses for these group of countries ranges from 6,811 kg/ha in Singapore to 159 kg/ha in the United Arab Emirates. Moreover, for countries with surplus balances, the rate of losses was at least about 85 per cent of the balance, and even more than double for all countries except Singapore, Jordan, and Brunei Darussalam. This indicates that even when NPK balances are positive, it does not imply that the surplus amounts are readily available in the soil for plant growth. Most or part of it could be lost through erosion, leaching, gaseous losses, etc.

Trends

Regional and sub-regional level trends: Figure 2.3 shows that total soil NPK nutrient balance was -46.3 million tons in 2002 and it reached -61.2 million tons in 2013 across Asia; an increase in depletion. The rate of depletion was 98.9 kg/ha in 2002, and it increased to 126.2 kg/ha by 2013 *(Figure 2.3B)*. Over the 12 year period, the average annual depletion rate was 107.5 kg/ha.

In Central Asia, the total balance was -2.68 million tons in 2002, and reached -2.76 million tons in 2013; a relatively small increase in depletion. The rate of depletion at the sub regional level was 133.2 kg/ha in 2002, which decreased to 116.7 kg/ha in 2013 *(Figure 2.3B)*. Over the 12-year period, the average annual depletion rate was 119.1 kg/ha.

In East Asia, total balance was -14.7 million tons in 2002, and reached -18.2 million tons in 2013; an increase in depletion. The rate of depletion at the sub regional level was 112.9 kg/ha in 2002, which increased to 145.6 kg/ha in 2013 *(Figure 2.3B)*. Over the 12-year period, the average annual depletion rate was 121.6 kg/ha.

In Southern Asia, total balance was -14.9 million tons in 2002, and reached -21.9 million tons in 2013; an increase in depletion. Compared to the other sub-regions, Southern Asia had the lowest rate of soil nutrient mining per ha. The rate of depletion at the sub regional level was 70.4 kg/ha in 2002, which increased to 102.1 kg/ha by 2013 *(Figure 2.3B)*. Over the 12-year period, the average annual depletion rate was 82.4 kg/ha.

In South East Asia, total balance was -9.4 million tons in 2002, and reached -13.8 million tons in 2013; an increase in depletion The rate of depletion at the sub regional level was 120.4 kg/ha in 2002, which increased to 145.7 kg/ha by 2013 (Figure 2.3B). Over the 12-year period, the average annual depletion rate was 135.5 kg/ha.

In West Asia, total balance was -4.69 million tons in 2002, and reached -4.55 million tons in 2013; showing a very small decline in soil nutrient depletion. Compared to the other sub-regions, West Asia had the highest rate of soil nutrient mining per ha. The rate of depletion at the sub regional level was 139.4 kg/ha in 2002, which increased to 151.3 kg/ha by 2013 *(Figure 2.3B)*. Over the 12-year period, the average annual depletion rate was 139.7 kg/ha.

Country level trends: Mainland China, India, and Indonesia had the highest total depletion. The sum of depletion in these three countries accounted for about 65.7 per cent of the total depletion in Asia in 2002 and 68.2 per cent in 2013. In 2002, the total balance for mainland China was -15.1 million tons (or 32.6 per cent of total depletion in Asia) and reached -18.6 million tons in 2013 (30.3 per cent of total depletion in Asia). The rate of depletion in mainland China was 120.1 kg/ha in 2002, which increased to 152.5 kg/ha in 2013. In India, the total balance was -11.3 million tons (24.5 per cent of the total in Asia) in 2002, and it reached -17.5 million tons (28.62 per cent of the total in Asia) in 2013. The rate of depletion was 66.6 kg/ha in 2002, and it increased to 103.4 kg/ha by 2013. Indonesia had -4 million tons (8.6 per cent of the total balance in Asia) in 2002 and it reached -5.7 million tons (9.2 per cent of the total balance in Asia) by 2013. The rate of depletion was 155.7 kg/ha in 2002, which increased to 170.9 kg/ha in 2013.

In 2002, these three countries as well as 31 more countries had negative balances *(Figure 2.4A)*. The 31 countries together accounted for 35.7 per cent of the total balance in Asia for this year. Amongst these, seven countries[10] had balances between -3.2 million tons in Turkey and -1 million tons in Bangladesh. The other 24 countries[11] had balances between -0.9 million tons in the Philippines and about 0.003 million tons in Cyprus. Amongst these 31 countries, there was a huge variation in the rate of depletion at the hectare level. Malaysia had the lowest depletion rate of 14.8 kg/ha and Uzbekistan had the highest rate at 240.6 kg/ha in 2002.

[10] *Turkey, Myanmar, Bangladesh, Thailand, Kazakhstan, Viet Nam, Iran.*

[11] *Philippines, Uzbekistan, Pakistan, Syearian Arab Republic, Iraq, Nepal, Afghanistan, Azerbaijan, Cambodia, Kyeargyzstan, Saudi Arabia, Lao PFR, Tajikistan, Malaysia, Sir Lanka, Yemen, Georgia, Republic of Korea, Armenia, Israel, Lebanon, Timor-Leste, Bhutan, Cyprus.*

FIGURE 2.3

Trends in soil NPK balance (panel A) and rates of soil NPK balance (panel B) for the sub-regions and Asia from 2002–2013.

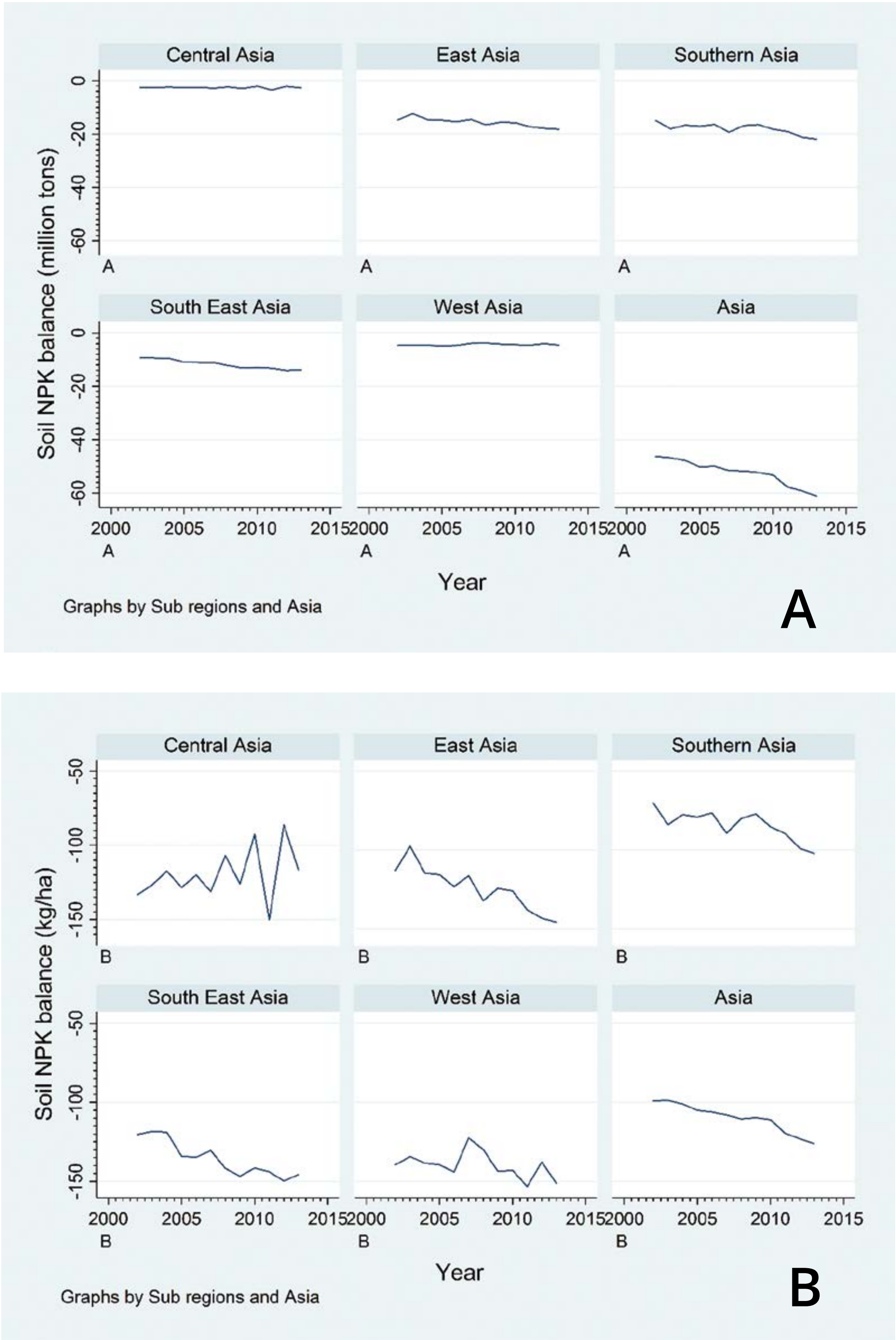


FIGURE 2.4 (PANEL A)

Trends in rate of soil NPK balance for countries with negative (panel A) and positive (panel B) balance from 2002 – 2013.

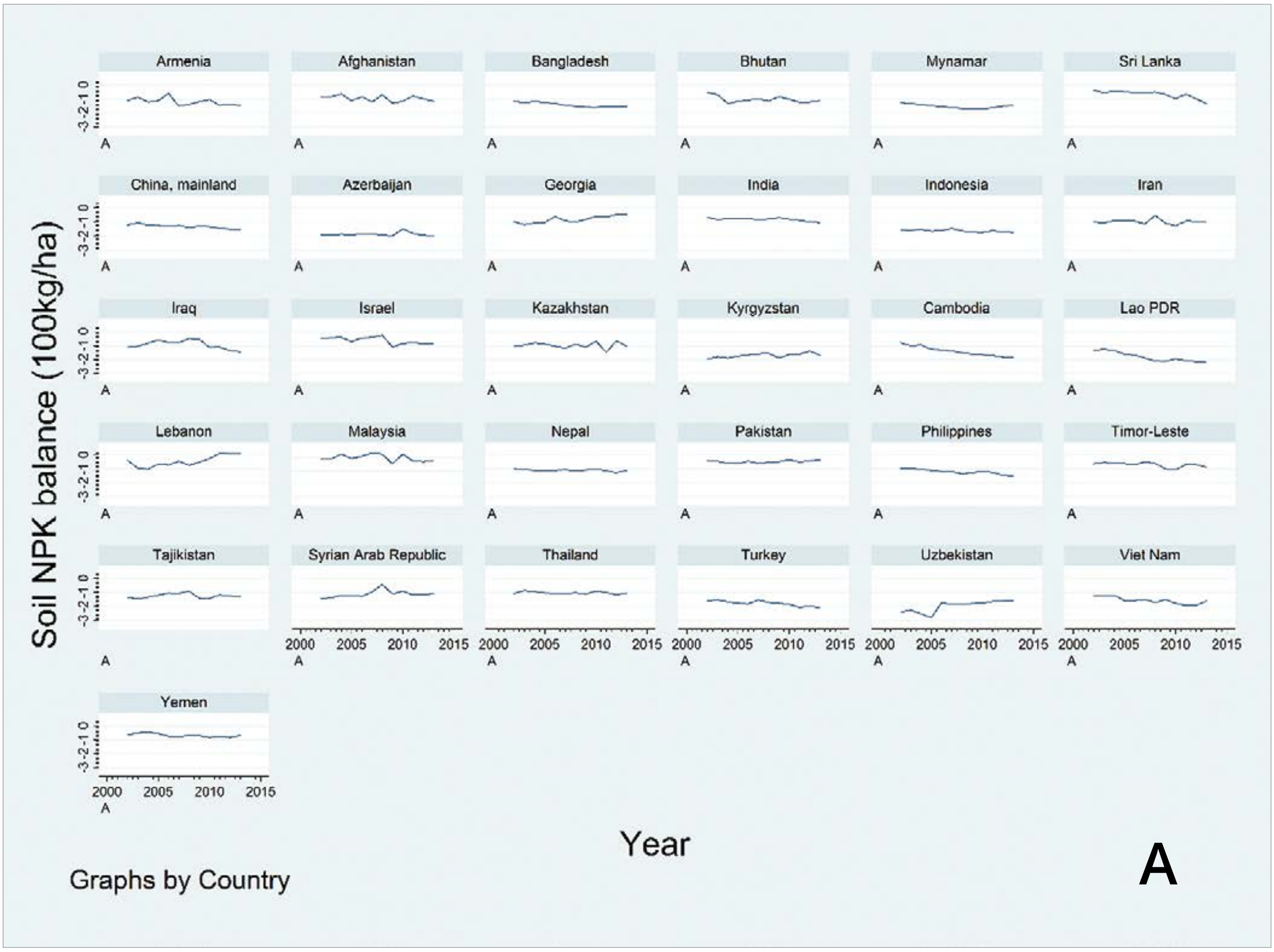
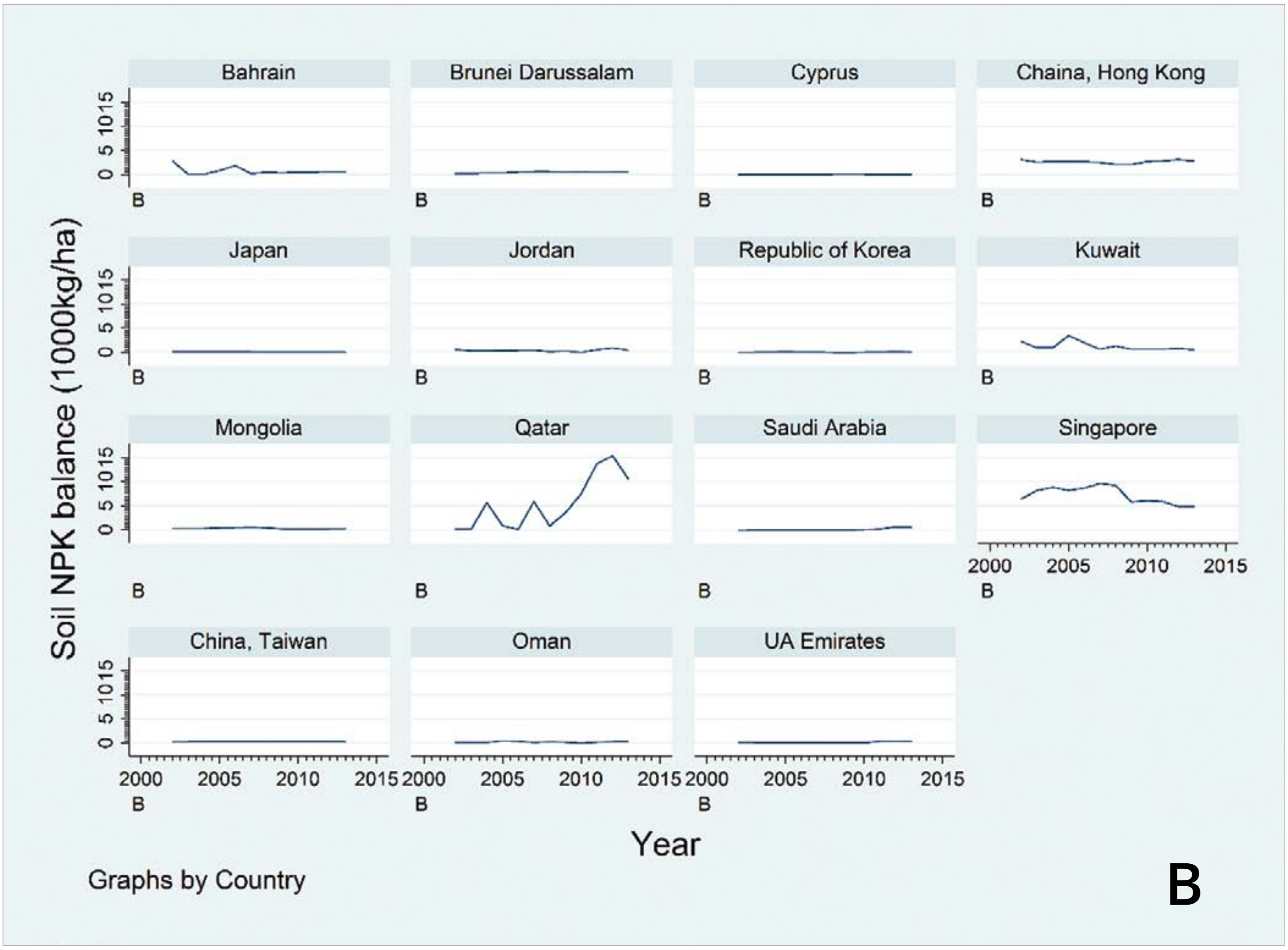


FIGURE 2.4 (PANEL B)

Trends in rate of soil NPK balance for countries with negative (panel A) and positive (panel B) balance from 2002 – 2013.



[12] *Turkey, Bangladesh, Myanmar, Philippines, Viet Nam, Kazakhstan Thailand, Iran.*

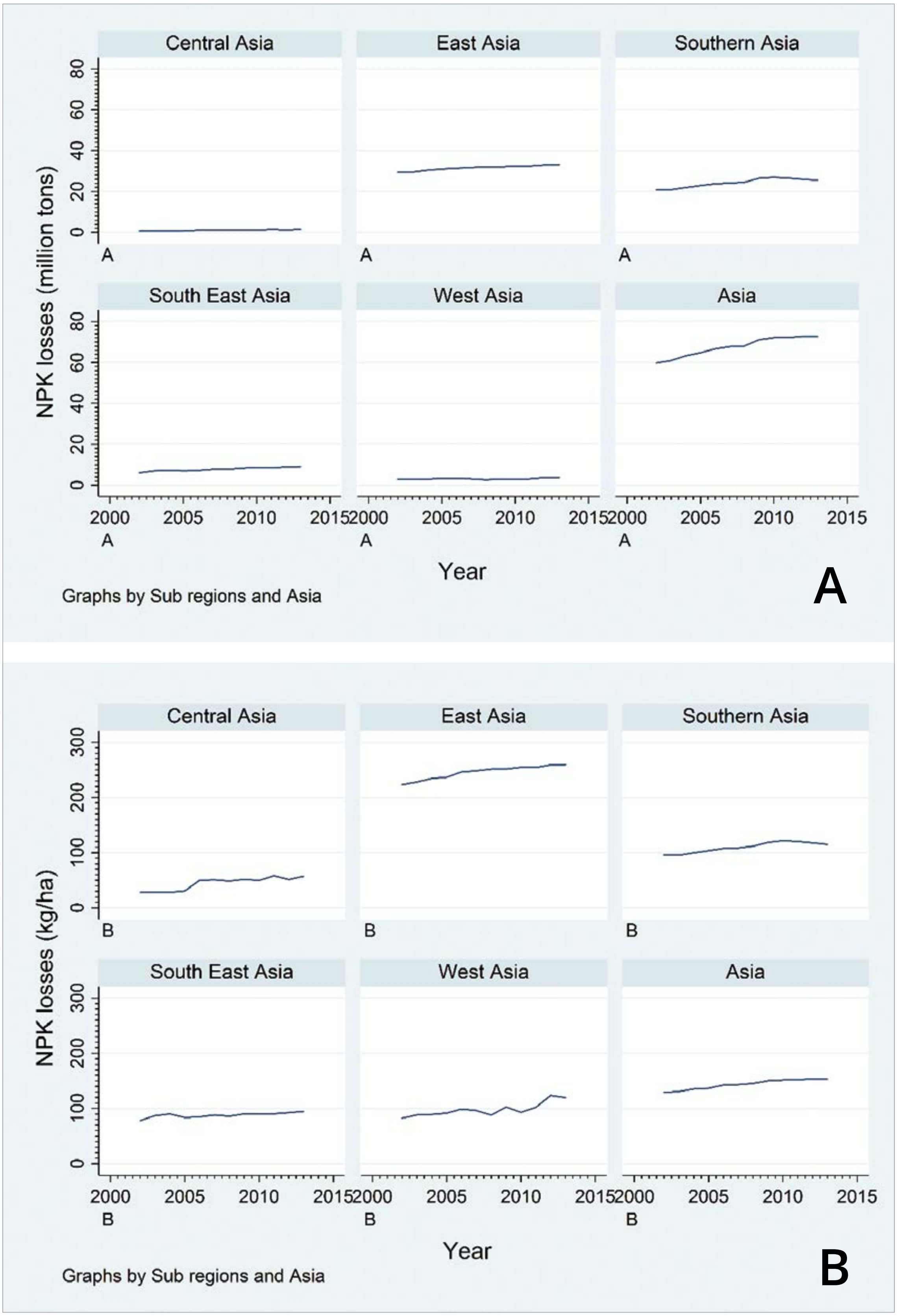
[13] *Cambodia, Pakistan, Uzbekistan, Nepal, Iraq, Syearian Arab Republic, Afghanistan, Lao PFR, Azerbaijan, Sir Lanka Kyeargyzstan, Malaysia, Tajikistan, Yemen, Armenia, Israel, Georgia, Timor-Leste, Bhutan.*

In 2013, other than mainland China, India, and Indonesia, 27 countries had negative balances, four countries less than in 2002. Philippines and the seven countries[12] with negative balances greater than 1 million tons in 2002 also had negative balances in 2013. These were between -3.7 million tons in Turkey and -1.3 million tons in Iran. This is an increasing trend of depletion across all of these countries, with some changes in the order of magnitude of the contributions of each country to the total balance of Asia. In the other 19 countries13 the balance was between -0.7 million tons in Cambodia and 0.01 million tons in Bhutan. Amongst the 30 countries with negative balances in 2013, there was a huge variation in the rate of depletion at the hectare level. Malaysia had the lowest depletion rate of 25 kg/ha and Lao PDR had the highest rate, which was 2200 kg/ha in 2013.

In 2002, 10 countries and two provinces of China had positive balances and this number increase to 14 countries and two provinces of China[14] by 2013 *(Figure 2.4B)*. However, the sum of all the positive balances in these countries counterbalanced only 1.45 per cent of the total deficit in the region in 2002 and only 1.52 per cent of the deficit in 2013. Among the 16 countries, four of them (Saudi Arabia, Republic of Korea, Lebanon, and Cyprus) had negative balances in 2002. Among the 12 countries with positive balances in 2002, the highest surplus was 0.205 million tons in Japan and the lowest

FIGURE 2.5

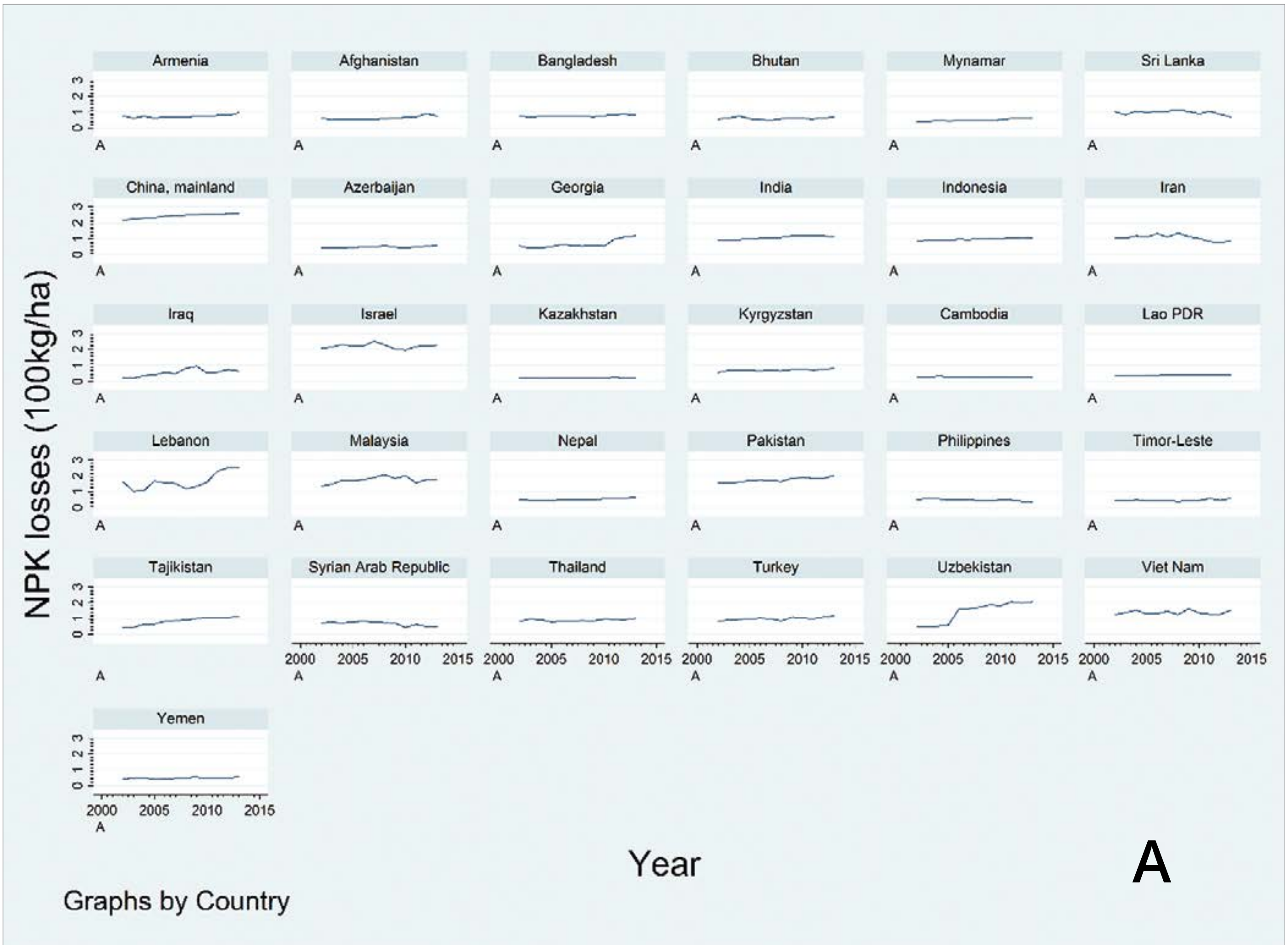
Trends in total NPK loss (panel A) and rate of loss (panel B) for the sub regions and Asia from 2002 – 2013.



14 *Saudi Arabia, Taiwan Province of China, Mongolia, Jordan, Japan, Qatar, Republic of Korea, United Arab Emirates, Oman, Kuwait, Brunei Darussalam, Singapore, China(Hong Kong), Cyprus, Bahrain, Lebanon.*

FIGURE 2.6 (PANEL A)

Trends in rate of NPK loss for countries with negative (panel A) and positive (panel B) average balance over the period 2002 – 2013.



surplus was 0.001 million tons in Qatar. In 2013, the highest surplus was 0.34 million tons in Saudi Arabia and the lowest was 0.002 million tons in Lebanon.

Trends in NPK losses from 2002 to 2013

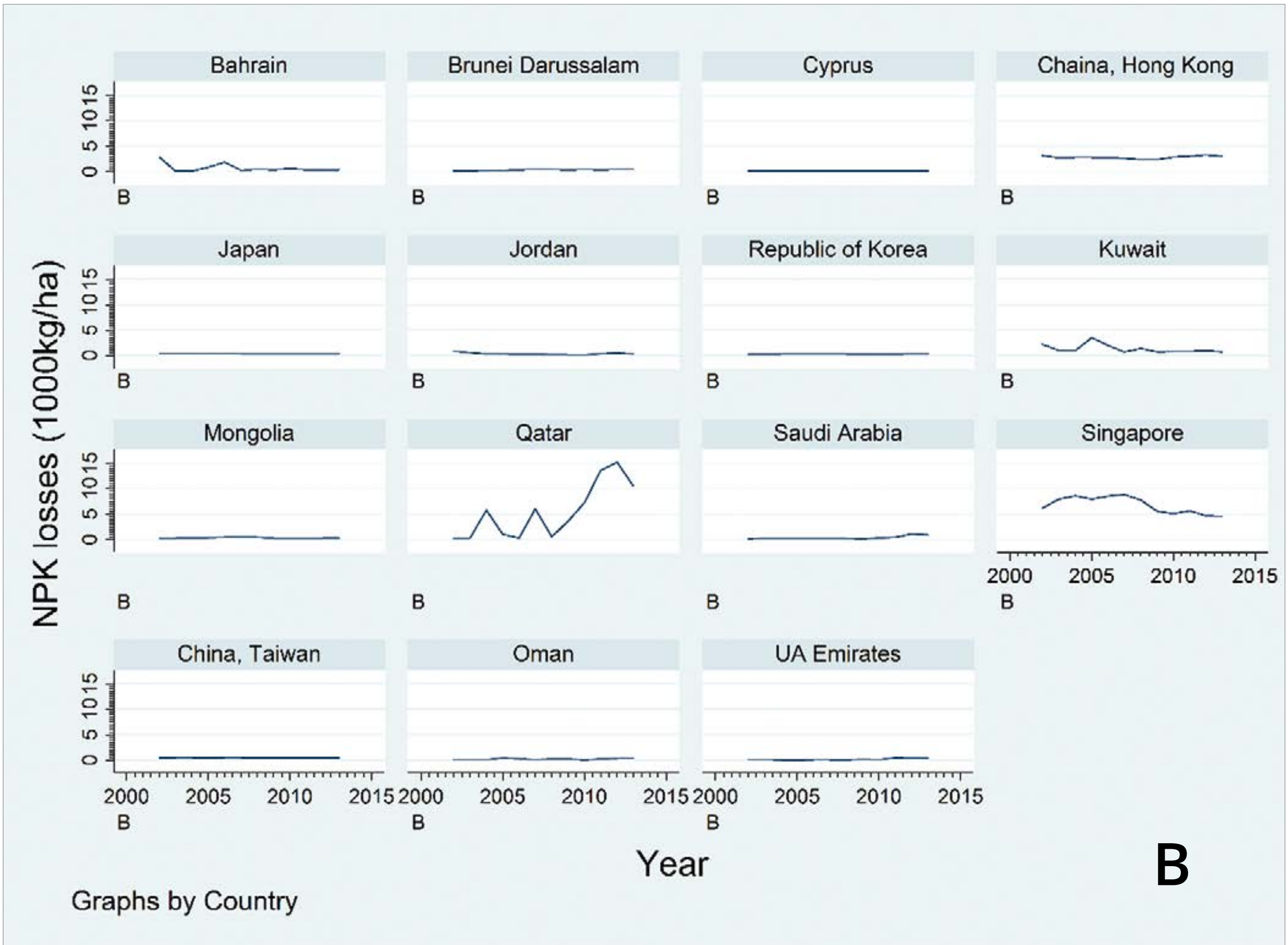
Regional and sub-regional level trends: Figure 2.5 shows that the total loss increased from 59.8 million tons in 2002 to 72.74 million tons in 2013. Over this period, the per hectare rate of loss also increased from 128.9 kg/ha to 153.2 kg/ha *(Figure 2.5B)*. The average annual rate of loss over the 12 years was 139.1 kg/ha.

In Central Asia, total soil loss in 2002 was 0.6 million tons and increased to 1.4 million tons by 2013. Similarly, the annual per hectare level rate of loss increased from 27.8 kg/ha in 2002 to 57.5 kg/ha in 2013. Central Asia had the lowest rate of loss compared to the other sub-regions. The average annual rate of loss over the 12 years was 45.1 kg/ha.

East Asia had the largest total loss as well as the highest rate of loss per ha. Total loss for the sub-region was 29.5 million tons in 2002 and increased to 33.1 million tons in 2013. The rate of loss also increased from 223.1 kg/ha in 2002 to 259.7 kg/ha in 2013. The average annual rate of loss over the 12 years was 246.1 kg/ha.

FIGURE 2.6 (PANEL B)

Trends in rate of NPK loss for countries with negative (panel A) and positive (panel B) average balance over the period 2002 – 2013.



In Southern Asia, total loss in 2002 was 20.8 million tons, and it increased to 25.5 million tons in 2013. The rate of loss in 2002 was 95.7 kg/ha and it increased to 114.9 kg/ha in 2013. The average annual rate of loss over the 12 years was 110.9 kg/ha.

Total loss in South East Asia in 2002 was 6.1 million tons and it reached 9.2 million tons in 2013. The rate of the loss was 78.2 kg/ha in 2002 and increased to 95.1 kg/ha in 2013. The average annual rate of loss over the 12 years was 90.3 kg/ha.

In West Asia, the total loss was 2.8 million tons in 2002, and it increased to 3.6 million tons in 2013. The rate of the loss increased from 82.6 to 119.8 kg/ha over the same period. The average annual rate of loss over the 12 years was 97.6 kg/ha.

Country level trends: *Figure 2.6* shows country level trends in total losses and rates of losses over the study period. In 2002, out of the 59.8 million tons lost across the continent, losses in mainland China were 27.4 million tons, accounting for 45.9 per cent of the total loss in Asia. The rate of loss in mainland China was 218.3 kg/ha. India accounted for the second largest share (26.1 per cent of the total loss in Asia) with a total loss of 15.6 million tons and a loss rate of 91.8 kg/ha. The sum of losses in these two countries plus losses in Pakistan (2.8 million tons), Indonesia (2.1 million tons), and

Turkey (1.7 million tons) was 49.7 million tons and accounts for 83.1 per cent of the total loss in Asia. The rates of losses ranged from 156.5 kg/ha in Pakistan, 82.9 kg/ha in Indonesia, and 83.4 kg/ha in Turkey. The sum of losses in the other 39 countries and two provinces of China all together was 10.1 million tons, equivalent to 17 per cent of the total loss in Asia in 2002.

In 2013, total loss in mainland China was 31.3 million tons and higher than 2002 by 3.9 million tons. Losses slightly decreased in its share compared to the total loss in Asia from 45.89 per cent in 2002 to 43.04 per cent in 2013. Contrary to that, India's share of the total loss across Asia increased slightly from 26.09 per cent in 2002 to 26.34 per cent in 2013. The total loss in India for 2013 was 19.2 million tons. The two countries together accounted for 69.4 per cent of the total 72.7 million tons of loss in Asia in 2013. Together with Pakistan (4 million tons), Indonesia (3.5 million tons), and Turkey (2.1 million tons) the five countries accounted for 82. 5 per cent of the total loss in Asia, whereas the remaining 17.6 per cent (12.8 million tons) was accounted for by the sum of losses in the rest of the 39 countries and the two provinces of China.

2.5. Econometric modelling of nutrient losses and soil nutrient depletion

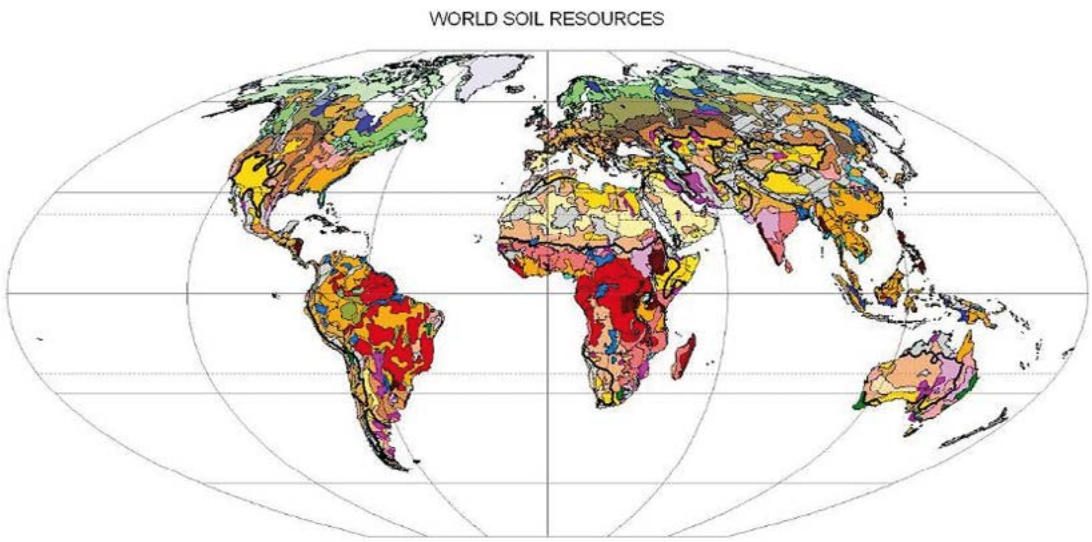
Results from the biophysical model show the level and trends of losses and depletions over the study period. Generating such information requires large amounts of data and very involved accounting exercise. Moreover, such information can only provide the level of nutrient flows and balances in soil for the period of time for which the accounting was done. Relating these biophysical indicators of land degradation with national socioeconomic and biophysical factors through econometric modelling allow for their inclusion in policy analyses. Moreover, econometric models of nutrient loss and soil nutrient balances could be used as an alternative to estimate and predict future levels using national level socioeconomic and biophysical data as predictor variables.

The next section presents the data and econometric models developed and estimation results from the models.

FIGURE 2.7

General digital map of the world's soils, using the international standard soil classification World Reference Base

(FAO, n.d.)



2.5.1. Data

In order to develop econometric models, results from *Chapter 2.4* were used as panel data for the study period. In addition, panel data on national level socioeconomic factors (GDP per capita, GDP, livestock population) and biophysical factors (forest cover, biomass carbon stock, arable and permanent crop land area, total land area, meadow and pasture land area) for the same period were obtained from FAOSTAT and World Bank databases (FAO, 2017; The World Bank, 2017).

Soil loss data for croplands of each country were generated using the methods described below in order to generate an understanding of topsoil loss/ha/year based on various soil orders. The data was then used as one of the biophysical factors in the econometric models of loss and depletion. This input data includes:

1. *Soil data – The World Resource Base Map of World Soil Resources* (FAO, n.d.)
2. *Country boundaries* (United Nations Geographic Information Working Group [UNGIWG], n.d.)
3. *Cropland data* (Global Land Cover Facility, 2017)

The following procedures to generating topsoil loss data for each country were used:

1. Soils data (shapefile) merged into units that are closely correlated to USDA soil taxonomy classes.

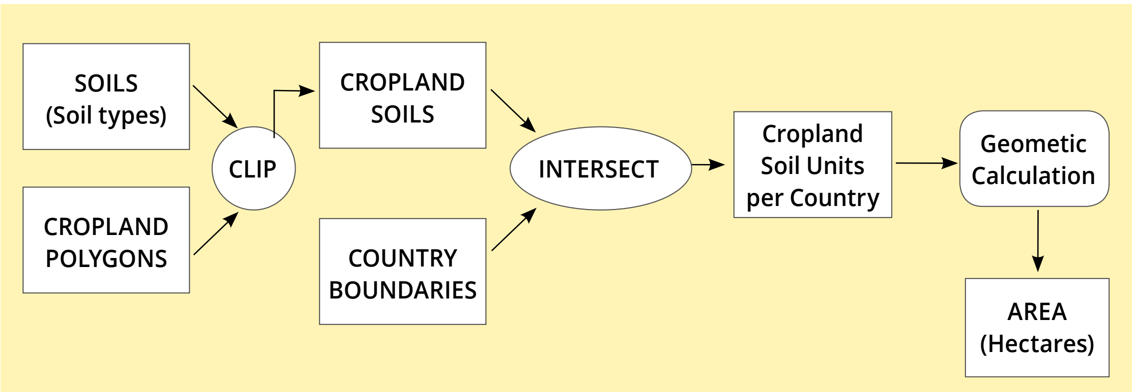
FAO	USDA
Acrisols, Alisols, Plinthosols	Ultisols
Andosols	Andisols
Arenosols	Aridisols
Calcisols, Cambisols, Luvisols (CL)	Aridisols
Calcisols, Regosols, Arenosols (CA)	Aridisols
Cambisols (CM)	Inceptisols
Durisols (DU)	Aridisols
Ferralsols, Acrisols, Nitisols (FR)	Oxisols
Fluvisols, Gleysols, Cambisols (FL)	Entisols
Gleysols, Histosols, Fluvisols (GL)	Inceptisols
Gypsisols, Calcisols (GY)	Aridisols
Leptosols, Regosols (LP)	Entisols
Lixisols (LX)	Alfisols
Luvisols, Cambisols (LV)	Alfisols
Nitisols (NT)	
Planosols (PL)	Alfisols
Podzols, Histosols (PZ)	Spodosols
Solonchaks, Solonetz (SC)	Aridisols
Vertisols (VR)	Vertisols

2. Spatial analysis performed on soils data using country boundaries to generate the area in hectares of each soil unit in the various countries.

3. Multiplication of soil unit area and annual rate of erosion for that unit results in the mass (tons) of soil eroded from that unit annually.

FIGURE 2.8

Analysis flow for generating Top Soil Loss Numbers



2.5.2. The empirical models of nutrient loss and soil nutrient depletion

Following the econometric modelling approach undertaken by the ELD in Africa (ELD & UNEP, 2015) and literature on the drivers of land degradation (Lal & Stewart, 2013; Nkonya et al., 2013), an econometric model of nutrient loss and soil nutrient depletion for agricultural ecosystems in Asia can be specified as:

$$NPK_{it}=\alpha_0+\alpha_{1it}+\alpha_2X_{2it}+\sum_{j=1}^{5}\alpha_{3j}R_{ji}+u_{it}$$

Where:

NPK_{it} represents the **average soil nutrient loss** (kg/ha/year) **and depletion** (1000 tonne/year), as indicators of degradation of supporting agricultural ecosystem services, for county i over time period t where t = 2002, 2003... 2013;

X_{1it} is a vector of **national level biophysical factors** (top soil loss in ton per hectare per year, forest cover in per cent of total land area, biomass carbon stock in million tons, arable and permanent cropland as per cent of total land area, meadow and pasture land as per cent of total land area) for country i over time period t where t = 2002, 2003... 2013;

X_{2it} is a vector of **national level economic factors** (income measured through GDP per capita in USD 1,000 units, size of the economy measured in terms of GDP in USD 100 billion units, and livestock density (in Tropical Livestock Units (TLU)* per hectare of arable and permanent croplands) for country i over time period I where I = 2002, 2003... 2013;

R_{ji} is a vector of **sub-regional dummies** for controlling sub-regional fixed effects (where *j* = 1, 2, ...5 for the five sub-regions in Asia, which are Central, East, South, South East, and West Asia) for country *i*;

α_0 to α_3 are parameters to be estimated from empirical data; and

Y_{it} is the error or stochastic term that captures the effect of unobserved factors in country *i* over time period *t* where *t* = 2002, 2003... 2013.

* *TLU (Tropical Livestock Unit) = 250 kg tropical cow; a head of camel = 1 TLU; a head of horse/mule = 0.8 TLU; a head of cattle = 0.7 TLU; a sheep or goat = 0.1 TLU; donkey=0.5 TLU; a chicken = 0.01 TLU (Jahnke, 1982)*

Our first hypothesis is that rate of top soil loss is positively and significantly correlated with both NPK loss and depletion. Secondly, large forest cover as well as biomass carbon stock are inversely related with both loss and balances and correlations are significant. This is based on the well-documented literature on the role forest ecosystems play in providing erosion control services to downstream and surrounding agricultural ecosystems as a supporting ecosystem service. Therefore, countries with relatively high forest cover and large biomass carbon stock would be likely to have lower losses and depletion relative to countries with less forest cover and smaller carbon stocks. Third, we anticipated that countries with relatively larger agricultural land covers in relation to the total land area (arable and permanent crop lands as per cent of total land as well as meadow and pasture lands as per cent of total land) are likely to have larger rates of loss as well as depletion and correlations are significant. Fourth, we anticipated significant correlations between the socioeconomic factors (GDP per capita, GDP, and livestock population) and loss as well as depletion, whereas we did not have a prior expectation about the direction of the relationship.

2.5.3. Empirical model results

Based on the above specification in equation 2.1, we did model specification tests for variants of econometric models (i.e. Ordinary Least Squares (OLS), Ordinary least squares with robust standard errors, Generalized Least Squares (GLS), Fixed Effect and Random Effect) for each of the NPK loss and soil NPK depletion as response variables. The model types range from simple OLS to panel data fixed and random effect regression models. The results for the NPK loss model are presented in Table 2.4 whereas the model for soil NPK depletion is presented in Table 2.5.

The results in all the 5 different types of econometric models consistently indicate that the NPK loss as well as soil NPK depletion are significantly correlated with four of the five biophysical factors (top soil loss, forest cover, arable and permanent crop land area, meadow and pasture land area) and all of the three socioeconomic factors (GDP per capita, GDP, and Livestock population). In addition, unlike soil NPK depletion, NPK loss is significantly correlated with biomass carbon stock. Moreover, we have found that sub-regional fixed effects also affect both NPK loss and soil NPK depletion.

We reported results of the OLS model with robust standard errors, the fixed and random effect models. Our data set consists of a panel of all the response and right hand side variables of equation 2.1 for the period 2002 to 2013. As a result, panel data econometric model specification that controls effects of each individual year in the panel is appropriate. In a panel model, the individual effect terms can be modelled as either random or fixed effects. If the individual effects are correlated with the other explanatory variables in the model, the fixed effect model is consistent and the random effects model is inconsistent. On the other hand, if the individual effects are not correlated with the other national level explanatory variables in the model, both random and fixed effects are consistent and random effects are efficient. The Haussmann test statistic for the NPK loss model *(Table 2.4)* is significant at $p < 5$ per cent indicating that the fixed effect model is efficient. Whereas the test for the soil NPK depletion model *(Table 2.5)* is insignificant, indicating the random effect model is efficient. We further dropped insignificant variables from the fixed effect model in the case of the NPK loss model and the random effect model in the case of the soil NPK depletion model and run Haussmann specification test for the fixed and random effect models with only significant national level explanatory variables. This consistently resulted in the restricted fixed effect model in case of NPK loss and the restricted random effect model in case of soil NPK depletion which are efficient for estimating the NPK loss and NPK depletions respectively. The R2 values in both models are reasonably high in both models. For example, in the case of the NPK loss model *(Table 2.4)*, close to 76 per cent of the variations in log-transformed NPK loss (kg/ha/year) could be explained by the variations in the national level biophysical and socioeconomic factors and the sub regional fixed effects used in the right hand side of equation 2.1. Similarly, about 68 per cent of variation in log-transformed soil NPK depletion (1000s ton/year) could be explained by the variations in these factor variables and sub-regional fixed effects *(Table 2.5)*.

Biophysical factors and land degradation

The coefficients for top soil loss in the restricted fixed effect NPK loss model *(Table 2.4)* and the restricted random effect soil NPK depletion model *(Table 2.5)* are positive and significant at 5 per cent and 1 per cent level respectively. The direction of the effect is consistent with our hypothesis that rate of top soil loss is positively and significantly correlated with both NPK loss and soil NPK depletion. Figure 2.9 confirms the directional relationship between aggregate NPK loss and top soil erosion and the relationship between soil NPK depletion and top soil loss. Since in both models the dependent variables and top soil loss are in log forms, the coefficients for the log-transformed top soil loss in tons per hectare per year can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in

FIGURE 2.9

Relationship between NPK loss and top soil loss (panel A) and soil NPK depletion and top soil loss (Panel B)

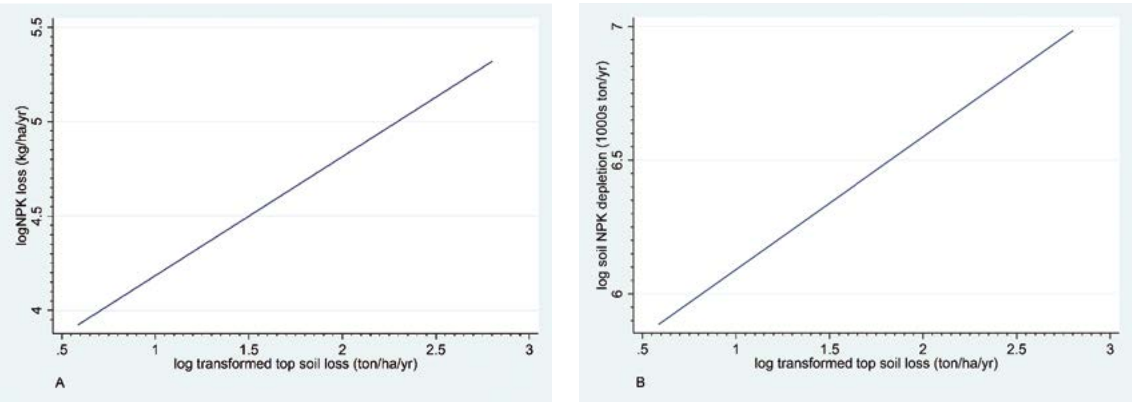
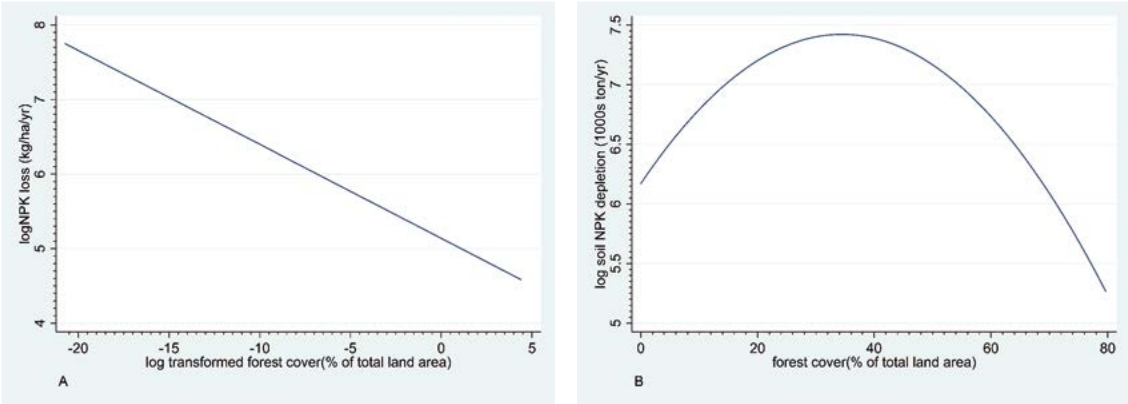


FIGURE 2.10

Relationship between NPK loss and forest cover (panel A) and soil NPK depletion and forest cover (Panel B)



the log-transformed top soil loss in tons per hectare per year increases log-transformed NPK loss (kg/ha/year) by 0.16 units whereas the log-transformed soil NPK depletion (1000s ton/year) by 0.317 units. In percentage terms, ceteris paribus, a 1 per cent increase in top soil loss (tons/ha/year) would cause NPK loss (kg/ha/year) to increase by about 0.16 per cent and a one percent increase in topsoil loss (billion tons/year) would cause soil NPK depletion (1000s ton/year) to increase by about 0.317 per cent. Similarly, a 1 per cent decrease in top soil loss (tons/ha/year) would reduce NPK loss (kg/ha/year) by about 0.16 per cent and a 1 percent decrease in topsoil loss (in billion tons/year) would reduce soil NPK depletion (1000s ton/year) by about 0.317 per cent.

The coefficients for forest cover in the restricted fixed effect NPK loss model *(Table 2.4)* and the restricted random effect soil NPK depletion model *(Table 2.5)* are negative and both are significant at $p < 1$ per cent. The direction of the effect is consistent with our expectation that large forest cover is associated with lower rates of NPK loss and soil NPK depletion.

Figure 2.10 confirms the directional relationship between aggregate NPK loss and forest cover and the relationship between soil NPK depletion and forest cover. Since in restricted fixed effect NPK loss model the dependent variable and forest cover are in log forms, the coefficients for the log-transformed forest cover (as percentage of total

FIGURE 2.11

Relationship between NPK loss and forest biomass carbon stock (panel A) and soil NPK depletion and forest biomass carbon stock (Panel B)

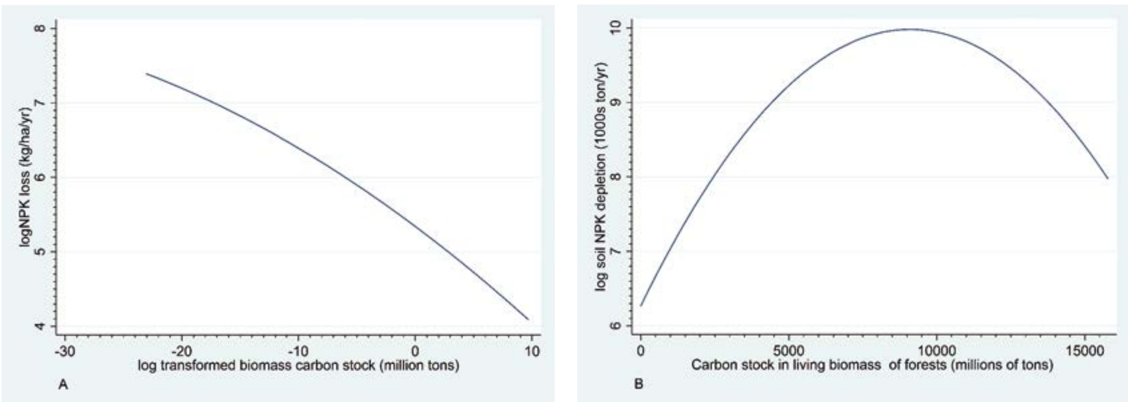


TABLE 2.4

Models for Agricultural Land Degradation in Asia (log transformed NPK Loss in kg/ha/year)

Variables	OLS2 (robust SE)	Fixed Effect	Random Effect	Restricted fixed effect
Biophysical factors				
Top soil loss ton / ha / year (log-transformed)	0.165 (0.042) [3.930][a]	0.142 (0.063) [2.270][b]	0.165 (0.063) [2.610][a]	0.160 (0.062) [2.580][b]
Forest cover as % of total land (log-transformed)	-0.042 (0.018) [-2.300][b]	-0.040 (0.012) [-3.430][a]	-0.042 (0.012) [-3.560][a]	-0.036 (0.010) [-3.430][a]
Biomass carbon stock in million tons (log-transformed)	-0.032 (0.005) [-6.660][a]	-0.033 (0.007) [-4.400][a]	-0.032 (0.008) [-4.260][a]	-0.034 (0.006) [-5.440][a]
Arable & permanent crop land as % of total land (log-transformed)	0.153 (0.037) [4.140][a]	0.169 (0.035) [4.850][a]	0.153 (0.035) [4.400][a]	0.156 (0.034) [4.640][a]
Meadow and pasture land as % of total land	0.007 (0.002) [3.540][a]	0.008 (0.002) [4.650][a]	0.007 (0.002) [4.090][a]	0.008 (0.002) [4.920][a]
Socioeconomic factors				
GDP per capita in 1000 USD (log-transformed)	0.316 (0.028) [11.420][a]	0.348 (0.026) [13.510][a]	0.316 (0.025) [12.860][a]	0.353 (0.025) [13.880][a]
GDP in 100 Billions of current USD	0.006 (0.003) [2.470][b]	0.007 (0.003) [2.010][b]	0.006 (0.003) [1.800][c]	0.007 (0.003) [2.640][a]
Livestock in 1000s of TLU/ha of arable and permanent crop land (log-transformed)	0.598 (0.042) [14.200][a]	0.608 (0.037) [16.430][a]	0.598 (0.037) [16.100][a]	0.598 (0.036) [16.430][a]
Region 1 (1 = Central Asia, 0 = otherwise)	-0.506 (0.123) [-4.120][a]	-0.456 (0.145) [-3.150][a]	-0.023 (0.106) [-0.220]	-0.419 (0.110) [-3.810][a]
Region 2 (1 = East Asia, 0 = otherwise)	(omitted)	(omitted)	0.483 (0.125) [3.860][a]	
Region 3 (1 = Southern Asia, 0 = otherwise)	-0.173 (0.110) [-1.580][d]	-0.097 (0.140) [-0.690]	0.310 (0.095) [3.280][a]	
Region 4 (1 = South East Asia, 0 = Otherwise)	-0.042 (0.119) [-0.350]	0.029 (0.138) [0.210]	0.442 (0.093) [4.780][a]	
Region 5 (1 = West Asia, 0 = Otherwise)	-0.483 (0.104) [-4.640][a]	-0.468 (0.125) [-3.750][a]	(omitted)	-0.445 (0.077) [-5.810][a]
Constant	-0.430 (0.403) [-1.070]	-0.595 (0.396) [-1.500][d]	-0.914 (0.368) [-2.480][b]	-0.557 (0.379) [-1.470][d]
N	540	540	540	540
F (df, N)	170.750[a]	139.500[a]		167.120[a]
R2	0.758	0.757	0.758	0.756
Adj. R2				
Root MSE	0.587			
Mean VIF	3.280			
No. of groups (Year 2002 – 2013)		12	12	12
Wald chi2			1650.260[a]	
Log_L				
R2 within		0.764	0.764	0.763
R2 between		0.809	0.809	0.809
corr (u_i, Xb)		-0.174		-0.176
F test u_i=0, F(df, N)		1.670[c]		1.730[c]
Hausman Test (Chi2)			16.25[b]	17.39[a]

Values in () are standard errors, Values in [] are t-statics for the OLS and fixed effect models and z-statistics for the other models.
Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.

TABLE 2.5

Models for Agricultural Land Degradation in Asia (log-transformed soil NPK depletion in 1000s tonne/year)

Variables	OLS2 (robust SE)	Fixed Effect	Random Effect	Restricted random effect
Biophysical factors				
Top soil loss in billions of tons per year (log-transformed)	0.317 (0.023) [14.020][a]	0.319 (0.020) [15.640][a]	0.317 (0.020) [15.660][a]	0.317 (0.018) [17.960][a]
Forest cover as % of total land	-0.009 (0.002) [-5.400][a]	-0.009 (0.002) [-4.630][a]	-0.009 (0.002) [-4.630][a]	-0.009 (0.002) [-5.540][a]
Biomass carbon stock in million tons (log-transformed)	0.001 (0.005) [0.270]	0.002 (0.007) [0.230]	0.001 (0.007) [0.210]	
Arable & permanent crop land as % of total land (log-transformed)	0.510 (0.041) [12.480][a]	0.516 (0.035) [14.810][a]	0.510 (0.034) [14.800][a]	0.505 (0.031) [16.260][a]
Meadow and pasture land as % of total land (log-transformed)	0.024 (0.007) [3.350][a]	0.024 (0.008) [2.890][a]	0.024 (0.008) [2.860][a]	0.025 (0.007) [3.330][a]
Socioeconomic factors				
GDP per capita in 1000 USD	-0.007 (0.003) [-2.770][a]	-0.006 (0.003) [-2.400][b]	-0.007 (0.003) [-2.680][a]	-0.007 (0.002) [-3.160][a]
GDP in 100 Billions of current USD	0.027 (0.004) [6.810][a]	0.028 (0.004) [7.550][a]	0.027 (0.004) [7.500][a]	0.028 (0.003) [7.950][a]
Livestock in 1000s of TLU/ha of arable and permanent crop land (log-transformed)	0.541 (0.057) [9.580][a]	0.548 (0.049) [11.130][a]	0.541 (0.049) [11.010][a]	0.535 (0.042) [12.650][a]
Region 1 (1 = Central Asia, 0 = otherwise)	(omitted)	(omitted)	0.097 (0.102) [0.950]	
Region 2 (1 = East Asia, 0 = otherwise)	-1.076 (0.147) [-7.310][a]	-1.095 (0.168) [-6.520][a]	-0.979 (0.150) [-6.540][a]	-0.984 (0.127) [-7.770][a]
Region 3 (1 = Southern Asia, 0 = otherwise)	-0.108 (0.091) [-1.190]	-0.114 (0.123) [-0.930]	-0.011 (0.100) [-0.110]	
Region 4 (1 = South East Asia, 0 = otherwise)	0.454 (0.113) [4.030][a]	0.449 (0.145) [3.100][a]	0.551 (0.124) [4.440][a]	0.557 (0.098) [5.710][a]
Region 5 (1 = West Asia, 0 = otherwise)	-0.097 (0.088) [-1.100]	-0.104 (0.102) [-1.020]	(omitted)	
Constant	2.288 (0.492) [4.650][a]	2.229 (0.404) [5.520][a]	2.191 (0.398) [5.510][a]	2.266 (0.359) [6.310][a]
N	540	540	540	540
F (df, N)	132.090[a]	92.800[a]		
R2	0.681	0.681	0.681	0.680
Adj. R2				
Root MSE	0.604			
Mean VIF	3.340			
No. of groups (Year 2002 – 2013)		12	12	12
Wald chi2			1123.260[a]	1126.200[a]
Log_L				
R2 within		0.683	0.683	0.683
R2 between		0.122	0.123	0.123
corr (u_i, Xb)		-0.054		
F test u_i=0, F(df, N)		0.470		
Hausman Test (Chi2)			3.92	3.77

Values in () are standard errors, Values in [] are t-statics for the OLS and fixed effect models and z-statistics for the other models.
Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.

land area) can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in the log-transformed forest cover (as percentage of total land area) decreases log-transformed NPK loss (kg/ha/year) by 0.036 units. Whereas in the case of the restricted random effect soil NPK depletion model, forest cover is in linear form and hence we have a log-linear model. In such a case, the interpretation is that a one-unit increase in forest cover (as per cent of total land area) causes the log-transformed soil NPK depletion to decrease by 0.009 units. In percentage terms, *ceteris paribus,* a 1 per cent increase in forest cover (percentage of total land area) would cause NPK loss (kg/ha/year) to decrease by about 0.036 per cent and soil NPK depletion (1000s ton/year) to decrease by about 0.9 per cent. Similarly, a 1 per cent decrease in forest cover (percentage of total land area) would increase NPK loss (kg/ha/year) by about 0.036 per cent and soil NPK depletion (1000s ton/year) by about 0.9 per cent.

The coefficient for biomass carbon stock in the restricted fixed effect NPK loss model *(Table 2.4)* is negative and significant at $p < 1$ per cent whereas the coefficient for same variable is positive but insignificant in the case of the full OLS2, fixed and random effect models of soil NPK depletion. The direction of the effect in the case of the NPK loss model is consistent with our expectation that countries with higher biomass carbon stock are likely to have lower rates of NPK loss. Figure 2.11A confirms the directional relationship between aggregate NPK loss and forest biomass carbon.

Since in restricted fixed effect NPK loss model the dependent variable and biomass carbon stock are in log forms, the coefficients for the log-transformed biomass carbon stock (million tons) can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in the log-transformed biomass carbon stock (million tons) decreases log-transformed NPK loss (kg/ha/year) by 0.034 units. In percentage terms, *ceteris paribus*, a 1 per cent increase in biomass carbon stock (million tons) would cause NPK loss (kg/ha/year) to decrease by about 0.034 per cent. Similarly, a 1 per cent decrease in biomass carbon stock (million tons) would increase NPK loss (kg/ha/year) by about 0.034 per cent.

The coefficients for arable and permanent crop land area in the restricted fixed effect NPK loss model *(Table 2.4)* and the restricted random effect soil NPK depletion model *(Table 2.5)* are positive and both are significant $p < 1$per cent. The direction of the effect is consistent with our hypothesis that countries with relatively larger agricultural land covers in relation to the total land area are likely to have larger rates of NPK loss as well as soil NPK depletion and the correlations are significant. Figure 2.12 confirms the directional relationship between aggregate NPK loss and arable and permanent cropland area and the relationship between soil NPK depletion and arable and permanent cropland area. Since in both models the dependent variables and arable and permanent crop land area are in log forms, the coefficients for the log-transformed arable and permanent crop

FIGURE 2.12

Relationship between NPK loss and arable & permanent cropland area (panel A) and soil NPK depletion and arable & permanent cropland area (Panel B)

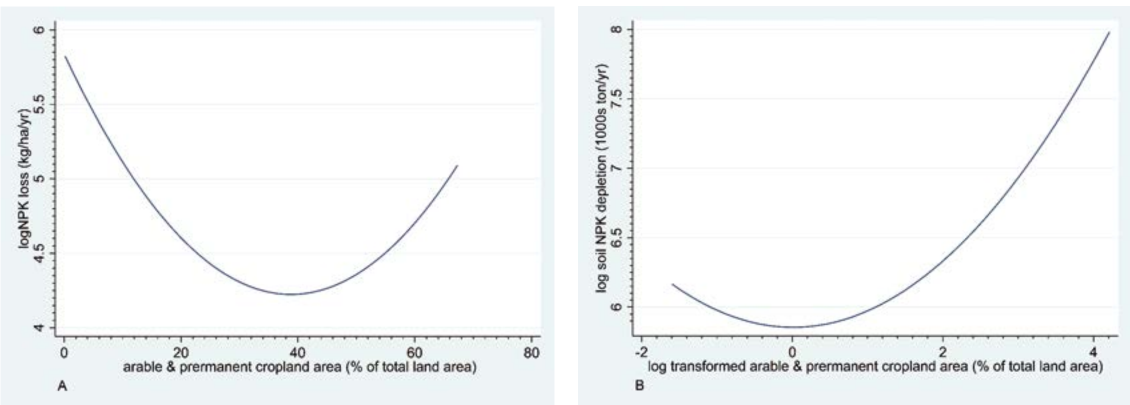
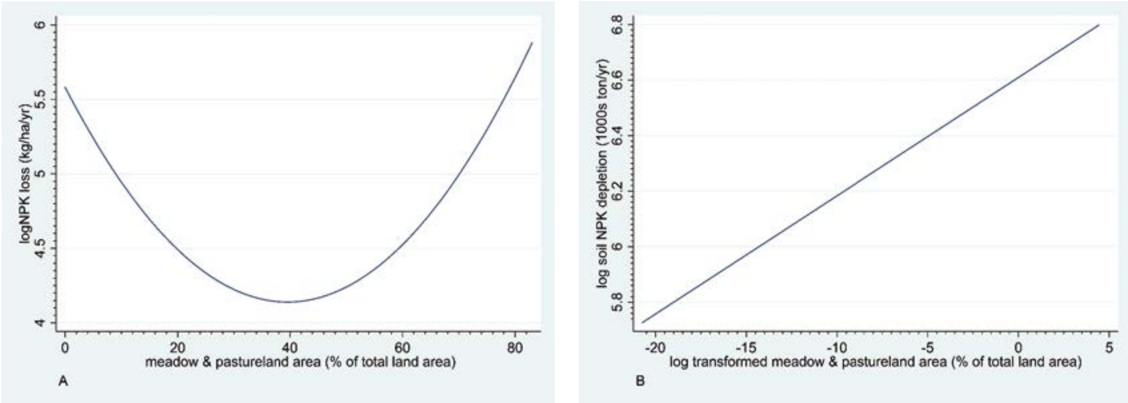


FIGURE 2.13

Relationship between NPK loss and meadow & pastureland area (panel A) and soil NPK depletion and meadow & pastureland area (Panel B)



land area (as percentage of total land area) can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in the log-transformed arable and permanent cropland area (as percentage of total land area) increases log-transformed NPK loss (kg/ha/year) by 0.156 units whereas the log-transformed soil NPK depletion (1000s ton/year) by 0.505 units. In percentage terms, *ceteris paribus*, a 1 per cent increase in arable and permanent cropland area would cause NPK loss (kg/ha/year) to increase by about 0.156 per cent and soil NPK depletion (1000s ton/year) to increase by about 0.505 per cent and vice versa.

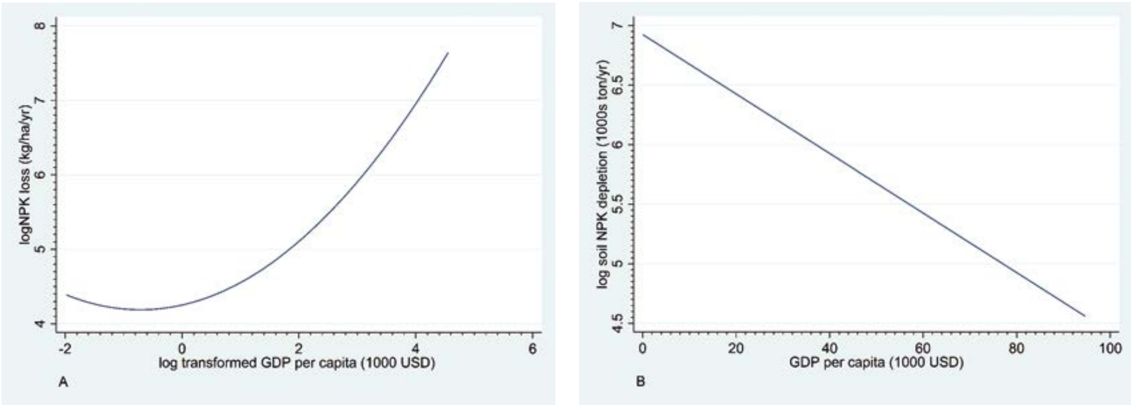
The coefficients for meadow and pasture land area in the restricted fixed effect NPK loss model *(Table 2.4)* and the restricted random effect soil NPK depletion model *(Table 2.5)* are also positive and both are significant at $p < 1$ per cent. The direction of the effect is consistent with our expectation that countries with relatively larger agricultural land covers, in this case meadow and pasture land area, in relation to the total land area are likely to have larger rates of NPK loss as well as soil NPK depletion and the correlations are significant. *Figure 2.13* confirms the directional relationship between aggregate NPK loss and meadow and pastureland area and the relationship between soil NPK depletion and meadow and pastureland area. Since in restricted fixed effect the NPK loss model the dependent variable and meadow and pasture land area are in log-linear form, the coefficients for the meadow and pasture land area (as percentage of total land area) can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in meadow and pasture land area (as percentage of total land area) increases log-transformed NPK loss (kg/ha/year) by 0.008 units. Whereas in the case of the restricted random effect soil NPK depletion model, meadow and pasture land area is in log form and hence we have a log-log model. In such a case, the interpretation is that a one-unit increase in log-transformed meadow and pastureland area (as percentage of total land area) causes the log-transformed soil NPK depletion to increase by 0.025 units. In percentage terms, *ceteris paribus,* a 1 per cent increase in meadow and pasture land area (as percentage of total land area) would cause NPK loss (kg/ha/year) to increase by about 0.8 per cent and soil NPK depletion (1000s ton/year) to increase by about 0.025 per cent and vice versa.

Socio-economic factors and land degradation

The coefficients for GDP per capita in the restricted fixed effect NPK loss model *(Table 2.4)* and the restricted random effect soil NPK depletion model *(Table 2.5)* are significant at $p < 1$ per cent. The direction of the effect is positive in the cases of the first whereas it is negative in the case of the second model. We had no a priori expectation about the direction of the effects. *Figure 2.14* confirms the directional relationship between aggregate NPK loss and GDP per capita and the relationship between soil NPK depletion and GDP per capita. Since in restricted fixed effect model the dependent variable

FIGURE 2.14

Relationship between NPK loss and GDP per capita (panel A) and soil NPK depletion and GDP per capita (Panel B)



NPK loss and GDP per capita are in log forms, the coefficients for the log-transformed GDP per capita (in USD 100) can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in the log-transformed GDP per capita (in USD 100) increases log-transformed NPK loss (kg/ha/year) by 0.353 units. Whereas in the case of the restricted random effect soil NPK depletion model, GDP per capita in linear form and hence we have a log-linear model. In such a case, the interpretation is that a 1-unit increase in GDP per capita causes the log-transformed soil NPK depletion to decrease by 0.007 units. In percentage terms, *ceteris paribus*, a 1 per cent increase in GDP per capita (in USD 100) would cause NPK loss (kg/ha/year) to increase by about 0.353 per cent and soil NPK depletion (1000s ton/year) to decrease by about 0.7 per cent and vice versa.

The coefficients for GDP in the restricted fixed effect NPK loss model *(Table 2.4)* and the restricted random effect soil NPK depletion model *(Table 2.5)* are positive and both are significant $p<1$ per cent. We had no a priori expectation on the directions of the effects. *Figure 2.15* confirms the directional relationship between aggregate NPK loss and GDP and the relationship between soil NPK depletion and GDP. Since in both models the dependent variables are in log forms and GDP is in linear form, we have a log-linear function and

FIGURE 2.15

Relationship between NPK loss and GDP (panel A) and soil NPK depletion and GDP (Panel B)

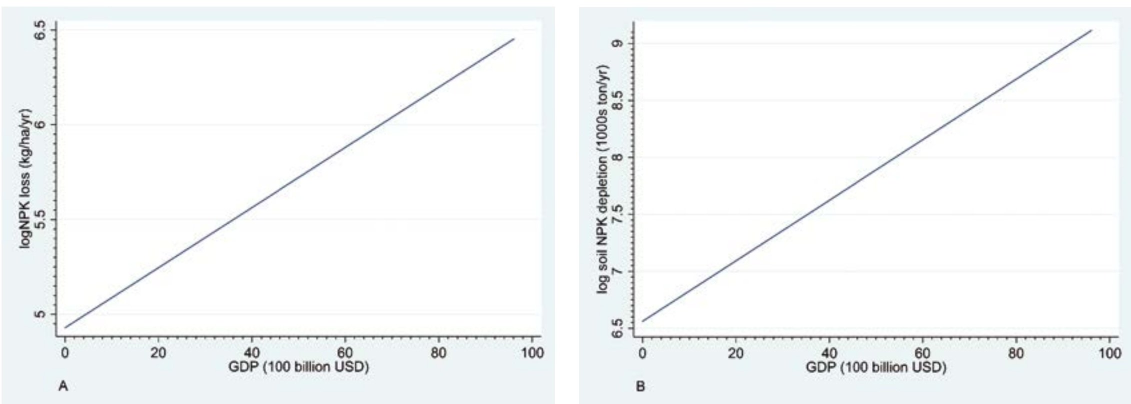
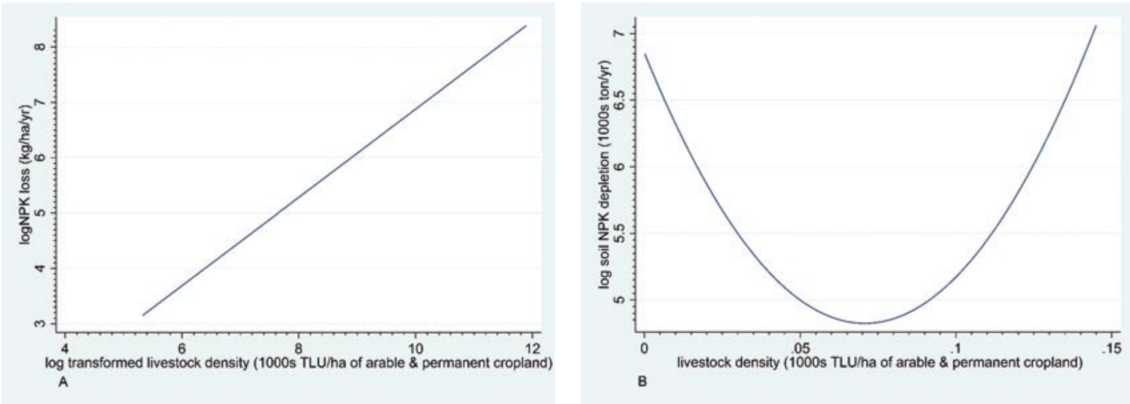


FIGURE 2.16

Relationship between NPK loss and livestock density (panel A) and soil NPK depletion and livestock density (Panel B)



the coefficients for GDP (in 100 billions of UDS) can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in GDP (in 100 billions of UDS) would lead to increase the log-transformed NPK loss (kg/ha/year) by 0.007 units and the log-transformed soil NPK depletion (1000s ton/year) by 0.028 units. In percentage terms, *ceteris paribus*, a 1 per cent increase in GDP (in 100 billions of UDS) would cause NPK loss (kg/ha/year) to increase by about 0.7 per cent and soil NPK depletion (1000s ton/year) to increase by about 2.8 per cent and vice versa. In other words, *ceteris paribus*, every 1 per cent growth in GDP (in 100 billions of UDS) of countries in Asia is at the cost of 0.7 per cent increase in NPK loss and 2.8 per cent increase in soil NPK depletions, which indicate economic growth at the cost of degradation in the quality of agricultural lands in the region.

The coefficients for livestock density in the restricted fixed effect NPK loss model *(Table 2.4)* and the restricted random effect soil NPK depletion model *(Table 2.5)* are positive and both are significant at 1 per cent level. Similar to the other socioeconomic factors, we had no priori expectation on the direction of the effects. *Figure 2.16* confirms the directional relationship between aggregate NPK loss and livestock density and the relationship between soil NPK depletion and livestock density. Since in both models the dependent variables and livestock density are in log forms, the coefficients for the log-transformed livestock density (1000s TLU/ha of arable and permanent cropland) can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in the log-transformed livestock density increases log-transformed NPK loss (kg/ha/year) by 0.598 units whereas the log-transformed soil NPK depletion (1000s ton/year) by 0.535 units. In percentage terms, *ceteris paribus*, a 1 per cent increase in top soil loss (tons/ha/year) would cause NPK loss (kg/ha/year) to increase by about 0.598 per cent and soil NPK depletion (1000s ton/year) to increase by about 0.535 per cent and vice versa.

Sub-regional fixed effects and land degradation

The coefficient for dummy of Region 5 (West Asia) in the restricted fixed effect NPK loss model is negatively correlated to log-transformed NPK loss (kg/ha/year) and the correlation is significant at 1 per cent level of significance. We had no prior expectation on the direction of the effect but the result implies that the rate of NPK loss in West Asian countries are relatively lower than the rate of NPK loss in countries in the other regions of Asia. Since the dependent variable is in log form and the regional dummy is linear, the coefficients for Region 5 can be interpreted as follows. Each one-unit increase in dummy for Region 5 from 0 to 1, which in other words mean the given other factors remain constant, the log-transformed NPK loss for a country located in West Asia is lower by 0.445 units than any other country in other regions of Asia.

The coefficient for dummy of Region 2 (East Asia) in the restricted random effect soil NPK depletion model is negatively correlated to log-transformed soil NPK depletion (1000s ton/year) and the correlation is significant at 1 per cent level of significance. We had no prior expectation on the direction of the effect but the result implies that the annual soil NPK depletion in East Asian countries is relatively lower than the annual soil NPK depletion in countries in the other regions of Asia. Since the dependent variable is in log form and the regional dummy is linear, the coefficients for Region 2 can be interpreted as follows. Each one-unit increase in dummy for Region 2 from 0 to 1, which in other words mean given other factors remain constant the log-transformed soil NPK depletion for a country located in East Asia is lower by 0.984 units than any other country in other regions of Asia.

The coefficient for dummy of Region 4 (Southeast Asia) in the restricted random effect soil NPK depletion model is negatively correlated to log-transformed soil NPK depletion (1000s ton/year) and the correlation is significant at 1 per cent level of significance. We had no prior expectation on the direction of the effect but the result implies that the annual soil NPK depletion in South East Asian countries is relatively lower than the annual soil NPK depletion in countries in the other regions of Asia. Since the dependent variable is in log form and the regional dummy is linear, the coefficients for Region 4 can be interpreted as follows. Each one-unit increase in dummy for Region 4 from 0 to 1, which in other words mean the given other factors remain constant, the log-transformed soil NPK depletion for a country located in South East Asia is higher by 0.557 units than any other country in other regions of Asia.

2.6. Econometric modelling of land degradation induced losses of agricultural production

In *Chapters 2.4* and *2.5* we have seen how NPK loss and soil NPK depletion can be estimated using the biophysical and econometric modelling approaches. One of the purposes of the above analyses is to generate national level NPK loss and soil NPK depletion data that can feed into the econometric modelling of regional crop production function with which we can assess the level of productivity loss associated with agricultural land degradation.

Therefore, in the following sections we will describe the data, the regional agricultural production function, and results of the empirical model.

2.6.1. Data

In order to develop econometric model of regional level crop production function panel data on aggregate crop yield was calculated based on FAOSTAT data on crop production and area harvested for the period 2002-2007. As discussed in *Chapter 2.4* the production data covers about 127 specific crop types.

Data on factor variables are obtained both from this study and FAOSTAT database. The data from this study are results of the NPK loss and soil NPK depletion from *Chapter 2.4* above for the 44 countries and two provinces of China for the period 2002–2013. The panel data for the same period from FAOSTAT are national level factor inputs (labour, arable and permanent cropland area, and national level consumption of commercial fertiliser in terms of NPK nutrients). We used total human population data as a proxy for labour.

2.6.2. The empirical model of agricultural production function: land degradation as factor

Following the econometric modelling approach in the ELD Africa study (ELD & UNEP, 2015) which takes into account the effect of land degradation on crop production, and the economic theory of production as a function of factor inputs, the relationship between agricultural land degradation and crop production in agricultural ecosystems of Asia can be specified as in equation 2.2 below:

$$Y_{it}=\beta_0+\beta_1 ALD_{it}+\beta_2 FI_{it}+\sum_{j=1}^{5}\beta_{3j}R_{ji}+\varepsilon_{it}$$

Where:

Y_{it} represents actual **aggregate crop yield** (in kg/ha/year), as a provisioning agricultural ecosystem service, for country i over time period t where t= 2002, 2003....2013;

ALD_{it} represents the vector of **agricultural land degradation indicators** (NPK loss in ton/ha/year and soil NPK depletion in 1000s of tons/year) for country i over time period t where t= 2002, 2003....2013;

FI_{it} is a vector of **national level agricultural factor inputs** (labour measured in terms of human populations in millions, arable and permanent cropland area in 1000s per hectare, and national level consumption of commercial fertiliser in terms of 1000s of tons of NPK nutrients) by country i over time period t where t= 2002, 2003....2013;

R_{ji} is a vector of **sub-regional dummies** for controlling sub-regional fixed effects (where j = 1, 2, ...5 for the five sub-regions in Asia, which are Central, East, South, South East, and West Asia) for country i

β represents the coefficients;

ε_{it} is the error or stochastic term that captures the effect of unobserved factors in country i over time period t.

We set the following hypotheses on the relationship between each of the factors on the right hand side of equation 2.2 and the response variable aggregate crop yield. Our first hypothesis is both NPK loss and soil NPK depletion as indicators of agricultural land degradation are negatively and significantly correlated with aggregate crop yield. Secondly, we anticipated that national level human population as a proxy for labour and national level consumption of commercial fertiliser are positively and significantly correlated with aggregate crop yield. Third, we anticipated a significant correlation between land area (arable and permanent cropland area) and aggregate crop yield but we did not have a prior expectation about the direction of the relationship. This is because based on the theory of production, either positive or negative correlations could be anticipated. At early stage of production that starts with small land area increasing land size would lead to increasing in yield per hectare and then there will be a point at which the marginal effect of change land size would be zero beyond which increasing land size would lead to decline in productivity.

2.6.3. Empirical model results

Based on the above specification in equation 2.2, we did model specification tests for variants of econometric models (i.e. Ordinary Least Squares (OLS), Ordinary least squares with robust standard errors, Generalized Least Squares (GLS), Fixed Effect and Random Effect) for aggregate yield as response variable. The model types range from simple OLS to panel data fixed and random effect regression models. The results are presented in *Table 2.6*.

The results in all the five different types of econometric models consistently indicate that aggregate yield is negatively and significantly correlated with NPK loss as well as soil NPK depletion indicating that land degradation reduces productivity in agriculture. In addition, unlike land area, which is negatively and significantly correlated with yield, both human population and commercial fertilizer consumption are positively and significantly correlated with aggregate yield. Moreover, we have found that sub-regional fixed effects also affect aggregate yield.

We reported results of the OLS model with robust standard errors, the fixed and random effect models. Our data set consists a panel of

TABLE 2.6

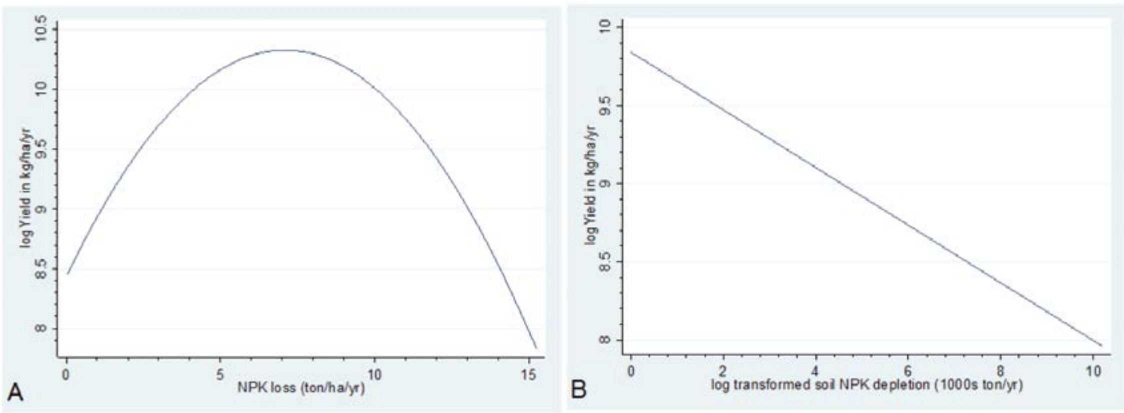
Models for yield of agricultural crops in Asia (log transformed yield in kg/ha/year)

Variables	OLS2 (robust SE)	Fixed Effect	Random Effect	Restricted random effect
Land degradation				
NPK loss in tons/ha/year	-0.055 (0.014) [-4.010][a]	-0.054 (0.017) [-3.250][a]	-0.055 (0.016) [-3.320][a]	-0.052 (0.016) [-3.240][a]
Soil NPK depletion in 1000s tons per year (log-transformed)	-0.150 (0.034) [-4.460][a]	-0.151 (0.027) [-5.500][a]	-0.150 (0.027) [-5.550][a]	-0.146 (0.026) [-5.680][a]
Inputs				
Labour: Human population in millions (log-transformed)	0.284 (0.036) [7.960][a]	0.283 (0.029) [9.750][a]	0.284 (0.029) [9.880][a]	0.276 (0.027) [10.300][a]
Land: Arable & permanent crop land in 1000s ha (log-transformed)	-0.324 (0.018) [-17.870][a]	-0.321 (0.017) [-18.730][a]	-0.324 (0.017) [-19.080][a]	-0.318 (0.016) [-20.240][a]
Fertilizer: NPK commercial fertilizer consumption in 1000s tons (log-transformed)	0.142 (0.018) [7.760][a]	0.141 (0.014) [9.730][a]	0.142 (0.014) [9.990][a]	0.141 (0.014) [9.970][a]
Region 1 (1 = Central Asia, 0 = otherwise)	(omitted)	(omitted)	-0.070 (0.074) [-0.940]	
Region 2 (1 = East Asia, 0 = otherwise)	-0.078 (0.083) [-0.940]	-0.072 (0.093) [-0.780]	-0.148 (0.066) [-2.240][b]	
Region 3 (1 = Southern Asia, 0 = otherwise)	-0.455 (0.057) [-7.960][a]	-0.452 (0.080) [-5.640][a]	-0.525 (0.059) [-8.940][a]	-0.409 (0.053) [-7.790][a]
Region 4 (1 = South East Asia, 0 = otherwise)	-0.045 (0.066) [-0.680]	-0.042 (0.075) [-0.560]	-0.115 (0.051) [-2.240][b]	
Region 5 (1 = West Asia, 0 = otherwise)	0.070 (0.057) [1.220]	0.073 (0.075) [0.980]	(omitted)	0.116 (0.044) [2.640][a]
Constant	10.614 (0.186) [57.180][a]	10.607 (0.188) [56.510][a]	10.684 (0.162) [65.800][a]	10.526 (0.153) [68.680][a]
N	552	552	552	552
F (df, N)	162.170[a]	100.710[a]		
R2	0.633	0.633	0.631	0.633
Adj. R2				
Root MSE	0.429			
Mean VIF	4.010			
No. of groups (Year 2002 – 2013)		12	12	12
Wald chi2			935.990[a]	937.470[a]
Log_L				
R2 within		0.631	0.631	0.630
R2 between		0.940	0.940	0.939
corr (u_i, Xb)		0.072		
F test u_i=0, F(df, N)		0.240		
Hausman Test (Chi2)			2.49	2.61

Values in () are standard errors, Values in [] are t-statics for the OLS and fixed effect models and z-statistics for the other models.
Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.

FIGURE 2.17

Relationship between aggregate crop yield & NPK loss (Panel A) & soil NPK depletion (Panel B)



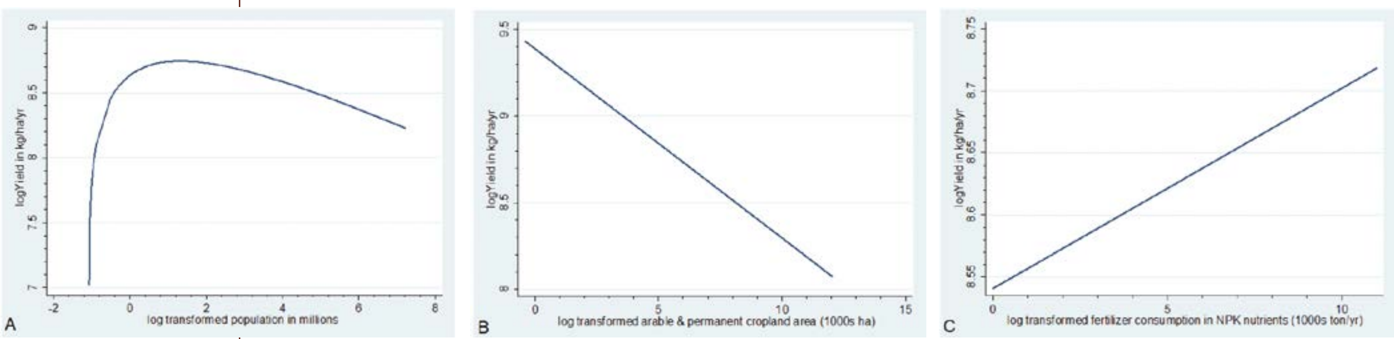
all the response and right hand side variables of equation 2.2 for the period 2002 to 2013. As a result, panel data econometric model specification that controls effects of each individual years in the panel is appropriate. The Haussmann test statistic in *Table 2.6* is insignificant indicating that the random effect model is efficient. We further dropped insignificant variable from the random effect model and run Haussmann specification test with only significant factor variables. This consistently resulted in the restricted random effect model as efficient for estimating aggregate yield. The R2 values are reasonably high and close to 63 per cent of the variations in log-transformed aggregate yield (kg/ha/year) could be explained by the variations in the national land agricultural land degradation and factor input variables.

Land degradation and yield

The coefficients for NPK loss as well as soil NPK depletion are both negative and significant at 1 per cent level. The direction of the effect is consistent with our hypothesis that land degradation is negatively and significantly correlated with aggregate crop yield. Figure 2.17 shows the directional relationship between aggregate crop yield and agricultural land degradation indicator variables and the relations are consistent with our expectations. Since aggregate crop yield is in log form and the NPK loss is linear and soil NPK loss is in log form, the coefficients for the NPK loss (tons/ha/year) and soil NPK depletion (1000s tons/year) can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit

FIGURE 2.18

Relationship between aggregate crop yield and labour (Panel A), land (Panel B) and fertilizer (Panel C)



increase in NPK loss (ton/ha/year) decreases the log-transformed aggregate crop yield (kg/ha/year) by 0.052 units whereas each one unit increase in the log-transformed soil NPK depletion (1000s tons/year) reduces the log-transformed aggregate crop yield by 0.146 units. In percentage terms, ceteris paribus, a 1 per cent increase in NPK loss (tons/ha/year) would cause aggregate crop yield (kg/ha/year) to decrease by about 5.2 per cent. Whereas a 1 per cent increase in soil NPK depletion (1000s tons/year) would cause aggregate crop yield to decrease by about 0.146 per cent and vice versa.

Factor inputs and yield

The coefficients for labour and fertilizer are both positive and significant at 1 per cent level. The direction of the effect is consistent with our hypothesis that labour and fertilizer inputs are positively and significantly correlated with aggregate crop yield. Whereas though we had no prior expectation about the direction of the effect of land as factor input on aggregate crop yield, we found that the coefficient for land is negatively and significantly correlated with aggregate crop yield. *Figure 2.18* confirms the directional relationship between aggregate crop yield and factor input variables.

Since aggregate crop yield as well as each of the factor input variables are in log form, the coefficients of the factor input variables can be interpreted as follows. Keeping all other factors constant *(ceteris paribus)*, each one-unit increase in log-transformed human population (in millions), log-transformed arable & permanent cropland area (in 1000s hectares), and log-transformed NPK commercial fertilizer consumption (in 1000s tons) would cause the log-transformed crop yield (kg/ha/year) to increase by 0.276 units, decrease by 0.318 units and increase by 0.141 units respectively. In percentage terms, *ceteris paribus*, a 1 per cent increase in log-transformed human population and log-transformed NPK commercial fertilizer consumption would cause aggregate crop yield to increase by about 0.276 per cent and 0.141 per cent respectively. Whereas a 1 per cent increase in log-transformed arable & permanent cropland area would cause aggregate crop yield to decrease by about 0.318 per cent and vice versa.

Sub-regional fixed effects and Yield

The coefficient for dummy of Region 3 (Souther Asia) and Region 5 (West Asia) in the restricted random effect model are statistically significant at 1 per cent and showed negative and positive correlations with aggregate crop yield respectively. We had no prior expectation on the direction of the effect but the result implies that, *ceteris paribus*, on average the aggregate crop yield in Southern Asian countries is relatively lower than the aggregate yield in countries in other sub-regions. Whereas keeping all other factors constant, the aggregate yield per hectare in countries of West Asia is relatively higher than the yield in other regions. These variations are due to unobserved sub-regional fixed effects.

2.7. Estimation and valuation of nutrient and crop production losses

2.7.1. Assumptions and links to SDG targets

In preceding sections, we have developed the econometric modelling approaches for estimating indicators of agricultural land degradation as a function of biophysical and socioeconomic factors controlling for sub-regional fixed effects. Furthermore, we developed regional level aggregate crop yield econometric model as a function of the agricultural land degradation indicator variables (NPK loss and soil NPK depletion) and factor inputs controlling for sub-regional fixed effects.

In this section, we will apply the models for estimating national level nutrient losses and soil nutrient depletions induced by topsoil loss and hence the national level aggregate crop production losses due to top soil loss induced NPK losses and soil NPK depletion. The estimations of top soil loss induced national level NPK loss and soil NPK depletion as well as the associated aggregate crop production losses are based on the assumptions in *Box 4*. The assumptions are based on econometric model results in *Chapter 2.6* above which allow us to make consistent application of the concept of land degradation neutrality *(Figure 2.19)* and linking our results to indicators and sub indicators of the Sustainable Development Goals 15.3, 15.2, 15.1, 2.4, and 2.3 (see *Box 6* for SDG targets and indicators) and other targets.

Based on the above assumptions, we estimate the baseline agricultural land degradation indicators used in this study (NPK loss and soil NPK depletion) and the associated baseline aggregate food production losses. Furthermore, we applied the replacement cost method for valuation of the nutrients and market price method for valuation of the crop production losses. In the subsequent chapters we will show how the conceptual framework of LDN is related in assessing the economic value of losses in the baseline scenario, the cost and benefits of avoiding future (new) degradation and cost-benefit analysis and socioeconomic implications of achieving LDN in agricultural ecosystems and its complementarity with other Sustainable Development Goals.

2.7.2. Quantity and value of top soil loss induced NPK losses and soil NPK depletions

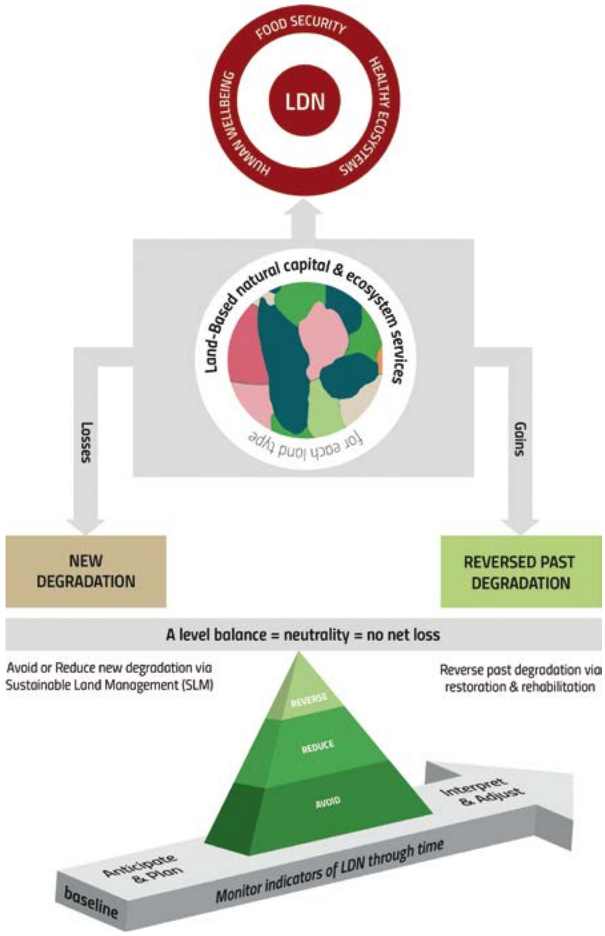
The last three columns of *Table 2.7* show the quantity and replacement cost value of top soil loss induced NPK loses for each country, sub-regions and Asia. The table also provides the replacement cost value of total NPK losses that we have seen in *Table 2.3* of *Chapter 2.4* so that we can see that the estimated quantity and replacement cost value for the top soil loss induced NPK losses are lower bound estimates.

Regional and sub-regional level quantity and replacement cost of topsoil induced NPK losses and soil NPK depletions: The rate of top soil loss from agricultural lands in Asia was 11.91 tons per hectare and from the total harvested area of

F I G U R E 2 . 1 9

The key elements of the scientific conceptual framework for Land Degradation Neutrality (LDN) and their interrelationships

(Source: Orr et al., 2017)



The target at the top of the figure expresses the vision of LDN, emphasizing the link between human prosperity and the natural capital of land – the stock of natural resources that provides flows of valuable goods and services. The balance scale in the center illustrates the mechanism for achieving neutrality: ensuring that future land degradation (losses) is counterbalanced through planned positive actions elsewhere (gains) within the same land type (same ecosystem and land potential). The fulcrum of the scale depicts the hierarchy of responses: avoiding degradation is the highest priority, followed by reducing degradation and finally reversing past degradation. The arrow at the bottom of the diagram illustrates that neutrality is assessed by monitoring the LDN indicators relative to a fixed baseline. The arrow also shows that neutrality needs to be maintained over time, through land use planning that anticipates losses and plans gains. Adaptive management applies learning from interim monitoring to inform mid-course adjustments to help ensure neutrality is achieved, and maintained in the future.

the 487 million hectares, the total estimated top soil loss amounts to 5.8 billion tons of soil. The corresponding estimated topsoil loss induced NPK loss in the region amounts to 52.1 million tons (about 107.1 kg/ha/year) or close to 77 per cent of the annual NPK losses in the region. The value of this supporting ecosystem service at a replacement cost price of commercial fertilizer (weighted average price 0.85 USD/kg of NPK nutrients in the 2013 prices) amounts to about USD 34.1 billion, or on average USD 90.94/ha *(Table 2.7)*.

Southern Asia accounts for 49 per cent of the annual top soil loss in Asia whereas the top soil loss induced NPK losses (52.1 million tons of NPK per year) and the replacement cost value of these losses (USD 34.1 billion) account for 35.78 and 36.01 per cent of the Asia level respectively. East Asia accounts for 23.14 per cent of the topsoil loss, 46.66 per cent of the top soil loss induced NPK loss and about 46 per cent of the replacement cost value of the loss in Asia. South East Asia is third in terms of total top soil loss accounting for 20.37 per cent as well as the top soil loss induced NPK losses and the replacement cost value, each accounting for 11.6 and 11.9 per cent respectively. The remaining close to 7.4 per cent of the total top soil loss, 6 per cent of the top soil loss induced NPK loss and 6.1 per cent of the total replacement cost value of the loss in Asia are accounted for by West and Central Asia.

BOX 5

Assumptions for estimation of NPK losses, Soil NPK depletion and crop losses

Rate of top soil loss is one of the national level biophysical factors in the NPK loss and soil NPK depletion econometric models *(Table 2.4 and 2.5)*. In estimating the effect of this factor on national level NPK loss and soil NPK depletion and the associated aggregate crop production loss using the yield model in Table 2.6, we assumed:

1. The average annual changes that were happening over the period 2002–2013 as a baseline. The models allow us estimating the NPK loss and soil NPK depletions that were taking place in the past 12 years over the indicated period and unless measures are going to be taken, these estimated results are likely to happen in future.
2. Business as usual versus avoiding top soil erosion. The business as usual assumption allow us to estimate the cost of doing nothing whereas the assumption of avoiding top soil erosion in its strictest sense imply the highest priority of LDN as well as the need for investment on sustainable land management.
3. The other factor variables used in the model remain constant. The implication of this assumption is consistent with the principle of "one-out all-out". For example among the biophysical factors in the models, we assume no change in forest cover, biomass carbon stock, arable and permanent cropland areas, as well as meadow and pasture land areas and all should remain at the 2013 state in each country. These indicators are also consistent with sub-indicators of SDG 15.3.1 *(Box 6)*.
4. The estimated top soil loss induced national level NPK loss and soil NPK depletion for the base year are considered as baseline indicators of national, sub-regional, and regional level of agricultural land and soil quality, which can be used as indicators for SDG 2.4 *(Box 6)*.
5. Based on the assumptions 1-4 and estimated results the level of factor inputs in the aggregate crop yield econometric model (Table 2.6) remain constant in estimating the effect of the estimated top soil loss induced NPK loss and soil NPK depletion on aggregate crop production loss. Here, the estimated crop production loss for the base year is assumed as indicator of the level of agricultural productivity loss. Whereas, if actions for avoiding the top soil loss would be implemented in future, the loss could be converted into benefit and hence can be used as indicator of improvement in agricultural land productivity. In other words, the crop productivity loss/gain is an alternative sub-indicator of SDG 15.3 *(Box 6)*.
6. Our models imply that efforts for example aimed at improving forest cover and biomass carbon would positively lead to reducing NPK loss and soil NPK depletion and hence increasing aggregate crop yield. Therefore, the estimations based on the assumptions 1-5 provide lower bound results.

BOX 6

SDG 15.3, 2.4, and 2.3 and their indicators

(Source: UN, n.d., UN, 2017a)

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Target 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral (LDN) world. LDN is a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems.

Indicator 15.3.1 Proportion of land that is degraded over total land area. Sub-indicators include land cover and land cover change, land productivity, and carbon stocks above and below ground.

Data for global, regional and national monitoring: Following the 2006 IPCC Guidelines concerning estimation methods at three levels of detail, from tier 1 (the default method) to tier 3 (the most detailed method), the following approach for indicator 15.3.1 are proposed:

- **Tier 1:** Earth observation, geospatial information and modelling
- **Tier 2:** Statistics based on estimated data for administrative or natural boundaries
- **Tier 3:** Surveys, assessments and ground measurements

Each of the tiers may have a unique approach as to how driver (land management/use) and state (land resources) variables interact in a land degradation assessment, which depends primarily on the data and upscaling methods available. Therefore, it has been noted that the above three sub-indicators will never fully capture the complexity of land degradation processes; and there will always be a need for other relevant national or sub-national indicators, data and assessments to account for national circumstances and contexts

Target: 15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements

Indicator 15.1.1 Forest area as a proportion of total land area

Target 15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally

Indicator 15.2.1 Progress towards sustainable forest management

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Target: 2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

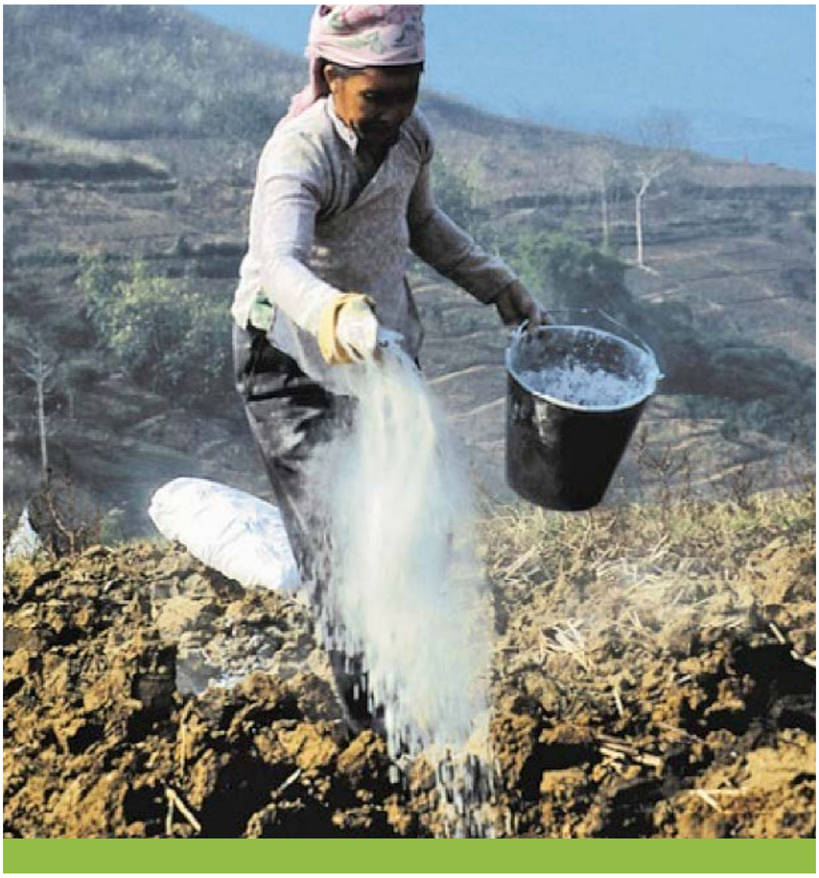
Indicator: 2.4.1 Proportion of agricultural area under productive and sustainable agriculture

Target 2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

Indicators: 2.3.1 Volume of production per labour unit by classes of farming/pastoral/forestry enterprise size

Indicator: 2.3.2 Average income of small-scale food producers, by sex and indigenous status

Top soil loss induced soil NPK depletion in the region amounts to about 49.5 million tons (101.7 kg/ha/year) or close to 94.6 per cent of the total soil NPK balance in the Asia. The replacement cost value of this total top soil loss induced soil NPK depletion amounts to about USD 30.1 billion. Southern Asia accounts for 34.36 per cent of the quantity and 33.82 per cent of this value followed by East Asia (29.82 per cent of the quantity and 30.1 per cent of the value), and southern East Asia (22.43 per cent of the quantity and 23.3 per cent of the value). West and Central Asia together account for the remaining 13.4 per cent in quantity and 12.8 per cent in value of the top soil loss induced soil NPK depletion in Asia.



Country level quantity and replacement cost of topsoil induced NPK losses soil NPK depletions: Out of the 44 countries and two provinces of China covered in this study, India, mainland China, and Indonesia all together account for close to 71.6 per cent of the total annual 5.8 billion tons of top soil loss in Asia. India accounts for 42.38 per cent, followed by mainland China (22.21 per cent) and Indonesia (7 per cent). The remaining 28.4 per cent of the annual top soil loss from the 48.7 million ha of agricultural land in the region is accounted for by other 41 countries and two provinces of China.

In terms of the top soil loss induced NPK loss and its replacement cost value, mainland China ranks first with 22.8 million tons of NPK loss and replacement cost value of about USD 14.7 billion, each accounting for 43.8 and 43.2 per cent of the corresponding Asia level values respectively. India ranks second with 14.05 million tons per annum of top soil induced NPK losses that has a replacement cost value of about USD 9.3 billion. This accounts for close to 27 per cent of the loss in quantity and 27.4 per cent of the value of the corresponding Asia level figures. Therefore, the two countries account for close to 71 per cent of the quantity Asia level top soil induced NPK loss and 70.6 per cent of the value. Together with Indonesia, the three countries account for close to 75 per cent of both the quantity and monetary value of the top soil loss induced NPK loss in Asia with the rest of the countries all together accounting for the remaining 25 per cent.

Seven countries (Mainland China, India, Indonesia, Turkey, Myanmar, Thailand, and Kazakhstan) all together account for 82.33 per cent of the total quantity and 82.24 per cent of the value of top soil loss induced quantity and value of soil NPK depletion in Asia. The first two countries account for 57.11 per cent of the Asia level estimated 49.5 million tons of top soil loss induced soil NPK depletion and 56.88 per cent of it value of USD 30.1 billion. The remaining less than 18 per cent of both in value and quantity is accounted for by the 37 countries and two provinces of China.

2.7.3. Quantity and value of estimated aggregate crop production losses

Table 2.9 shows the average annual crop production, yield in tons per hectare per year and the quantity and value of aggregate crop production losses due to top soil induced NPK losses as well as soil NPK depletion.

Regional and sub-regional level quantity and value of crop production losses: Over the period 2002-2013, Asia had been producing on average close to 2.47 billion tons of crop outputs on the 487 million hectares of agricultural land area and the average productivity for the region was 5.07 tons/ha/year. Over the same period on average for every

TABLE 2.7

Quantity and replacement cost value of total and top soil loss induced NPK losses

Country	Area harvested in 1000s ha	Top soil loss in millions tons/yr	NPK losses in 1000s tons	Replacement cost of_NPK Losses 2013, USD million	Replacement cost of NPK loss in USD/ha	Top soil loss induced NPK loss kg/ha/yr	Top soil loss induced NPK loss in 1000s tons	Replacement cost of NPK_Los in USD million
Afghanistan	3305.2	17.94	207.39	138.44	41.47	48.14	159.68	106.59
Armenia	283.9	1.13	20.55	13.69	48.42	55.73	15.82	10.54
Azerbaijan	1256.9	7.05	62.33	44.27	34.74	38.04	47.99	34.09
Bahrain	3.3	0.04	2.59	1.38	412.62	597.86	1.99	1.06
Bangladesh	8646.4	138.57	659.48	451.52	52.37	58.75	507.77	347.65
Bhutan	101.3	0.86	5.88	3.84	38.20	45.44	4.53	2.95
Brunei Darussalam	8.5	0.14	3.63	2.47	274.46	318.24	2.79	1.90
Cambodia	3255.2	40.79	95.94	73.36	21.54	22.76	73.87	56.48
China Hong Kong SAR	2.0	.	5.65	3.46	1749.15	2204.72	4.35	2.66
China, mainland	123000.0	1287.55	29616.88	19110.44	156.49	186.17	22803.48	14714.06
Cyprus	94.7	0.44	15.18	8.94	105.17	127.73	11.69	6.88
Georgia	463.1	2.07	30.11	19.25	45.92	52.35	23.19	14.82
India	170000.0	2456.87	18253.64	12102.77	71.43	82.91	14054.37	9318.51
Indonesia	29500.0	406.45	2920.04	1996.00	65.76	75.69	2248.28	1536.82
Iran	13000.0	63.49	1379.45	864.54	68.18	82.08	1062.11	665.65
Iraq	3304.5	31.49	167.60	117.16	40.12	41.96	129.04	90.21
Israel	289.4	1.98	63.63	39.57	138.57	169.12	48.99	30.47
Japan	2951.0	22.62	1033.13	631.57	215.59	269.04	795.46	486.28
Jordan	190.9	1.61	70.63	36.73	188.52	278.12	54.38	28.28
Kazakhstan	16600.0	157.89	346.60	254.12	14.87	15.95	266.86	195.66
Republic of Korea	1746.0	19.72	523.95	325.37	190.41	231.39	403.41	250.52
Kuwait	12.0	0.12	14.30	8.86	756.41	1013.99	11.01	6.82

Kyrgyzstan	919.1	4.54	64.16	42.90	46.63	53.75	49.40	33.03
Lao PDR	1198.3	18.08	46.19	35.70	28.69	29.38	35.57	27.49
Lebanon	245.3	2.86	40.48	26.00	108.68	128.67	31.17	20.02
Malaysia	4961.9	76.92	870.72	558.06	109.82	134.67	670.41	429.68
Mongolia	241.1	1.81	79.50	50.49	216.03	268.07	61.21	38.88
Myanmar	11600.0	126.15	570.69	399.75	33.67	37.66	439.40	307.79
Nepal	2377.5	12.38	128.66	85.64	36.29	41.74	99.06	65.94
Oman	55.6	0.48	13.74	8.89	160.01	191.10	10.58	6.85
Pakistan	19500.0	129.03	3421.97	2213.80	112.52	134.86	2634.74	1704.51
Philippines	10300.0	161.13	511.27	348.90	33.49	38.31	393.65	268.64
Qatar	5.5	0.05	29.13	20.58	3786.62	4140.07	22.43	15.85
Saudi Arabia	827.4	6.58	300.34	202.98	282.00	307.01	231.25	156.28
Singapore	0.8	0.01	5.32	3.12	4120.38	5222.53	4.10	2.40
Sri Lanka	1700.5	22.58	162.36	110.46	63.89	73.96	125.01	85.05
Syrian Arab Republic	4518.6	36.67	306.79	192.17	42.45	52.13	236.22	147.96
Taiwan Province of China	636.7	9.61	326.25	199.52	318.10	394.56	251.20	153.62
Tajikistan	869.0	3.86	73.18	50.55	58.10	64.80	56.35	38.92
Thailand	16300.0	228.37	1468.09	976.71	59.10	69.37	1130.35	752.02
Timor-Leste	149.8	0.27	7.27	4.67	31.00	37.72	5.59	3.60
Turkey	18600.0	135.55	1845.04	1182.89	65.16	76.73	1420.59	910.76
United Arab Emirates	163.6	1.82	26.01	15.98	141.81	160.57	20.03	12.30
Uzbekistan	3624.6	30.35	511.18	374.09	103.56	108.70	393.58	288.03
Viet Nam	9582.2	122.83	1330.29	869.68	89.51	106.87	1024.25	669.61
Yemen	1040.0	7.00	49.58	34.22	31.95	36.69	38.18	26.35
Central Asia	22083.3	196.64	995.12	721.66	32.68	34.70	766.19	555.64
East Asia	128333.3	1341.31	31585.36	20320.85	158.34	189.50	24319.10	15646.01
South East Asia	86666.7	1181.14	7829.45	5268.43	60.79	69.56	6028.28	4056.42
Southern Asia	218333.3	2841.72	24218.83	15971.01	73.15	85.41	18647.26	12296.86
West Asia	31333.3	236.94	3058.04	1973.55	62.99	75.14	2354.54	1519.54
ASIA	486666.7	5797.75	67686.81	44255.50	90.94	107.09	52115.37	34074.46

TABLE 2.8

Quantity and replacement cost value of total and top soil loss induced soil NPK depletion

Country	Area harvested in 1000s ha	Top soil loss in millions tons	NPK soil balance in 1000s tons	Replacement cost of soil NPK depletion in USD millions/yr	Replacement cost of Depleted Soil NPK in USD/ha	Top soil loss induced NPK depletion from soil kg/ha/yr	Top soil induced NPK depletion from soil 1000s tons	Replacement cost top soil induced NPK_from soil in USD millions
Afghanistan	3305.2	17.94	-329.86	200.16	59.33	93.38	312.02	189.34
Armenia	283.9	1.13	-34.49	21.40	75.69	114.54	32.62	20.24
Azerbaijan	1256.9	7.05	-233.33	141.69	109.92	175.46	220.70	134.02
Bahrain	3.3	0.04	2.52	-1.33	-395.98	-713.89	-2.38	-1.25
Bangladesh	8646.4	138.57	-1236.07	760.68	88.29	135.34	1169.21	719.53
Bhutan	101.3	0.86	-10.65	6.61	65.32	99.09	10.07	6.25
Brunei Darussalam	8.5	0.14	4.27	-2.78	-307.46	-459.67	-4.03	-2.63
Cambodia	3255.2	40.79	-474.61	317.78	90.38	132.83	448.93	300.59
China Hong Kong SAR	2.0	.	5.25	-3.10	-1569.47	-2516.83	-4.97	-2.93
China, mainland	123000.0	1287.55	-16084.27	9816.50	80.45	124.23	15214.23	9285.50
Cyprus	94.7	0.44	2.39	-2.17	-27.69	-30.98	-2.26	-2.05
Georgia	463.1	2.07	-39.66	20.04	45.25	76.75	37.51	18.96
India	170000.0	2456.87	-13803.05	8298.28	48.98	77.02	13056.41	7849.40
Indonesia	29500.0	406.45	-4786.33	2970.40	97.31	152.89	4527.42	2809.73
Iran	13000.0	63.49	-1284.06	715.21	55.42	92.82	1214.60	676.53
Iraq	3304.5	31.49	-314.27	169.83	54.62	89.11	297.27	160.64
Israel	289.4	1.98	-18.40	12.33	43.77	60.64	17.40	11.66
Japan	2951.0	22.62	155.00	-60.46	-20.26	-49.01	-146.62	-57.19
Jordan	190.9	1.61	73.36	-39.17	-199.85	-353.56	-69.39	-37.05
Kazakhstan	16600.0	157.89	-1645.26	1010.29	58.83	93.32	1556.27	955.64
Republic of Korea	1746.0	19.72	50.26	-18.80	-10.95	-27.47	-47.54	-17.79
Kuwait	12.0	0.12	12.93	-7.51	-657.58	-1155.68	-12.23	-7.10

Kyrgyzstan	919.1	4.54	-157.18	90.83	98.58	161.74	148.68	85.91
Lao PDR	1198.3	18.08	-221.44	146.74	115.81	171.26	209.46	138.80
Lebanon	245.3	2.86	-11.56	6.07	23.87	42.76	10.93	5.74
Malaysia	4961.9	76.92	-31.34	76.24	14.67	5.27	29.64	72.12
Mongolia	241.1	1.81	73.81	-42.00	-186.33	-320.21	-69.82	-39.73
Myanmar	11600.0	126.15	-1802.86	1128.66	95.04	146.54	1705.34	1067.61
Nepal	2377.5	12.38	-260.88	157.95	66.95	103.85	246.77	149.41
Oman	55.6	0.48	12.49	-7.21	-131.18	-215.74	-11.81	-6.82
Pakistan	19500.0	129.03	-934.71	552.01	27.83	45.24	884.15	522.15
Philippines	10300.0	161.13	-1248.32	782.13	74.24	113.75	1180.80	739.82
Qatar	5.5	0.05	29.12	-20.62	-3792.48	-5083.13	-27.55	-19.50
Saudi Arabia	827.4	6.58	1.05	-27.83	-56.72	-36.49	-0.99	-26.32
Singapore	0.8	0.01	5.64	-3.24	-4300.83	-6811.96	-5.34	-3.07
Sri Lanka	1700.5	22.58	-122.09	79.47	44.41	66.16	115.48	75.17
Syrian Arab Republic	4518.6	36.67	-503.94	264.92	59.05	105.53	476.68	250.59
Tajikistan	869.0	3.86	-108.45	63.13	72.69	118.10	102.59	59.72
Taiwan Province of China	636.7	9.61	193.75	-110.46	-176.03	-288.15	-183.27	-104.49
Thailand	16300.0	228.37	-1662.29	1029.61	62.08	96.67	1572.37	973.92
Timor-Leste	149.8	0.27	-10.62	6.70	43.46	66.50	10.04	6.34
Turkey	18600.0	135.55	-3302.76	1937.66	107.11	168.76	3124.10	1832.85
United Arab Emirates	163.6	1.82	21.46	-11.65	-108.83	-166.82	-20.30	-11.02
Uzbekistan	3624.6	30.35	-719.84	406.90	112.62	187.86	680.90	384.89
Viet Nam	9582.2	122.83	-1513.09	967.41	98.84	148.38	1431.24	915.08
Yemen	1040.0	7.00	-73.38	46.46	43.18	65.74	69.41	43.94
Central Asia	22083.3	196.64	-2630.73	1571.15	71.15	112.68	2488.43	1486.16
East Asia	128333.3	1341.31	-15606.18	9581.68	74.66	115.03	14762.01	9063.38
South East Asia	86666.7	1181.14	-11740.98	7419.64	85.61	128.14	11105.88	7018.30
Southern Asia	218333.3	2841.72	-17981.36	10770.38	49.33	77.90	17008.71	10187.78
West Asia	31333.3	236.94	-4376.44	2502.91	79.88	132.12	4139.71	2367.52
ASIA	486666.7	5797.75	-52335.69	31845.75	65.44	101.72	49504.73	30123.13

TABLE 2.9

Quantity and value of aggregate crop production losses due to top soil loss induced NPK losses and soil NPK depletions

			Crop production losses due top soil loss induced NPK losses			Crop production losses due top soil loss induced soil NPK depletion		
	Production in 1000s tons/yr	Yield in ton/ ha/yr	ESS Trade of Index (Yield loss/NPK loss)	Yield loss in 1000Ton	Value of yield_ Loss in USD million/yr	ESS Trade of Index (Yield loss/NPK depletion)	Yield loss in 1000Ton	Value of yield_ Loss in USD million/yr
Afghanistan	7388	2.22	0.116	18.87	11.04	12.912	3910.62	2289.07
Armenia	2254	7.95	0.416	6.64	2.83	38.349	1193.37	507.82
Azerbaijan	5732	4.56	0.239	11.5	6.43	13.813	3034.24	1696.42
Bahrain	35	10.63	0.550	1.02	1.21	-18.735	18.51	22
Bangladesh	36810	4.26	0.223	113.7	30.96	16.681	19485.52	5306.1
Bhutan	342	3.41	0.179	0.81	0.59	18.808	181.19	133.02
Brunei Darussalam	18	2.10	0.109	0.32	0.22	-2.565	9.53	6.55
Cambodia	12074	3.55	0.186	14.29	6.42	14.083	6391.19	2869.23
China Hong Kong SAR	40	20.28	1.005	4.37	4.05	-4.326	21.17	19.62
China, mainland	994660	8.12	0.424	9690.93	5460.67	34.742	526522.5	296685.9
Cyprus	553	5.90	0.309	3.61	2.15	52.057	292.62	174.58
Georgia	1578	3.38	0.177	4.16	2.16	25.779	835.08	434.3
India	494069	2.91	0.153	2162.21	1513.86	20.167	261535.2	183111.8
Indonesia	227932	7.66	0.401	913.06	331.77	26.521	120655.7	43841.65
Iran	57590	4.44	0.232	246.87	193.06	26.565	30485.42	23840.78
Iraq	9405	2.93	0.154	20.33	15.52	19.28	4978.56	3799.81
Israel	4027	13.94	0.728	35.6	37.08	140.195	2131.81	2220.64
Japan	31087	10.53	0.549	436.54	807.78	-302.427	16455.88	30450.09
Jordan	2046	10.76	0.56	29.03	12.55	109.963	1083.28	468.44
Kazakhstan	23933	1.43	0.075	20.5	6.14	8.263	12669.11	3795.8
Republic of Korea	21368	12.27	0.639	257.48	187.79	998.157	11310.99	8249.66

Kuwait	332	28.06	1.433	15.7	11.89	-17.744	175.81	133.12
Kyrgyzstan	4225	4.60	0.241	11.93	5.35	15.173	2236.29	1002.49
Lao PDR	5455	4.49	0.236	8.56	3.02	14.123	2887.66	1019.03
Lebanon	2470	10.10	0.528	16.55	11.02	-113.071	1307.75	870.84
Malaysia	86415	17.35	0.907	613.16	102.35	35.438	45743.68	7635.26
Mongolia	473	1.91	0.1	6.3	2.85	-3.761	250.46	113.23
Myanmar	32447	2.79	0.146	64.81	49.85	10.125	17175.63	13211.16
Nepal	7451	3.14	0.164	16.43	5.84	15.995	3944.23	1400.96
Oman	587	10.51	0.548	5.86	6.59	-51.028	310.5	349.09
Pakistan	55516	2.84	0.148	393.3	248.19	34.429	29387.43	18545.2
Philippines	49047	4.74	0.248	97.48	31.43	22.33	25962.9	8369.88
Qatar	60	10.90	0.517	10.64	12.46	-10.546	31.6	37
Saudi Arabia	6413	7.94	0.413	97.68	142.68	-37.889	3394.5	4958.18
Singapore	14	17.43	0.801	3.22	3.25	-1.446	7.18	7.25
Sri Lanka	7618	4.47	0.234	29.27	9.71	39.576	4032.46	1337.62
Syrian Arab Republic	12303	2.72	0.143	33.95	25.74	14.537	6512.74	4938
Taiwan Province of China	7337	11.53	0.599	150.25	111.78	-21.39	3883.97	2889.47
Tajikistan	3753	4.32	0.226	13.5	8.26	19.678	1986.53	1215.96
Thailand	85557	5.25	0.275	311.98	73.21	28.86	45289.33	10627.36
Timor-Leste	322	2.16	0.113	0.64	0.39	17.859	170.51	103.94
Turkey	84579	4.57	0.239	341.05	174.52	14.365	44771.63	22910.2
United Arab Emirates	987	6.59	0.344	6.81	8.33	-31.548	522.36	638.69
Uzbekistan	20099	5.55	0.29	123.46	87.48	16.624	10639.49	7539.09
Viet Nam	57839	6.01	0.314	323.68	124.27	21.746	30616.77	11754.84
Yemen	2750	2.64	0.139	5.32	4.35	21.756	1455.53	1189.43
Central Asia	52010	2.36	0.221	169.39	107.23	11.064	27531.43	13553.33
East Asia	1058333	8.25	0.434	10545.88	6574.92	37.83	558445	338408
South East Asia	557118	6.43	0.39	2351.21	726.17	26.554	294910.08	99446.17
Southern Asia	666785	3.05	0.16	2981.46	2013.26	20.752	352962.08	235964.5
West Asia	136110	4.34	0.274	645.45	477.51	17.405	72049.88	45348.54
ASIA	2466667	5.07	0.32	16693.38	9899.09	17.405	1308333.3	732720.5

kilogram of NPK loss caused by top soil loss, crop productivity was declining by 0.32 kilogram of crop outputs. Whereas for every 1 kilogram of soil NPK depletion caused by top soil loss, the regional level crop yield loss was 17.05 kilograms. These values can be considered as ecosystem trade-off indices.

From the total land area cultivated, the total annual production loss due to top soil loss induced NPK loss amounts to about 16.7 million tons of crops with a total value of about USD 9.9 billion at the weighted average price of crops produced in the region. In other words, avoiding top soil loss induced NPK loss in agricultural lands of Asia would increase productivity by about 0.68 per cent per year. Whereas the total annual production loss due to top soil loss induced soil NPK depletion amounts to about 1.31 billion tons or close to 53 per cent of the annual total crop production in the region. The corresponding value of this annual loss at the weighted average crop prices amounts to close to USD 732.7 billion. This implies that avoiding top soil induced soil NPK depletion in agricultural lands of Asia would increase the regional level productivity from the 5.07 to 7.76 tons per hectare per year.

East Asia accounts for close to 43 per cent of Asia's crop production, 63 per cent in quantity and 66.4 per cent in the value of crop loss caused by top soil loss induced NPK losses, and about 43 per cent in quantity and 46.2 per cent in value of crop losses caused by top soil loss induced soil NPK depletions in Asia. Southern Asia accounts for close to 27 per cent of Asia's crop production, 17 per cent in quantity and 20.4 per cent in the value of crop loss caused by top soil loss induced NPK losses, and about 27 per cent in quantity and 32.2 per cent in value of crop losses caused by top soil loss induced soil NPK depletions in Asia.

Whereas South East Asia accounts for close to 23 per cent of Asia's crop production, 14.1 per cent in quantity and 7.3 per cent in the value of crop loss caused by top soil loss induced NPK losses, and about 22.5 per cent in quantity and 13.6 per cent in value of crop losses caused by top soil loss induced soil NPK depletions in Asia. West and Central Asia together account for the remaining 7.6 per cent of Asia's crop production, 5.9 per cent in quantity and 6.9 per cent in the value of crop loss caused by top soil loss induced NPK losses, and about 7.6 per cent in quantity and 8 per cent in value of crop losses caused by top soil loss induced soil NPK depletions in Asia.

Country level quantity and value of crop production losses: Six countries (Mainland China, India, Indonesia, Malaysia, Thailand, and Turkey) all together were producing 80 per cent of the 2.47 billion tons of average annual crop production in Asia over the period 2002-2013, with mainland China and India accounting for 40.32 per cent and 20.03 per cent respectively. The remaining 20 per cent were produced in the 38 countries and two provinces of China. The crop loss caused by top soil loss induced NPK loss in the six countries (Mainland China, India, Indonesia, Malaysia, Thailand, and Turkey) also accounts for close to 84.1 per cent in quantity and about 77.3 per cent in the value the corresponding loss in Asia. Whereas the crop loss caused by top soil loss induced soil NPK depletion in these six countries accounts for close to 79.8 per cent in quantity and 77 per cent in the value of corresponding crop loss in Asia.

2.8. Conclusions

This study covers 44 Asian countries and two provinces of China, which all together have been cultivating more than 127 crop types on about 487 million hectares per year over the period 2002-2013. These lands account for 87.43 per cent of the total arable and permanent cropland of all the countries covered in the study. Land cultivated with cereals covers the largest area (59.06 per cent) of the 487 million hectares, followed by oil crops with 18.22 per cent and pulses accounting for 6.7 per cent. The other crop categories all together cover the remaining 16.03 per cent of the cultivated land

Our study shows an increasing trend of agricultural land degradation. Total soil NPK nutrient balance was -46.27 million tons in 2002 and it reached -61.17 million tons in 2013 at Asia level, indicating an increasing soil NPK depletion over the indicated period. The average annual soil NPK nutrient balance for Asia during the study period was -60.42 million tons indicating an annual depletion of 52.34 million tons of NPK from soil nutrient reserves of arable and permanent croplands of the region.

There was also a substantial variation in the rate of nutrient depletion between countries. 31 countries[15] have negative soil NPK nutrient balances. In this group of countries the highest

[15] *Uzbekistan, Azerbaijan, Lao PDR, Turkey, Kyeargyzstan, Indonesia, Viet Nam, Myanmar, Cambodia, Bangladesh, China(mainland), Tajikistan, Kazakhstan, Iran, Armenia, Philippines, Syearian Arab Republic, Nepal, Bhutan, Thailand, Afghanistan, Iraq, Georgia, India, Sir Lanka, Timor-Leste, Yemen, Israel, Pakistan, Lebanon, Malaysia.*

[16] *Singapore, Qatar, China(Hong Kong), Kuwait, Brunei Darussalam, Jordan, Mongolia, China(Taiwan), Oman, United Arab Emirates, Japan, Republic of Korea, Cyprus, Saudi Arabia.*

depletion rate was 198.6 kg/ha/year in Uzbekistan and the lowest was 6.3 kg/ha/year in Malaysia.

The remaining 13 countries[16] and the two provinces of China showed surplus in NPK soil balances.

Total NPK loss on the other hand increased from 59.8 million tons in the year 2002 to 72.74 million tons in 2013 and the annual NPK nutrient losses for the region was 67.69 million tons for the study period and this accounts for close to 39 per cent of the total nutrient input or output. Mainland China, India, and Indonesia are the three countries with the highest total soil NPK nutrient depletion accounting for about 65.73 per cent of the total depletion in Asia in the year 2002 and 68.19 per cent in the year 2013. The three countries also account for about 75.54 per cent of the total NPK loss in Asia in 2002 and 74.16 per cent of the total NPK loss in 2013.

The econometric models of land degradation consistently indicate that the NPK loss as well as soil NPK depletion are significantly correlated with biophysical factors (top soil loss, forest cover, arable and permanent crop land area, meadow and pasture land area) and socioeconomic factors (GDP per capita, GDP, and Livestock population). This indicates that the models can be used for estimation and prediction of the level of soil nutrient depletion and total soil nutrient losses in the region using national level statistic on the indicated biophysical and socioeconomic factors, which is simpler than using the biophysical approach of auditing soil nutrient balance. Moreover, the econometric modelling approach allows policy analysis showing the correlation with socioeconomic and biophysical factors and relating nutrient losses and soil nutrient depletions in agriculture with other land uses (forest cover, pasture and meadow lands).

The econometric models of aggregate crop yield consistently indicate that aggregate crop yield is negatively and significantly correlated with NPK loss as well as soil NPK depletion indicating that land degradation reduces productivity in agriculture in Asia.

Using the econometric models and based on plausible assumptions consistent with the concept of land degradation neutrality, results of this study indicated that the annual rate of top soil loss over the period 2002-2013 from agricultural lands in Asia was 11.91 tons per hectare. From the total harvested area of the 487 million hectares, the total estimated top soil loss amounts to 5.8 billion tons.

- The corresponding estimated topsoil loss induced NPK loss in the region amounts to 52.1 million tons or close to 77 per cent of the annual NPK losses in the region. The value of this supporting ecosystem service at a replacement cost price of commercial fertilizer amounts to about USD 34.1 billion.

- Top soil loss induced soil NPK depletion in the region amounts about 49.5 million tons or close to 94.6 per cent of the total soil NPK balance in the Asia. The replacement cost value of this total top soil loss induced soil NPK depletion amounts to about USD 30.1 billion.

- The total annual production loss due to top soil loss induced NPK loss amounts to about 16.7 million tons of crops with a total value of about USD 9.9 billion at the weighted average price of crops produced in the region. In other words, avoiding top soil loss induced NPK loss in agricultural lands of Asia would increase productivity by about 0.68 per cent per year.

- Whereas the total annual production loss due to top soil loss induced soil NPK depletion amounts to about 1.31 billion tons or close to 53 per cent of the annual total crop production in the region. The corresponding value of this annual loss at the weighted average crop prices amounts to close to USD 732.7 billion. This implies, that avoiding top soil induced soil NPK depletion in agricultural lands of Asia would increase the regional level productivity from the 5.07 to 7.76 tons per hectare per year.

Thus, Asian countries as well as regional and global stakeholders need to take action against top soil loss induced soil nutrient depletions and total nutrient losses that are aggravating agricultural land degradation in the region. This may require investment in SLM technologies on agricultural lands in Asia. To make such interventions, the first step is to assess the cost of investing in sutainable land management technologies. The next chapter will address this issue.

CHAPTER

03 Costs of Sustainable Land Management for Achieving Agricultural Land Degradation Neutrality in Asia

3.1. Introduction

In the previous chapter, we have seen the level and trends of top soil loss induced nutrient losses and soil nutrient depletions in agricultural ecosystems of Asian countries and the level of associated aggregate crop production losses due to land degradation. Avoiding land degradation therefore would enable Asian countries to increase agricultural productivity without going to the extensive margin that may otherwise require conversion of other land uses. Therefore, in order to increase agricultural productivity investing in sustainable land management technologies is important. The objective of this chapter is to develop a meta-transfer function for costs of SLM technologies using econometric methods and based on available data from the WOCAT database on establishment and maintenance costs of SLM technologies in Asia (WOCAT, n.d.a). The chapter also aims to estimate national level costs of SLM technologies for the countries and provinces covered in this study based on the econometric model to be developed.

The next sections of the chapter provide descriptions on the WOCAT database on costs of SLM technologies, available data for Asian countries, econometric methods used to develop regional level meta-transfer functions for establishment and maintenance costs of SLM technologies in Asia, and estimated national level cost for each country covered in the study.

3.2. WOCAT data on costs of SLM technologies in Asia

The WOCAT network encourages countries across the globe to fill-out a standard questionnaire that collects site-specific background biophysical and socioeconomic data on SLM technologies, and their perceived benefits and costs. Once the questionnaire for a specific SLM technology is reported, WOCAT organizes and publishes a brief summary of the technology. The main components of the information on specific SLM technologies compiled in the database includes background information on:

Land use problems that triggered the need for the SLM technology at the site: These include information on land use before degradation, climate, and kind of land degradation experienced prior to the SLM intervention. It also provides information on the SLM conservation measure that was implemented, the stage of the intervention (was the SLM intervention designed to prevent, mitigate or rehabilitate land degradation?), who initiated the intervention (was it the land users, experimenters or researchers or externally imposed?), and the level of technical knowledge required to implement the SLM intervention. Furthermore, it highlights the main causes of land degradation at the site, and main technical functions of the SLM intervention.

The natural environment: This background information at the SLM site include average annual rainfall, altitude (meters above sea level), land form (plateau, plains, ridges, mountain slopes, hill slopes, foot slopes, valley floors), slope (flat, gentle, moderate, rolling, hilly, steep, very steep), soil depth, soil texture and biodiversity.

The human environment: This background information at the SLM site include forestland or woodlands per household, population density, land ownership patterns, land use rights, relative level of household wealth, importance of off-farm income, access to services and infrastructure,

market orientation, and the goods and services provided by forests or woodlands at the site.

Establishment cost (USD/ha): quantity and capital costs of labour, equipment and construction materials initially used to setup (construct/build) the SLM technology.

Maintenance or recurrent costs (USD/ha/year): quantity and recurrent costs of labour, equipment and construction materials required to maintain functionality of the SLM intervention on annual basis.

Other: the questionnaire and the database also provide additional information that can be used to qualitatively assess the onsite and offsite costs and benefits of the SLM intervention: production and socioeconomic, socio-cultural, ecological, off-site contributions to human wellbeing and livelihoods, and the land user perceived benefits and costs, and the extent of acceptance/adoption of the technology.

The WOCAT database (WOCAT, n.d.a) also classifies the SLM technologies into four broad classes, which are also described and reported in (Giger, Liniger, & Schwilch, 2015b) as:

- **Agronomic measures:** measures that improve soil cover (e.g. green cover, mulch), measures that enhance organic matter/soil fertility (e.g. manuring), soil surface treatment (e.g. conservation tillage), sub-surface treatment (e.g. deep ripping).
- **Structural measures:** terraces (bench, forward/backward slopping), bunds, banks (level, graded), dams, pans, ditches (level, graded), walls, barriers and palisades.
- **Vegetative measures:** plantation/reseeding of tree and shrub species (e.g. live fences, tree crows), grasses and perennial herbaceous plants (e.g. grass strips).
- **Management measures:** change of land use types (e.g. area enclosure), change of management intensity level (e.g. from grazing to cut and carry), major change in timing of activities, and controlling/change of species composition.

In the database, a specific technology may also include a combination of two or more of the above measures, for the purpose of this study such a technology is termed as mixed SLM technology.

Until March 2017, the WOCAT database consists of about 830 SLM technologies, collected, documented, and assessed by the WOCAT network. The database covers SLM technologies from 79 countries and are classified into complete, incomplete, and draft based on the quality of information documented and assessed by the WOCAT network. Out of the total registered SLM technologies in the database, about 550 are classified as complete. Giger, Liniger, Sauter & Schwilch (2015a) used 363 of these SLM technologies of which 149 were from Asian countries and assessed what costs accrue to local stakeholders as well as the perceived short and long-term cost-benefit ratios. Giger and colleagues also argue that a wide range of the existing SLM practices generate considerable benefits not only for the land users but also for other stakeholders. High initial investment costs related with some of the technologies may constitute a barrier to the adoption by land users.

Table 3.1 summarizes the total number of SLM technologies from 19 Asian countries registered in the WOCAT database over the period 1997 to 2016. The databases contains a total of 240 SLM technologies of which 51 are agronomic measure, 73 structural measures, 54 vegetative/biological measures, 28 management measures, and 34 mixed types. Out of the 240 technologies, about 72 per cent of the technologies include information on per hectare level establishment cost and

TABLE 3.1

Distribution of SLM technologies in Asia registered in the WOCAT database until March 2017

Country	Year	Agronomic		Structural		Vegetative /Biological/		Management		Mixed		Total	
		Total	With Cost info	Total	With Cost info	Total	With Cost info	Total	With Cost info	Total	With Cost info	Total	With Cost info
Afghanistan	2011-2016	1	1	10	6	3	2					14	9
Bangladesh	2001-2013	3	1	1		1						5	1
China, mainland	1997-2011	3	1	9	4	5	1	1				18	6
Cyprus	2014-2015	1	1	2	2							3	3
India	2002-2007	1	1	12	11	2		1		1	1	17	13
Kazakhstan	2003-2013	3	3	1	1	5	5					9	9
Kyeargyzstan	2004-2013	5	5	1	1			1				7	6
Cambodia	2014	4	4	2	1	5	4	1	1			12	10
Nepal	2003-2013	8	5	5	1	8	6	11	2	3	2	35	17
Philippines	1999-2016	11	9	6	4	8	6	1	1	5	4	31	24
Tajikistan	2004-2014	8	7	15	13	13	11	10	5	20	18	66	54
Syearian Arab Republic	1999-2012	1	1	2	2	1	1			1	1	5	5
Turkmenistan	2011			1	1	2	2					3	3
Thailand	1997-2000			2	2	1	1					3	3
Turkey	2008-2011	2	2	2	2			1	1			5	5
Uzbekistan	2011							1		3	3	4	3
Yemen	2013			1	1							1	1
Indonesia	2003			1								1	
Viet Nam	2015									1		1	
Total	1997-2016	51	41	73	52	54	39	28	11	34	29	240	172

Source: Compiled from the WOCAT database about 55 per cent have information on the annual maintenance cost on per hectare level. Further details on the specific technologies with cost information reported from each country and the reported establishment and maintenance costs are available in *Table A6* to *A10*.

A descriptive analysis of the technologies with cost information shows that the establishment cost ranges from zero, for Sweet Potato Relay Cropping as an agronomic measure reported from the Philippines *(Table A6)* in which the technology only requires recurrent labour costs, to USD 182,413/ha for agricultural terraces with dry-stone walls as a structural measure reported from Cyprus *(Table A7)*.

The mean establishment cost for the 172 technologies was about USD 2,880/ha *(Table 3.2)*. The sum of the establishment costs of the 172 SLM technologies was USD 495,240, of which about 67 per cent was as labour cost and close to 33 per cent was costs of materials. However, first calculating the ration of labour cost to total establishment cost for each technology and then taking the mean of the calculated ratios indicated that on average the

TABLE 3.2

Summary statistics of Establishment Costs of SLM technologies Registered in WOCAT database

Country	Year	Number of Resisted SLM Techno.	Mean Total cost USD/ha	Standard error of the mean	Mean Labour cost USD/ha	Standard error of the mean	Mean Material cost USD/ha	Standard error of the mean
Afghanistan	2011-2016	9	1570.45	577.82	913.01	291.15	657.43	345.23
Bangladesh	2013	1	600.00		600.00			
China, mainland	2001-2011	6	2900.88	1064.37	1751.50	954.60	1149.33	683.80
Cyprus	2014-2015	3	62646.00	59888.72	60931.33	60740.85	1714.67	1195.85
India	2002-2007	13	681.55	269.37	469.15	206.67	212.39	83.17
Kazakhstan	2003-2013	9	250.56	76.12	111.16	70.19	139.40	31.85
Kyeargyzstan	2004-2011	6	346.48	123.83	87.52	55.31	258.97	73.69
Cambodia	2014	10	379.18	257.60	14.38	5.79	364.80	259.31
Nepal	2003-2013	17	1089.07	393.71	408.32	132.87	680.75	334.69
Philippines	1999-2016	24	4430.13	3898.54	1849.06	1618.86	2602.31	2283.27
Tajikistan	2004-2012	54	1279.76	227.86	492.80	105.18	832.65	157.73
Syearian Arab Republic	1999-2012	5	1008.00	373.20	446.60	242.56	545.40	261.87
Turkmenistan	2011	3	2014.33	486.34	831.00	419.73	1216.67	65.24
Thailand	1997-2000	3	114.91	81.97	109.44	81.55	5.47	3.30
Turkey	2008-2011	5	917.60	380.87	224.33	164.34	783.00	349.72
Uzbekistan	2011	3	1895.94	830.76	107.50	54.73	1788.44	791.44
Yemen	2013	1	42530.00		42430.00		100.00	
Total	1997-2016	172	2879.31	1209.66	2023.24	1154.21	941.51	325.84

Note: Detail description of the specific technologies including the costs are available in Appendix Table A6-A10
Source: Compiled from the WOCAT database

TABLE 3.3

Summary statistics of Annual maintenance Costs of SLM technologies Registered in WOCAT database

Country	Year	Number of Resisted SLM Technologies	Mean Total cost USD/ha	Standard error of the mean	Mean Labour cost USD/ha	Standard error of the mean	Mean Material cost USD/ha	Standard error of the mean
Afghanistan	2014-2016	2.00	58.50	23.50	32.50	2.50	26.00	26.00
Bangladesh	2013	1.00	100.00		100.00			
China, mainland	2001-2011	6.00	172.82	57.32	131.98	41.61	40.83	38.27
Cyprus	2014-2015	2.00	1242.07	582.07	1028.57	795.57	213.50	213.50
India	2002-2006	8.00	30.68	14.32	18.66	7.13	12.01	8.96
Kazakhstan	2003-2012	5.00	60.15	22.07	41.39	17.28	18.76	6.47
Kyeargyzstan	2004-2011	6.00	69.97	25.93	25.42	5.90	44.55	25.50
Cambodia	2014	10.00	538.98	394.56	439.90	314.09	99.08	82.07
Nepal	2003-2013	9.00	267.00	132.75	127.11	49.94	139.89	90.08
Philippines	1999-2016	19.00	234.07	72.59	146.07	48.81	81.26	29.44
Tajikistan	2004-2012	46.00	501.89	138.28	451.97	137.42	51.02	15.96
Syearian Arab Republic	1999-2012	4.00	54.00	22.30	26.50	9.58	27.50	25.86
Turkmenistan	2011	3.00	174.00	24.68	130.33	20.50	43.67	43.67
Thailand	1997-2000	3.00	53.04	25.42	38.04	17.80	15.00	15.00
Turkey	2008-2011	4.00	417.75	265.79	136.25	56.10	281.50	210.83
Uzbekistan	2011	3.00	1321.35	542.72	1090.75	452.76	230.60	109.83
Yemen	2013	1.00	236.00		236.00			
Total	1997-2016	132.00	355.84	63.21	282.55	58.37	71.49	13.81

Note: Detail description of the specific technologies including the costs are available in Appendix Table A6-A10
Source: Compiled from the WOCAT database

labour cost for a specific SLM technology accounts for about 44.41 per cent of its total establishment cost per hectare. Of the total 172 SLM technologies for which data of establishment cost is reported in the WOCAT database, only 130 of the technologies have corresponding data on annual maintenance costs.

The descriptive result of the annual maintenance cost of 132 SLM technologies reported from 17 Asian countries shows that the costs vary from USD 3/ha in the case of living cashew fences reported from Cambodia as a vegetative measure *(Table A6)* to USD 4,625.5/ha reported from Tajikistan for mixed technology *(Table A10)*. The mean annual establishment cost for the pooled data was about USD 356/ha *(Table 3.3)*. First calculating the ratio of labour cost to total maintenance cost for each technology and then taking the mean of the calculated ratios indicated that on average the labour cost for a specific SLM technology accounts for about 75.68 per cent of its total annual maintenance cost per hectare.

3.3. Econometric approach for estimating meta-analytical transfer function of the cost of SLM technologies

The WOCAT database provides important quantitative information on observed establishment and maintenance costs of the different measures of SLM technologies. However, it is not possible to apply theses observed costs directly for the purpose of this study for at least the following reasons, which need to be addressed.

National Representativeness: The cost information for each technology reported from each country are site specific and it is important to relate theses site specific information to national level socioeconomic data through modelling.

Variation in time. The WOCAT data on cost information of the different SLM technologies is based on case studies conducted in different countries between 1990 and 2016. The data from the 19 Asian countries in *Table 3.1* for example, contains such case studies conducted between 1997 and 2016. The value of a currency unit – USD or any other currency – changes over time due to the economic changes that have been taking place at national, regional, and global scales. Therefore, a cost of specific SLM technology in 1997 may not remain the same as time changes. Therefore, adjustment of the costs reported is required to reflect the current situation.

Missing data problem: The WOCAT database on SLM technologies does not yet cover all countries. Until March 2016, the database contains case studies reported from 79 countries. In the case of Asia, only from 19 countries. Therefore, for this study that aims to cover up to 44 Asian countries and two provinces of China it is important to develop a meta-analytical transfer function using econometric modelling approaches.

In order to address the above issues, we developed variants of econometric models for the establishment and maintenance costs of the SLM technologies based on the following hypotheses that are guided by economic theory. First, we hypothesized that costs of SLM are negatively correlated with the size of national level human population and agricultural land area. We expected that wages and material costs in countries with relatively large population size are likely to be cheaper than in countries with smaller population sizes. In addition, we anticipated that costs of SLM are smaller in countries with relatively abundant agricultural lands than in countries with scarce agricultural land.

Contrarily, we hypothesized that cost of SLM technologies is positively correlated with national agricultural output and national income. We anticipated that costs of SLM are relatively high in countries where agricultural production and national income per capita are high relative to countries with lower levels of agricultural output and national income per capita. In addition, we hypothesized that sub-regional unobserved factors and the variations in the time that the cost information are reported might have correlation with the reported costs of the SLM technologies. Furthermore, costs may also depend by the type of measures of the SLM technologies.

Based on the above hypotheses, we developed variants of econometric models for the establishment and maintenance costs of SLM technologies based on the data in Appendices A6-A10 and national level data for the hypothesized explanatory variables from FAOSTAT and World Bank databases. The relationship between costs of the SLM technologies and the hypothesized national level explanatory variables can be specified as in equation 3.1 below:

$$C_{it}=\beta_0+\beta_1 P_{it}+\beta_2 L_{it}+\beta_3 Ap_{it}+\beta_4 I_{ji}+\beta_5 T_{il}+\beta_6 R_{ik}+\varepsilon_{it}$$

Where:

C_{it} = refers either the establishment or maintenance cost of a specific SLM technology measure in the WOCAT database reported by country i (i = 1, 2, ..., 19) at time t (t = 1997, 1999, ...,2016)

P_{it} is the total number of population in country i at time t

L_{it} is agricultural land area in 1000s ha in country i at time t

Ap_{it} is the agricultural production index for country i at time t

$\mathbf{I_{it}}$ is the per capita GDP of country I at time t

$\mathbf{T_{ik}}$ refers to the time invariant dummy to control for effect of variation in measures of the SLM technologies and assumes 1 if k is mixed SLM technology and 0 otherwise; where k = 1, 2, ..., 5 representing the agronomic, structural, biological, management, and mixed SLM technologies reported by country i.

$\mathbf{R_{ij}}$ is the time invariant dummy used to control for unobservable sub-regional variations and assumes 1 if country i is geographically located in sub-region j or 0 otherwise; where j= 1,2,...,5 representing the 5 sub-regions(Central Asia, South Asia, South East Asia, East Asia, and West Asia.

Based on the above specification in Equation 3.1, we modeled specification tests for variants of econometric models (i.e., Ordinary Least Squares (OLS), Ordinary least squares with robust standard errors, Generalized Least Squares (GLS), Fixed Effect and Random Effect) for each of the establishment and maintenance costs and the model types range from simple OLS to random effect regression models. The results for the establishment cost models are presented in *Table 3.4* and model results for the maintenance cost are presented in *Table 3.5*. The results in all the 5 different types of econometric models consistently indicate that the establishment cost is significantly correlated with agricultural land area whereas maintenance cost is consistently correlated with agricultural land area and GDP per capita at $p < 10$ per cent significance level. Moreover, at significance levels between 1 and 10 per cent, sub-regional fixed effects affect only establishment cost whereas the dummy for the technology type affects only maintenance costs.

We reported results of the OLS model with robust standard errors, the fixed and random effect models. Our data set consists of a panel of establishment and maintenance costs information for the period 1997 to 2016. As a result, panel data econometric model specification that controls effects of each individual years in the panel is appropriate. In a panel model, the individual effect terms can be modelled as either random or fixed effects. If the individual effects are correlated with the other explanatory variables in the model, the fixed effect model is consistent and the random effects model is inconsistent. On the other hand, if the individual effects are not correlated with the other national level explanatory variables in the model, both random and fixed effects are consistent and random effects are efficient. The Haussmann test statistics in both establishment and maintenance cost models (*Tables 3.4* and *3.5*) are not significant indicating that the random effect model is efficient. We further dropped insignificant variables from the random effect model and run Haussmann specification test for the fixed and random effect models with only significant national level explanatory variables. This consistently provided that the restricted random effect model is efficient for estimating both the establishment and maintenance costs.

The coefficient for agricultural land area in both the restricted random effect models for establishment and maintenance costs indicate that agricultural land area is negatively correlated to both establishment and maintenance costs and the correlations are statistically significant at 5 per cent level of significance. The direction of the effect is consistent with our hypothesis that countries with relatively larger agricultural land area are likely to have relatively cheaper costs of both establishment and maintenance costs of SLM technologies per hectare of land. Since in both models the dependent variables and agricultural land area are in log forms, the coefficients for agricultural land area in 1000s can be interpreted as follows. Each one unit increase in the log-transformed agricultural land area in 1000s hectares reduces log-transformed cost of establishment cost per hectare by 0.243 whereas the log-transformed cost of maintenance cost by 0.242 units respectively. In percentage terms, a 1 per cent increase in the agricultural land area in 1000s of hectare reduces establishment cost per hectare by 0.105 per cent and maintenancecost per hectare by the same 0.105 per cent.

The coefficient for log-transformed GDP per capita in both the restricted random effect models for establishment and maintenance costs indicate that GDP per capita is positively correlated to both establishment and maintenance costs and the correlations are statistically significant at 1 per cent level of significance. The direction of the effect is

TABLE 3.4

Models for Establishment Cost of SLM Technologies (log-transformed)

Factor variables	OLS2 (robust SE)	Fixed Effect	Random Effect full	Random Effect restricted
Human population in 1000s (log-transformed)	0.125 (0.211) [0.590]	0.292 (0.334) [0.870]	0.230 (0.294) [0.780]	
Agricultural land area in 1000s of ha (log-transformed)	-0.451 (0.206) [-2.190][b]	-0.463 (0.238) [-1.940][c]	-0.482 (0.217) [-2.230][b]	-0.243 (0.115) [-2.120][b]
Agricultural production index (log-transformed)	-0.559 (1.038) [-0.540]	-2.117 (2.021) [-1.050]	-1.086 (1.271) [-0.850]	
GDP in USD per capita (log-transformed)	0.497 (0.268) [1.850][c]	0.230 (0.349) [0.660]	0.348 (0.275) [1.260]	0.395 (0.193) [20.400][b]
SLM technology dummy, 1 = at least two or more SLM technology types, 0 = One type SLM technology	0.784 (0.366) [2.140][b]	0.620 (0.401) [1.550][d]	0.622 (0.380) [1.640][d]	
Region 1 (1 = Central Asia, 0 = otherwise)	(omitted)	(omitted)	-0.335 (0.840) [-0.400]	
Region 2 (1 = East Asia, 0 = otherwise)	0.651 (0.631) [1.030]	0.007 (1.169) [0.010]	-0.068 (0.912) [-0.080]	
Region 3 (1 = Southern Asia, 0 = otherwise)	1.881 (0.940) [2.000][b]	1.406 (1.551) [0.910]	1.243 (1.158) [1.070]	
Region 4 (1 = South East Asia, 0 = otherwise)	-1.136 (0.577) [-1.970][c]	-1.273 (1.204) [-1.060]	-1.595 (0.802) [-1.990][b]	-1.562 (0.476) [-3.280][a]
Region 5 (1 = West Asia, 0 = otherwise)	0.385 (1.049) [0.370]	0.273 (0.935) [0.290]	(omitted)	
Constant	8.156 (5.376) [1.520][d]	16.082 (10.207) [1.580][d]	11.463 (6.480) [1.770][c]	6.263 (1.451) [4.310][a]
N	130	129	129	129
F (df, N)	3.390[a]	2.710[a]		
R2	0.211	0.161	0.201	0.120
Adj. R2				
Root MSE	1.657			
Mean VIF	3.070			
No. of groups (Year as group variable)		18	18	18
Wald chi2			27.620[a]	15.420[a]
Log_L				
R2 within		0.193	0.191	0.114
R2 between		0.096	0.157	0.089
corr (u_i, Xb)		-0.161		
F test u_i=0, F(df, N)		2.100[b]		
Hausman Test (Chi2)			0.580	0.730
Prob Chi2			0.999	0.867

Values in () are standard errors, Values in [] are t-statics for the OLS and fixed effect models and z-statistics for the other models.
Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.

TABLE 3.5

Models for Annual Maintenance Cost of SLM Technologies (log-transformed)

Factor variables	OLS2 (robust SE)	Fixed Effect	Random Effect full	Random Effect restricted
Human population in 1000s (log-transformed)	-0.035 (0.212) [-0.170]	-0.046 (0.336) [-0.140]	-0.003 (0.264) [-0.010]	
Agricultural land area in 1000s of ha (log-transformed)	-0.342 (0.165) [-2.080][b]	-0.337 (0.239) [-1.410]	-0.351 (0.204) [-1.720][c]	-0.242 (0.106) [-2.270][b]
Agricultural production index (log-transformed)	0.708 (0.763) [0.930]	1.568 (2.038) [0.770]	0.950 (0.918) [1.030]	
GDP in USD per capita (log-transformed)	0.556 (0.165) [3.370][a]	0.662 (0.352) [1.880][c]	0.585 (0.242) [2.420][b]	0.486 (0.178) [2.730][a]
SLM technology dummy, 1 = at least two or more SLM technology types, 0 = One type SLM technology	1.361 (0.387) [3.520][a]	1.406 (0.402) [3.500][a]	1.414 (0.378) [3.740][a]	1.388 (0.363) [3.820][a]
Region 1 (1 = Central Asia, 0 = otherwise)	-1.374 (0.968) [-1.420]	(omitted)	-0.039 (0.767) [-0.050]	
Region 2 (1 = East Asia, 0 = otherwise)	-0.946 (0.698) [-1.360]	0.941 (1.174) [0.800]	0.352 (0.867) [0.410]	
Region 3 (1 = Southern Asia, 0 = otherwise)	(omitted)	1.646 (1.561) [1.050]	1.219 (1.110) [1.100]	
Region 4 (1 = South East Asia, 0 = otherwise)	-1.521 (0.658) [-2.310][b]	-0.128 (1.213) [-0.110]	-0.366 (0.721) [-0.510]	
Region 5 (1 = West Asia, 0 = otherwise)	-1.273 (0.850) [-1.500][d]	0.239 (0.942) [0.250]	(omitted)	
Constant	1.795 (4.216) [0.430]	-4.466 (10.302) [-0.430]	-0.976 (4.908) [-0.200]	3.147 (1.383) [2.280][b]
N	132	131	131	131
F (df, N)	7.030[a]	2.360[b]		
R2	0.213	0.209	0.222	0.191
Adj. R2				
Root MSE	1.580			
Mean VIF	5.43			
No. of groups (Year as group variable)		18	18	18
Wald chi2			29.070[a]	24.320[a]
Log_L				
R2 within		0.170	0.165	0.135
R2 between		0.255	0.324	0.251
corr (u_i, Xb)		-0.138		
F test u_i=0, F (df, N)		1.150		
Hausman Test (Chi2)			0.880	1.720
Prob Chi2			0.999	0.632

Values in () are standard errors, Values in [] are t-statics for the OLS and fixed effect models and z-statistics for the other models.
Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %. † Convergence not achieved.

consistent with our hypothesis that countries with relatively larger per capita income are likely to have relatively expensive costs of both establishment and maintenance costs of SLM technologies per hectare of land. Since in both models the dependent variables and GDP per capita are in log forms, the coefficients for agricultural GDP per capita can be interpreted as follows. Each one-unit increase in the log-transformed GDP per capita increases log-transformed cost of establishment cost per hectare by 0.395 and the log-transformed cost of maintenance cost by 0.486 units respectively. In percentage terms, a 1 per cent increase in the GDP per capita increases establishment per hectare by 0.171 per cent and maintenance cost per hectare by the same 0.21 per cent.

The coefficient for dummy of Region 4 (Southeast Asia) in the restricted random effect model for establishment cost is negatively correlated to log-transformed establishment cost per hectare and the correlation is significant at 1 per cent level of significance. We had no prior expectation on the direction of the effect but the result implies that establishment cost in South East Asian countries are relatively lower than countries in the other regions of Asia. Since the dependent variable is in log form and the regional dummy is linear, the coefficients for Region 4 can be interpreted as follows. For each one-unit increase in dummy for Region 4 from 0 to 1, which in other words mean the given other factors remain constant, the log-transformed establishment cost for a country located in South Asia is lower by -1.562 units than any other country in other regions of Asia. In percentage terms, the establishment cost in a country in Southeast Asia is by 79.03 per cent lower than the establishment cost per hectare for a country in other regions of Asia.

The coefficient for dummy for the type of SLM technology in the restricted random effect model for the maintenance cost is positively correlated to log-transformed maintenance cost per hectare and the correlation is significant at 1 per cent level of significance. We had no prior expectation on the direction of the effect but the result implies that establishment costs for mixed SLM technologies are relatively higher than specific SLM technologies. Since the dependent variable is in log form and the dummy for SLM technology is linear, the coefficients for SLM technology can be interpreted as follows. For each one-unit increase in the dummy from 0 to 1, which in other words mean the given other factors remain constant, a change from using a single type of SLM technology (say agronomic) to a mixed SLM technology increases the log-transformed maintenance cost by 1.388 units. In percentage terms, the maintenance cost per hectare for mixed SLM technologies is about 300 per cent higher than maintenance cost per hectare of any of the other specific SLM technologies.

Finally, we used theses restricted models as meta-transfer function and estimated the national level establishment and maintenance costs of SLM technologies for 44 Asian countries and two provinces of China for the year 2013 using the national level data on agricultural land area and GDP per capita for the 2013. Results are presented in *Table 3.6* below.

Table 3.6 shows the estimated maintenance and establishment costs of SLM technologies for 44 Asian countries and two provinces of China based on the restricted random effect models in *Table 3.4*

TABLE 3.6

Establishment and maintenance costs of SLM technologies (2013 Prices)

Country/Region	Establishment cost of SLM in USD/ha	Annual Maintenance cost of SLM in USD/ha
Afghanistan	424.16	132.58
Armenia	1852.55	678.84
Azerbaijan	1686.21	648.19
Bahrain	15314.92	6705.49
Bangladesh	735.74	239.98
Bhutan	2138.18	757.00
Brunei Darussalam	3538.39	7710.62
Cambodia	176.77	275.08
China Hong Kong SAR	20152.39	9204.98
China, mainland	529.09	203.27
Cyprus	8887.39	4016.71
Georgia	1662.80	610.87
India	420.64	143.31
Indonesia	158.44	275.39
Iran	1030.09	401.48
Iraq	1536.43	592.92
Israel	6391.27	2902.16
Japan	4342.58	2043.73
Jordan	2372.59	891.78
Kazakhstan	865.21	352.06
Republic of Korea	4216.33	1869.70
Kuwait	9725.64	4532.38
Kyrgyzstan	744.91	246.27
Lao PDR	245.16	391.32
Lebanon	3548.26	1423.67
Malaysia	423.00	819.07
Mongolia	611.07	222.90
Myanmar	135.37	209.37
Nepal	774.42	244.29
Oman	4016.88	1738.14
Pakistan	605.99	204.39
Philippines	214.56	365.47
Qatar	14843.06	7268.50
Saudi Arabia	1275.70	559.58
Singapore	7566.95	16778.04
Sri Lanka	1568.58	567.23
Syrian Arab Republic	926.03	325.28
*Taiwan Province of China	3093.01	1864.32
Tajikistan	813.05	262.18
Thailand	258.81	474.98
Timor-Leste	353.14	552.86
Turkey	1371.17	561.67
United Arab Emirates	7568.79	3550.36
Uzbekistan	673.35	229.97
Viet Nam	182.99	298.75
Yemen	701.78	238.98
Central Asia	777.54	227.31
East Asia	6029.58	1567.43
South East Asia	591.07	1217.87
Southern Asia	2210.92	322.39
West Asia	6307.79	3719.77
ASIA	3675.79	1980.76

**The regional average is taken for the country because of lack of data for model variables used for estimation.*

and *3.5* and input data on the explanatory variables (Agricultural land area in 1000 ha and GDP per capita) from FAO and World Bank database for each of the 44 Asian countries and two provinces of China except for Taiwan Province of China. In the previous chapter, we used 2013 prices for valuation of top soil loss induced nutrient losses, and nutrient depletions and associated losses in crop production. Therefore, it is consistent with the used agricultural land area and GDP per capita of 2013 for estimating establishment and maintenance costs in 2013 prices. Accordingly, the estimated establishment costs in 2013 prices range from USD 135.37/ha in Myanmar to USD 20,152.39 in China Hong Kong SAR. The average establishment cost is USD 3,675.79/ha. Sub-regional level aggregation of estimated results indicate the average in South East Asia is the lowest (USD 591.07/ha) whereas the average East Asia is highest (USD 6,029.58/ha). In the case of annual maintenance cost per hectare, estimated results ranges from 132.58 USD/ha in Afghanistan to USD 167,78.04/ha in Singapore. The mean annual maintenance cost is USD 1,980.76/ha. Sub-region wise comparison of annual maintenance costs indicates the mean for Central Asia is the lowest (USD 227.31/ha) whereas West Asia (USD 3,719.77/ha) is the highest.

3.4. Conclusions

The results of this chapter indicate that the R^2 values for the restricted establishment cost and maintenance cost models are 0.12 and 0.19 respectively indicating that the variations in the explanatory variables could only explain 12 and 19 per cent of the variations in the log-transformed establishment cost per hectare and log-transformed maintenance cost per hectare. This is partly because of the fact that the data points and number of countries that reported such cost information in the WOCAT database are relatively small. As sample size (data points) increases, it is likely that the explanatory power of the models will also improve. In the future, as more data from more countries is available in the WOCAT database it is possible to update and improve the models by including more data points. Despite this, the coefficients of the explanatory variables are both consistent and efficient as indicated by the Haussmann specification test statistics. Moreover, the models require relatively few variables (particularly two variables: agricultural land area and GDP per capita, which are available from FAO and World Bank databases) as input data for estimation purposes.

Thus, the estimated national level establishment and maintenance costs of SLM technologies could be used as an important input in further cost-benefit analysis of possible actions for avoiding land degradation and the associated losses of provisioning ecosystem services of agricultural ecosystems in Asia.

CHAPTER

04

Cost Benefit Analysis and Benefit-Cost Ratios of Achieving Agricultural Land Degradation Neutrality in Asia

4.1. Introduction

The analyses in the previous chapters provide the insights on the extent of top soil erosion induced NPK loss and soil NPK depletion in agricultural lands and the associated crop production losses that 44 Asian countries and two provinces of China have been experiencing over the last decade. Moreover, we have also seen in *Chapter 3* the national average of initial and maintenance costs of SLM technologies. Based on the results of the previous chapters, the objective of this chapter is to make a cost benefit analysis of avoiding top soil loss and the associated NPK loss and soil NPK depletion through investing in SLM technologies. The chapter specifically aims to assess what will be happening in the future:

- How much will it cost each country, sub-region, and Asia as a whole to avoid top soil induced NPK loss and soil NPK depletion in the next 13 years (2018-2030);
- How much are the present values of the benefits of avoiding top soil loss induced NPK loss and soil NPK depletion; and,
- Compare the benefits and costs of avoiding top soil loss induced NPK loss and soil NPK depletion at country, sub-regional, and Asia level.

Thus, the next section of the chapter discusses how the net present value and benefit cost ratios are calculated. The section also provides the assumptions on the flows of future benefits and costs. We also present the results of the cost benefit analysis followed by the results of the sensitivity analysis and a summary.

4.2. The net present value and benefit cost ratio

We applied the net present value (NPV) as a main decision criterion to evaluate the economic profitability of avoiding top soil induced NPK loss and soil NPK depletion in agricultural lands of Asia. NPV sums up the discounted annual flows of net benefits, which in turn is the difference of discounted benefits and discounted costs of avoiding top soil loss induced NPK losses and soil NPK depletions, over the life of the project. The NPV of a project is the amount by which it increases net worth in present value terms. Therefore, the decision rule is to accept a project, in this case a SLM project aimed at avoiding top soil loss induced NPK losses and soil NPK depletions in agricultural lands, with non-negative NPV and reject otherwise:

$$NPV_i = \sum_{t=1}^{T} \left[(B_{it} - C_{it})(1 + r_i)^{-1} \right]$$

Where:

NPV_i is Net Present Value (in USD) of avoiding top soil loss induced NPK losses and soil NPK depletion in agricultural lands for country i

B_{it} is benefit (in USD) of avoiding top soil loss induced NPK loss and soil NPK depletion in agricultural lands of country i at time t,

C_{it} is the cost (in USD) of avoiding top soil loss induced NPK loss and soil NPK depletion in agricultural lands for country i at time t,

r is real discount rate in country i

t is time in years (t = 1, 2, ...T) where t=1 in year 2018, t=2 in year 2019, ..., and T= 13 in year 2030

i is a subscript for country and/or province

Calculating NPV requires decision on three important parameters that may necessitate making some plausible and policy relevant assumptions. These are the discounting period, the flows of costs and benefits over the discount period, and the discount rate.

Discounting period: The first is to determine a reasonable period over which countries make proper planning, implantation, and monitoring and evaluation of investments in SLM technologies on agricultural lands that could enable to avoid top soil loss induced NPK loss and soil NPK depletion. In the determination of the discount period, taking national and global scale development goals and the time set to achieve such goals into consideration is an important factor so that the results of the study can be integrated into national, regional, and global development goals. In this regard, we have selected a period of 13 years (2018 to 2030), which is also a period for which the world has already launched the post-2015 Sustainable Development Goals (UN, 2017a) after taking lessons from the last 15 years of efforts for achieving the Millennium Development Goals.

Flow of costs and benefits: Once the project period is determined, the next step is to estimate the flows of costs and benefits for each year of the discounting period. The following plausible assumptions were made in determining the flows of costs and benefits. The basic assumptions for determining flows of costs and benefits are given in *Box 7*.

Rate of discount: In the evaluation of public projects in the framework of cost-benefit analysis, the choice of discount rate has been a focus of

BOX 7

Assumptions on the flows of costs and benefits

In addition to the assumptions 1-6 in Box 5 of the previous chapter and the results of the estimations in Chapter 2.7, we assumed the following in deriving the flows of benefits and costs interventions for avoiding top soil loss and the associated losses of supporting and provisioning services of Agricultural lands in Asia.

1. We assumed that each country would establish sustainable land management structures on 10% of the cropland area (see column 1 of Table 2.8 for the land area) and all the croplands will have these top soil loss controlling structures by the end of the first 10 years.
2. The per hectare investment costs for establishment and annual maintenance of sustainable land management structures/technologies are based on the results in Chapter 3 (Table 3.6). In addition to these costs, we take into account additional operational costs amounting to 25 per centof the sum of these investment costs for planning and implementation and another 15 per cent of the investment costs for monitoring and evaluations. The planning and implementation costs are for each year over the project period whereas the monitoring and evaluation costs are in 2020, 2025, and 2030.
3. We assumed that maintenance costs start from the 2nd year on wards.
4. In the case of flows of benefits of avoiding top soil loss induced NPK losses and soil NPK depletions of action, we assumed zero benefits at t = 1, and benefits start to flow from 2nd year onwards in terms of avoided NPK losses, avoided soil NPK depletions, and avoided crop production losses or in other words increasing productivity. These benefits are based on results in Chapter 2 (Tables 2.7, 2.8 and 2.9)
5. Sustainable land management technologies vary in their effectiveness in reducing soil erosion owing to different factors. Bench-terraces for example are reported to have more than 75 per cent effectiveness in reducing soil erosion . In this study, considering avoiding degradation as the highest priority in the LDN concept, we assumed avoiding top soil loss to the maximum possible (100 per cent reduction in top soil loss). Moreover, results in Chapter 2 show that avoiding top soil loss would result in reducing top soil loss induced NPK loss by 77 per cent of the total annual NPK losses and 95 per cent of the total soil NPK depletions estimated for each country and regions.

continuous debate in the economics literature. The two schools of thought in this regard are representing the descriptive and prescriptive approaches to choosing the social discount rate (Arrow et al., 1995). The descriptive approach relates social discount rates to financial market interest rates (Baum, 2009) and argues for a positive rate of discount based on the logic that consumers have positive time preference and they require an incentive, in the form of payment of interest, to save and hence postpone consumption. Based on the notion of consumer sovereignty and considering society as the summation of individual consumers, this school argues that positive social discount rate reflecting society's positive time preference should be applied in making intertemporal choices (Perman et al., 2011). The prescriptive school argues that society should not adopt the preferences of individuals and hence the market rate of interest suggests the use of prescribed discount rates derived from fundamental ethical views. Such a view for example has to consider the issue of intergenerational equity in the analysis of projects and societal issues with long-term effects, for example, climate change (Dasgupta, 2008; Perman et al., 2011; Ramsey, 1928; Stern, 2008).

In a perfectly competitive market where there is efficiency and optimal allocation of resources, the market interest rate is considered as the appropriate social discount rate. However, in the real world where markets are imperfect, there are four alternatives in the choice of social discount rate. These include the social rate of time preference (SRTP), marginal social opportunity cost of capital, the weighted average of the two, and the shadow price of capital. The SRTP is the rate at which a society is willing to postpone a unit of current consumption in exchange for higher consumption in future. Proponents of the use of SRTP as a social discount rate argue that public projects displace current consumption, and flows of costs and benefits to be discounted are flows of consumption goods either postponed or gained (Diamond, 1968; Kay, 1972; Marglin, 1963; Sen, 1961). The SRTP is mostly approximated by after tax rate of return on government bonds. The second alternative is the marginal social opportunity cost of capital, which is based on the notion of resource scarcity. Proponents of this alternative (e.g., Diamond & Mirrlees, 1971) argue that because public and the private sector compete for the same pool of funds and hence public investment crowds out private investment, and public sector investment should yield at least the same return as the private investment. Otherwise, social welfare could be better increased by reallocation of resources to the private sector, which gives higher returns. Real pretax rate of return on top-rated corporate bonds is considered as good proxy of the marginal social opportunity cost of capital (Moore, Boardman, Vining, Weimer, & Greenberg, 2004).The third alternative is taking the weighted average of the SRTP and marginal social opportunity cost, however this approach suffers from lack of clear rule on how to set the weights. The fourth alternative is the shadow price of capital, based on the contributions by Feldstein (1972), Bradford (1975), and Lind (1982) among others. This method tries to reconcile the other three alternatives. Further details on this and all the alternative approaches can be found in the review of (Zhuang, Liang, Lin, & Guzman, 2007).

The above review indicate that there is no a one-fit-for all method or way of choosing the discount rate. Therefore, for our analysis we used real interest rate of each country for discounting as reported in the World Bank Database. We were able to get data on the real interest rates for the period 1990-2015 for 36 countries and China Hong Kong SAR out of the 44 countries and two provinces of China from the World Bank Database. Some countries have complete data for the indicated period and others do not. We took the geometric mean of the available data for each country to determine the real interest rate for a country. For countries with no data, we took the arithmetic mean of the real interest rates of the 36 countries and China Hong Kong SAR.

Benefit cost ratios and annuity: As a second decision criterion, we also calculated the benefit cost ratio. Moreover, for each country the annuity values of the PV of costs, PV of benefits, and NPV were calculated and compared with the average GDP and agricultural GDPs of the respective countries. All values in USD are based on 2013 prices.

Sensitivity analysis: We conducted sensitivity analysis to observe the sensitivity of NPVs and BCR to changes in important parameters used in the cost benefit analysis. These include changes in the discount rates, weighted average prices of crops, capital and maintenance costs of SLM technologies, and their effectiveness in controlling top soil loss.

4.3. Present values of costs of achieving agricultural LDN in Asia

Regional and sub regional level PV of costs: *Table 4.1* shows the present value total cost of avoiding top soil loss through investments in the next 13 years (2018-2030) on SLM technologies on agricultural lands of each country. The present value of the total costs of investing in SLM technologies on a total of 486.7 million hectares of agricultural land in the region is estimated at about USD 1,214 billion or USD 2,494 /ha. The share of establishment cost of SLM technologies accounts for close to 18.8 per cent of the PV of the total cost whereas the PV of maintenance costs of the established structures account for close to 57.8 per cent of the PV of the total cost. The PV of the planning and implementation costs account for close to 20.5 per cent whereas PV of monitoring and evaluation account for the remaining 2.9 per cent of the PV of the total cost. The share of these different cost components to PV total cost vary across regions and between countries.

The present value of the total cost of investing in SLM technologies on the 218.3 million hectares of agricultural land in Southern Asia is estimated at about USD 390.83 billion or USD 1,790/ha. These cost accounts for close to 32.2 per cent of the PV of total cost for Asia. In southern Asia, the share of establishment cost of SLM technologies accounts for close to 22.8 per cent of the PV of the total cost whereas the PV of maintenance costs of the established structures account for 53.6 per cent of the PV of the total cost. The PV of the planning and implementation costs for the region accounts for 20.69 per cent whereas PV of monitoring and evaluation account for the remaining 2.96 per cent.

The present value of the total cost of investing in SLM technologies on the 128.3 million hectares of agricultural land in East Asia is estimated at about USD 383 billion or USD 2,984 /ha. These costs account for close to 31.6 per cent of the PV of total cost for Asia. In East Asia, the share of establishment cost of SLM technologies is close to 20.2 per cent of the PV of the total cost, whereas the PV of maintenance costs of the established structures is 56.3 per cent of the PV of the total cost. The PV of the planning and implementation costs for the region is 20.62 per cent whereas PV of monitoring and evaluation accounts for the remaining 2.96 per cent.

The present value of the total cost of investing in SLM technologies on the 86.7 million hectares of agricultural land in South East Asia is estimated at about USD 224.1 billion or USD 2,586/ha. These costs are close to 18.46 per cent of the PV of total cost for Asia. In South East Asia, the share of establishment cost of SLM technologies accounts for only 6.3 per cent of the PV of the total cost, whereas the PV of maintenance costs of the established structures is 70.9 per cent of the PV of the total cost. The PV of the planning and implementation costs for the region is 19.96 per cent whereas PV of monitoring and evaluation is the remaining 2.87 per cent.

The present value of the total cost of investing in SLM technologies on the 31.3 million hectares of agricultural land in West Asia is estimated at about USD 156.2 billion or USD 4,986 /ha. These costs are 12.9 per cent of the PV of total cost for Asia. In West Asia, the share of establishment cost of SLM technologies accounts for 21.97 per cent of the PV of the total cost, whereas the PV of maintenance costs of the established structures is 54.6 per cent of the PV of the total cost. The PV of the planning and implementation costs for the region is 20.54 per cent, whereas PV of monitoring and evaluation is the remaining 2.87 per cent.

The present value of the total cost of investing in SLM technologies on the close to 13.5 million hectares of agricultural land in Central Asia is estimated at about USD 59.8 billion or USD 2,706/ ha. These costs are only 4.92 per cent of the PV of total cost for Asia. In Central Asia, the share of establishment cost of SLM technologies is 22.57 per cent of the PV of the total cost whereas the PV of maintenance costs of the established structures is close to 54 per cent of the PV of the total cost. The PV of the planning and implementation costs for the region is 20.54 per cent whereas PV of monitoring and evaluation is the remaining 2.86 per cent.

Country level PV of costs: Ten countries (Mainland China, India, Iran, Turkey, Japan, Indonesia, Thailand, Kazakhstan, Pakistan, and Malaysia) all together are close to 85.2 per cent of the total 486.7 million hectares of agricultural land. The PV of investing in SLM technology on this much of land in the ten countries is close to 80 per cent of the USD 1,214 billion present value of the total cost for the region. Mainland China alone is 25.3 per cent of the land and 23.3 per cent of the PV of the total cost whereas India is close to 35 per cent of the land

TABLE 4.1

Present value of costs of SLM (discounting period 2018-2030)

Country/region			PV of Costs of SLM in Million USD					PVTC_SLM in USD/ha
	Agric. Land area in 1000s ha	Real discount rate	Establishment	Maintenance	Planning & Implementation	Monitoring & Evaluation	Total	
Afghanistan	3305.2	0.081	938	1654	696	95	3383	1024
Armenia	283.9	0.167	247	388	167	22	823	2902
Azerbaijan	1256.9	0.111	1243	2436	977	131	4787	3809
Bahrain	3.3	0.057	38	101	37	5	180	54848
Bangladesh	8646.4	0.071	4441	8430	3462	475	16809	1944
Bhutan	101.3	0.078	147	296	119	16	578	5706
Brunei Darussalam	8.5	0.018	27	418	115	17	576	67882
*Cambodia	3255.2	0.057	430	4097	1173	166	5866	1802
China Hong Kong SAR	2.0	0.046	31	91	33	5	159	80000
China, mainland	123000.0	0.019	58547	157359	58427	8399	282733	2299
Cyprus	94.7	0.036	696	2072	741	105	3615	38163
Georgia	463.1	0.140	401	685	287	38	1411	3047
India	170000.0	0.058	52940	109799	43850	6080	212669	1251
Indonesia	29500.0	0.048	3648	39982	11287	1608	56526	1916
Iran	13000.0	-0.047	17568	61293	21659	3339	103859	7989
Iraq	3304.5	0.063	3677	8485	3259	451	15873	4803
Israel	289.4	0.051	1420	4022	1454	204	7099	24534
Japan	2951.0	0.029	11004	34986	12316	1760	60066	20354
Jordan	190.9	0.052	347	813	312	44	1516	7941
*Kazakhstan	16600.0	0.057	10770	26818	10068	1402	49058	2955
Republic of Korea	1746.0	0.038	6046	17552	6324	896	30818	17651
Kuwait	12.0	0.041	94	283	101	14	492	41000
Kyrgyzstan	919.1	0.183	305	411	188	24	927	1010

Lao PDR	1198.3	0.081	196	1760	507	70	2533	2114
Lebanon	245.3	0.059	644	1569	593	82	2888	11773
Malaysia	4961.9	0.035	1742	22248	6194	893	31077	6263
Mongolia	241.1	0.213	59	81	37	5	181	755
Myanmar	11600.0	-0.010	1657	19932	5592	841	28022	2416
Nepal	2377.5	0.019	1664	3675	1459	209	7007	2947
Oman	55.6	0.038	183	519	188	27	917	16493
*Pakistan	19500.0	0.057	8840	18246	7304	1014	35404	1816
Philippines	10300.0	0.050	1713	18300	5179	737	25929	2517
Qatar	5.5	0.014	75	262	90	13	440	80000
*Saudi Arabia	827.4	0.057	789	2118	777	108	3793	4583
Singapore	0.8	0.044	5	67	18	3	92	116250
Sri Lanka	1700.5	0.019	2406	6083	2303	331	11123	6541
Syrian Arab Republic	4518.6	0.009	3982	10146	3849	558	18535	4102
Taiwan Province of China	636.7	0.057	1472	5431	1826	256	8986	14112
Tajikistan	869.0	0.036	585	1242	496	70	2393	2754
Thailand	16300.0	0.054	3181	36028	10138	1438	50785	3116
Timor-Leste	149.8	0.096	33	277	80	11	402	2677
*Turkey	18600.0	0.057	19044	47739	17884	2490	87157	4686
*United Arab Emirates	163.6	0.057	926	2658	955	133	4672	28557
*Uzbekistan	3624.6	0.057	1825	3814	1520	211	7369	2033
Viet Nam	9582.2	0.035	1458	15725	4448	641	22272	2324
Yemen	1040.0	0.067	520	1046	421	58	2045	1966
Central Asia	22083.3		13484	32285	12271	1707	59748	2706
East Asia	128333.3		77161	215500	78962	11320	382943	2984
South East Asia	86666.7		14091	158832	44733	6425	224081	2586
Southern Asia	218333.3		88945	209477	80852	11559	390832	1790
West Asia	31333.3		34328	85341	32091	4483	156243	4986
ASIA	**486666.7**		**228008**	**701434**	**248910**	**35494**	**1213747**	**2494**

** Data on real interest rate for these countries is not available in the World Bank database and the arithmetic mean of the real interest rates of all other countries, is therefore, used for the countries with no data.*

but about 17.5 per cent of the PV of the total cost. In case of the other 8 countries' share to Asia level PV of total cost, Iran is 8.56 per cent, Turkey (7.2 per cent), Japan (5 per cent), Indonesia (4.7 per cent), Thailand (4.2 per cent), Kazakhstan (4 per cent), Pakistan (2.9 per cent), and Malaysia (2.6 per cent). The remaining 34 countries and two provinces of China are 14.8 per cent of the agricultural land and close to 20 per cent of the present value of the total cost. The PV of total costs per hectare varies from USD 755/ha in Mongolia to USD 116,250 /ha in Singapore. Further details on the different types of costs for each country and the per hectare level PV of total costs can be seen from *Table 4.1*.

4.4. Present values of benefits of achieving agricultural LDN in Asia

Table 4.2 shows the present value benefits of avoiding top soil loss induced NPK losses, soil NPK depletions, and the associated crop losses through investment in SLM technologies on agricultural lands in Asia.

PV of avoided NPK losses and soil NPK depletions: The present value of avoided NPK losses induced by top soil loss through investment in SLM technologies in Asia is estimated at about USD 189.4 billion or USD 389/ha whereas the PV of avoided soil NPK depletion is about USD 164.2 billion or USD 337/ha. East Asia is close to 52 per cent of the PV of avoided NPK loss and 35.1 per cent of the PV of avoided soil NPK depletion in Asia. Southern Asia is the second in terms of the PV of both avoided NPK losses and soil NPK depletions and is 32 and 31 per cent respectively. South East Asia accounts for 11.3 per cent of the PV of avoided NPK losses and close to 23.2 per cent of the PV of avoided soil NPK depletions in Asia. West and Central Asia together is 5.12 per cent of the PV of avoided NPK loss and about 10.7 per cent of the PV of avoided soil NPK depletion in Asia.

PV of total benefits as avoided crop production losses: The present value of the flows of total benefits as avoided crop production losses from investment of SLM technologies on the 486.7 million hectares of agricultural land over the period 2018-2030, is estimated at about USD 4,216.2

billion or USD 8,663/ha. About 98.4 per cent of this benefit is accounted for by the PV of benefits of avoided crop production losses due to avoided soil NPK depletion whereas the PV of benefits of avoided crop production losses due to avoided NPK losses is only 1.6 per cent. In terms of share of sub-regions to PV of the total benefits from avoided crop losses, East Asia is close to 51 per cent, followed by Southern Asia (29.7 per cent), and South East Asia (12.85 per cent). Whereas West Asia is 5.12 per cent and Central Asia is only 1.44 per cent of the PV of total benefits of avoided crop production losses in Asia.

At the country level, ten countries (Mainland China, India, Indonesia, Iran, Turkey, Myanmar, Pakistan, Viet Nam, Thailand, and Kazakhstan) all together account for 91.3 per cent of the PV of avoided NPK losses, 90.1 per cent of the PV of avoided soil NPK losses, and 87.2 per cent of the PV of total benefits of avoided crop production losses. Mainland China and India each account for 45.3 per cent and 19.8 per cent of the PV of the total benefits of avoided crop losses in Asia. The remaining, less than 9 per cent of the PV of avoided NPK losses and avoided soil NPK depletions and about 11.8 per cent of the PV of total benefits of avoided crop production losses, are accounted for by the other 34 countries and two provinces.

4.5. NPV and benefit cost ratios of achieving agricultural LDN in Asia

Table 4.3 shows the net present value and benefit cost ratios (BCR) of avoiding crop production losses through investment in SLM technologies for avoiding top soil loss induced soil NPK depletion and NPK losses from agricultural lands in Asia.

Regional and sub-regional level NPV and BCR: The net present value at Asia level is estimated at about USD 3,002.4 billion or USD 6,169/ha whereas the BCR is about 3.47. Out of the continental level NPV, the NPV in East Asia is about 58.7 per cent, Southern Asia is 28.5 per cent, followed by South East Asia is 10.6 per cent. The remaining close to 2 per cent of the NPV is accounted by West and Central Asia. Moreover, sub regional level BCR and per hectare level NPV are the highest in East Asia (BCR=5.61 and USD 13,766/ha) and the lowest in Western Asia (BCR=1.38 and USD 1,908/ha).

Country level NPV and BCR: Seven countries (Mainland China, Saudi Arabia, Uzbekistan, Iran, Myanmar, Indonesia, and Japan) together account for 88.34 per cent of the Asia level NPV and have BCR ranging from 3.02 in Japan to 6.75 in mainland China. Another 14 countries and one province of China (Viet Nam, Tajikistan, Iran, Afghanistan, Yemen, Pakistan, Cambodia, Oman, Kyeargyzstan, Syearian Arab Republic, Kuwait, Philippines, Israel, Taiwan Province of China, and Jordan) all together are 11.1 per cent of the total NPV for Asia and the BCR in these countries and Taiwan Province of China ranges from 1.52 in Jordan to 2.92 in Viet Nam. This implies that the 21 countries and Taiwan Province of China all together are 99.44 per cent of the Asia level NPV. The following ten countries (Lao PDR, Republic of Korea, Lebanon, Malaysia, Bangladesh, Nepal, Turkey, Iraq, and Azerbaijan) is about 1.8 per cent of the regional level NPV. The BCR in these countries ranges from 1.06 in Azerbaijan to 1.49 in Lao PDR. The remaining countries and China Hong Kong SAR have negative NPV and BCR ranging from 0.07 in Brunei Darussalam to 0.98 in Thailand.

4.6. Sensitivity analysis

Sensitivity analysis results indicate that for most countries[17] with base case positive NPVs, a given percentage change in the real discount rate causes a relatively less and opposite change in the NPV. Whereas for 4 countries (Azerbaijan, Armenia, Iraq and Kyeargyzstan), a given percentage change in the real discount rate of a ±25 per cent change , will cause NPV to change by a higher but opposite percentage change. Moreover, the BCR for the countries with the 31 countries and Taiwan Province of China, which have positive NPV value in the base case, would remain higher than 1 for a 25 to 50 per cent increase in the real discount rates *(Table 4.4)*.

The NPV for 17 of the 32 countries with base case positive NPV, a given percentage change in the total costs of SLM technologies (all types of costs considered in this study which include establishment, maintenance, planning and implementation, as well as monitoring and evaluation costs) would cause a relatively higher percentage change in the NPV. Whereas for the remaining 15 countries[18] NPV changes in a relatively lower percentage to a given percentage change in total costs of SLM technologies *(Table 4.5)*.

[17] *Bangladesh, Afghanistan, Lao DRP, Turkey, Lebanon, Yemen, Taiwan, Jordan, Pakistan, Israel, India, Uzbekistan, Cambodia, Saudi Arabia, Philippines, Indonesia, Kuwait, Republic of Korea, Oman, Tajikistan, Malaysia, Viet Nam, Japan, Nepal, China (mainland), Syearian Arab Republic, Myanmar, Iran .*

[18] *Oman, Cambodia, Pakistan, Yemen, Afghanistan, Iran, Tajikistan, Viet Nam, Japan, Indonesia, Myanmar, India, Uzbekistan, Saudi Arabia, China (mainland).*

TABLE 4.2

Present value of benefits of SLM in USD millions (discounting period 2018-2030)

Country/region			PV of Costs of SLM in Million USD					
	Agric. Land area in 1000s ha	Real discount rate	Replacement cost value of avoided NPK loss	Replacement cost value of avoided soil NPK depletion	Value of Gains in yield due to avoided NPK loss	Value of Gains in yield due to avoided soil NPK depletion	Value total of yield gains	Value of total yield gains in USD/ha
Afghanistan	3305.2	0.081	402	714	42	8638	8680	2626
Armenia	283.9	0.167	21	41	6	1021	1027	3617
Azerbaijan	1256.9	0.111	102	401	19	5073	5092	4051
Bahrain	3.3	0.057	5	-6	6	100	106	32121
Bangladesh	8646.4	0.071	1412	2923	126	21559	21685	2508
Bhutan	101.3	0.078	11	24	2	514	516	5094
Brunei Darussalam	8.5	0.018	12	-17	1	42	43	5059
*Cambodia	3255.2	0.057	258	1375	29	13128	13157	4042
China Hong Kong SAR	2.0	0.046	13	-15	20	98	118	59000
China, mainland	123000.0	0.019	92949	58657	34495	1874175	1908670	15518
Cyprus	94.7	0.036	37	-11	12	951	963	10169
Georgia	463.1	0.140	36	46	5	1052	1057	2282
India	170000.0	0.058	42112	35472	6841	827506	834347	4908
Indonesia	29500.0	0.048	7553	13809	1631	215464	217095	7359
Iran	13000.0	-0.047	7825	7953	2269	280251	282520	21732
Iraq	3304.5	0.063	391	696	67	16456	16523	5000
Israel	289.4	0.051	146	56	178	10634	10812	37360
Japan	2951.0	0.029	2821	-332	4686	176636	181322	61444
Jordan	190.9	0.052	135	-177	60	2238	2298	12038
*Kazakhstan	16600.0	0.057	895	4372	28	17367	17395	1048

Republic of Korea	1746.0	0.038	1347	-96	1010	44354	45364	25982
Kuwait	12.0	0.041	36	-37	62	693	755	62917
Kyrgyzstan	919.1	0.183	60	156	10	1821	1831	1992
Lao PDR	1198.3	0.081	103	521	11	3824	3835	3200
Lebanon	245.3	0.059	90	26	50	3913	3963	16156
Malaysia	4961.9	0.035	2352	395	560	41797	42357	8536
Mongolia	241.1	0.213	59	-60	4	171	175	726
Myanmar	11600.0	-0.010	2528	8770	410	108525	108935	9391
Nepal	2377.5	0.019	417	946	37	8866	8903	3745
Oman	55.6	0.038	37	-37	35	1874	1909	34335
*Pakistan	19500.0	0.057	7799	2389	1136	84850	85986	4410
Philippines	10300.0	0.050	1303	3588	152	40587	40739	3955
Qatar	5.5	0.014	105	-129	82	244	326	59273
*Saudi Arabia	827.4	0.057	715	-120	653	22685	23338	28206
Singapore	0.8	0.044	12	-16	17	37	54	67500
Sri Lanka	1700.5	0.019	536	474	61	8435	8496	4996
Syrian Arab Republic	4518.6	0.009	1021	1730	178	34085	34263	7583
Taiwan Province of China	636.7	0.057	703	-478	511	13220	13731	21566
Tajikistan	869.0	0.036	212	326	45	6628	6673	7679
Thailand	16300.0	0.054	3510	4545	342	49598	49940	3064
Timor-Leste	149.8	0.096	12	21	1	348	349	2330
*Turkey	18600.0	0.057	4167	8386	798	104821	105619	5678
*United Arab Emirates	163.6	0.057	56	-50	38	2922	2960	18093
*Uzbekistan	3624.6	0.057	1318	1761	400	34494	34894	9627
Viet Nam	9582.2	0.035	3678	5027	683	64570	65253	6810
Yemen	1040.0	0.067	111	185	18	5007	5025	4832
Central Asia	22083.3		2485	6615	483	60309	60792	2753
East Asia	128333.3		97892	57677	40727	2108333	2149060	16746
South East Asia	86666.7		21322	38018	3837	537919	541756	6251
Southern Asia	218333.3		60515	50896	10514	1241667	1252181	5735
West Asia	31333.3		7210	10998	2267	213771	216038	6895
ASIA	486666.7		189424	164204	57827	4158333	4216160	8663

** Data on real interest rate for these countries is not available in the World Bank database and geometric mean of the real interest rates of all other countries, is therefore, used for the countries with no data.*

TABLE 4.3

Net Present Value and Benefit Cost Ratios of SLM in USD millions (discounting period 2018-2030)

Country/region	Agric. Land area in 1000s ha	Real discount rate	NPV1	NPV1 in USD/ha	BCR1	NPV2	NPV2 in USD/ha	BCR2
Afghanistan	3305.2	0.081	6088	1842	3.33	5296	1602	2.55
Armenia	283.9	0.167	392	1381	1.62	203	715	1.25
Azerbaijan	1256.9	0.111	1413	1124	1.38	306	243	1.06
Bahrain	3.3	0.057	-32	-9697	0.77	-74	-22424	0.59
Bangladesh	8646.4	0.071	8813	1019	1.69	4875	564	1.29
Bhutan	101.3	0.078	73	721	1.18	-62	-612	0.90
Brunei Darussalam	8.5	0.018	-402	-47294	0.10	-533	-62706	0.07
*Cambodia	3255.2	0.057	8630	2651	2.78	7291	2240	2.15
China Hong Kong SAR	2.0	0.046	-4	-2000	0.97	-41	-20500	0.74
China, mainland	123000.0	0.019	1692763	13762	8.84	1625937	13219	6.75
Cyprus	94.7	0.036	-1806	-19071	0.35	-2652	-28004	0.27
Georgia	463.1	0.140	-29	-63	0.96	-354	-764	0.74
India	170000.0	0.058	671609	3951	5.13	621678	3657	3.92
Indonesia	29500.0	0.048	173465	5880	4.94	160569	5443	3.81
Iran	13000.0	-0.047	203659	15666	3.59	178662	13743	2.72
Iraq	3304.5	0.063	4361	1320	1.40	650	197	1.07
Israel	289.4	0.051	5370	18556	1.99	3712	12827	1.53
Japan	2951.0	0.029	135332	45860	3.94	121255	41089	3.02
Jordan	190.9	0.052	1137	5956	1.99	782	4096	1.52
*Kazakhstan	16600.0	0.057	-20193	-1216	0.46	-31663	-1907	0.35
Republic of Korea	1746.0	0.038	21766	12466	1.93	14546	8331	1.48
Kuwait	12.0	0.041	379	31583	2.05	264	22000	1.57
Kyrgyzstan	919.1	0.183	1115	1213	2.56	903	982	1.97
Lao PDR	1198.3	0.081	1880	1569	1.94	1302	1087	1.49

Lebanon	245.3	0.059	1749	7130	1.80	1074	4378	1.38
Malaysia	4961.9	0.035	18367	3702	1.76	11280	2273	1.36
Mongolia	241.1	0.213	35	145	1.22	-6	-25	0.94
Myanmar	11600.0	-0.010	87345	7530	5.03	80912	6975	3.88
Nepal	2377.5	0.019	3563	1499	1.67	1895	797	1.27
Oman	55.6	0.038	1207	21709	2.71	992	17842	2.07
*Pakistan	19500.0	0.057	58899	3020	3.17	50582	2594	2.43
Philippines	10300.0	0.050	20726	2012	2.03	14810	1438	1.57
Qatar	5.5	0.014	-10	-1818	0.97	-113	-20545	0.74
*Saudi Arabia	827.4	0.057	20430	24692	8.24	19545	23622	6.32
Singapore	0.8	0.044	-18	-22500	0.75	-39	-48750	0.58
Sri Lanka	1700.5	0.019	7	4	1.00	-2627	-1545	0.76
Syrian Arab Republic	4518.6	0.009	20135	4456	2.43	15729	3481	1.85
Taiwan Province of China	636.7	0.057	6828	10724	1.99	4746	7454	1.53
Tajikistan	869.0	0.036	4846	5577	3.65	4280	4925	2.79
Thailand	16300.0	0.054	10731	658	1.27	-845	-52	0.98
Timor-Leste	149.8	0.096	39	260	1.13	-53	-354	0.87
*Turkey	18600.0	0.057	38837	2088	1.59	18463	993	1.22
*United Arab Emirates	163.6	0.057	-623	-3808	0.91	-1712	-10465	0.70
*Uzbekistan	3624.6	0.057	29255	8071	6.19	27525	7594	4.74
Viet Nam	9582.2	0.035	48069	5016	3.78	42980	4485	2.92
Yemen	1040.0	0.067	3459	3326	3.21	2980	2865	2.46
Central Asia	22083.3		15023	680	1.33	1045	47	1.02
East Asia	128333.3		1858333	14481	7.34	1766667	13766	5.61
South East Asia	86666.7		368832	4256	3.13	317675	3665	2.42
Southern Asia	218333.3		950000	4351	4.20	858333	3931	3.20
West Asia	31333.3		96368	3076	1.81	59794	1908	1.38
ASIA	486666.7		3291667	6764	4.52	3002425	6169	3.47

** Data on real interest rate for these countries is not available in the World Bank database and geometric mean of the real interest rates of all other countries, is therefore, used for the countries with no data. Note: NPV1 and BCR1 are based on considering only Establishment and maintenance costs of SLM whereas NPV2 and BCR2 take additional costs for annual planning and implementation as well as 3 years monitoring and evaluation costs (2020, 2025 and 2030) over the period 2018 to 2030.*

TABLE 4.4

Sensitivity of NPV and BCR to changes in real discount rate

Country	Baseline			25% increase in real discount rate		25% decrease in real discount rate		50% increase in real discount rate		50%decrease in real discount rate	
	NPV	BCR	Real discount rate	%Change in NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR
China, mainland	1625937	6.8	1.9	-4.2	6.7	2.7	6.7	-8.2	6.7	9.0	6.8
Saudi Arabia	19545	6.3	5.7	-11.1	6.2	8.5	6.2	-20.8	6.2	27.8	6.5
Uzbekistan	27525	4.7	5.7	-11.3	4.7	8.3	4.6	-21.0	4.6	28.1	4.9
India	621678	3.9	5.8	-11.6	3.9	8.4	3.8	-21.6	3.8	29.2	4.0
Myanmar	80912	3.9	-1	2.4	3.9	-1.1	3.9	4.8	3.9	-4.5	3.9
Indonesia	160569	3.8	4.8	-9.6	3.8	6.4	3.7	-18.1	3.8	23.2	3.8
Japan	121255	3.0	2.9	-6.3	3.0	3.6	3.0	-12.1	3.0	14.1	3.1
Viet Nam	42980	2.9	3.5	-7.3	2.9	4.2	2.9	-14.0	2.9	16.8	2.9
Tajikistan	4280	2.8	3.6	-7.8	2.8	4.6	2.7	-15.0	2.7	18.2	2.8
Iran	178662	2.7	-4.7	13.2	2.7	-3.5	2.9	28.4	2.8	-21.4	2.7
Afghanistan	5296	2.6	8.1	-15.7	2.5	11.5	2.5	-28.6	2.4	43.0	2.7
Yemen	2980	2.5	6.7	-13.6	2.4	9.0	2.4	-25.0	2.4	35.3	2.5
Pakistan	50582	2.4	5.7	-11.8	2.4	7.5	2.4	-22.1	2.4	29.7	2.5
Cambodia	7291	2.1	5.7	-11.2	2.1	6.2	2.1	-20.9	2.1	28.0	2.2
Oman	992	2.1	3.8	-8.4	2.1	4.1	2.0	-16.0	2.0	19.6	2.1
Kyrgyzstan	903	2.0	18.3	-29.0	1.9	30.3	2.0	-48.8	1.8	110.7	2.2
Syrian Arab Rep.	15729	1.8	0.9	-2.3	1.8	0.7	1.8	-4.5	1.8	4.7	1.9
Philippines	14810	1.6	5.0	-10.3	1.6	2.5	1.5	-19.4	1.6	25.2	1.6
Kuwait	264	1.6	4.1	-9.8	1.6	3.2	1.5	-18.5	1.5	23.2	1.6
Taiwan Province of China	4746	1.5	5.7	-12.6	1.5	4.2	1.5	-23.4	1.5	31.7	1.6
Israel	3712	1.5	5.1	-11.9	1.5	3.7	1.5	-22.3	1.5	29.5	1.6
Jordan	782	1.5	5.2	-12.3	1.5	4.1	1.5	-22.9	1.5	30.4	1.6

Lao PDR	1302	1.5	8.1	-15.6	1.5	5.2	1.4	-28.5	1.5	42.9	1.5
Republic of Korea	14546	1.5	3.8	-9.2	1.5	1.9	1.5	-17.5	1.5	21.6	1.5
Lebanon	1074	1.4	5.9	-14.6	1.4	3.2	1.3	-27.0	1.3	37.4	1.4
Malaysia	11280	1.4	3.5	-7.8	1.4	-1.0	1.3	-14.9	1.4	18.1	1.4
Bangladesh	4875	1.3	7.1	-19.1	1.3	3.9	1.3	-34.8	1.2	51.8	1.3
Nepal	1895	1.3	1.9	-5.8	1.3	-0.8	1.3	-11.3	1.3	12.6	1.3
Armenia	203	1.2	16.7	-38.5	1.2	25.5	1.2	-64.3	1.1	147.2	1.4
Turkey	18463	1.2	5.7	-16.5	1.2	-1.9	1.2	-30.5	1.2	42.3	1.2
Iraq	650	1.1	6.3	-45.6	1.1	-46.6	1.1	-82.9	1.0	124.6	1.1
Azerbaijan	306	1.1	11.1	-56.0	1.0	-16.2	1.0	-96.6	1.0	185.1	1.1
Thailand	-845	1.0	5.4	9.5	1.0	201.0	1.0	16.9	1.0	-26.7	1.0
Mongolia	-6	0.9	21.3	101.8	0.9	-14.7	1.0	155.2	0.8	-533.4	1.1
Bhutan	-62	0.9	7.8	2.7	0.9	33.7	0.9	3.9	0.9	-12.3	0.9
Timor-Leste	-53	0.9	9.6	-11.0	0.9	48.1	0.8	-20.2	0.9	29.6	0.9
Sri Lanka	-2627	0.8	1.9	-2.3	0.8	7.3	0.8	-4.5	0.8	4.9	0.8
China Hong Kong SAR	-41	0.7	4.6	-5.7	0.7	13.9	0.7	-10.9	0.7	13.1	0.8
Georgia	-354	0.7	14.0	-8.8	0.7	28.4	0.7	-16.4	0.7	21.2	0.8
Qatar	-113	0.7	1.4	-2.1	0.7	4.6	0.7	-4.1	0.7	4.4	0.7
United Arab Emirates	-1712	0.7	5.7	-8.0	0.7	15.4	0.7	-15.0	0.7	19.2	0.7
Bahrain	-74	0.6	5.7	-8.2	0.6	14.4	0.6	-15.5	0.6	19.9	0.6
Singapore	-39	0.6	4.4	-8.3	0.6	12.2	0.6	-15.7	0.6	19.7	0.6
Kazakhstan	-31663	0.4	5.7	-9.0	0.3	12.4	0.3	-17.0	0.3	22.2	0.4
Cyprus	-2652	0.3	3.6	-6.4	0.3	8.0	0.3	-12.3	0.3	14.7	0.3
Brunei Darussalam	-533	0.1	1.8	-3.8	0.1	4.1	0.1	-7.4	0.1	8.2	0.1
Central Asia	1045	1.0		-79.5	1.0	-111.1	1.0	-141.9	1.0	239.1	1.0
East Asia	1766667	5.6		-4.2	5.6	2.8	5.5	-8.5	5.6	9.4	5.6
Southern Asia	858333	3.2		-6.3	3.1	5.8	3.2	-11.2	3.1	19.4	3.3
South East Asia	317675	2.4		-6.3	2.4	3.2	2.3	-11.9	2.5	15.5	2.4
West Asia	59794	1.4		-11.7	1.4	1.8	1.4	-21.7	1.4	29.9	1.4
Asia	3002425	3.5		-5.5	3.5	3.6	3.4	-10.2	3.5	13.3	3.4

TABLE 4.5

Sensitivity of NPB and BCR to changes in total cost of SLM

	Baseline		25% increase in total cost		25% decrease in total cost		50% increase in total cost		50%decrease in total cost	
	NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR
China, mainland	1625937	6.8	-4.3	5.4	4.3	9.0	-8.5	4.5	8.7	13.5
India	19545	6.3	-4.9	5.1	4.9	8.4	-9.4	4.3	9.7	12.6
Iran	27525	4.7	-6.7	3.8	6.7	6.3	-12.9	3.2	13.4	9.5
Indonesia	621678	3.9	-8.6	3.1	8.6	5.2	-16.5	2.6	17.1	7.8
Japan	80912	3.9	-8.7	3.1	8.7	5.2	-17.2	2.6	17.3	7.8
Myanmar	160569	3.8	-8.8	3.1	8.8	5.1	-17.5	2.5	17.6	7.6
Pakistan	121255	3.0	-12.4	2.4	12.4	4.0	-24.2	2.0	24.8	6.0
Viet Nam	42980	2.9	-13.0	2.3	13.0	3.9	-25.7	2.0	25.9	5.8
Uzbekistan	4280	2.8	-14.0	2.2	14.0	3.7	-27.1	1.9	28.0	5.6
Saudi Arabia	178662	2.7	-14.5	2.2	14.5	3.6	-28.7	1.8	29.1	5.4
Turkey	5296	2.6	-16.0	2.0	16.0	3.4	-30.6	1.7	31.9	5.1
Syrian Arab Republic	2980	2.5	-17.2	2.0	17.2	3.3	-33.1	1.7	34.3	4.9
Philippines	50582	2.4	-17.5	1.9	17.5	3.2	-33.8	1.6	35.0	4.9
Republic of Korea	7291	2.1	-20.1	1.7	20.1	2.9	-39.8	1.4	40.2	4.3
Malaysia	992	2.1	-23.1	1.7	23.1	2.8	-45.1	1.4	46.2	4.1
Cambodia	903	2.0	-25.7	1.6	25.7	2.6	-47.9	1.3	51.4	3.9
Afghanistan	15729	1.8	-29.5	1.5	29.5	2.5	-57.6	1.2	58.9	3.7
Bangladesh	264	1.6	-46.6	1.3	46.6	2.1	-90.9	1.1	93.1	3.1
Taiwan Province of China	14810	1.6	-43.8	1.3	43.8	2.1	-86.8	1.0	87.5	3.1
Tajikistan	4746	1.5	-47.3	1.2	47.3	2.0	-92.6	1.0	94.7	3.1
Israel	3712	1.5	-47.8	1.2	47.8	2.0	-93.2	1.0	95.6	3.1
Yemen	782	1.5	-48.5	1.2	48.5	2.0	-94.1	1.0	97.0	3.0

Nepal	1302	1.5	-48.6	1.2	48.6	2.0	-96.1	1.0	97.2	3.0
Lao PDR	14546	1.5	-53.0	1.2	53.0	2.0	-103.4	1.0	105.9	3.0
Lebanon	1074	1.4	-67.2	1.1	67.2	1.8	-130.4	0.9	134.4	2.8
Oman	11280	1.4	-68.9	1.1	68.9	1.8	-136.8	0.9	137.8	2.7
Kyrgyzstan	4875	1.3	-86.2	1.0	86.2	1.7	-166.0	0.9	172.4	2.6
Jordan	1895	1.3	-92.4	1.0	92.4	1.7	-180.0	0.9	184.9	2.5
Iraq	203	1.2	-101.2	1.0	101.2	1.7	-190.5	0.8	202.4	2.5
Azerbaijan	18463	1.2	-118.0	1.0	118.0	1.6	-229.2	0.8	236.0	2.4
Kuwait	650	1.1	-610.1	0.9	610.1	1.4	-1181.7	0.7	1220.1	2.1
Armenia	306	1.1	-391.4	0.9	391.4	1.4	-749.5	0.7	782.8	2.1
Mongolia	-6	0.9	698.7	0.9	-698.7	0.8	1296.3	1.3	-1397.4	0.6
Singapore	-39	0.6	59.2	0.6	-59.2	0.5	117.7	0.8	-118.4	0.4
China Hong Kong SAR	-41	0.7	97.5	0.7	-97.5	0.6	190.1	1.0	-195.0	0.5
Timor-Leste	-53	0.9	191.2	0.9	-191.2	0.7	377.5	1.2	-382.4	0.6
Bhutan	-62	0.9	233.4	0.9	-233.4	0.7	449.7	1.2	-466.9	0.6
Bahrain	-74	0.6	60.6	0.6	-60.6	0.5	117.8	0.8	-121.1	0.4
Qatar	-113	0.7	96.9	0.7	-96.9	0.6	190.3	1.0	-193.9	0.5
Georgia	-354	0.7	99.6	0.7	-99.6	0.6	189.0	1.0	-199.3	0.5
Brunei Darussalam	-533	0.1	27.0	0.1	-27.0	0.1	53.8	0.1	-54.0	0.0
Thailand	-845	1.0	1501.9	1.0	-1501.9	0.8	2979.2	1.3	-3003.8	0.7
United Arab Emirates	-1712	0.7	68.2	0.7	-68.2	0.6	132.9	0.9	-136.5	0.5
Sri Lanka	-2627	0.8	105.9	0.8	-105.9	0.6	206.7	1.0	-211.7	0.5
Cyprus	-2652	0.3	34.1	0.3	-34.1	0.2	66.6	0.4	-68.1	0.2
Kazakhstan	-31663	0.4	38.7	0.4	-38.7	0.3	75.2	0.5	-77.5	0.2
Central Asia	1045	1.0	-1429.7	1.0	1429.7	0.8	-2773.5	1.4	2859.5	0.7
East Asia	1766667	5.6	-5.5	5.6	5.4	4.5	-10.6	7.5	10.8	3.8
Southern Asia	858333	3.2	-11.0	3.2	11.7	2.6	-21.8	4.3	23.1	2.2
South East Asia	317675	2.4	-17.6	2.4	17.6	1.9	-35.0	3.2	35.3	1.6
West Asia	59794	1.4	-65.3	1.4	65.3	1.1	-126.9	1.8	130.7	0.9
Asia	3002425	3.5	-10.3	3.5	10.0	2.8	-20.0	4.6	20.0	2.3

TABLE 4.6

Sensitivity of NPV and BCR to changes in aggregate crop prices

	Baseline		25 % increase in crop prices		25 % decrease in crop prices		50 % increase in crop prices		50 % decrease in crop prices	
	NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR
China, mainland	1625937	6.8	29.3	8.4	-29.3	5.1	58.4	10.1	-58.7	3.4
India	621678	3.9	33.6	4.9	-33.6	2.9	67.0	5.9	-67.1	2.0
Iran	178662	2.7	39.5	3.4	-39.5	2.0	78.8	4.1	-79.1	1.4
Indonesia	160569	3.8	33.8	4.8	-33.8	2.9	67.5	5.7	-67.6	1.9
Japan	121255	3.0	37.4	3.8	-37.4	2.3	74.2	4.5	-74.8	1.5
Myanmar	80912	3.9	33.7	4.8	-33.7	2.9	67.2	5.8	-67.3	1.9
Pakistan	50582	2.4	42.5	3.0	-42.5	1.8	84.7	3.6	-85.0	1.2
Viet Nam	42980	2.9	38.0	3.6	-38.0	2.2	75.7	4.4	-75.9	1.5
Uzbekistan	27525	4.7	31.7	5.9	-31.7	3.6	63.2	7.1	-63.4	2.4
Saudi Arabia	19545	6.3	29.9	7.9	-29.9	4.7	59.2	9.5	-59.7	3.2
Turkey	18463	1.2	143.0	1.5	-143.0	0.9	285.4	1.8	-286.0	0.6
Syrian Arab Republic	15729	1.8	54.5	2.3	-54.5	1.4	108.7	2.8	-108.9	0.9
Philippines	14810	1.6	68.8	2.0	-68.8	1.2	137.4	2.4	-137.5	0.8
Republic of Korea	14546	1.5	78.0	1.8	-78.0	1.1	154.9	2.2	-155.9	0.7
Malaysia	11280	1.4	93.9	1.7	-93.9	1.0	187.0	2.0	-187.8	0.7
Cambodia	7291	2.1	45.1	2.7	-45.1	1.6	90.2	3.2	-90.2	1.1
Afghanistan	5296	2.6	41.0	3.2	-41.0	1.9	81.8	3.8	-81.9	1.3
Bangladesh	4875	1.3	111.2	1.6	-111.2	1.0	222.1	1.9	-222.4	0.6
Taiwan Province of China	4746	1.5	72.3	1.9	-72.3	1.1	143.2	2.3	-144.7	0.8
Tajikistan	4280	2.8	39.0	3.5	-39.0	2.1	77.8	4.2	-78.0	1.4
Israel	3712	1.5	72.8	1.9	-72.8	1.1	145.0	2.3	-145.6	0.8
Yemen	2980	2.5	42.2	3.1	-42.2	1.8	84.2	3.7	-84.3	1.2
Nepal	1895	1.3	117.4	1.6	-117.4	1.0	234.6	1.9	-234.9	0.6

Lao PDR	1302	1.5	73.6	1.9	-73.6	1.1	147.1	2.2	-147.2	0.7
Lebanon	1074	1.4	92.2	1.7	-92.2	1.0	183.8	2.1	-184.4	0.7
Oman	992	2.1	48.1	2.6	-48.1	1.6	95.7	3.1	-96.2	1.0
Kyrgyzstan	903	2.0	50.7	2.5	-50.7	1.5	101.3	3.0	-101.4	1.0
Jordan	782	1.5	73.5	1.9	-73.5	1.1	145.9	2.3	-147.0	0.8
Iraq	650	1.1	635.1	1.3	-635.1	0.8	1268.8	1.6	-1270.1	0.5
Azerbaijan	306	1.1	416.4	1.3	-416.4	0.8	832.1	1.6	-832.8	0.5
Kuwait	264	1.6	71.6	2.0	-71.6	1.2	139.7	2.3	-143.1	0.8
Armenia	203	1.2	126.2	1.6	-126.2	0.9	252.2	1.9	-252.4	0.6
Mongolia	-6	0.9	-673.7	1.2	673.7	0.7	-1342.6	1.4	1347.4	0.5
Singapore	-39	0.6	-34.2	0.7	34.2	0.4	-62.4	0.8	68.4	0.3
China	-41	0.7	97.5	0.7	-97.5	0.6	190.1	1.0	-195.0	0.5
Hong Kong SAR	-41	0.7	-72.5	0.9	72.5	0.6	-137.9	1.1	145.0	0.4
Timor-Leste	-53	0.9	-166.2	1.1	166.2	0.7	-332.1	1.3	332.4	0.4
Bhutan	-62	0.9	-208.4	1.1	208.4	0.7	-416.4	1.4	416.9	0.5
Bahrain	-74	0.6	-35.6	0.7	35.6	0.4	-70.1	0.9	71.1	0.3
Qatar	-113	0.7	-71.9	0.9	71.9	0.6	-132.4	1.1	143.9	0.4
Georgia	-354	0.7	-74.6	0.9	74.6	0.6	-149.1	1.1	149.3	0.4
Brunei Darussalam	-533	0.1	-2.0	0.1	2.0	0.1	-4.0	0.1	4.0	0.0
Thailand	-845	1.0	-1476.9	1.2	1476.9	0.7	-2948.3	1.5	2953.8	0.5
United Arab Emirates	-1712	0.7	-43.2	0.9	43.2	0.5	-86.2	1.0	86.5	0.3
Sri Lanka	-2627	0.8	-80.9	1.0	80.9	0.6	-161.4	1.1	161.7	0.4
Cyprus	-2652	0.3	-9.1	0.3	9.1	0.2	-18.1	0.4	18.1	0.1
Kazakhstan	-31663	0.4	-13.7	0.4	13.7	0.3	-27.5	0.5	27.5	0.2
Central Asia	1045	1.0	1454.7	1.3	-1454.7	0.8	2903.2	1.5	-2909.5	0.5
East Asia	1766667	5.6	30.3	7.0	-30.3	4.2	60.7	8.4	-60.6	2.8
Southern Asia	858333	3.2	36.6	4.0	-35.9	2.4	72.6	4.8	-72.7	1.6
South East Asia	317675	2.4	42.6	3.0	-42.6	1.8	85.1	3.6	-85.3	1.2
West Asia	59794	1.4	90.3	1.7	-90.3	1.0	180.1	2.1	-180.7	0.7
Asia	3002425	3.5	34.8	4.3	-35.1	2.6	69.6	5.2	-70.2	1.7

TABLE 4.7

Sensitivity of NPV and BCR to changes in effectiveness of SLM technologies

	Baseline		75 % decrease in effectiveness of SLM = 25% effective		50% decrease i n effectiveness of SLM = 50% effective		25% decrease in effectiveness of SLM = 75% effective	
	NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR	%Change in NPV	BCR
China, mainland	1625937	6,8	-88,0	1,7	-58,7	3,4	-29,3	5,1
India	621678	3,9	-100,7	0,98	-67,1	2,0	-33,6	2,9
Iran	178662	2,7	-118,6	0,7	-79,1	1,4	-39,5	2,0
Indonesia	160569	3,8	-101,4	0,95	-67,6	1,9	-33,8	2,9
Japan	121255	3,0	-112,2	0,8	-74,8	1,5	-37,4	2,3
Myanmar	80912	3,9	-101,0	0,97	-67,3	1,9	-33,7	2,9
Pakistan	50582	2,4	-127,5	0,6	-85,0	1,2	-42,5	1,8
Viet Nam	42980	2,9	-113,9	0,7	-75,9	1,5	-38,0	2,2
Uzbekistan	27525	4,7	-95,1	1,2	-63,4	2,4	-31,7	3,6
Saudi Arabia	19545	6,3	-89,6	1,6	-59,7	3,2	-29,9	4,7
Turkey	18463	1,2	-429,1	0,3	-286,0	0,6	-143,0	0,9
Syearian Arab Republic	15729	1,8	-163,4	0,5	-108,9	0,9	-54,5	1,4
Philippines	14810	1,6	-206,3	0,4	-137,5	0,8	-68,8	1,2
Republic of Korea	14546	1,5	-233,9	0,4	-155,9	0,7	-78,0	1,1
Malaysia	11280	1,4	-281,6	0,3	-187,8	0,7	-93,9	1,0
Cambodia	7291	2,1	-135,3	0,5	-90,2	1,1	-45,1	1,6
Afghanistan	5296	2,6	-122,9	0,6	-81,9	1,3	-41,0	1,9
Bangladesh	4875	1,3	-333,6	0,3	-222,4	0,6	-111,2	1,0
Taiwan Province of China	4746	1,5	-217,0	0,4	-144,7	0,8	-72,3	1,1
Tajikistan	4280	2,8	-116,9	0,7	-78,0	1,4	-39,0	2,1
Israel	3712	1,5	-218,4	0,4	-145,6	0,8	-72,8	1,1
Yemen	2980	2,5	-126,5	0,6	-84,3	1,2	-42,2	1,8
Nepal	1895	1,3	-352,3	0,3	-234,9	0,6	-117,4	1,0
Lao PDR	1302	1,5	-220,9	0,4	-147,2	0,7	-73,6	1,1
Lebanon	1074	1,4	-276,6	0,3	-184,4	0,7	-92,2	1,0
Oman	992	2,1	-144,3	0,5	-96,2	1,0	-48,1	1,6
Kyeargyzstan	903	2,0	-152,0	0,5	-101,4	1,0	-50,7	1,5
Jordan	782	1,5	-220,5	0,4	-147,0	0,8	-73,5	1,1
Iraq	650	1,1	-1905,2	0,3	-1270,1	0,5	-635,1	0,8
Azerbaijan	306	1,1	-1249,1	0,3	-832,8	0,5	-416,4	0,8
Kuwait	264	1,6	-214,7	0,4	-143,1	0,8	-71,6	1,2
Armenia	203	1,2	-378,6	0,3	-252,4	0,6	-126,2	0,9
Mongolia	-6	0,9	2021,1	0,2	1347,4	0,5	673,7	0,7
Singapore	-39	0,6	102,7	0,1	68,4	0,3	34,2	0,4
China Hong Kong SAR	-41	0,7	217,5	0,2	145,0	0,4	72,5	0,6
Timor-Leste	-53	0,9	498,6	0,2	332,4	0,4	166,2	0,7
Bhutan	-62	0,9	625,3	0,2	416,9	0,5	208,4	0,7
Bahrain	-74	0,6	106,7	0,1	71,1	0,3	35,6	0,4
Qatar	-113	0,7	215,8	0,2	143,9	0,4	71,9	0,6
Georgia	-354	0,7	223,9	0,2	149,3	0,4	74,6	0,6
Brunei Darussalam	-533	0,1	6,1	0,0	4,0	0,0	2,0	0,1
Thailand	-845	1,0	4430,7	0,2	2953,8	0,5	1476,9	0,7
United Arab Emirates	-1712	0,7	129,7	0,2	86,5	0,3	43,2	0,5
Sri Lanka	-2627	0,8	242,6	0,2	161,7	0,4	80,9	0,6
Cyprus	-2652	0,3	27,2	0,1	18,1	0,1	9,1	0,2
Kazakhstan	-31663	0,4	41,2	0,1	27,5	0,2	13,7	0,3
Central Asia	1045	1,0	-4364,2	0,3	-2909,5	0,5	-1454,7	0,8
East Asia	1766667	5,6	-91,3	1,4	-60,6	2,8	-30,3	4,2
Southern Asia	858333	3,2	-109,1	0,8	-72,7	1,6	-35,9	2,4
South East Asia	317675	2,4	-127,9	0,6	-85,3	1,2	-42,6	1,8
West Asia	59794	1,4	-271,0	0,3	-180,7	0,7	-90,3	1,0
Asia	3002425	3,5	-105,3	0,9	-70,2	1,7	-35,1	2,6

Moreover, the BCR of 24 countries of the 32 with base case positive NPV remains greater than or equal to 1 for a 25 to 50 per cent increase in the total cost of SLM technologies. Whereas the other 8 countries (Lebanon, Malaysia, Bangladesh, Nepal, Armenia, Turkey, Iraq, and Azerbaijan), which are among countries with base cases positive NPV, will have BCR less than 1 if the total cost of SLM technologies increase by 25 to 50 per cent.

For all countries with base case positive NPV, a given percentage change in the weighted average prices of crops would cause a higher percentage change in the NPV. For example, a 25 per cent increase in weighted average crop prices would cause the NPVs of each of these countries to increase by greater than 25 per cent *(Table 4.6)*. Moreover, for about half of the 32 countries a 50 per cent decrease in weighted average crop price would result in their BCR to decline to a value less than 1 whereas a 50 per cent increases in the weighted average crop prices would almost double the BCR of all the 32 countries with the base case positive NPVs.

Finally, the net present value of all countries with base case positive NPV is highly sensitive to changes in the effectiveness of SLM technologies in controlling top soil loss. For example a 50 per cent decrease in the effectiveness of SLM technologies in controlling top soil loss induced nutrient depletion and nutrient loss and hence the associated crop losses would lead the NPV to decline by a greater than 50 per cent change. Except for 4 of the 32 countries (Armenia, Turkey, Iraq, and Azerbaijan), which have base case positive NPV, a decline in the effectiveness of SLM to 75 per cent in controlling top soil loss and the associated nutrient and crop productivity losses, would still result in positive NPV and hence BCR higher than 1 *(Table 4.7)*. A drop in the effectiveness of SLM to 50 per cent and 25 per cent in controlling top soil loss and the associated nutrient depletion and crop productivity loss would result the number of countries with positive NPV and BCR greater than 1 to drop to 16 and 3 respectively. The three countries, which will still have positive NPV and BCR greater than or equal to 1 at an effectiveness rate of 25 per cent of the SLM technologies, are mainland China, Saudi Arabia, and Uzbekistan.

4.7. Conclusions

The present value of the total costs of investing in SLM technologies on a total of 487 million hectares of agricultural land in Asia is estimated at about USD 1,214 billion or USD 2,494/ha. Of this cost, 18.8 per cent is as establishment cost, 57.8 per cent maintenance costs, 20.5 per cent planning and implementation costs, and the remaining 3 per cent is for monitoring and evaluation. Whereas the present value of flows of total benefits of avoided crop production losses from investment of SLM technologies on the 487 million hectares of agricultural land over the period 2018-2030, is estimated at about USD 4,216.2 billion or USD 8,663/ha.

The NPV at Asia level is estimated at about USD 3,002.4 billion or USD 6,169/ha whereas the BCR is about 3.47. Out of the continental level NPV, the NPV in East Asia is about 58.7 per cent, Southern Asia is 28.5 per cent, followed by South East Asia at 10.6 per cent. The remaining close to 2 per cent of the NPV is accounted for by West and Central Asia. Moreover, sub regional level BCR and per ha level NPV are the highest in East Asia (BCR=5.61 and USD 13,766/ha) and the lowest in Western Asia (BCR=1.38 and USD 1,908/ha).

A total of 30 countries and one province of China have positive NPV and hence benefit cost ratio ranging from 1.06 in Azerbaijan to 6.75 in mainland China. Mainland China and six other countries with the top BCR (Saudi Arabia, Uzbekistan, Iran, Myanmar, Indonesia, and Japan) all together account for 88.34 per cent of the Asia level NPV. These countries have BCR ranging from 3.02 in Japan to 6.75 in mainland China.

The sensitivity analyses indicated that the results of the NPV and BCR are robust to changes in the different parameters used in the analysis. Thus, investing in SLM technologies on agricultural land for avoiding top soil loss induced soil nutrient depletion and nutrient losses will be a profitable intervention for most of the countries covered in this study. Moreover, such an investment not only enables countries to increase their agricultural productivity and achieve SDG 15.3 in achieving land degradation neutrality but it also has other spillover effects and implications for achieving other related targets of the Sustainable Development Goals. The next chapter will provide insights on this.

05 Policy Implications of Achieving Agricultural Land Degradation Neutrality in Asia

5.1. Introduction

In the last chapter we have looked at how investing in sustainable land management technologies for avoiding top soil loss from agricultural lands in Asia and hence achieving land degradation neutrality in agriculture would be profitable for most countries. The objective of this chapter is to assess further implications for achieving other Sustainable Development Goals.

Thus, the next sections of this chapter discuss the policy implications of investment in SLM technologies for achieving SDG 15.3 in Asian countries would contribute for achieving a number of related Sustainable Development Goals.

5.2. Implication to economic growth (SDG 8.1)

In order to assess the implication of achieving agricultural land degradation neutrality to SDG 8, which aims at *"promoting sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (UN, n.d.)"*, we developed an indicator, which measures the contribution of real annuity of the net present value to the growth of real GDP per capita, as described below.

1. First, we estimated the annuity value of the NPV2 in *Table 4.3* for each country and sub region.
2. Based on World Bank database on GDP deflator, we deflated the annuity by the GDP deflator to convert it in to real prices.
3. We calculated the real annuity as a percentage of real GDP of 2015 as well as real agricultural GDP of 2015. For countries with positive NPV, these results indicate by how much percent the real GDP and real agricultural GDP of each country on average would grow over the period 2018-2030 if these countries invest in SLM technologies on their agricultural lands.
4. Furthermore, we calculated the annual geometric mean population growth for each country for the period 2018-2030 based on projected population data from FAO database. Economists estimate real GDP per capita growth as the difference between real GDP growth rate and human population growth rate. Accordingly, we estimated the contribution of real annuity of the NPV to real GDP per capita growth as the difference between real annuity as percentage of real GDP of 2015 and the estimated annual geometric mean of the population growth.

This indicator is consistent with indicator 8.1.1 "Annual growth rate of real GDP per capita" set to measure target 8.1 of SDG 8. Target 8.1 states *"Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries (UN, n.d.)".*

The results in Table 5.1 indicate that for 31 countries and Taiwan Province of China, which have a positive NPV, the real annuity as percentage of real GDP of 2015 ranges from 0.02 per cent in Kuwait to 9.27 per cent in Myanmar. The real annuity as percentage of agricultural GDP for countries with positive NPV ranges from 1.26 per cent in Azerbaijan to 34.67 per cent in Myanmar. This implies that investing of SLM technologies to avoid top soil loss induced NPK losses and soil NPK depletions and the associated losses in aggregate crop yield would result the economies of these countries and their agricultural sector to grow by the indicated rates.

Among these 31 countries and Taiwan Province of China with positive NPV, in 12 countries (Myanmar, Uzbekistan, Tajikistan, Cambodia, India, Kyeargyzstan, Iran, Afghanistan, Viet Nam, Lebanon, mainland China, and Indonesia) population grow over the next 13 years (2018-2030) is projected to growth at an annual rate of -1.01 per

TABLE 5.1

Implications for economic growth (relative to 2015 GDP) for countries with positive NPV

Country/region	NPV2	Annuity factor	Annuity at current prices	NPV2 Real Prices	Annuity at constant prices	Annuity as % Real Agri GDP of 2013	Annuity as % of Real GDP of 2015	Average Annual Population growth (2018-30)	Rela GDP per capita growth
Myanmar	80912	13.94	5805.47	62963	4517.63	34.67	9.27	0.73	8.54
Tajikistan	4280	10.24	417.77	486	47.47	21.32	5.32	1.75	3.57
*Uzbekistan	27525	9.03	3049.54	514	56.9	25.02	4.57	0.88	3.69
*Cambodia	7291	9.03	807.74	4271	473.16	15.84	4.48	1.29	3.19
Afghanistan	5296	7.88	672.33	2051	260.37	16.02	3.48	1.94	1.54
India	621678	8.95	69488.3	516311	57710.88	19.06	3.33	1	2.33
Syearian Arab Republic	15729	12.21	1288.35	8280	678.24	.	3.19	3.25	-0.06
Kyeargyzstan	903	4.85	186.12	85	17.61	17.76	2.83	1.14	1.69
Iran	178662	18.46	9677.51	33611	1820.57	24.37	2.28	0.69	1.59
Viet Nam	42980	10.3	4171.74	29480	2861.37	11.41	2.15	0.76	1.39
*Pakistan	50582	9.03	5604.1	20492	2270.36	8.24	2.07	1.7	0.37
Indonesia	160569	9.5	16898.52	124898	13144.41	14.5	1.96	0.88	1.08
Lao PDR	1302	7.85	165.96	593	75.58	4.9	1.34	1.45	-0.11
China, mainland	1625937	11.42	142332.2	1423404	124602.8	14.56	1.29	0.15	1.14
Yemen	2980	8.51	350.3	96	11.33	.	0.93	1.99	-1.06
Nepal	1895	11.44	165.69	679	59.38	2.37	0.78	0.97	-0.19
Philippines	14810	9.41	1573.78	8450	897.93	5.24	0.54	1.35	-0.81
Armenia	203	5.18	39.3	86	16.65	1.93	0.37	-0.1	0.47
Malaysia	11280	10.28	1097.61	10361	1008.14	4.38	0.37	1.14	-0.77
*Saudi Arabia	19545	9.03	2165.48	20338	2253.34	14.81	0.34	1.38	-1.04
Bangladesh	4875	8.3	587.64	2653	319.78	1.94	0.3	0.95	-0.65
*Turkey	18463	9.03	2045.52	1241	137.52	3.34	0.28	0.67	-0.39
Japan	121255	10.72	11307.01	120094	11198.69	23.18	0.26	-0.37	0.63
Lebanon	1074	8.91	120.58	941	105.57	5.32	0.26	-1.01	1.27
Jordan	782	9.31	83.96	335	35.97	5.36	0.22	1.12	-0.9
Oman	992	10.13	97.97	1019	100.58	8.92	0.14	0.77	-0.63
Israel	3712	9.33	398.07	3310	354.94	.	0.13	1.42	-1.29
Republic of Korea	14546	10.14	1434.19	13666	1347.37	4.51	0.1	0.27	-0.17
Taiwan Province of China	4746	9.03	525.8	4440	491.96	.	0.1	-0.1	0.2
Azerbaijan	306	6.72	45.53	119	17.74	1.26	0.09	0.56	-0.47
Iraq	650	8.68	74.94	553	63.68	.	0.04	2.62	-2.58
Kuwait	264	9.91	26.62	308	31.06	3.7	0.02	1.52	-1.5

cent in Lebanon to 1.94 per cent in Afghanistan. Whereas the share of real annuity of the NPV to real GDP of these countries range between 0.26 per cent in Lebanon to 9.27 per cent in Myanmar. In other words, among the 12 countries, the smallest contribution of real annuity to the growth of real GDP per capita is 1.08 per cent in Indonesia in which the real annuity as percent of real GDP is 1.96 per cent and population is projected to grow at an annual rate of 0.88 per cent. Whereas the highest contribution of real annuity to real GDP per capita growth is 8.54 per cent in Myanmar with 9.27 per cent of real annuity as percent of real GDP and population growth rate of 0.73 per cent. Mainland China and India are among this group of countries and the contribution of real annuity of the NPV to real GDP per capita growth is estimated at about 1.14 per cent for mainland China and 2.33 per cent for India. This implies that investing in SLM technologies on agricultural lands of mainland China and India for avoiding top soil loss induced NPK losses and soil NPK depletions over the next 13 year would on average contribute real GDP per capita to grow by about 1.14 per cent and 2.33 per cent respectively.

In another 3 countries (Japan, Armenia, Pakistan) and Taiwan Province of China which have positive NPV, the contribution of real annuity to real GDP per capita growth is 0.63 per cent for Japan, 0.47 per cent for Armenia, 0.37 per cent for Pakistan, and 0.2 per cent for Taiwan Province of China. For the remaining 16 countries (Syearian Arab Republic, Lao PDR, Republic of Korea, Nepal, Turkey, Azerbaijan, Oman, Bangladesh, Malaysia, Philippines, Jordan, Saudi Arabia, Yemen, Israel, Iraq, and Kuwait) real annuity as percentage of real GDP ranges from 0.02 per cent in Kuwait (with population growth rate of 1.52 per cent) to 3.19 per cent in Syearian Arab Republic, which as a projected population growth rate of 3.25 per cent. In these countries, the projected population growth rate is higher than the real annuity as percentage of real GDP.

5.3. Implication to rural employment (SDG 8.5)

Target 8.5 of SDG number 8 states, *"By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value"*. The corresponding indicator 8.5.1 set is the average hourly earnings of female and male employees, by occupation, age and persons with disabilities (UN, n.d.). In order to assess the implication of achieving agricultural LDN to target 8.5, specifically *"achieving full productive employment"* we estimated the number of rural employment opportunities that investment in SLM technologies on agricultural lands of countries with positive NPV could generate over the remaining 13 years of the SDG time period as described below.

1. First, we estimated the annuity values of the present values of establishment and maintenance cost of SLM technologies (Table 4.1).

2. Based on the WOCAT data on establishment and maintenance costs that we used for developing econometric models of establishment and maintenance costs, labour cost on average is 44.4 per cent of the establishment cost and 75.68 per cent of the maintenance cost. We applied these ratios to calculate the annuity values of the PV of labour costs for establishment and maintenance of SLM technologies.

3. We estimated the number of rural job opportunities the annuity of the PV of labour cost estimated in step 2 above could generate at two alternative wage rates as lower-bound and upper-bound wage rates. We divided the annuity of the PV of total labour costs by the upper and lower bound wage rates to get the upper and lower bound number of job opportunities. We considered the international poverty line per capita daily income of USD 3.1 at PPP USD from World Bank database as the lower bound wage rate. Here for each country we calculated the corresponding annual lower and upper bound wage rate at current USD using the following formula:

    a. Lower bound wage rate in USD/person/year = (USD 3.10 in PPP/day * 365.25 Days/year)/ (Official Exchange Rate/ PPP conversion factor). We collected PPP conversion factor from Economy Watch (n.d.)

    b. Upper bound wage rate = Per capita GDP of 2015

TABLE 5.2

Implications costs of SLM technologies for rural employment

Country	A: Annuity of PV total establishment cost of SLM technologies (Millions of USD/ Year)	B: Annuity of PV total maintenance cost of SLM technologies (Millions of USD/ year)	C: Annuity of PV labour cost establishment of SLM technologies	D: Annuity of PV labour cost of maintenance of SLM technologies (Millions USD/year)	E = C+D: Annuity of (PVESMNT) PV labour cost of establishment and maintenance of SLM technologies (Millions USD/year)	F: Wage 1 = Per capita poverty line in USD/year/person based on 2015 prices	G = E/F: Number of rural jobs at wage 1 that PVESTMNT could generate (1000 Jobs/ year)	H: Wage 2 = GDP per capita in 2015 prices	E/H = Number of rural jobs at wage 2 that PVESTMNT could generate (1000 Jobs/year)
Myanmar	119	1430	53	1082	1135	519	2188	1161	977.33
Tajikistan	57	121	25	92	117	571	205	926	126.47
Uzbekistan	202	423	90	320	410	593	690	2232	183.47
Cambodia	48	454	21	344	365	377	968	1159	314.75
Afghanistan	119	210	53	159	212	550	385	594	356.29
India	5917	12273	2628	9288	11916	504	23700	1593	7479.26
Syrian Arab Republic	326	831	145	629	774	2065	375	2184	354.36
Kyeargyzstan	63	85	28	64	92	609	151	1106	83.16
Iran	952	3320	423	2513	2935	1357	2162	5376	545.96
Viet Nam	142	1526	63	1155	1218	392	3108	2072	587.91
Pakistan	979	2022	435	1530	1965	380	5171	1435	1369.58
Indonesia	384	4208	170	3185	3355	711	4720	3346	1002.56
Lao PDR	25	224	11	170	181	353	512	1818	99.42
China, mainland	5125	13775	2276	10425	12701	592	21500	8041	1579.61
Yemen	61	123	27	93	120	404	298	1406	85.50
Nepal	145	321	65	243	308	521	591	743	414.08
Philippines	182	1945	81	1472	1553	490	3166	2904	534.60
Armenia	48	75	21	57	78	730	107	3489	22.33
Malaysia	170	2165	75	1638	1714	689	2487	9768	175.44
Saudi Arabia	87	235	39	178	216	555	390	20482	10.57
Bangladesh	535	1016	238	769	1007	371	2710	1212	830.90
Turkey	2110	5289	937	4003	4940	1084	4559	9126	541.33
Japan	1026	3262	456	2469	2925	2312	1265	34629	84.46
Lebanon	72	176	32	133	165	630	262	8048	20.55
Jordan	37	87	17	66	83	467	177	4940	16.74
Oman	18	51	8	39	47	565	83	15551	3.01
Israel	152	431	68	326	394	1356	291	37130	10.61
Republic of Kore	596	1731	265	1310	1574	891	1767	27397	57.47
Taiwan Province of China	163	602	72	455	528	614	860	22393	23.57
Azerbaijan	185	363	82	275	357	670	533	5439	65.59
Iraq	424	978	188	740	928	499	1861	4944	187.73
Kuwait	9	29	4	22	26	769	34	29301	0.88
Total countries with +Ve NPV	20480	59779	9095	45243	54338	748	87275	8772	18146

The result in *Table 5.2* shows that the sum of annuities of the PV of labour costs of establishment and maintenance cost of SLM for the 31 countries and Taiwan Province of China that have positive NPV amounts to USD 80.26 billion of which 59.78 billion is in terms of labour cost for maintenance of SLM technologies. The lower bound average wage rate corresponding to the USD 3.1 PPP per day international poverty line for the 31 countries is estimated at USD 748 per person per year. At this level of wage, the USD 80.26 billion annuity of labour cost could generate about 87.26 million rural jobs per year in the 31 countries as an upper-bound job opportunities. Whereas if we consider the upper bound wage, which is the per capita 2015 GDP of each country, the average for the 31 countries was about USD 8,772 per person per year. At this wage rate, the USD 80.26 billion annuity of labour cost could generate about 18.15 million rural jobs per year in the 31 countries and Taiwan Province of China as a lower-bound job opportunities. The upper bound rural job opportunities range from 34,530 jobs per year in Kuwait to 23.7 millionjobs per year in India. India and mainland China together is 51.8 per cent of the total upper-bound job opportunities that investment in SLM technologies could generate. Fifteen out of the 31 countries with positive NPV (India,mainland China, Pakistan, Indonesia, Turkey, Philippines, Viet Nam, Bangladesh, Malaysia, Myanmar, Iran, Iraq, Republic of Korea, Japan, and Cambodia) is about 94.2 per cent of the total upper-bound job opportunities.

5.4. Implications for poverty reduction (SDG 1.1 and SDG 1.2)

In order to assess the implication of achieving agricultural land degradation neutrality to SDG 1, which aims at *"Ending poverty in all its forms everywhere (UN, n.d.)"*, we assessed how the annuity of the NPV would contribute to extreme poverty eradication and poverty reduction targets for 18 countries with national level poverty gap data and positive NPV as described below.

1. First we collected data on poverty gap index at USD 3.1 PPP of international poverty line from the World Bank database for 25 countries with poverty gap data reported for different years ranging from 2003 to 2014. Because such data is generated based on national level household consumption and income surveys, which are usually conducted every five years, we assumed these levels of national level poverty indicators as baseline.

2. We calculated annual poverty gap reduction rate by dividing the poverty gap by 12, where 12 indicates the number of years from 2019 to 2030 where flows of benefits from SLM intervention will realize.

3. We calculated the total cost of poverty gap reduction for each country and each year (2018 to 2030) as a product of the international poverty line per capita annual income, the cumulative annual poverty gap reduction rate, and projected total population of the year.

4. We estimated the PV of this total cost of poverty reduction and annuity of the cost using the same real discount rate used for the NPV analysis in *Chapter 4*.

5. We calculated the ratio of Annuity of the NPV in *Chapter 4* to annuity of the cost of poverty reduction and used as indicator of how the annuity of the NPV of investing in SLM on agricultural lands would provide countries with national income that could be possibly used for reducing poverty and achieving SDG 1.1 and 1.2.

SDG 1 indicates *"By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than USD 1.25 a day"* as target 1.1 whereas target 1.2 aims *"By 2030, reducing at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions (UN, n.d.)"*. The result in Table 5.3 shows that in 2015, about 318.5 million people were living below the international poverty line (per capita daily income of USD 3.10 PPP or on average per capita income below USD 504 per year for the 18 countries in 2013 prices. This is about 10.1 per cent of the total 3.78 billion people living in the 18 countries as of the 2015 population data from the FAO database. Assuming same level of poverty gap, which implies no action against poverty reduction, the total number of people under this international poverty line in the 18 countries will grow to about 442 million, indicating a cumulative 15.85 per cent increase than the number of people with income

TABLE 5.3

Implications for Poverty reduction

Country/region	A: Poverty gap in % based on per capita daily income of 3.1 PPP USD as poverty line	Year	B: Population below poverty line in 1000s as of 2015	C: Total population in 1000s that need to be lifted out of poverty by 2030	D: Poverty gap reduction rate in % per year	E: Poverty line per capita income in USD/year in 2013 prices	F: Present value of reducing poverty gap to zero by 2030 (in Millions of USD)	G: Annuity of NPV of investment on SLM technologies (in Millions USD/year)	H: Annuity of Present value of reducing poverty gap to zero by 2030 (in Millions USD/year)	Ratio of G to H (NPV/H)
Armenia	3.06	2014	92.34	91.58	0.26	625.38	123.38	39.30	23.84	1.65
Bangladesh	16.95	2010	27288.76	31604.95	0.25	372.24	46890.45	587.64	5651.89	0.10
China, mainland	2.52	2013	34676.43	35671.74	0.21	589.11	133190.00	142332.20	11659.26	12.21
Azerbaijan	0.60	2008	58.52	64.36	0.05	512.82	100.13	45.53	14.91	3.05
India	18.46	2011	242019.90	282005.70	1.54	460.24	571872.80	69488.30	63921.30	1.09
Indonesia	9.58	2014	24674.61	28307.16	0.80	555.38	75580.59	16898.52	7954.21	2.12
Iran	0.12	2013	94.93	106.23	0.01	861.61	1046.53	9677.51	56.69	170.72
Kyeargyzstan	2.98	2014	8.81	10.04	0.25	457.38	176.73	186.12	36.43	5.11
*Cambodia	4.05	2012	630.90	769.13	0.34	372.94	1264.36	807.74	140.08	5.77
Lao PDR	14.72	2012	1001.26	1249.65	1.23	340.60	1536.12	165.96	195.74	0.85
Malaysia	0.49	2009	148.62	176.92	0.04	555.90	519.59	1097.61	50.56	21.71
Nepal	14.68	2010	4185.81	4859.71	1.22	473.30	14107.80	165.69	1233.34	0.13
*Pakistan	8.55	2013	16153.08	20940.29	0.71	375.78	34105.91	5604.10	3778.69	1.48
Philippines	11.68	2012	11761.69	14433.62	0.97	457.39	30670.03	1573.78	3259.11	0.48
Tajikistan	17.42	2014	1477.54	1933.97	1.45	441.63	4395.47	417.77	429.05	0.97
*Turkey	0.54	2013	424.80	473.67	0.05	758.36	1620.65	2045.52	179.56	11.39
*Uzbekistan	46.39	2003	13867.59	15956.71	3.87	484.13	34742.29	3049.54	3849.19	0.79
Viet Nam	3.09	2014	2887.53	3251.31	0.26	378.04	6628.44	4171.74	643.37	6.48
Sum			381453	441907			958571	258355	103160	2.50

below this poverty line in 2015. The present value of the cost of reducing the poverty gap in the 18 countries by an average of 0.78 percentage points per year over the period 2018 to 2030, is estimated at about USD 958.6 billion with annuity of USD 103.2 billion. Whereas the sum annuity of NPV of investing in SLM technologies for avoiding top soil loss induced losses of NPK and soil NPK depletion and hence avoiding the corresponding crop production losses is about USD 258.4 billion, which in other words is 2.5 times the annuity of the PV of cost of poverty reduction. This implies that investing in SLM technologies and achieving agricultural land degradation neutrality would enable countries to have economic resources, which can enable them to reduce poverty gap to zero by 2030. For 12 countries (Armenia, Iran, Malaysia, mainland China, Turkey, Viet Nam, Cambodia, Kyeargyzstan, Azerbaijan, Indonesia, Pakistan, and India), the annuity of the NPV of investing in SLM is higher than the annuity of the PV of the cost of poverty reduction and the ratio of the two ranges from 1.1 in India to about 171 in Iran. For this countries the annuity of the NPV of investing in SLM would provide more than sufficient economic resource for reducing the poverty gap to zero by 2030. For the remaining 6 countries, the annuity of the NPV amounts to about 10 per cent of the annuity of the PV of cost of reducing poverty, which is for Bangladesh, to about 97 per cent in Tajikistan.

5.5. Implications on food security (SDG 2.3 and SDG 2.4)

In order to assess the implication of achieving agricultural land degradation neutrality to SDG 2, which aims at *"Ending hunger, achieve food security and improved nutrition and promote sustainable agriculture (UN, n.d.)"*, we developed an indicator, which is the domestic per capita food crop production with and without investment in SLM technologies in the next 13 year as described below.

1. Based on the results in *Table 2.9* of *Chapter 2* and the proportion of food crops to total aggregate

crop production data from FAOSATA, we estimated the baseline aggregate food crop production for each country based for the year 2002-2013. We assumed the average of the 12 years as baseline in the case of business as usual, where there will not be investment in SLM technologies and the same food crop production levels will continue over the period 2019 to 2030.

2. We calculated the per capita food crop production for each country for the period 2018 to 2030 by dividing the aggregate domestic food crop production data from step 1 above by the projected human population data for 2019-2030 from FAOSTAT database.

3. We also calculated the food gains due to avoided crop production losses form avoiding top soil loss induced NPK losses and soil NPK depletion by multiplying with the proportion of food crops to total aggregate crop production.

4. The gains in food crop per capita due to avoided production losses from avoiding top soil loss induced NPK losses and soil NPK depletions is calculated by dividing the result in step 3 with projected human population of 2019-2030.

The result in *Table 5.4* shows that the baseline per capita domestic food crop production at Asia level was 713 kg and this will decline to 639 kg by 2019. The figure will drop to 605 kg by 2025 and to 587 by 2030 under the business as usual case, which assumes no investment in SLM to avoid top soil loss induced NPK losses and the associated crop losses. Whereas if countries invest in SLM technologies on their agricultural lands the gain in per capita domestic food crop production will be about 293 kg by 2019, 280 kg by 2025 and 271 kg by 2030. This implies that investment in SLM to avoid topsoil loss induced production losses will increase the total per capita domestic food crop production to 858 kg at Asia level by 2030, which is 20.4 per cent higher than the baseline per capita domestic food production.

At country level, the baseline per capita domestic food crop production ranges from 4.2 kg in Singapore to 3193 kg in Malaysia. In fifteen countries and the two provinces of China (Georgia, Japan, Taiwan Province of China, Armenia, Thailand, China Hong Kong SAR, Republic of Korea, Sir Lanka, mainland China, Azerbaijan, Iran, Cyprus, Turkey, Indonesia, Kazakhstan, Lebanon, and Uzbekistan) investment in SLM technologies would result in increasing per capita domestic food production by rates higher than the average for Asia. In the above countries such an investment by 2030 would result in increased per capita domestic food production by about 21 per cent in Uzbekistan to close to 73.6 per cent in Georgia compared to the baseline per capita domestic food crop production.

By 2030, the per capita domestic food crop production in another 9 countries (Viet Nam, Bhutan, India, Myanmar, Mongolia, Malaysia, Kyeargyzstan, Cambodia, and Singapore) will increase by 12.86 per cent in Singapore to 18.36 per cent in Viet Nam compared to the baseline. Whereas in 11 countries (Lao PDR, Brunei Darussalam, Israel, Bangladesh, Philippines, Saudi Arabia, Pakistan, Syearian Arab Republic, Jordan, Nepal, and Tajikistan) it increases between 0.75 per cent in Tajikistan to 9.52 per cent in Lao PDR in comparison to the baseline. In the remaining 9 countries (Bahrain, Timor-Leste, Yemen, Afghanistan, Kuwait, Oman, Iraq, United Arab Emirates, and Qatar) even if this countries will go for investing in SLM technologies, per capita domestic food crop production will continue to decline. By 2030 the per capita food crop production level in these countries will be lower by at least 0.9 per cent in Bahrain to 30.1 per cent in Qatar than the baseline.

The above analysis imply that for almost 35 countries and the two provinces of China, investment in SLM technologies for achieving LDN in agriculture or SDG targets 15.3 can also increase per capita domestic food production and agricultural productivity and hence simultaneously achieve some of the elements of SDG 2.3 and 2.4. Target 2.3 requires countries to achieve *"by 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment"*. Whereas SDG 2.4 states *"by 2030 ensuring sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation*

TABLE 5.4

Implications to food security (Domestic food crop production per capita 2018-2030)

Country/region	Baseline per capita domestic food crop production in kg	Per capita domestic food crop production by 2019 BAU	Avoided per capita domestic food crop production losses in kg by 2019	Per capita domestic food crop production by 2025 BAU	Avoided per capita domestic food crop production losses in kg by 2025	Per capita domestic food crop production by 2030 BAU	Avoided per capita domestic food crop production losses in kg by 2030
Armenia	753.2	742.80	39.51	744.39	277.36	753.30	400.98
Afghanistan	281.8	211.46	11.01	183.79	68.43	168.47	89.61
Bahrain	33.5	24.25	1.33	22.27	8.71	21.30	11.90
Bangladesh	401.8	356.27	11.43	331.74	75.36	318.58	103.38
Bhutan	500.0	426.75	22.46	400.00	148.88	385.95	205.21
Brunei Darussalam	62.2	53.25	2.21	49.34	14.52	47.24	19.86
Myanmar	871.5	802.80	30.89	760.68	206.62	737.09	286.01
Sri Lanka	383.0	362.81	19.27	355.68	132.75	353.73	188.61
China, mainland	984.9	936.62	38.32	922.59	265.15	922.16	378.61
Cyprus	523.9	461.35	24.51	438.09	164.33	425.15	227.83
Azerbaijan	646.8	569.21	29.98	543.46	202.14	534.36	283.94
Georgia	359.9	397.00	21.10	400.99	149.32	407.81	216.95
China Hong Kong SAR	5.8	5.36	0.34	5.14	2.30	5.03	3.21
India	433.2	380.28	19.12	353.35	125.80	338.08	171.94
Indonesia	968.6	855.72	45.17	801.14	299.10	771.37	411.42
Iran	797.7	703.95	37.19	665.81	248.71	650.53	347.14
Iraq	325.1	236.60	12.24	196.77	73.21	173.94	92.45
Israel	576.7	476.28	25.24	430.30	162.11	402.79	216.78
*Kazakhstan	1499.0	1310.95	68.82	1232.41	457.40	1192.37	632.20
Japan	244.8	247.24	13.47	253.07	96.26	258.78	140.62
Jordan	343.5	256.27	13.77	239.43	91.10	224.66	122.11
Kyeargyzstan	795.5	679.91	35.69	624.36	232.59	595.30	316.80

*Cambodia	854.9	739.60	38.66	672.84	249.87	635.74	337.28
Republic of Korea	442.5	419.83	22.65	411.06	155.78	406.86	220.27
Kuwait	121.7	79.52	4.51	71.08	28.69	66.60	38.40
Lao PDR	897.9	761.81	39.78	684.56	254.41	642.35	341.03
Lebanon	592.9	410.27	22.20	456.82	171.42	466.86	250.26
Malaysia	3193.0	2737.20	144.99	2516.92	945.13	2393.33	1283.89
Mongolia	176.8	152.85	8.18	140.66	53.43	134.46	72.96
Nepal	555.6	494.55	13.25	459.78	87.21	441.03	119.50
*Pakistan	342.8	276.66	14.56	244.36	91.76	226.67	121.59
Philippines	675.7	575.46	24.35	521.90	156.86	490.55	210.62
Timor-Leste	316.0	255.05	13.28	222.84	82.88	204.29	108.55
Qatar	52.4	25.10	1.75	22.62	11.20	21.46	15.19
*Saudi Arabia	246.1	192.57	10.32	174.03	66.34	163.87	89.24
Singapore	4.2	3.42	0.18	3.22	1.17	3.12	1.62
Tajikistan	514.3	414.82	21.66	364.36	135.93	338.03	180.15
Syearian Arab Republic	648.2	631.51	32.41	481.37	179.30	429.47	228.53
Taiwan Province of China	320.4	313.38	17.23	314.89	121.19	317.36	174.49
Thailand	1291.3	1250.39	66.55	1246.36	465.01	1253.42	668.07
Oman	209.1	122.86	6.60	115.96	43.78	111.98	60.40
*Turkey	1204.8	1043.07	55.23	996.66	372.12	964.22	514.30
*United Arab Emirates	187.6	103.41	5.46	94.57	35.50	89.89	48.21
*Uzbekistan	741.5	646.36	34.22	603.80	226.33	583.75	312.59
Viet Nam	814.7	732.30	31.76	691.16	211.85	670.62	293.65
Yemen	124.1	95.61	4.97	82.87	30.82	75.67	40.20
Central Asia	940	805.19	423.11	745.62	396.75	715.59	380.76
East Asia	893	849.74	353.68	841.03	350.05	841.03	350.05
Southern Asia	438	380.18	185.03	350.81	173.00	334.50	164.95
South East Asia	1023	906.68	449.79	849.86	425.91	818.56	410.22
West Asia	630	511.74	269.77	460.91	246.78	431.47	231.02
ASIA	713	639.41	292.82	605.63	279.93	587.03	271.33

to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality (UN, n.d.)".

5.6. Implication for natural capital accounting

Earlier studies indicate that soils form very slowly and it takes between 200 and 1000 years to form 2.5 cm or 1 inch of topsoil under cropland conditions, and even longer under pasture and forest land conditions (Hudson, 1982; Lal, 1984; Pimentel et al., 1995) Integrating the value of soil and other interrelated natural resources, in the social accounting system requires an integrated valuation method. The overall study in general has a number of implications, both in terms of the methods applied and the results found, in contributing to efforts that aim at integrating natural capital accounting in the system of social accounting matrices. For example, the parameter estimates for the econometric models of land for soil nutrient loss and soil nutrient depletion as a function of national level biophysical and socio-economic factors can be used for estimating the effect of changes in forests and their biomass carbon stock as a natural capital on the level of soil nutrient and productivity of agricultural ecosystems. It can also be used to estimate how changes in size of economy and per capita GDP affect soil quality (nutrients) and hence estimate further the GDP of a country that is adjusted for land degradation. In other words if GDP growth leads to soil nutrient depletion, it implies in the conventional economic term that there is depreciation of the natural capital. That amount of depreciations has to be deducted from the GDP and hence land degradation adjusted GDP can be estimated. Thus, we can assess the implicit value of soil and the nutrients it contains and integrate the value in the social accounting system.

5.7. Conclusions

The above sections of this chapter highlighted that investment in SLM technologies for achieving SDG 15.3 in Asian countries would contribute to achieving a number of related Sustainable Development Goals.

Economics Growth (SDG 8.1): Investing on SLM technologies to avoid top soil loss induced NPK losses and soil NPK depletions and the associated losses in aggregate crop yield would result the economies of 31 Asian countries with positive NPV to grow by an average rate of 0.02 to 9.27 per cent per year over until 2030.

Rural Employment (SDG 8.5): Close to 80.3 billion USD per year in present value is required as labor cost to establish and maintain SLM technologies on agricultural lands of 31 Asian countries with positive NPV. At a lower bound average wage rate of USD 748 per person per year, which corresponds to PPP USD 3.1 per day international poverty line for the 31 countries, the USD 80.26 billion annuity of labor cost could generate about 87.26 million rural jobs annually in the 31 countries over the next 13 years.

Poverty reduction (Sustainable Development Goals 1.1 and 1.2): The sum annuity of NPV of investing in SLM technologies for avoiding top soil loss induced losses of NPK and soil NPK depletion and hence avoiding the corresponding crop production losses in 18 countries is about USD 258.4 billion. This NPV is 2.5 times the annuity of the PV of cost of reducing poverty gap in this countries to zero by 2030 and lifting close to 442 million people up to a daily income level of the 3.10 PPP USD.

Food Security (Sustainable Development Goals 2.3 and 2.4): Investment in SLM to avoid topsoil loss induced crop production losses will increase the total per capita domestic food crop production from 713 to 858 kg at Asia level by 2030. This implies that with the growing population it is still possible to increase per capita domestic food production and agricultural productivity and hence simultaneously achieve some of the elements SDG 2.3 and 2.4.

Natural Capital Accounting: The methods applied in this study highlighted soil and its nutrients as natural capital could be accounted in the national accounting system of nations and depreciations in such natural capital can be estimated and deducted from the conventional GDP and hence land degradation adjusted GDP can be estimated.

Conclusions

Achieving Sustainable Development Goal 15.3 through investments in sustainable land management on the 487 million hectares of land in Asia over the next 13 years would allow a considerable number of Asian countries to achieve a number of other related Sustainable Development Goals. These include:

SDG 8.1 states: "Sustain **per capita economic growth** in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries (UN, 2017a)" with the corresponding indictaor 8.1.1 "Annual growth rate of real GDP per capita".

- For 31 Asian countries and Taiwan Province of China that have positive NPV, the **real annuity of the NPV as percentage of real GDP of 2015 ranges from 0.02 per cent in Kuwait to 9.27 per cent in Myanmar.** Whereas the real annuity as percentage of agricultural GDP for countries with positive NPV ranges from 1.26 per cent in Azerbaijan to 34.67 per cent in Myanmar. This implies that investing in SLM technologies to avoid top soil loss induced NPK losses and soil NPK depletions and the associated losses in aggregate crop yield would result the economies of these countries and their agricultural sector to grow by the above indicated rates.

- In 12 countries (Myanmar, Uzbekistan, Tajikistan, Cambodia, India, Kyeargyzstan, Iran, Afghanistan, Viet Nam, Lebanon, mainland China, and Indonesia) with positive NPV, the smallest contribution of real annuity to the growth of real GDP per capita is 1.08 per cent. This is in Indonesia in which the real annuity as percent of real GDP is 1.96 per cent and population is projected to grow at an annual rate of 0.88 per cent. Whereas the **highest contribution of real annuity to real GDP per capita growth is 8.54 per cent in Myanmar that has 9.27 per cent of real annuity as percent of real GDP and population growth rate of 0.73 per cent.** Mainland China and India are among this group of countries and the contribution of real annuity of the NPV to real GDP per capita growth is estimated at about 1.14 per cent for mainland China and 2.33 per cent for India. This implies that investing in SLM technologies on agricultural lands of China mainland and India for avoiding top soil loss induced NPK losses and soil NPK depletions over the next 13 year would on average contribute real GDP per capita to grow by about 1.14 per cent and 2.33 per cent respectively.

SDG 8.5 states, "By 2030, achieve **full and productive employment** and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value". The corresponding indicator 8.5.1 set is the average hourly earnings of female and male employees, by occupation, age and persons with disabilities (UN, 2017a).

- The **sum of annuities of the PV of labour costs of establishment and maintenance cost of SLM** for the 31 countries with positive NPV amounts to **USD 80.26 billion** of which **59.78 billion is in terms of labour cost** for maintenance of SLM technologies. The lower bound average wage rate corresponding to the 3.1 PPP USD/day international poverty line for the 31 countries is estimated at 748 USD per person per year. At this level of wage, the USD 80.26 billion annuity of labour cost could generate about 87.26 million rural jobs per year in the 31 countries as upper-bound job opportunities. The **upper bound rural job opportunities** range from **34,530 jobs per year in Kuwait to 23.7 million jobs per year in India.** India and mainland China together account for 51.8 per cent of the total upper-bound job opportunities that investment in SLM technologies could generate. Fifteen out of the 31 countries with positive NPV (India, mainland China, Pakistan, Indonesia, Turkey, Philippines, Viet Nam, Bangladesh, Malaysia, Myanmar, Iran, Iraq, Republic of Korea, Japan, and Cambodia) account for about 94.2 per cent of the total upper-bound job opportunities.

SDG 1.1 indicates "By 2030, **eradicate extreme poverty** for all people everywhere, currently measured as people living on less than USD 1.25 a day" whereas **SDG 1.2** aims "By 2030, **reducing** at least by half the proportion of men, women and children of all ages living in **poverty** in all its dimensions according to national definitions (UN, 2017a)."

- The **present value of the cost of reducing the poverty gap** by an average of 0.78 percentage points per year in the 18 countries over the period 2018 to 2030 is estimated at about **USD 959 billion** with annuity of 103 billion. These countries include Armenia, Bangladesh, mainland China, Azerbaijan, India, Indonesia, Iran, Kyeargyzstan, Cambodia, Lao PDR, Malaysia, Nepal, Pakistan, Philippines, Tajikistan, Turkey, Uzbekistan, and Viet Nam. Whereas **the sum annuity of NPV of investing in SLM technologies is about 258.4 billion USD**, which in other words is **2.5 times the annuity of the PV of cost of poverty reduction**. This implies that by 2030, **investing in SLM technologies** and achieving agricultural land degradation neutrality would enable countries to have economic resources, which can enable them to **reduce the poverty gap to zero by 2030.**

SDG 2 aims to "**Ending hunger**, achieve food security and improved nutrition and promote sustainable agriculture (UN, 2017a)." Moreover, SDG 2.3 requires countries to achieve "by 2030, **double the agricultural productivity** and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment". Whereas SDG 2.4 states "by 2030 **ensuring sustainable food production systems** and implement resilient agricultural practices that **increase productivity and production**, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality (UN, 2017a)."

- The **baseline per capita domestic food crop production at Asia level was 713 kg** and will decline to 639 kg by 2019. **The figure will further drop** to 605 kg by 2025 and **to 587 by 2030 under the business as usual case,** which assumes no investment in SLM to avoid top soil loss induced NPK losses and the associated crop losses. Whereas **if countries invest in SLM technologies** on their agricultural lands the **gain in per capita domestic food crop production** will be about 293 kg by 2019, 280 kg by 2025 and **271 kg by 2030.** This implies that **investment in SLM** to avoid topsoil loss induced production losses **will increase the total per capita domestic food crop production to 858 kg at Asia level by 2030**, which is 20.4 per cent higher than the baseline per capita domestic food production. At country level, the baseline per capita domestic food crop production ranges from 4.2 kg in Singapore to 3,193 kg in Malaysia.

- **For almost 35 countries and the two provinces of China,** investment in SLM technologies for achieving LDN in agriculture or SDG 15.3, **it is also possible to increase per capita domestic food production and agricultural productivity** and hence simultaneously achieve some of the elements of **SDG 2.3 and 2.4.**

In conclusion, this study clearly indicates that in addition to achieving Sustainable Development Goal 15.3, which aims at achieving a land degradation neutral world, investment in sustainable land management on agricultural lands in the next decade (2018-2030) would enable most Asian countries covered in this study to achieve a number of other related Sustainable Development Goals. These include economic growth and employment creation (SDG 8.1 and 8.5), eradicating extreme poverty and reduction of poverty (SDG 1.1 and 1.2), achieving food security through doubling agricultural productivity and income as well as ensuring sustainable food production systems (SDG 2.3 and 2.4). Moreover, the results of this study are an important contribution in providing the methods and results for integrating particularly the value of soil as natural capital in the nations' social accounting matrices of nations.

References

Arrow, K., Cline, W.R., Maler, K.-G., Munasinghe, M., Squitieri, R., & Stiglitz, J.E. (1995). Intertemporal equity, discounting, and economic efficiency. *Climate Change 1995 – Economic and Social Dimensions of Climate Change*, 125–144.

Bai, Z.G., Dent, D.L., Olsson, L., & Schaepman, M.E. (2008). Proxy global assessment of land degradation. *Soil Use and Management, 24*(3), 223–234.

Baum, S. (2009). Description, Prescription and the Choice of Discount Rates. *Ecological Economics, 69*(1), 197–205.

Bhattacharyya, R., Ghosh, B., Mishra, P., Mandal, B., Rao, C., Sarkar, D., Das, K., Anil, K., Lalitha, M., Hati, K., Franzluebbers, A. (2015). Soil Degradation in India: Challenges and Potential Solutions. *Sustainability, 7*(12), 3528–3570.

Bradford, D. (1975). Constraints on Government Investment Opportunities and the Choice of Discount Rate. *American Economic Review, 65*(5), 887–899.

Central Asian Countries Initiative on Land Management (CACILM). (2016). Addressing Land Degradation in Central Asia: Challenges and Opportunities (Policy Brief).

Chakravarty, S., K., S., P., C., N., A., & Shukl, G. (2012). Deforestation: Causes, Effects and Control Strategies. In C.A. Okia (Ed.), *Global perspectives on sustainable forest management.* Rijeka, Croatia: InTech.

Commission on Sustainable Development (CSD). (1996). Progress Report on Chapter 10 of Agenda 21. New York, USA: United Nations.

Common, M.S., & Stagl, S. (2005). *Ecological economics: An introduction* (3. printing). Cambridge: Cambridge Univ. Press.

Convention on Biological Diversity (CBD). (n.d.). Aichi Biodiversity Targets. Retrieved from https://www.cbd.int/sp/targets/default.shtml

Dasgupta, P. (2008). Discounting climate change. *Journal of Risk and Uncertainty, 37*(2-3), 141–169.

Deng, X., & Li, Z. (2016). Economics of Land Degradation in China. In E. Nkonya, A. Mirzabaev, & J. von Braun (Eds.), *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development*. Cham: Springer International Publishing.

Diamond, P. (1968). Opportunity Cost of Public Investment: Comment. *The Quarterly Journal of Economics, 84,* 682–688.

Diamond, P., & Mirrlees, J. (1971). Optimal Taxation and Public Production: I-Production Efficiency. *American Economic Review, 61*(1), 8–27.

Dobermann, A., Santa Cruz, P.C., & Cassman, K.G. (1995). Potassium balances and soil potassium supplying power in intensive irrigated rice ecosystems. In (pp. 199–229).

Economics of Land Degradation Initiative (ELD). (2015). Report for policy and decision makers: Reaping economic and environmental benefits from sustainable land management. Bonn, Germany.

Economics of Land Degradation Initiative (ELD). (2016). Central Asia Report. Bonn, Germany.

Economics of Land Degradation Initiative (ELD), & United Nations Environment Program (UNEP). (2015). The Economics of Land Degradation in Africa: Benefits of Action Outweigh the Costs: A complementary report to the ELD Initiative. Bonn, Germany.

Economy Watch. (n.d.). Economy Watch: Follow the Money. Retrieved from http://www.economywatch.com/

Eswaran, H., Lal, R., & Reich, P.F. (2001). Land degradation: an overview. In E.M. Bridges, I.D. Hannam, L.R. Oldeman, F. Penin de Vires, S.J. SCherr, & S. Sompatpanit (Eds.), *Responses to Land Degradation: Proc. 2nd International Conference on Land Degradation and Desertification, Khon Kaen, Thailand.* New Delhi, India: Oxford Press.

European Environment Agency (EEA). (2016). The DPSIR framework. Retrieved from https://www.eea.europa.eu/publications/92-9167-059-6-sum/page002.html

Feldstein, M. (1972). “The Inadequacy of Weighted Discount Rates”. In R. Layard (Ed.), *Cost–Benefit Analysis.* Middlesex, UK: Penguin Books.

Food and Agriculture Organization of the United Nations (FAO). (n.d.). Soil degradation. Retrieved from http://www.fao.org/soils-portal/soil-degradation-restoration/en

Food and Agriculture Organization of the United Nations (FAO). (2016). Integrated policy for forests, food security and sustainable livelihoods: Lessons from the Republic of Korea. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO). (2017). FAOSTAT. Retrieved from http://www.fao.org/faostat/en/#data

Gibbs, H.K., & Salmon, J.M. (2015). Mapping the world's degraded lands. *Applied Geography, 57*, 12–21.

Giger, M., Liniger, H., Sauter, C., & Schwilch, G. (2015a). Economic Benefits and Costs of Sustainable Land Management Technologies: An Analysis of WOCAT's Global Data. *Land Degradation & Development, 52.*

Giger, M., Liniger, H., & Schwilch, G. (2015b). *Economic Benefits and Costs of Technologies for Sustainable Land Management (SLM): A Preliminary Analysis of Global WOCAT Data.*

Global Land Cover Facility. (2017). MODIS Land Cover. Retrieved from http://glcf.umd.edu/data/lc/

Gomiero, T. (2016). Soil Degradation, Land Scarcity and Food Security: Reviewing a Complex Challenge. *Sustainability, 8*(3), 281.

Henao, J., & Baanante, C.A. (1999). *Estimating rates of nutrient depletion in soils of agricultural lands of Africa.* Alabama, USA: Citeseer.

Hudson, N. (1982). Cornell paperbacks. *Soil conservation* (2nd ed.). Ithaca, N.Y.: Cornell University Press.

International Soil Reference and Information Centre (ISRIC). (1990). Global Assessment of Human-induced Soil Degradation (GLASOD). Retrieved from http://www.isric.org/projects/global-assessment-human-induced-soil-degradation-glasod

Jahnke, H.E. (1982). Livestock Production Systems and Livestock Development in Tropical Africa. Kieler Wissenschaftsverlag Vauk, Kiel, Germany

Jarvis, L.S. (1991). Overgrazing and Range Degradation in Africa: The Need and the Scope for Government Control of Livestock Numbers. *East Africa Economic Review, 7*(1).

Kay, J. (1972). Social Discount Rate. *Journal of Public Economics, 1,* 259–378.

Khor, M. (2011). Land Degradation Causes $10 Billion Loss to South Asia Annually. Retrieved from https://www.globalpolicy.org/global-taxes/49705-land-degradation-causes-10-billion-loss-to-southasia-%20annually-.html

Khuldorj, B., Bum-Ayush, M., Dagva, S., Myagmar, D., & Shombodon, D. (2012). Mongolia's Sustainable Development Agenda; Progresses, Bottelnecks and Vision for the Future. Ulaanbaatar, Mongolia.

Krishnapillay, D.B., Kleine, M., Rebugio, L.L., & Lee, D.K.J. (2007). Rehabilitation of Degraded Forest Lands in Southeast Asia – A Synthesis. *Keep Asia Green - Volume I "Southeast Asia",* 7–20.

Krutilla, J.V. (1967). Conservation Reconsidered. *The American Economic Review, 57*(4), 777–786.

Lager, B. (2015). Agroforestry is taking root in North Korea. Retrieved from https://www.siani.se/blog/agroforestry-taking-root-north-korea/

Lal, R. (1984). Productivity assessment of tropical soils and the effects of erosion. In F.R. Rijsbermans & M.G. Wolman (Eds.), *Quantification of the Effect of Erosion on Soil Productivity in an International Context* (pp. 70–94). Delft, Netherlands: Delft Hydraulics Laboratory.

Lal, R., & Stewart, B.A. (Eds.). (2013). *Advances in soil science. Principles of sustainable soil management in agroecosystems.* Boca Raton, London, New York: CRC Press.

Lind, R. (1982). A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Option. R. Lind, k. Arrow, G. Corey, P. Dasgupta, A. Sen, T. Stauffer, J.E. Stiglitz, J.A. Stockfisch, R. Wilson (Eds.), *Discounting for Time and Risk in Energy Policy.* Washington DC, USA: Resources for the Future.

Liniger, H.P., Studer, R.M., Hauert, C., & Gurtner, M. (2011). Sustainable Land Management in Practice – Guidelines and Best Practices for Sub-Saharan Africa.

Marglin, S.A. (1963). The Opportunity Costs of Public Investment. *The Quarterly Journal of Economics, 77*(2), 274–289.

Millenium Ecosystem Assessment (MEA). (2005). Ecosystems and Human Well-Being: Synthesis. Washington DC, USA: Island Press.

Mirzabaev, A. (2014, November). *IPBES Thematic Assessment of Land Degradation and Restoration.* 3. Nationales Forum zu IPBES, University of Bonn.

Mirzabaev, A., Goedecke, J., Dubovyk, O., Djanibekov, U., Bao Le, Q., & Aw-Hassan, A. (2016). Economics of Land Degradation in Central Asia. In E. Nkonya, A. Mirzabaev, & J. von Braun (Eds.), *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development* (261-290). Cham: Springer International Publishing.

Montanarella, L., Pennock, D. J., McKenzie, N., Badraoui, M., Chude, V., Baptista, I., Mamo, T., Yemefack, M., Aulakh, S. M., Yagi, K., Young H. S., Vijarnsorn, P., Zhang, G.-L., Arrouays, D., Black, H., Krasilnikov, P., Sobocká, J., Alegre, J., Henriquez, C.R., de Lourdes Mendonça-Santos, M., Taboada, M., Espinosa-Victoria, D., AlShankiti, A., AlaviPanah, S. K., Elsheikh, E. A. E. M., Hempel, J., Camps Arbestain, M., Nachtergaele, F., Vargas, R. (2016). World's soils are under threat. SOIL, 2(1), 79–82.

Moore, M.A., Boardman, A.E., Vining, A.R., Weimer, D.L., & Greenberg, D.H. (2004). "Just give me a number!": Practical values for the social discount rate. *Journal of Policy Analysis and Management, 23*(4), 789–812.

Mutert, E.W. (1996). Plant Nutrient Balances in Asia and Pacific Region: Facts and Consequences for Agricultural Production. In (pp. 73–112).

National Aeronautics and Space Administration (NASA). (n.d.). Earth Observatory. Retrieved from https://earthobservatory.nasa.gov/

Nkonya, E., Braun, J. von, Mirzabaev, A., Le, Q.B., Kwon, H.Y., & Kirui, O. (2013). Economics of Land Degradation Initiative: Methods and Approach for Global and National Assessments (ZEF - Discussion Papers on Development Policy No.183).

Nkonya, E., Gerber, N., Braun, J. von, & Pinto, A. de. (2011). Economics of land degradation: The costs of action versus inaction, 68 (Issue briefs). Washington DC, USA.

Noel, S., & Soussan, J. (2010). Economics of Land degradation: Supporting Evidence-Based Decision Making – Methodology for Assessing Costs of Degradation and Benefits of Sustainable Land Management: Paper commissioned by teh Global Mechanism of the UNCCD to the Stockholm Environment Institute (SEI). Bonn, Germany.

Oldeman, L.R. (1992). Global Extent of Soil Degradation: ISRIC Bi-Annual Report 1991-1992.

Orr, B. J., Cowie, A. L., Castillo Sanchez, V. M., Chasek, P., Crossman, N. D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G. I., Minelli, S., Tengberg, A. E., Walter, S., Welton, S. (2017). Scientific Conceptual Framework for Land Degradation Neutrality: A Report of the Science-Policy Interface. Bonn, Germany.

Pearce, D.W. (1993). *Economic values and the natural world.* Cambridge, Mass.: MIT Press.

Perman, R., Ma, Y., Common, M.S., Maddison, D., & McGilvray, J. (2011). *Natural resource and environmental economics* (4th edition). Harlow, England, London, New York, Boston, San Francisco, Toronto, Sydney, Tokyo, Singapore, Hong Kong, Seoul, Taipei: Addison Wesley Pearson.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R.

(1995). Environmental and economic costs of soil erosion and conservation benefits. Science, 267(5201), 1117–1123.

Plottu, E., & Plottu, B. (2007). The concept of Total Economic Value of environment: A reconsideration within a hierarchical rationality. *Ecological Economics, 61*(1), 52–61.

Ramsey, F.P. (1928). A Mathematical Theory of Saving. *The Economic Journal, 38*(152), 543–559.

Schakirow, A. (2016). Kasachstan schenkt dem Aralsee ein neues Leben. Retrieved from http://newsderwoche.de/welt/asien/524-kasachstan-schenkt-dem-aralsee-ein-neues-leben.html

Schoene, D., Killmann, W., Lüpke, H. von, & LoycheWilkie, M. (2007). Definitional issues related to reducing emissions from deforestation in developing countries, 5 (Forests and Climate Change Working Paper). Rome, Italy.

Sen, A. (1961). On Optimizing the Rate of Saving. *Economic Journal, 71*, 479–496.

Sheldrick, W.F., Syers, J.K., & Lingard, J. (2002). A conceptual model for conducting nutrient audits at national, regional, and global scales. *Nutrient Cycling in Agroecosystems, 62*(1), 61–72.

Squires, V. (2009). Land Degradation and teh Food Crisis in the ASEAN Region. Adelaide, Australia.

Stern, N. (2008). The Economics of Climate Change. *American Economic Review, 98*(2), 1–37.

Stibig, H.-J., Achard, F., Carboni, S., Raši, R., & Miettinen, J. (2014). Change in tropical forest cover of Southeast Asia from 1990 to 2010. *Biogeosciences, 11*(2), 247–258.

Stoorvogel, J., & Smaling, E.M.A. (1990). Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000, 28 (Report). Wageningen, The Netherlands.

Svensson, I. (2008). The Land Degradation Assessment in Drylands (LADA) Project. Wageningen, The Netherlands.

Tan, Z.X., Lal, R., & Wiebe, K.D. (2005). Global Soil Nutrient Depletion and Yield Reduction. *Journal of Sustainable Agriculture, 26*(1), 123–146.

The World Bank. (2017). World Bank Open Data. Retrieved from https://data.worldbank.org/

Tsogtbaatar, J. (2004). Deforestation and reforestation needs in Mongolia. *Forest Ecology and Management, 201*(1), 57–63.

United Nations (UN). (2017a). Revised list of global Sustainable Development Goal indicators. Retrieved from https://unstats.un.org/Sustainable Development Goals/indicators/Official%20Revised%20List%20of%20global%20SDG%20indicators.pdf

United Nations (UN). (n.d.). Sustainable Development Knowledge Platform. Retrieved from https://sustainabledevelopment.un.org/topics/desertificationlanddegradationanddrought

United Nations (UN). (2017b). World Population Prospects: Key findings & advance tables [2017 Revision]. New York, USA. https://esa.un.org/unpd/wpp/publications/Files/WPP2017_KeyFindings.pdf

United Nations Convention to Combat Desertification (UNCCD). (n.d. a). About the Convention. Retrieved from http://www2.unccd.int/convention/about-convention

United Nations Convention to Combat Desertification (UNCCD). (n.d. b). Combating desertification in Asia. Retrieved from http://www.unccd.int/en/regional-access/Asia/Pages/default.aspx

United Nations Convention to Combat Desertification (UNCCD). (2012a). Combating desertification in Asia. Bonn, Germany.

United Nations Convention to Combat Desertification (UNCCD). (2014a). Desertification: The invisible frontline. Bonn, Germany. http://www2.unccd.int/sites/default/files/documents/12112014_Invisible%20frontline_ENG.pdf

United Nations Convention to Combat Desertification (UNCCD). (2014b). Land Degradation Neutrality: resilience at local, national and regional levels. Bonn, Germany.

United Nations Convention to Combat Desertification (UNCCD). (2014c). The Land in Numbers: Livelihoods at a Tipping Point. Bonn, Germany.

United Nations Convention to Combat Desertification (UNCCD). (2016b). Unlocking the market for land degradation neutrality. Bonn, Germany.

United Nations Convention to Combat Desertification (UNCCD). (2017). Global Land Outlook: First Edition. Bonn, Germany. http://www2.unccd.int/sites/default/files/documents/2017-09/GLO_Full_Report_low_res.pdf

United Nations Environment Assembly (UNEA). (2016). Land Degradation, Desertification "Most Critical Challenges" in West Asia, as Rolling Conflicts Damage Environment, Human Health.

United Nations Environment Program (UNEP). (2016). GEO-6 Regional Assessment for Asia and the Pacific. Nairobi, Kenya.

United Nations Environment Program (UNEP), World Meterological Organisation (WMO), & United Nations Convention to Combat Desertification (UNCCD). (2016). Global Assessment of Sand and Dust Storms. Nairobi, Kenya.

United Nations Geographic Information Working Group (UNGIWG). (n.d.). Home. Retrieved from http://www.ungiwg.org/

United States Geological Survey (USGS). (n.d.). US: Geological Survey. Retrieved from https://www.usgs.gov/

Viek, P.L.G., Khamzina, A., & Tamene L. (Eds.). (2017). *Land degradation and the Sustainable Development Goals: Threats and potential remedies*. Nairobi, Kenya.

Weisbrod, B.A. (1964). Collective-Consumption Services of Individual-Consumption Goods. *The Quarterly Journal of Economics, 78*(3), 471.

World Overview of Conservation Approaches and Technologies (WOCAT). (n.d.a). Global Database on Sustainable Land Management. Retrieved from https://qcat.wocat.net/en/wocat/

World Overview of Conservation Approaches and Technologies (WOCAT). (n.d.b). WOCAT & SLM. Retrieved from https://www.wocat.net/wocat-slm

Xianqing, L., Cunshan, Y., & Dehai, X. (1996). Input and output of soil nutrients in high- yield paddy fields in South China. In *Proceedings of the International Symposium on Maximizing Rice Yields through Improved Soil and Environmental Management* (pp. 93–97).

Young, A. (1994). *Land degradation in South Asia: Its severity, causes and effects upon the people*. Rome, Italy.

Zhuang, J., Liang, Z., Lin, T., & Guzman, F. de. (2007). Theory and Practice in the Choice of Social Discount Rate for Cost-Benefit Analysis: A Survey, 94 (ERD Working Paper Series).

List of figures

List of tables

List of boxes

Appendix

(Note: Statistical tables compiled by FAO provide data on land use changes, crop production and forest carbon which could be used as a proxy indicators for land cover change, land productivity and soil organic carbon)

Changes in land use, cereal crops, livestock, and carbon by region and country
(CA = Central Asia, EA = Eastern Asia, SA = Southern Asia, SEA = South East Asia, WA = West Asia)

TABLE A1

Change in Asia land 'use' area (1,000 ha) by region and country, 2000 – 2013

Region	Country	Country area			Land area			Agricultural area			Forest area			Other land		
		2000	2013	Change	2000	2013	Change	2000	2013	Change	2000	2013	Change	2000	2013	Change
CA	**Kazakhstan**	272,490.20	272,490.20	0	269,970	269,970	0	215,393.30	216,994.10	1,601	3,365	3,309	-56	51,211.70	49,666.90	-1,545
CA	**Tajikistan**	14,255	14,255	0	13,996	13,996	0	4,573	4,875	302	410	411.2	1	9,013	8,709.80	-303
CA	**Kyeargyzstan**	19,995	19,994.90	0	19,180	19,180	0	10,714	10,585.80	-128	858.3	653	-205	7,607.70	7,941.20	334
CA	**Uzbekistan**	44,740	44,740	0	42,540	42,540	0	27,325	26,770	-555	3,212	3,242.14	30	12,003	12,527.86	525
CA	**Turkmenistan**	48,810	48,810	0	46,993	46,993	0	35,500	33,838	-1,662	4,127	4,127	0	7,366	9,028	1,662
EA	**China, mainland**	956,292	956,291.10	-1	938,822	938,821.10	-1	522,003	514,553	-7,450	177,000.50	205,236.90	**28,236**	242,608.50	221,875.13	**-20,733**
EA	**Taiwan Province of China**	3,596	3,596	0	3,541	3,541	0	851	800	-51	0	0	0	0	0	0
EA	**Hong Kong SAR**	110	110	0	105	105	0	7	5.1	-2	0	0	0	0	0	0
EA	**China, Macao SAR**	2	3.03	1	2	3.03	1	0	0	0	0	0	0	0	0	0
EA	**Republic of Korea**	9,926	10,026.60	101	9,646	9,746.60	**101**	1,973	1,768.70	-204	6,288	6,199.20	-89	1,385	1,778.70	394
EA	**Japan**	37,780	37,796.20	16	36,450	36,456	6	5,258	4,537	-721	24,876	24,961.20	85	6,316	6,957.80	642
EA	**Democratic People's Republic of Korea**	12,054	12,054	0	12,041	12,041	0	2,550	2,630	80	6,933	5,285	-1,648	2,558	4,126	1,568
EA	**Mongolia**	156,412	156,412	0	155,356	155,356	0	130,470	113,309.90	**-17,160**	11,717	12,747.36	1,030	13,169	29,298.74	**16,130**
SA	**India**	328,726	328,726	0	297,319	297,319	0	180,975	180,280	-695	65,390	70,325.20	4,935	50,954	46,713.80	-4,240
SA	**Bhutan**	4,007.70	3,839.40	-168	3,980	3,811.70	-168	530	519.6	-10	2,606	2,735.08	129	844	557.02	-287
SA	**Sri Lanka**	6,561	6,561	0	6,271	6,271	0	2,350	2,740	390	2,192	2,083.20	-109	1,729	1,447.80	-281
SA	**Afghanistan**	65,286	65,286	0	65,286	65,286	0	37,753	37,910	157	1,350	1,350	0	26,183	26,026	-157
SA	**Maldives**	30	30	0	30	30	0	9	7.9	-1	1	1	0	20	21.1	1
SA	**Bangladesh**	14,846	14,846	0	13,017	13,017	0	9,400	9,108	-292	1,468	1,434.20	-34	2,149	2,474.80	326
SA	**Nepal**	14,718	14,718	0	14,335	14,335	0	4,249.10	4,121	-128	3,900	3,636	-264	6,185.90	6,578	392
SA	**Pakistan**	79,610	79,610	0	77,088	77,088	0	36,698	36,280	-418	2,116	1,558	-558	38,274	39,250	976
SA	**Iran (Islamic Republic of)**	174,515	174,515	0	162,855	162,855	0	62,884	46,161	-16,723	9,325.66	10,691.98	1,366	90,645.34	106,002.02	15,357
SE	**Viet Nam**	32,924	33,097.20	173	31,106	31,007	-99	8,780	10,873.70	2,094	11,727	14,515	2,788	10,599	5,618.30	-4,981

SE	**Indonesia**	191,093	191,093	0	181,157	181,157	0	47,177	57,000	**9,823**	99,409	92,378.80	**-7,030**	34,571	31,778.20	-2,793
SE	**Lao People's Democratic Republic**	23,680	23,680	0	23,080	23,080	0	1,806	2,335	529	16,525.99	18,383.07	1,857	4,748.01	2,361.93	-2,386
SE	**Philippines**	30,000	30,000	0	29,817	29,817	0	11,234	12,440	1,206	7,027	7,560	533	11,556	9,817	-1,739
SE	**Thailand**	51,312	51,312	0	51,089	51,089	0	19,834	22,110	2,276	17,011	16,339	-672	14,244	12,640	-1,604
SE	**Malaysia**	33,080	33,080	0	32,855	32,855	0	7,021.30	7,839	818	21,591	22,166.60	576	4,242.70	2,849.40	-1,393
SE	**Singapore**	68	71.7	4	67	70.7	4	1.2	0.67	-1	16.35	16.35	0	49.45	53.68	4
SE	**Brunei Darussalam**	577	577	0	527	527	0	10	14.4	4	397	380	-17	120	132.6	13
SE	**Timor-Leste**	1,487	1,487	0	1,487	1,487	0	337	380	43	854	708.4	-146	296	398.6	103
SE	**Cambodia**	18,104	18,104	0	17,652	17,652	0	4,770	5,800	1,030	11,546	9,711.80	-1,834	1,336	2,140.20	804
SE	**Myanmar**	67,659	67,659	0	65,354	65,308	-46	10,812	12,587	1,775	34,868	30,133.80	-4,734	19,674	22,587.20	2,913
WA	**Iraq**	43,832	43,524	**-308**	43,737	43,432	**-305**	8,300	9,230	930	818	825	7	34,619	33,377	-1,242
WA	**Armenia**	2,974	2,974	0	2,847	2,847	0	1,323	1,682.10	359	333	331.6	-1	1,191	833.3	-358
WA	**Oman**	30,950	30,950	0	30,950	30,950	0	1,173	1,468.50	296	2	2	0	29,775	29,479.50	-296
WA	**Syearian Arab Republic**	18,518	18,518	0	18,378	18,363	-15	13,711	13,921	210	432	491	59	4,235	3,951	-284
WA	**Azerbaijan**	8,660	8,660	0	8,260.50	8,265.90	5	4,740.40	4,769.80	29	871.8	1,086.96	215	2,648.30	2,409.14	-239
WA	**Lebanon**	1,045	1,045	0	1,023	1,023	0	595	658	63	131	137.14	6	297	227.86	-69
WA	**Kuwait**	1,782	1,782	0	1,782	1,782	0	148	153.6	6	4.85	6.25	1	1,629.15	1,622.15	-7
WA	**Qatar**	1,161	1,161	0	1,161	1,161	0	66	67.61	2	0	0	0	1,095	1,093.39	-2
WA	**Bahrain**	71	77	6	71	77	6	9.2	8.6	-1	0.37	0.57	0	61.43	67.83	6
WA	**Cyprus**	925	925	0	924	924	0	141.5	109	-33	171.61	172.76	1	610.89	642.24	31
WA	**Israel**	2,207	2,207	0	2,164	2,164	0	566	520.3	-46	153	160.6	8	1,445	1,483.10	38
WA	**Jordan**	8,878	8,932	54	8,824	8,878	54	1,069	1,056.60	-12	97.5	97.5	0	7,657.50	7,723.90	66
WA	**Occupied Palestinian Territory**	602	602	0	602	602	0	372	262	-110	9.08	9.17	0	220.92	330.83	110
WA	**Yemen**	52,797	52,797	0	52,797	52,797	0	23,669	23,546	-123	549	549	0	28,579	28,702	123
WA	**United Arab Emirates**	8,360	8,360	0	8,360	8,360	0	552	382.3	-170	310	320.48	10	7,498	7,657.22	159
WA	**Georgia**	6,970	6,970	0	6,949	6,949	0	3,000	2,551.40	-449	2,760.60	2,822.40	62	1,188.40	1,575.20	387
WA	**Saudi Arabia**	214,969	214,969	0	214,969	214,969	0	173,785	173,295	-490	977	977	0	40,207	40,697	490
WA	**Turkey**	78,356	78,356	0	76,963	76,963	0	40,479	38,423	-2,056	10,183	11,510.20	1,327	26,301	27,029.80	729
ASIA TOTAL		**3,199,802.90**	**3,199,693.33**	**-110**	**3,105,775.50**	**3,105,331.03**	**-444**	**1,678,947**	**1,653,291.68**	**-25,655**	**567,911.61**	**593,792.11**	**25,881**	**862,916.89**	**862,273.24**	**-644**

Source: FAOSTAT

TABLE A2

Change in cereal crops by country, 2000 – 2014

Region	Country	Area harvested (ha)			Production (tons)			Yield (hg/ha)		
		2000	2014	Change	2000	2014	Change	2000	2014	Change
CA	Turkmenistan	825,000	514,500	-310,500	1,751,000	1,432,000	-319,000	21,224	27,833	6,609
CA	Tajikistan	415,790	396,393	-19,397	544,977	1,249,940	704,963	13,107	31,533	18,426
CA	Kyeargyzstan	580,709	595,670	14,961	1,550,090	1,355,894	-194,196	26,693	22,763	-3,930
CA	Uzbekistan	1,606,700	1,633,300	26,600	3,913,800	7,842,200	3,928,400	24,359	48,014	23,655
CA	Kazakhstan	12,240,229	14,583,480	2,343,251	11,539,491	17,100,400	5,560,909	9,428	11,726	2,298
EA	Republic of Korea	1,165,478	884,129	-281,349	7,500,695	5,852,213	**-1,648,482**	64,357	66,192	1,835
EA	Japan	2,045,099	1,908,262	-136,837	12,796,001	11,602,880	-1,193,121	62,569	60,803	-1,766
EA	Taiwan Province of China	375,703	302,794	-72,909	2,112,369	1,905,663	-206,706	56,224	62,936	6,712
EA	Hong Kong SAR	0	0	0	0	0	0	0	0	0
EA	Democratic People's Republic of Korea	1,233,677	1,282,580	48,903	2,942,000	5,525,200	2,583,200	23,847	43,079	19,232
EA	Mongolia	183,434	315,033	131,599	142,100	518,793	376,693	7,747	16,468	8,721
EA	China, mainland	85,264,010	94,694,000	**9,429,990**	405,224,140	557,407,200	**152,183,060**	47,526	58,864	11,338
SA	India	102,402,400	98,618,000	-3,784,400	234,931,192	293,993,000	59,061,808	22,942	29,811	6,869
SA	Bhutan	74,170	53,310	-20,860	106,650	166,909	60,259	14,379	31,309	16,930
SA	Maldives	65	79	14	113	190	77	17,385	24,051	6,666
SA	Sri Lanka	867,548	954,755	87,207	2,896,040	3,629,377	733,337	33,382	38,014	4,632
SA	Nepal	3,330,740	3,480,052	149,312	7,115,587	9,562,680	2,447,093	21,363	27,479	6,116
SA	Bangladesh	11,672,247	12,499,360	827,113	39,503,000	55,069,990	15,566,990	33,844	44,058	10,214
SA	Afghanistan	2,406,000	3,344,733	938,733	1,940,000	6,758,259	4,818,259	8,063	20,206	12,143
SA	Pakistan	12,650,400	13,870,000	1,219,600	30,460,700	38,106,000	7,645,300	24,079	27,474	3,395
SA	Iran (Islamic Republic of)	7,022,132	8,689,890	1,667,758	12,873,964	17,062,140	4,188,176	18,333	19,634	1,301
SE	Singapore									
SE	Malaysia	725,700	699,468	-26,232	2,205,800	2,731,762	525,962	30,395	39,055	8,660

SE	Timor-Leste	72,000	65,443	-6,557	139,449	191,297	51,848	19,368	29,231	9,863
SE	Brunei Darussalam	460	2,260	1,800	299	1,940	1,641	6,500	8,584	2,084
SE	Lao People's Democratic Republic	768,370	1,201,221	432,851	2,318,700	5,414,865	3,096,165	30,177	45,078	14,901
SE	Viet Nam	8,398,412	8,996,724	598,312	34,537,275	50,178,717	15,641,442	41,124	55,774	14,650
SE	Myanmar	7,134,557	7,763,320	628,763	22,125,724	28,775,450	6,649,726	31,012	37,066	6,054
SE	Philippines	6,548,528	7,351,234	802,706	16,900,660	26,739,008	9,838,348	25,808	36,373	10,565
SE	Thailand	11,228,225	12,194,032	965,807	30,529,251	37,836,899	7,307,648	27,190	31,029	3,839
SE	Cambodia	1,960,563	3,260,000	1,299,437	4,183,064	9,874,000	5,690,936	21,336	30,288	8,952
SE	Indonesia	15,293,000	17,634,326	2,341,326	61,575,000	89,854,891	28,279,891	40,264	50,955	10,691
WA	Bahrain									
WA	Turkey	13,954,138	11,553,065	-2,401,073	32,248,694	32,707,656	458,962	23,110	28,311	5,201
WA	Syearian Arab Republic	3,058,195	2,535,039	-523,156	3,512,791	2,695,686	-817,105	11,486	10,634	-852
WA	Saudi Arabia	616,368	222,720	-393,648	2,167,394	878,160	-1,289,234	35,164	39,429	4,265
WA	Georgia	306,616	217,830	-88,786	417,752	437,400	19,648	13,625	20,080	6,455
WA	Cyprus	51,480	25,303	-26,177	47,950	7,087	-40,863	9,314	2,801	-6,513
WA	Occupied Palestinian Territory	31,054	16,540	-14,514	67,842	27,700	-40,142	21,846	16,747	-5,099
WA	Qatar	1,760	310	-1,450	7,215	2,030	-5,185	40,994	65,484	24,490
WA	Oman	3,317	4,110	793	11,449	47,420	35,971	34,516	115,377	80,861
WA	Kuwait	1,220	2,454	1,234	2,835	53,607	50,772	23,238	218,447	195,209
WA	Lebanon	50,850	52,220	1,370	122,800	176,700	53,900	24,149	33,838	9,689
WA	United Arab Emirates	56	4,154	4,098	364	68,380	68,016	65,000	164,612	99,612
WA	Israel	74,846	80,705	5,859	182,870	359,001	176,131	24,433	44,483	20,050
WA	Jordan	33,096	62,353	29,257	57,133	90,747	33,614	17,263	14,554	-2,709
WA	Armenia	156,585	193,337	36,752	220,819	585,105	364,286	14,102	30,263	16,161
WA	Yemen	619,583	727,069	107,486	672,237	699,962	27,725	10,850	9,627	-1,223
WA	Iraq	2,490,350	2,779,880	289,530	904,480	6,080,210	5,175,730	3,632	21,872	18,240
WA	Azerbaijan	640,726	980,520	339,794	1,496,224	2,297,996	801,772	23,352	23,437	85
WA	Turkey	78,356	78,356	0	76,963	76,963	0	26,301	27,029.80	729
ASIA TOTAL		**320,583,586**	**3,199,693.33**	**-110**	**3,105,775.50**	**3,105,331.03**	**-444**	**862,916.89**	**862,273.24**	**-644**

Source: FAOSTAT

TABLE A3

Change in Asia livestock (head) by country, 2000 – 2014

Region	Country	Cattle and Buffaloes			Sheep and Goats			Total Livestock		
		2000	2014	Change	2000	2014	Change	2000	2014	Change
CA	Kyeargyzstan	932,273	1,458,377	526,104	3,806,543	5,829,024	2,022,481	4,738,816	7,287,401	2,548,585
CA	Turkmenistan	1,400,000	2,300,000	900,000	8,000,000	16,300,000	8,300,000	9,400,000	18,600,000	9,200,000
CA	Tajikistan	1,049,889	2,110,228	1,060,339	2,178,000	5,056,572	2,878,572	3,227,889	7,166,800	3,938,911
CA	Kazakhstan	4,007,200	5,861,200	1,854,000	9,656,700	17,560,604	7,903,904	13,663,900	23,421,804	9,757,904
CA	Uzbekistan	5,268,300	10,607,300	5,339,000	8,886,000	17,737,600	8,851,600	14,154,300	28,344,900	14,190,600
EA	China, Macao SAR									
EA	Japan	4,588,000	3,962,000	-626,000	45,000	30,300	-14,700	4,633,000	3,992,300	-640,700
EA	Mongolia	3,824,700	3,413,851	-410,849	26,225,200	45,223,676	18,998,476	30,049,900	48,637,527	18,587,627
EA	Taiwan Province of China	163,826	147,398	-16,428	315,135	161,070	-154,065	478,961	308,468	-170,493
EA	Democratic People's Republic of Korea	579,000	575,000	-4,000	2,461,000	3,833,000	1,372,000	3,040,000	4,408,000	1,368,000
EA	Hong Kong SAR	1,750	2,000	250	215	700	485	1,965	2,700	735
EA	Republic of Korea	2,133,720	3,189,951	1,056,231	445,662	268,100	-177,562	2,579,382	3,458,051	878,669
EA	China, mainland	116,543,400	141,040,000	24,496,600	279,258,008	390,024,600	110,766,592	395,801,408	531,064,600	135,263,192
SA	Maldives									
SA	Bhutan	357,637	301,905	-55,732	54,208	59,642	5,434	411,845	361,547	-50,298
SA	Sri Lanka	1,452,100	1,425,470	-26,630	506,400	310,090	-196,310	1,958,500	1,735,560	-222,940
SA	Iran (Islamic Republic of)	8,760,700	8,785,000	24,300	79,657,000	72,348,000	-7,309,000	88,417,700	81,133,000	-7,284,700
SA	Bangladesh	23,200,000	24,988,000	1,788,000	35,232,000	57,825,000	22,593,000	58,432,000	82,813,000	24,381,000
SA	Nepal	10,549,118	12,422,528	1,873,410	7,177,057	10,966,747	3,789,690	17,726,175	23,389,275	5,663,100
SA	Afghanistan	2,900,000	5,349,000	2,449,000	22,300,000	20,544,000	-1,756,000	25,200,000	25,893,000	693,000
SA	Indonesia	13,413,277	16,506,900	3,093,623	19,992,559	34,932,100	14,939,541	33,405,836	51,439,000	18,033,164
SA	India	285,755,000	297,000,000	11,245,000	182,980,000	196,000,000	13,020,000	468,735,000	493,000,000	24,265,000
SA	Pakistan	44,673,000	74,300,000	29,627,000	71,510,000	95,700,000	24,190,000	116,183,000	170,000,000	53,817,000

SE	Thailand	6,313,270	5,918,663	-394,607	181,539	491,447	309,908	6,494,809	6,410,110	-84,699
SE	Philippines	5,503,253	5,348,790	-154,463	6,275,000	3,720,789	-2,554,211	11,778,253	9,069,579	-2,708,674
SE	Cambodia	3,686,271	3,555,000	-131,271	0	0	0	3,686,271	3,555,000	**-131,271**
SE	Brunei Darussalam	6,876	3,200	-3,676	4,844	11,000	6,156	11,720	14,200	2,480
SE	Singapore	200	200	0	500	670	170	700	870	170
SE	Malaysia	875,934	883,940	8,006	394,704	595,407	200,703	1,270,638	1,479,347	208,709
SE	Timor-Leste	220,000	290,000	70,000	100,500	252,000	151,500	320,500	542,000	221,500
SE	Viet Nam	7,025,100	7,746,200	721,100	543,867	1,600,275	1,056,408	7,568,967	9,346,475	1,777,508
SE	Lao People's Democratic Republic	2,185,000	2,919,000	734,000	121,700	481,000	359,300	2,306,700	3,400,000	1,093,300
SE	Myanmar	13,423,240	18,969,000	5,545,760	1,782,263	6,945,000	5,162,737	15,205,503	25,914,000	10,708,497
WA	United Arab Emirates	96,050	87,000	-9,050	1,773,464	4,070,000	2,296,536	1,869,514	4,157,000	2,287,486
WA	Qatar	14,831	12,000	-2,831	393,021	553,000	159,979	407,852	565,000	157,148
WA	Bahrain	11,000	10,500	-500	42,000	58,500	16,500	53,000	69,000	16,000
WA	Jordan	65,408	69,900	4,492	2,395,379	3,747,000	1,351,621	2,460,787	3,816,900	1,356,113
WA	Kuwait	20,555	27,310	6,755	769,308	781,432	12,124	789,863	808,742	18,879
WA	Cyprus	54,074	60,884	6,810	579,000	562,400	-16,600	633,074	623,284	-9,790
WA	Lebanon	77,000	87,000	10,000	771,000	1,012,000	241,000	848,000	1,099,000	251,000
WA	Occupied Palestinian Territory	23,688	35,000	11,312	875,254	938,000	62,746	898,942	973,000	74,058
WA	Israel	395,000	461,000	66,000	442,000	682,000	240,000	837,000	1,143,000	306,000
WA	Oman	299,000	365,000	66,000	1,323,000	2,510,000	1,187,000	1,622,000	2,875,000	1,253,000
WA	Georgia	1,157,023	1,250,700	93,677	633,400	856,800	223,400	1,790,423	2,107,500	317,077
WA	Syearian Arab Republic	987,217	1,098,391	111,174	14,554,739	20,143,917	5,589,178	15,541,956	21,242,308	5,700,352
WA	Armenia	478,797	678,315	199,518	548,580	717,574	168,994	1,027,377	1,395,889	368,512
WA	Saudi Arabia	290,506	520,000	229,494	12,463,490	15,100,000	2,636,510	12,753,996	15,620,000	2,866,004
WA	Yemen	1,283,000	1,768,000	485,000	13,111,000	19,068,000	5,957,000	14,394,000	20,836,000	6,442,000
WA	Azerbaijan	1,961,381	2,697,495	736,114	5,773,841	8,645,420	2,871,579	7,735,222	11,342,915	3,607,693
WA	Iraq	1,465,000	3,113,000	1,648,000	8,200,000	9,900,000	1,700,000	9,665,000	13,013,000	3,348,000
WA	Turkey	11,219,000	14,244,673	3,025,673	38,030,000	41,462,349	3,432,349	49,249,000	55,707,022	6,458,022
ASIA TOTAL		**590,692,564**	**687,968,283**	**97,275,719**	**872,772,080**	**1,135,618,819**	**262,846,739**	**1,463,462,644**	**1,823,585,088**	**360,122,444**

Source: FAOSTAT

TABLE A4

Change in number of cattle and buffaloes/ha of agricultural land by country, 2000 – 2011

Region	Country	2000	2011	Change
CA	Kazakhstan	0.02	0.03	0.01
CA	Turkmenistan	0.04	0.07	0.03
CA	Kyeargyzstan	0.09	0.13	0.04
CA	Uzbekistan	0.19	0.34	0.15
CA	Tajikistan	0.23	0.42	0.19
EA	China Hong Kong SAR	na	na	na
EA	China, Macao SAR	na	na	na
EA	China, mainland	na	na	na
EA	Taiwan Province China	na	na	na
EA	China	0.24	0.2	-0.04
EA	Mongolia	0.03	0.02	-0.01
EA	Democratic People's Republic of Korea	0.23	0.23	0
EA	Japan	0.87	0.93	0.06
EA	Republic of Korea	1.08	1.91	0.83
SA	Maldives	na	na	na
SA	Bhutan	0.67	0.6	-0.07
SA	Sri Lanka	0.62	0.61	-0.01
SA	Iran (Islamic Republic of)	0.14	0.18	0.04
SA	Afghanistan	0.08	0.15	0.07
SA	Bangladesh	2.47	2.69	0.22
SA	India	1.57	1.8	0.23
SA	Nepal	2.5	2.87	0.37
SA	Pakistan	1.66	2.53	0.87
SE	Brunei Darussalam	0.69	0.44	-0.25
SE	Lao People's Democratic Republic	1.19	1.14	-0.05
SE	Viet Nam	0.8	0.75	-0.05
SE	Cambodia	0.77	0.73	-0.04
SE	Philippines	0.49	0.46	-0.03
SE	Indonesia	0.29	0.3	0.01
SE	Malaysia	0.11	0.13	0.02
SE	Myanmar	1.24	1.32	0.08
SE	Thailand	0.32	0.4	0.08
SE	Timor-Leste	0.65	0.73	0.08
SE	Singapore	0.17	0.27	0.1
WA	Oman	0.28	0.19	-0.09
WA	Qatar	0.22	0.15	-0.07
WA	Armenia	0.36	0.33	-0.03
WA	United Arab Emirates	0.17	0.16	-0.01
WA	Bahrain	1.2	1.2	0
WA	Saudi Arabia	0	0	0
WA	Jordan	0.06	0.07	0.01
WA	Syearian Arab Republic	0.07	0.08	0.01
WA	Turkey	0.28	0.3	0.02
WA	Yemen	0.05	0.07	0.02
WA	Iraq	0.18	0.23	0.05
WA	Georgia	0.39	0.45	0.06
WA	Occupied Palestinian Territory	0.06	0.12	0.06
WA	Kuwait	0.14	0.23	0.09
WA	Cyprus	0.38	0.48	0.1
WA	Azerbaijan	0.41	0.56	0.15
WA	Israel	0.7	0.86	0.16

Source: FAOSTAT

TABLE A5

Changes in carbon stock in living forest biomass (million tons) by country, 2000 – 2013

Region	Country	2000	2013	Change
CA	Kazakhstan	136.61	136.79	0.18
CA	Kyeargyzstan	33.7	17.3	-16.4
CA	Tajikistan	2.8	2.8	0
CA	Turkmenistan	11.3	11.7	0.4
CA	Uzbekistan	14	32.74	18.74
EA	China Hong Kong SAR			
EA	China, Macao SAR			
EA	China, mainland	5,351.90	6,615.58	1,263.68
EA	Taiwan Province of China			
EA	Democratic People's Republic of Korea	206	159.6	-46.4
EA	Japan	1,381	1,647.68	266.68
EA	Mongolia	626	569.95	-56.05
EA	Republic of Korea	240	397.4	157.4
SA	Afghanistan	38.3	38.3	0
SA	Bangladesh	81.63	98.07	16.44
SA	Bhutan	278	291.12	13.12
SA	India	2,377	2,708.20	331.2
SA	Iran (Islamic Republic of)	249.1	203.15	-45.95
SA	Maldives	0.04	0.04	0
SA	Nepal	520	485	-35
SA	Pakistan	271	189.6	-81.4
SA	Sri Lanka	79.86	72.88	-6.98
SE	Brunei Darussalam	76	72	-4
SE	Cambodia	537	445.4	-91.6
SE	Indonesia	16,151	13,032.40	-3,118.6
SE	Lao People's Democratic Republic	1,129.88	1,072.45	-57.43
SE	Malaysia	2,600	2,687.40	87.4
SE	Myanmar	1,814	1,592.36	-221.64
SE	Philippines	649.3	643.08	-6.22
SE	Singapore	1.84	1.66	-0.18
SE	Thailand	881	869.8	-11.2
SE	Timor-Leste	96.09	71.77	-24.32
SE	Viet Nam	927	1,009.40	82.4
WA	Armenia	15.68	15.47	-0.21
WA	Azerbaijan	47.85	66.26	18.41
WA	Bahrain	0.02	0.03	0.01
WA	Cyprus	2.73	3.67	0.94
WA	Georgia	202.64	212.25	9.61
WA	Iraq	44.9	50.21	5.31
WA	Israel	4.2	4.36	0.16
WA	Jordan	2.36	2.36	0
WA	Kuwait	0.27	0.38	0.11
WA	Lebanon	1.59	1.74	0.15
WA	Occupied Palestinian Territory	0.5	0.56	0.06
WA	Oman	0.11	0.12	0.01
WA	Qatar	0	0	0
WA	Saudi Arabia	5.93	5.93	0
WA	Syearian Arab Republic	23.71	29.88	6.17
WA	Turkey	604.1	772.87	168.77
WA	United Arab Emirates	15.49	16.02	0.53
WA	Yemen	5.16	5.16	0
ASIA TOTAL		**39,738.59**	**38,375.89**	**-1,362.7**

Source: FAOSTAT

TABLE A6

Establishment and maintenance costs of Agronomic SLM Technologies in Asia (Source: WOCAT Database)

S.No	Country	Specific type of technology	Year	Establishment cost USD/ha	Maintenance cost USD/ha
1	Afghanistan	Cultivation of Hing (Ferula asafoetida) in the watershed	2016	127.92	
2	Bangladesh	Usage of Gher boundary for cropping	2013	600.00	100.00
3	Cambodia	Production and use of rice husk biochar in rice seed beds and vegetable production.	2014	50.00	24.25
4	Cambodia	Mulching with water hyacinth (Eichhornia crassipes) after the monsoon floods	2014	2664.50	45.00
5	Cambodia	Compost application on rice fields	2014	71.00	140.00
6	Cambodia	Adapted System of Rice Intensification (SRI) principles in Kampong Change	2014	15.00	364.00
7	China, mainland	Orchard terraces with bahia grass cover	2001	1840.00	376.00
8	Cyprus	Fodder provision to goats and sheep to reduce grazing pressure on natural vegetation	2014	4132.00	660.00
9	India	Holistic demonstration	2004	1259.00	124.10
10	Kazakhstan	Creation of artificial pasturable phytocenosis at north desert subzone	2003	38.00	7.00
11	Kazakhstan	Soil-protective minimal technology of the tillage and sowing	2004	90.00	90.00
12	Kazakhstan	Water-conservation technology at cultivation of the cotton in south. K	2003	745.00	125.00
13	Kyeargyzstan	Poplar trees for bio-drainage	2004	920.00	30.00
14	Kyeargyzstan	Production and application of biohumus	2011	350.00	38.00
15	Kyeargyzstan	Cultivation of sainfoin on high mountain pastures – Suusamyear Valley (in the frame of CACILM = Central Asian Countries Initiative for Land Management)	2011	146.90	38.30
16	Kyeargyzstan	The ridge sowing technology (CACILM)	2011	300.00	142.50
17	Kyeargyzstan	Growing cereals by using minimum tillage (CACILM)	2011	50.00	159.00
18	Nepal	Riverbed farming	2013	562.00	165.00

19	Nepal	Traditional irrigated rice terraces	2003	840.00	
20	Nepal	No-till garlic cultivation	2011	51.30	
21	Nepal	Improved cattleshed for urine collection	2008	12.00	
22	Nepal	Legume integration	2008	6.50	
23	Philippines	Improved pasture under citrus	2016	3616.41	10.52
24	Philippines	Planted Vegetative Strips (PVS)	2001	144.00	40.00
25	Philippines	Compact Farming for Vegetables Production	2016	222.22	243.32
26	Philippines	Contour Straight Block Layout	2015	585.00	279.00
27	Philippines	Sweet Potato Relay Cropping	2016	0.00	391.50
28	Philippines	Conservation Tillage Practices for Corn production	2001	541.20	
29	Philippines	Residue Incorporation (Corn)	2001	282.35	
30	Philippines	In "situ" Decomposition of Banana Stalk	2006	60.00	
31	Philippines	Modified Rapid Composting	2015	39.99	
32	Syearian Arab Republic	Adding Soil	2006	200.00	
33	Tajikistan	Perennial Herbaceous Fodder Plants for Intact Canopy Cover	2005	58.00	12.00
34	Tajikistan	Drainage Ditches in Steep Sloping Cropland	2005	8.00	21.00
35	Tajikistan	Vertical growing of potatoes in pits, by the gradual addition of further layers of soil	2011	105.00	100.00
36	Tajikistan	Orchard-based Agroforestry (intercropping)	2005	31.00	218.00
37	Tajikistan	Crop rotation including annual crops and Esparcet cultivation	2012	225.60	1282.00
38	Tajikistan	Drip irrigation using polyethylene sheeting and intermittent cloth strips.	2011	425.00	2000.00
39	Tajikistan	Pest management with pheromone insect traps	2011	16.00	
40	Turkey	Fodder Crop Production	2011	50.00	1200.00
41	Turkey	Strip farming	2008	921.00	

Source: Compiled based on data from the WOCAT database

TABLE A7

Establishment and maintenance costs of Structural SLM Technologies in Asia (Source: WOCAT Database)

S.No	Country	Specific type of technology	Year	Establishment cost USD/ha	Maintenance cost USD/ha
1	Afghanistan	Stone wall	2011	2389.60	
2	Afghanistan	Contour Tied Trench	2013	1450.00	
3	Afghanistan	Micro irrigation in poplar plantation	2014	973.00	82.00
4	Afghanistan	Contour Trench Bund	2011	942.00	
5	Afghanistan	Staggered Contour Trench	2015	644.80	
6	Afghanistan	Terracing in Watershed	2016	201.59	35.00
7	Cambodia	Irrigation of paddy fields using water-pumping wheels (Norias)	2014	60.00	32.50
8	China, mainland	Progressive bench terrace	2011	6398.00	219.60
9	China, mainland	Check dam for land	2008	5929.00	131.80
10	China, mainland	Bench terraces on loess soil	2009	1823.30	263.50
11	China mainland	Zhuanglang loess terraces	2006	1290.00	35.00
12	Cyprus	Agricultural terraces with dry-stone walls	2015	182413.00	1824.13
13	Cyprus	Carob tree protection from rats	2014	1393.00	
14	India	Diversion Weir	2007	3600.00	
15	India	Dug-Out Well	2006	1250.00	10.00
16	India	Integrated Farming System	2005	783.70	
17	India	Farm pond	2004	469.43	7.30
18	India	Forest catchment treatment	2002	400.00	50.00
19	India	Dugout Sunken Pond with Catchment Treatment	2004	363.00	21.00
20	India	Sunken streambed structure	2002	240.00	5.00
21	India	Contour Trench cum Bund	2004	200.00	
22	India	Pepsee micro-irrigation system	2005	95.00	21.00
23	India	Sunken gully pits	2006	40.00	

24	India	Contour "V" Ditch	2006	40.00	
25	Kazakhstan	Creation of haloxylon pasture-protective strips at north desert	2003	282.00	
26	Kyeargyzstan	Spring cleaning and creating a water point	2011	312.00	12.00
27	Nepal	Rooftop rainwater harvesting system	2006	126.90	15.00
28	Philippines	Small Water Impounding Project (SWIP)	2000	94000.00	1275.00
29	Philippines	Rain fed paddy rice terraces	2003	2700.00	40.00
30	Philippines	Stone bunds and small basins	2002	1020.00	40.00
31	Philippines	Sediment Traps	2015	125.38	154.92
32	Syearian Arab R.	Semi-circle bunds	2012	1966.00	54.00
33	Syearian Arab R.	Stone Wall Bench Terraces	1999	1460.00	20.00
34	Tajikistan	Solar greenhouses	2011	3900.00	2000.00
35	Tajikistan	Water wheel pump system	2011	3280.00	
36	Tajikistan	Spiral water pumps	2011	696.00	10.00
37	Tajikistan	Orchard-based Agroforestry (establishment of orchard)	2005	470.00	210.00
38	Tajikistan	Two Room Stove	2011	428.00	4.00
39	Tajikistan	Rehabilitation of iron water gates to improve distribution of irrigation water	2011	411.00	22.00
40	Tajikistan	Roof Top Rain Water Harvesting - Concrete tank	2011	397.00	5.00
41	Tajikistan	Energy efficiency measures to increase the application of organic fertilizers.	2011	386.70	3.30
42	Tajikistan	Landslide prevention using drainage trenches lined with fast growing trees.	2011	280.00	16.50
43	Tajikistan	Terrace with Tree Barrier	2005	165.00	15.00
44	Tajikistan	Natural spring catchment protection	2011	108.47	19.50
45	Tajikistan	Roof top rainwater harvesting stored in a polythene lined earth retention tank	2011	27.64	8.85
46	Tajikistan	A woollen water retention bed installed under the roots of a tree irrigated by a pipe feed	2011	0.30	
47	Thailand	Small level bench terraces	2000	275.00	90.00
48	Thailand	Cut-off drain	1997	4.32	4.32
49	Turkey	Drip irrigation	2011	2100.00	300.00
50	Turkey	Woven Wood Fences	2011	1350.00	110.00
51	Turkmenistan	Stabilization and afforestation of sand dunes around settlements	2011	2159.00	222.00
52	Yemen	Bench terraces covered with small stones	2013	42530.00	236.00

Source: Compiled based on data from the WOCAT database

TABLE A8

Establishment and maintenance costs of Biological SLM Technologies in Asia (Source: WOCAT Database)

S.No	Country	Specific type of technology	Year	Establishment cost USD/ha	Maintenance cost USD/ha
1	Afghanistan	Alfalfa intercropping in terraced fruit orchard	2014	5788.00	
2	Afghanistan	Riverbank stabilization	2015	1617.10	
3	Cambodia	Cashew living fences	2014	51.50	3.00
4	Cambodia	Stabilization of irrigation channels in sandy soils with old rice bags and Pandanus plants	2014	87.50	10.00
5	Cambodia	Growing stylo grass (Stylosanthes guianensis) as cattle fodder between and under mango trees	2014	357.25	590.00
6	Cambodia	Multipurpose use of sugar palm grown on rice field dykes.	2014	35.00	4049.00
7	China, mainland	Shelterbelts for farmland in sandy areas	2002	125.00	11.00
8	Kazakhstan	Creation of a perennial grass seed area (CACILM)	2012	144.35	17.50
9	Kazakhstan	Off-season irrigation of fields and pastures as a mechanism for pasture improvement	2011	477.68	61.24
10	Kazakhstan	creation of meliorative plantings for struggle with erosion	2003	220.00	
11	Kazakhstan	Technology of fastening Aral sea's drained bottom' s soil	2003	190.00	
12	Kazakhstan	Fallow restoration by no-tillage seeding	2013	68.03	
13	Nepal	Landslip and stream bank stabilization	2003	2925.00	70.00
14	Nepal	Using Salix plant to protect stream banks	2013	770.00	74.00
15	Nepal	Hedgerow technology	2013	127.00	125.00
16	Nepal	Improved terraces	2003	1287.50	342.00
17	Nepal	Kiwi fruit cultivation	2011	5650.00	1300.00

18	Nepal	Rehabilitation of degraded communal grazing land	2004	233.00	
19	Philippines	WINDBREAKS	2006	61.00	13.00
20	Philippines	Vetiver grass system or Vetiver grass technology	2002	150.00	20.00
21	Philippines	Pressing of Cogon Grass (Imperata cylindrica)	2015	28.44	26.68
22	Philippines	Firebreaks/ Greenbreaks	2015	26.67	31.11
23	Philippines	Ecological engineering for biological pest control in lowland rice agroecosystems	2016	184.50	40.00
24	Philippines	Trees as Buffer Zones	2015	117.00	78.00
25	Syearian Arab Republic	Range Pitting and Reseeding	1999	1351.00	117.00
26	Tajikistan	Buffer Strip on Steep Sloping Cropland	2005	10.00	4.00
27	Tajikistan	Gully Rehabilitation with Native Trees	2012	157.00	5.60
28	Tajikistan	Wind forest strips for land protection against wind erosion on sandy soils	2011	101.00	38.00
29	Tajikistan	Planting of fruit trees to increase slope stabilisation	2011	2319.60	55.00
30	Tajikistan	Establishment of living seabuckthorn fences for the protection of reforestation sites (CACILM)	2011	3052.00	67.90
31	Tajikistan	Shelterbelts with Russian Silverberry for the protection of irrigated fields	2011	2070.00	85.00
32	Tajikistan	Irrigation of orchards by using low cost drip irrigation technique	2011	1415.00	104.00
33	Tajikistan	Tree nurseries to test tree species adapted to local climate	2011	526.50	256.50
34	Tajikistan	Growing of fodder crops on steep slopes in arid highlands	2010	4015.50	324.50
35	Tajikistan	Saxaul plantation for stabilization of sandy soils	2011	159.80	672.00
36	Tajikistan	Conversion of stony slopes into an irrigated apricot orchard	2011	1979.00	
37	Thailand	Vegetative erosion control and cons. Crop.	1997	65.40	64.80
38	Turkmenistan	Growing Arundo reeds (Arundo donax L.) to create buffer zones around households (CACILM)	2011	2775.00	140.00
39	Turkmenistan	Planting forest on mountain slopes using moisture accumulating trenches (CACILM)	2011	1109.00	160.00

Source: Compiled based on data from the WOCAT database

TABLE A9

Establishment and maintenance costs of Management measures of SLM in Asia (Source: WOCAT Database)

S.No	Country	Specific type of technology	Year	Establishment cost USD/ha	Maintenance cost USD/ha
1	Cambodia	Biogas system at household level fed daily with cattle manure	2014	400.00	132.00
2	Nepal	Plastic film technology	2013	618.00	130.00
3	Nepal	System of Rice Intensification	2006	1030.00	
4	Nepal	Organic pest management	2008	10.00	
5	Philippines	Alternate Wetting and Drying	2016	7.77	
6	Tajikistan	Rotational grazing supported by additional water points	2010	7881.00	748.00
7	Tajikistan	Irrigated agro-biodiversity system in arid high mountain area	2010	1027.00	768.90
8	Tajikistan	Orchard establishment on a former wheat plot, by planting fruit tree seedlings in combination with sowing Alfalfa	2012	3313.20	2613.00
9	Tajikistan	Reduced pressure on forest resources by improved thermal insulation in private houses	2011	402.00	
10	Tajikistan	Pasture management in Western Pamir		150.00	
11	Turkey	Rotational Grazing	2008	167.00	61.00

Source: Compiled based on data from the WOCAT database

TABLE A10

Establishment and maintenance costs of mixed measures of SLM Technologies in Asia (Source: WOCAT Database)

S.No	Country	Specific type of technology	Year	Establishment cost USD/ha	Maintenance cost USD/ha
1	Syearian Arab R.	Furrow-enhanced runoff harvesting for olives	2004	63.00	25.00
2	Tajikistan	Passive solar greenhouses for winter commercial vegetable production	2011	671.00	89.00
3	Philippines	Vegetable Terracing	2015	546.63	627.33
4	Philippines	Natural Vegetative Strips (NVS)	1999	278.00	238.00
5	Tajikistan	Mulching in rain fed vineyards on terraces in the loess hill zone	2011	963.00	295.00
6	Philippines	Multi-Story Cropping	2001	1390.00	490.00
7	Tajikistan	Rehabilitation of poor soils through agroforestry	2011	1086.00	978.20
8	Philippines	Organic-Based System of Rice Intensification	2016	196.45	413.33
9	Uzbekistan	Use of mineralized artesian water to organize irrigated crop farming in the Kyzyl-Kum (CACILM)	2011	910.00	2104.26
10	Tajikistan	Conversion of grazing land to fruit and fodder plots	2004	2690.00	570.00
11	Tajikistan	Orchard-based agroforestry	2004	550.00	210.00
12	Tajikistan	Integrated Technologies for Household Plots	2011	1679.00	330.00
13	Tajikistan	Integrated stone wall and poplar tree perimeter fencing	2011	1236.00	179.00
14	Tajikistan	Gradual development of bench terraces from contour ditches	2011	995.50	145.60
15	Tajikistan	Bee-keeping in uplands	2011	65.00	
16	Tajikistan	Infilling of gullies with vegetative structures	2011	20.50	15.00
17	Tajikistan	Cascading Rock Irrigation Channel	2011	3366.00	285.00
18	Tajikistan	Gully rehabilitation	2011	775.00	
19	Nepal	Riverbank Protection	2013	4126.00	182.00
20	Nepal	Gully plugging using check dams	2004	139.00	
21	Tajikistan	Rehabilitation of grazing areas through planting of Izen perennial shrubs		499.60	50.40
22	Tajikistan	Combined cut-and-carry and fruit-production system with terraces	2008	1428.00	121.00
23	Uzbekistan	Afforestation for rehabilitation of degraded irrigated croplands (CACILM)	2011	3547.10	278.80
24	Tajikistan	Silvo-pastoralism: Orchard with integrated grazing and fodder production	2012	526.80	391.10
25	Uzbekistan	Improvement of land under arid conditions through the creation of pistachio plantations (CACILM)	2011	1230.72	1581.00
26	Tajikistan	Planting poplar forest in the flood plains of high mountain river areas	2010	4757.50	3092.40
27	Tajikistan	Mixed fruit tree orchard with intercropping of Esparcet and annual crops in Muminabad District	2012	6209.00	4625.50
28	India	Dug-out sunken pond cum contour bund	2004	120.00	7.00
29	Tajikistan	Bottle irrigation of a newly planted orchard	2011	1592.00	

Source: Compiled based on data from the WOCAT database

TABLE A11

Poverty Indices

Country/region	Poverty-Head Count Ratio 3 USD	Poverty-Head Count Ratio 2 USD	Poverty-gap 3 USD	Poverty-gap 2 USD	Year
Armenia	14.62	2.31	3.06	0.41	2014
Afghanistan					
Bahrain					
Bangladesh	56.8	18.52	16.95	3.31	2010
Bhutan	13.33	2.17	2.99	0.41	2012
Brunei Darussalam					
Myanmar					
Sri Lanka	14.59	1.92	3.03	0.29	2012
China, mainland	11.09	1.85	2.52	0.35	2013
Cyprus					
Azerbaijan	2.51	0.49	0.6	0.16	2008
Georgia	25.27	9.77	8.5	2.89	2014
China Hong Kong SAR					
India	57.96	21.23	18.46	4.27	2011
Indonesia	36.44	8.25	9.58	1.25	2014
Iran	0.66	0.08	0.12	0.03	2013
Iraq					
Israel					
*Kazakhstan	0.26	0.04	0.05	0.01	2013
Japan					
Jordan					
Kyeargyzstan	17.47	1.29	2.98	0.23	2014
*Cambodia	21.58	2.17	4.05	0.28	2012
Republic of Korea					
Kuwait					
Lao PDR	46.86	16.72	14.72	3.61	2012
Lebanon					
Malaysia	2.71	0.28	0.49	0.04	2009
Mongolia	2.7	0.22	0.46	0.03	2014
Nepal	48.44	14.99	14.68	3.05	2010
*Pakistan	36.88	6.07	8.55	0.87	2013
Philippines	37.61	13.11	11.68	2.74	2012
Timor-Leste	80.01	46.76	32.86	12.09	2007
Qatar					
*Saudi Arabia					
Singapore					
Tajikistan	56.67	19.51	17.42	4.06	2014
Syearian Arab Republic					
Taiwan Province of China					
Thailand	0.92	0.04	0.12	0	2013
Oman					
*Turkey	2.62	0.33	0.54	0.06	2013
*United Arab Emirates					
*Uzbekistan	87.82	66.79	46.39	25.32	2003
Viet Nam	12.02	3.06	3.09	0.62	2014

TABLE A12

Poverty Indices

	Weighted prices 2013 in USD per ton	Nutrient price in USD/ton		
	Crops	N	P_2O_5	K_2O
Armenia	426	618	645	512
Afghanistan	585	618	645	512
Bahrain	1188	618	645	512
Bangladesh	272	618	645	512
Bhutan	734	618	645	512
Brunei Darussalam	688	618	645	512
Myanmar	769	618	645	512
Sri Lanka	332	618	645	512
China, mainland	563	618	645	512
Cyprus	597	618	645	512
Azerbaijan	559	618	645	512
Georgia	520	618	645	512
China Hong Kong SAR	927	618	645	512
India	700	618	645	512
Indonesia	363	618	645	512
Iran	782	618	645	512
Iraq	763	618	645	512
Israel	1042	618	645	512
Kazakhstan	300	618	645	512
Japan	1850	618	645	512
Jordan	432	618	645	512
Kyeargyzstan	448	618	645	512
Cambodia	449	618	645	512
Republic of Korea	729	618	645	512
Kuwait	757	618	645	512
Lao PDR	353	618	645	512
Lebanon	666	618	645	512
Malaysia	167	618	645	512
Mongolia	452	618	645	512
Nepal	355	618	645	512
Pakistan	631	618	645	512
Philippines	322	618	645	512
Timor-Leste	610	618	645	512
Qatar	1171	618	645	512
Saudi Arabia	1461	618	645	512
Singapore	1009	618	645	512
Tajikistan	612	618	645	512
Syearian Arab Republic	758	618	645	512
Taiwan Province of China	744	618	645	512
Thailand	235	618	645	512
Oman	1124	618	645	512
Turkey	512	618	645	512
United Arab Emirates	1223	618	645	512
Uzbekistan	709	618	645	512
Viet Nam	384	618	645	512
Yemen	817	618	645	512

Published by

For further information and feedback please contact:

ELD Secretariat
Mark Schauer
c/o Deutsche Gesellschaft
für Internationale Zusammenarbeit (GIZ) GmbH
Friedrich-Ebert-Allee 36
53113 Bonn
Germany
T + 49 228 4460-3740
E info@eld-initiative.org
I www.eld-initiative.org

This report was published with the support of the partner organisations of the ELD Initiative and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).

Design: kippconcept GmbH, Bonn
Printed in the EU on FSC-certified paper
Bonn, March 2018

www.eld-initiative.org