

# Environmental Livelihood Security in Southeast Asia and Oceania

A Water-Energy-Food-Livelihoods Nexus  
Approach for Spatially Assessing Change

White Paper





# **Environmental Livelihood Security**

## in Southeast Asia and Oceania

A Water-Energy-Food-Livelihoods Nexus Approach for Spatially  
Assessing Change

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## LIST OF ACRONYMS

ACCA	Automated Cropland Classification Algorithm
ADB	Asian Development Bank
APAR	Absorbed Photosynthetically Active Radiation
APEC	Asia-Pacific Economic Cooperation
AVHRR	Advanced Very High Resolution Radiometer
BN	Bayesian network
BOM	Bureau of Meteorology
CARE	Cooperative for assistance and relief everywhere
CEDA	Committee for Economic Development of Australia
CEPAR	Center of Excellence in Population Ageing Research
CGIAR	Consultative Group on International Agricultural Research
CHS	Commission on Human Security
CIDA	Canadian International Development Agency
CM	Companion Modelling
CMIP5	Coupled Model Intercomparison Project Phase 5
CNES	Centre National d'Etudes Spatiales
CSD	Commission on Sustainable Development
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
CTOH	Center for Topographic studies of the Ocean and Hydrosphere
CVA	Capacities and Vulnerability Analysis
DFID	Department for International Development, UK
DLA	Detailed Livelihood Assessment
DUSDES	Deputy Undersecretary of Defence for Environmental Security
ENSO	El Niño-Southern Oscillation
ESA	European Space Agency
ESCAP	Economic and Social Commission for Asia and the Pacific
ESH	Ecosystem Health
ET	Evapotranspiration
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GEC	Global Economic Crisis
GHG	Green House Gas
GHM	Global Hydrological Models
GIS	Geographic Information System
GMB	Group Model Building
GPM	Global Precipitation Mission
HDI	Human Development Index

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HDR	Human Development Report
HUGE	Human, gender and environmental security
ICISS	International Commission on Intervention and State Sovereignty
IEA	International Energy Agency
FAO-IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IISD	International Institute for Sustainable Development
ILA	Initial Livelihood Impact Appraisal
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
IWRM	Integrated Water Resources Management
JAXA	Japan Aerospace Exploration Agency
LAI	Leaf Area Index
LAT	Livelihood Assessment Toolkit
LB	Livelihood Baseline
MA	Millennium Ecosystem Assessment
MARPOL	International Marine Pollution Convention for the Prevention of Pollution from Ships
MDG	Millennium Development Goal
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NGO	Nongovernmental Organisation
NIR	Near-Infrared
NTFP	Non-timber Forest Product
PACRAIN	Pacific Rainfall Database
PAR	Photosynthetically Active Radiation
PIC	Pacific Island Communities
PIFACC	Pacific Islands Framework for Action on Climate Change
PLA	Participatory Learning and Action
PM	Participatory Modelling
PNG	Papua New Guinea
PPP	Purchasing Power Parity
PR	Precipitation Radar
PRA	Participatory Rural Appraisal
PS	Participatory Simulation
PTD	Participatory Technology Development
RCP	Representative Concentration Pathway

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RRA	Rapid Rural Appraisal
SAIL	Scattering by Arbitrary Inclined Leaves
SAP	Structural Adjustment Programme
SAR	Satellite Aperture Radar
SDG	Sustainable Development Goal
SAO	Southeast Asia and Oceania
SEB	Surface-Energy-Balance
SEEA	System of Integrated Environmental and Economic Accounting
SIDS	Small Island Developing States
SL	Sustainable Livelihoods
SLA	Sustainable Livelihoods Approach
SLF	Sustainable Livelihood Framework
SLR	Sea-Level Rise
SPCZ	South Pacific Convergence Zone
SPI	Standardized Precipitation Index
SPOT	Satellite Pour l'Observation de la Terre
SRDI	Soil and Resource Development Institute
SRTM	Shuttle Radar Topography Mission
SST	Sea Surface Temperature
SVP	Shared Vision Planning
TEK	Traditional Ecological Knowledge
TRMM	Tropical Rainfall Measuring Mission
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFPA	United Nations Population Fund
US	United States
USA	United States of America
USDAT	Undersecretary of Defence for Acquisition and Technology
VGI	Volunteered Geographic Information
VI	Vegetation Index
WCED	World Commission on Environment and Development
WDR	World Development Report
WPM	West Pacific Monsoon

## EXECUTIVE SUMMARY

This document addresses the need for explicit inclusion of livelihoods within the environment nexus (water-energy-food security), not only responding to literature gaps but also addressing emerging dialogue from existing nexus consortia. We present the first conceptualization of ‘environmental livelihood security’, which combines the nexus perspective with sustainable livelihoods. The geographical focus of this paper is Southeast Asia and Oceania, a region currently wrought by the impacts of a changing climate. Climate change is the primary external forcing mechanism on the environmental livelihood security of communities in Southeast Asia and Oceania which, therefore, forms the applied crux of this paper. Finally, we provide a primer for using geospatial information to develop a spatial framework to enable geographical assessment of environmental livelihood security across the region. We conclude by linking the value of this research to ongoing sustainable development discussions, and for influencing policy agendas. The paper is split into three main parts:

### **Part I: The Environment of Southeast Asia and Oceania**

The first part of this paper provides background environmental information to introduce the geography of Southeast Asia and Oceania and the importance of sustainable livelihoods and water-energy-food security in the region. The first component describes the state of the environment including details on climate, climate change and important environmental impacts such as sea-level rise, pollution, and changes in extreme events. The next section investigates vulnerabilities and pressures – social, cultural, political and environmental – on the geographical system, with clear reference to climate adaptation and socioecological resilience. Finally, water, energy and food securities are discussed in detail, providing theoretical grounding and an applied link to climate change and issues of governance.

### **Part II: Conceptualizing ‘Environmental Livelihood Security’**

Having described both the natural and human environmental systems in Part I, this part provides a full conceptualization of what we term ‘Environmental Livelihood Security’. A substantive literature review is provided to bring together the theory of environmental security with sustainable livelihoods, in order to introduce environmental livelihood security as a means of conceptualizing livelihoods within the nexus. Multiple facets of governance provide influential material and provide synergy to the theory discussed in Part I.

### **Part III: Geospatial Information for Assessing Environmental Livelihood Security in Southeast Asia and Oceania**

The final part of this paper explores the potential for using quantitative and qualitative geospatial information to monitor the environment and livelihoods in Southeast Asia and Oceania. This provides a primer for enabling measurement of environmental livelihood security in the region. Potential indicators and available datasets for monitoring water-energy-food security, the vulnerabilities and pressures, and toolkits for sustainable livelihoods are discussed.





## INTRODUCTION

**Environmental livelihood security refers to the challenges of maintaining global food security and universal access to freshwater and energy to sustain livelihoods and promote inclusive economic growth, whilst sustaining key environmental systems' functionality, particularly under variable climatic regimes.**

Environmental security, a concept complementary to sustainable development, “investigates the heightened vulnerability people have to certain environmental stresses – which may be due to natural processes and phenomena as well as to unsustainable social activity” (Upreti 2013: 221). Falkenmark (2001) argues that bridging the concepts of environmental, food and water security is integral to the successful future of humanity (or one that is secure for humans). Attempting to create this bridge, at least in part, Hoff (2011) conceptualized the nexus approach to human protection where availability of water resources underpins food, water and energy security. The quality of human lives is inextricably linked to water which forms the core of the hydrologic, food production and livelihood systems (Kemp-Benedict et al. 2009). Whilst Hoff (2011) identified the role of the food, water and energy nexus in influencing human security, and Khagram et al. (2003) identified the relationship between human security and livelihoods, limited research exists conceptualizing and quantifying the relationship between food-water-energy security and sustainable livelihoods, particularly under a changing climate. In addition, Brauch (2005) stated that the analysis of environmental security issues at a regional level requires a spatial approach and should account for the temporal dimensions of environmental change. This is reiterated by Upreti (2013) who highlighted the need to differentiate between macro- and micro-scale environmental security, both of which are strongly influenced by the environmental and social geography of a region; environmental insecurity, extenuated by the impacts of climate changes (e.g., more frequent extreme events), is often experienced more adversely by the poor and vulnerable of developing nations (Brauch 2005; Brauch et al. 2008, 2009, 2011, 2016; Scheffran et al. 2012).

In this document we present the concept of environmental livelihood security (ELS) which aims to address this research void explicitly highlighted by Brauch (2005), where the need for increased conceptual work on the environmental dimensions of human security has been identified. This paper also acknowledges the need for a multidisciplinary approach, to bring together researchers with the ability to link these concepts, in theory and practice (from both a quantitative and qualitative research perspective) to examine the influence of environmental resources availability on livelihood security within Southeast Asia and Oceania (SAO); a region where livelihoods have high interdependency with the environment. The conceptual approach taken to explore issues of environmental livelihood security in Southeast Asia and Oceania combines nexus-thinking (e.g., Hoff 2011) with that of sustainable livelihoods (e.g., DFID 1999) and also discusses the use of spatial information to examine environmental livelihood security within the region.

The final version of this paper was, in part, the product of a workshop held at the University of Western Australia (June 2014) where, through a World Universities Network grant, academics and regional partners met to discuss the nexus-livelihoods concept. Expertise of workshop academic attendees ranged from sociologists to geomorphologists, and inclusion of regional partners insured that discussions were centered on policy-relevant outputs. The SAO region, defined for the purposes of this work in Figure 1, is an environmentally diverse region experiencing climatic variability at a wide range of temporal and spatial scales (BOM and CSIRO 2011). This paper provides applied grounding regarding the environmental geography of this broad region in Part I,

a strong theoretical background to the concept of *environmental livelihood security* in Part II, and an appraisal of potential geospatial data and methodologies for assessing environmental livelihood security within the SAO region in Part III.



Figure 1. Countries of Southeast Asia and Oceania (SAO) which constitute the geographical region referred to in this paper: Australia, Brunei, Cambodia, East Timor, Fiji, Indonesia, Kiribati, Lao PDR, Malaysia, Marshall Islands, Micronesia, Myanmar, Nauru, New Zealand, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Tonga, Tuvalu, Vanuatu and Vietnam.

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**PART I:  
THE ENVIRONMENT OF SOUTHEAST ASIA  
AND OCEANIA**

# 1. STATE OF THE ENVIRONMENT

## 1.1 Climate

Climatic regions of SEO can be divided into four broad regions (Figure 2) (Preston et al. 2006). The Arid and Semiarid Asia region (Figure 2) is characterized by an arid tropical climate with hot summers (Preston et al. 2006) and cold winters with “mid-latitude westerlies” dominating (Cheng et al. 2012). Precipitation in the area occurs mainly between April and September with the westerlies carrying water from the Atlantic, Mediterranean and Caspian (Cheng et al.2012). Long-term precipitation trends in the area are believed to be controlled by possible incursions of the Asian summer monsoon and high-latitude ice volume variation but the processes are poorly documented and little understood (Cheng et al. 2012). Temperate Asia receives the greater part of precipitation during the summer wet season, driven by the East Asian Monsoon. The area has been affected by severe droughts and floods which are thought to be associated with the El Niño-Southern Oscillation (Preston et al. 2006).

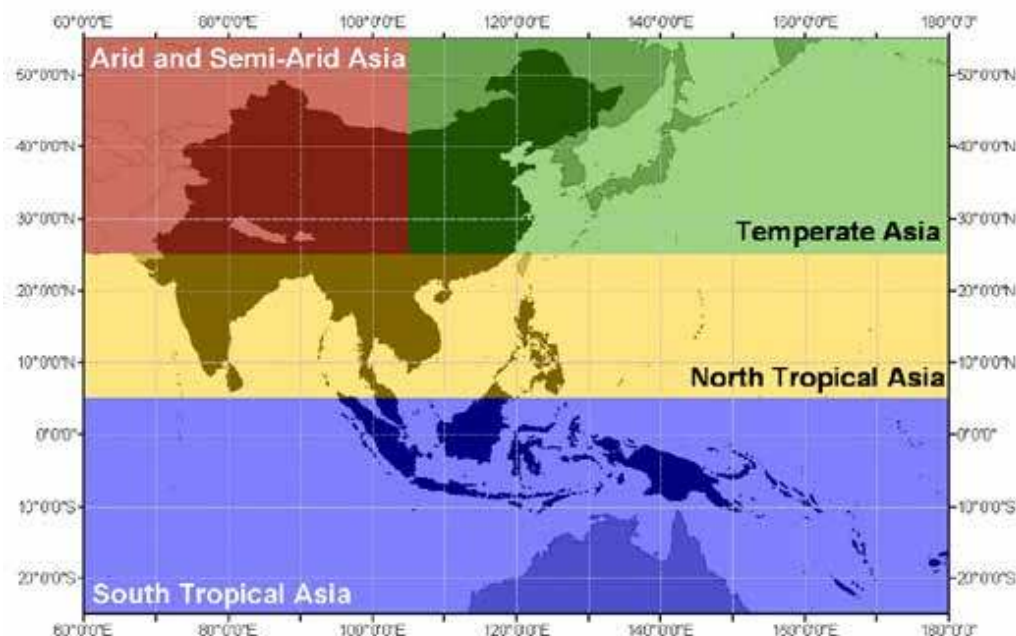


Figure 2. General climatic subregions within SAO (Source: Preston et al. 2006).

Climate in the North Tropical Asia and South Tropical Asia is characterized by minimal seasonal temperature variation but with marked seasonal rainfall variation resulting in distinct wet and dry seasons (CSIRO and BOM 2011). The region is dominated by three large-scale wind convergence zones and associated rainfall: the Intertropical Convergence Zone (ITCZ) just north of the equator; the South Pacific Convergence Zone (SPCZ); and the West Pacific Monsoon (WPM) (Figure 3). The El Niño-Southern Oscillation (ENSO), a coupled atmosphere-ocean phenomenon responsible for most of the climate variability in the Tropical Asia and the Pacific Region, operates at time scales of approximately 2 to 7 years (BOM and CSIRO 2011) and has a strong influence on climate conditions. El Niño is characterized by a basin-wide warming of the tropical Pacific Ocean east of the dateline, while the converse state, La Niña, is characterized by a cooling of these waters, also east of the dateline. These events are associated with fluctuation of the Southern Oscillation,

a global-scale tropical and subtropical pressure pattern (BOM and CSIRO 2011). ENSO is closely linked with variations in the main convergence zones with shifts in the location of the zones which influence rainfall, sea level and the risk of tropical cyclones. The Interdecadal Pacific Oscillation and the Pacific Decadal Oscillation are natural patterns of climate variability which also influence the climate in this region (BOM and CSIRO 2011).

Given the climate characteristics of the SAO region, this area is perceived to be highly vulnerable to climate change as the area geographically comprises many island nations (particularly small island developing states; SIDS). Many of these islands have limited land area, low elevation and high dependency on ocean ecosystems for survival, leaving them highly exposed to the potential negative impacts of future climatic change (Hay and Mimura 2013).

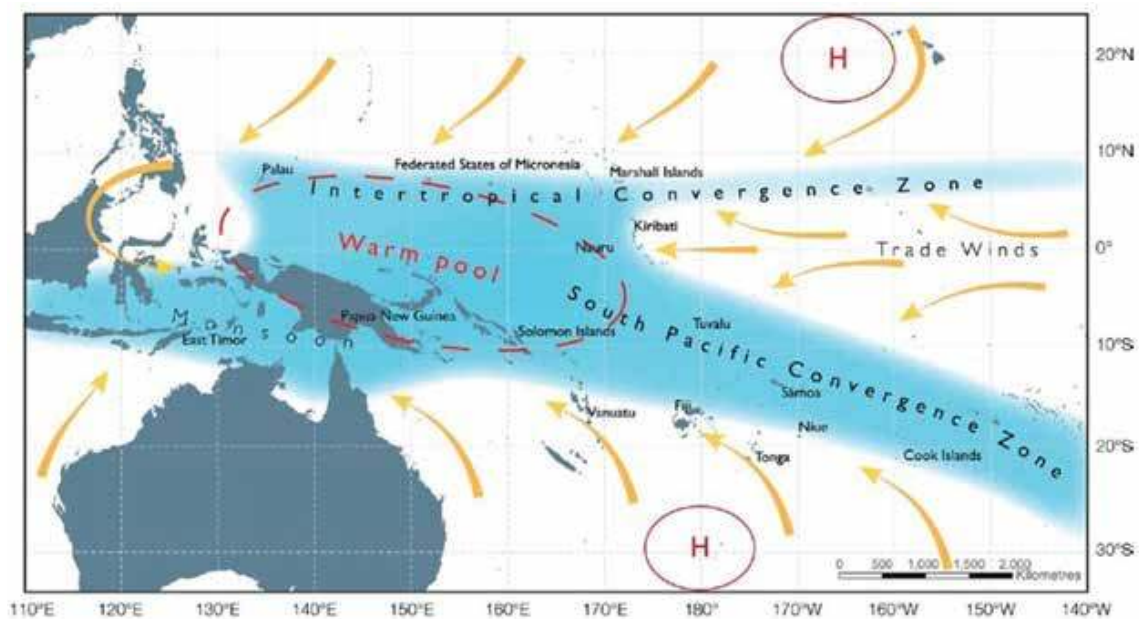


Figure 3. The average positions of the dominant climatic features of the South Pacific region, November to April. Yellow arrows show the direction of near surface winds, blue shading represents rainfall bands (i.e., convergence zones with relatively low pressure), the dashed red oval depicts the West Pacific Warm Pool. The typical positions of moving high pressure systems are represented by the red 'H' (Source: CSIRO and BOM 2011).

## 1.2 Climate Change

Many countries in SAO are at significant risk of extreme events (BOM and CSIRO 2011). Some regions experience very high seasonal rainfall variations associated with the West Pacific Monsoon (BOM and CSIRO 2011). Anthropogenic climate warming is predicted to produce shifts in, or exaggeration of, preexisting natural variability, such as ENSO, which can result in flooding or drought thresholds being crossed more often (Collins et al. 2010). Physical processes that determine characteristics of ENSO will likely be modified by climate change, but it is not yet possible to say whether ENSO activity will be enhanced or lessened, or if the frequency of associated events will be impacted (Collins et al. 2010). Changes in the frequency and intensity of extreme events are likely to be responsible for the primary impacts of climate change on society (Katz and Brown 1992) with changes in frequency of these events having greater impact than changes in mean temperature and precipitation (Mitchell et al. 1990). In addition to broad global change, there are many local and regional influences on climate, including urbanization, elevation, and proximity to water bodies, which can affect changes in extreme events (Choi et al. 2009).

### 1.2.1 Temperature

Greater negative impacts on nature and society will come from increases in extreme climate events, such as prolonged periods of hot days and intense heavy rainfall days, than from changes in climate means (Choi et al. 2009). Attempting to quantify the relationship between temperature means and extremes, research by Griffiths et al. (2005) found trends for 1961-2003 in daily temperatures and extremes to be spatially consistent across the SAO region, with increases in mean maximum and mean minimum temperature, decreases in cold nights and cool days, and increases in warm nights. This is consistent with findings by Choi et al. (2009) which show that for the 1955–2007 period, the annual frequency of cool nights [days] has decreased by 6.4 days/decade [3.3 days/decade], and the frequency of warm nights [days] has increased by 5.4 days/decade [3.9 days/decade]. The strongest changes in extremes are observed in northern tropical regions including Malaysia and Thailand (Choi et al. 2009). These results support the hypothesis that changes in mean temperature may be useful in predicting changes in extremes (Griffiths et al. 2005).

Increases in atmospheric temperature reported throughout the SAO region are expected to continue into the future (IPCC 2013). The magnitude of the projected warming is likely to be different throughout the globe due to geographic and atmospheric factors. Warming in the Pacific region is projected to be approximately 70% as large as the magnitude of global average warming; this is due to the high proportion of ocean which warms at a slower rate than land (IPCC 2013). BOM and CSIRO (2011) provide atmospheric temperature projections for the Pacific region centered on three 20-year periods (relative to 1990 baseline temperatures):

- By 2030, the projected regional warming is around +0.5 to 1.0 °C, regardless of the emissions scenario.
- By 2055, the warming is generally +1.0 to 1.5 °C with regional differences depending on the emissions scenario.
- By 2090, the warming is around: +1.5 to 2.0 °C for low emissions scenario, +2.5 to 3.0 °C for A2 (high emissions scenario).

Large increases in the incidence of extremely hot days and warm nights are also projected (BOM and CSIRO 2011). Atmospheric temperature increases will likely change the global hydrological cycle leading to more atmospheric moisture. Though uncertain, the consequences of increased atmospheric moisture could result in less frequent and more intense precipitation events throughout SAO (Trenberth et al. 2007).

### 1.2.2 Precipitation

Unlike the situation for temperature means, seasonal and annual precipitation do not show substantial, spatially consistent trends (Choi et al. 2009). Utilizing data from 143 weather stations across the SAO region, Choi et al. (2009) found there to be no systematic, regional trends in total precipitation, or in the frequency and duration of extreme precipitation events over the 1995-2007 time period. The standardized precipitation index (SPI; Lloyd-Hughes and Saunders 2002), a measure of drought (based on rainfall), indicates a trend towards fewer events at the end of the century (BOM and CSIRO 2011). Based on the SPI model, for all predicted emissions scenarios, the frequency of moderate droughts is projected to decline in the central Pacific (BOM and CSIRO 2011). Particular decreases in moderate drought occurrence are projected over the eastern

equatorial cold tongue region (drought occurrence expected to decrease from 3-4 times every 20 years to 2-3 by 2090) and the central western Pacific, including Papua New Guinea, the Solomon Islands and southern Palau (drought occurrence expected to decrease by 1-2 times every 20 years to 0-1 by 2090) (BOM and CSIRO 2011). Similar patterns are reported for mild and severe droughts (BOM and CSIRO 2011). Complementing SPI model, BOM and CSIRO (2011) report that atmospheric projections also predict droughts will occur less often in the region. This is in contrast to studies of observational studies such as in Fiji, which indicate increases in drought frequency (Deo 2011). Furthermore, research indicates that an increase in atmospheric moisture due to global warming may increase drought frequency while having little effect on precipitation (Trenberth et al. 2007). With these contrasting results in mind, it is clear that there are still many unknowns when considering extreme climate events in Southeast Asia and Oceania.

### 1.3 Tropical Cyclones

Tropical cyclones affect many coastal and island communities throughout SAO. These severe storms present significant hazards including extreme winds, storm surge inundation, salt water intrusion, flooding and landslides from intense rainfall. The majority of tropical cyclones in the southern hemisphere occur during November-April, with an average of one to two cyclones per day during the January-March maximum period (BOM and CSIRO 2011). Most tropical cyclones in the southern hemisphere are spatially distributed in the South Pacific between the Australian coast and the International Date Line, from about 12°S to 22°S (BOM and CSIRO 2011). In the western North Pacific, where cyclones are referred to as typhoons, increased frequency of storms are the result of favorable cyclonic development conditions, including high relative humidity, vertical wind shear velocity, sea-surface temperatures and convective available potential energy (Camargo et al. 2007).

Despite high exposure of SAO to tropical cyclones, there have been relatively few studies attempting to quantify the severe storm hazards in this region (BOM and CSIRO 2011). Present global climate models struggle to sufficiently simulate features of the current climate that strongly influences frequency and intensity of tropical cyclones (e.g., regional patterns of sea-surface temperature, ENSO, and the West Pacific Monsoon) and temporal and spatial resolutions are insufficient to capture small-scale features of these systems, such as high wind speeds (BOM and CSIRO 2011). Methods have been sought to either identify relationships between tropical cyclones and large-scale environmental conditions; or to identify weather features with tropical cyclone characteristics (i.e., a closed low pressure system accompanied by strong winds) directly from climate model outputs (BOM and CSIRO 2011).

Globally, tropical cyclone intensity is suggested to increase by about 2-11% (BOM and CSIRO 2011). A report by BOM and CSIRO (2011) presents several significant findings in terms of tropical cyclone frequency and intensity predictions for the Pacific region based on a number of climate model analysis methods, with outputs suggesting tropical cyclone frequency is likely to decrease by the end of the century (BOM and CSIRO 2011). Most simulations project an increase in the proportion of the most severe storms in the southwest Pacific with maximum intensity storms moving southward (BOM and CSIRO 2011). Models in the South Pacific indicate a reduction in cyclonic wind hazard north of 20 °S and regions of increased hazard south of 20 °S, which coincides with projected increases in the number of tropical cyclones occurring south of 20 °S and a shift to further southern latitudes at which storms are most intense (BOM and CSIRO 2011).

### 1.4 Rise of Sea Level

Global sea-level change is occurring as a result of thermal expansion, the melting of land ice and groundwater extraction (Nicholls and Cazenave 2010). Sea-level rise is threatening people and ecosystems in many coastal areas and islands in SAO. Satellite altimetry data indicate the greatest increases in sea level have occurred in the North Tropical Asia region with considerable increases also around Papua New Guinea and Western Australia (Figure 4) (AVISO+ 2014). The IPCC (2013) stated that the mean rate of global average sea-level rise was 1.7 mm per year between 1901 and 2010 and 2.0 mm per year between 1971 and 2010 based on a comprehensive series of proxy records, tide gauge records and satellite altimetry data. Process-based models suggest that changes in glacier and ice sheet contributions will result in 0.28 to 0.98 m sea-level rise by 2100 (IPCC 2013; Figures 5 and 6).

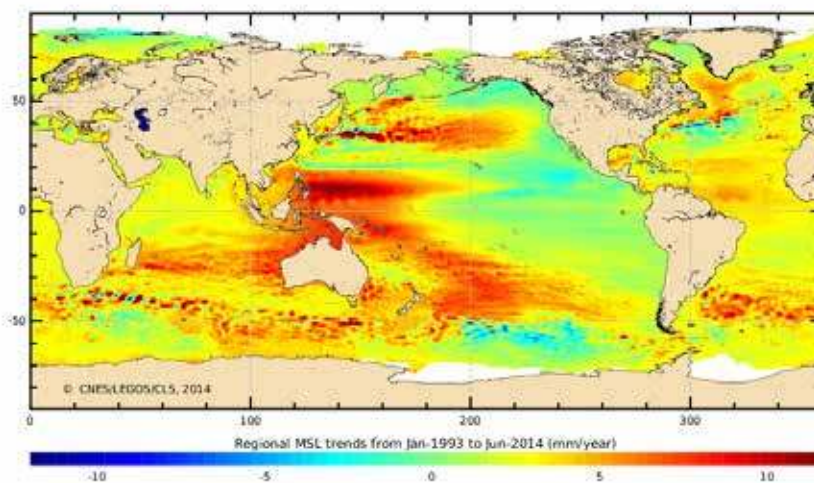


Figure 4. Mean sea-level changes based on satellite altimetry data from 1992 to 2013 (Source: AVISO+ 2014).

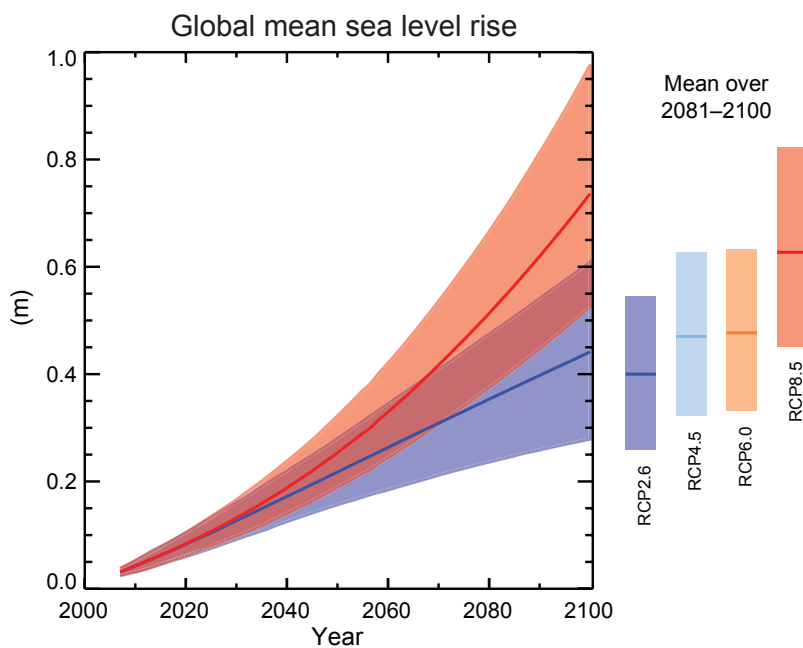


Figure 5. IPCC projections for global mean sea-level rise over the 21st century relative to 1986-2005 for four different scenarios. The assessed likely ranges for the mean from 2081 to 2100 for all RCP scenarios are shown as colored vertical bars (Source: IPCC 2013).



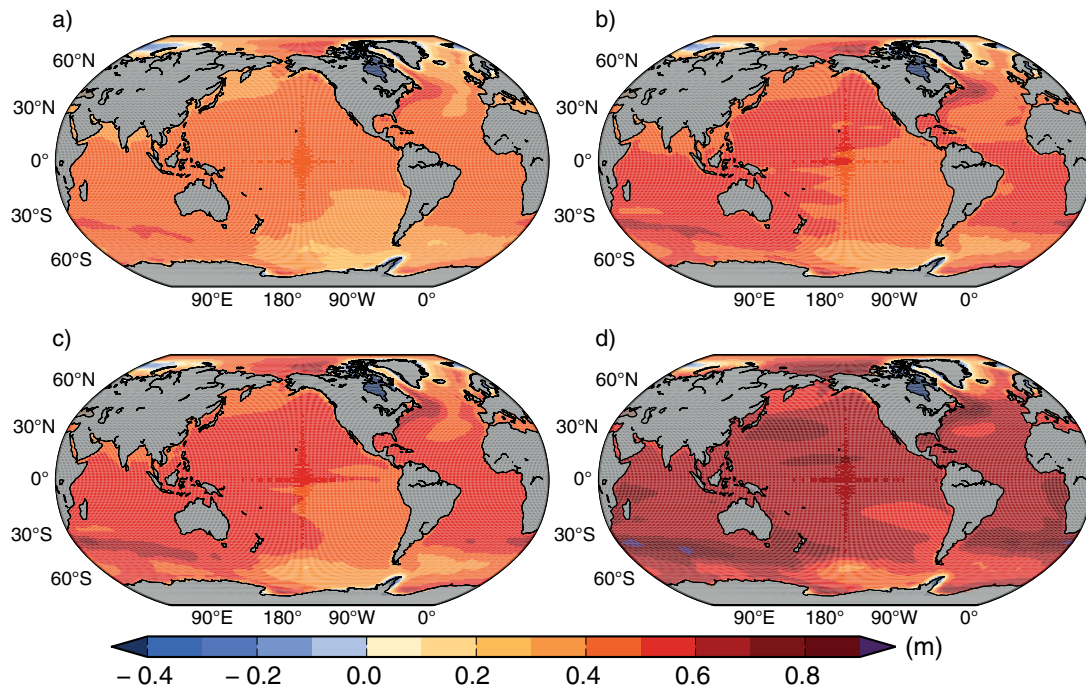


Figure 6. Mean net regional sea-level change (meters) evaluated from 21 CMIP5 models for the RCP scenarios between 1986-2005 and 2081-2100 (Source: IPCC 2013).

Globally, ocean temperature increases have been largest near the surface with the IPCC reporting that the upper 75 m warmed by  $0.11\text{ }^{\circ}\text{C}$  per decade from 1971 to 2010 (IPCC 2013). BOM and CSIRO (2011) also reported a general increase in sea-surface temperatures in the Pacific Ocean since 1950. In addition, they report a decline in salinity in the western tropical Pacific Ocean and an increase in salinity to the east. These salinity changes are related to relative rates of evaporation versus precipitation (IPCC 2013) and have caused an increase in the stratification of the upper Pacific Ocean (BOM and CSIRO 2011). Projections suggest the temperature of ocean surface waters (i.e., the top 100 m) will increase globally by approximately  $0.6$  to  $2.0\text{ }^{\circ}\text{C}$  by 2100 (IPCC 2013). This warming is likely to be most pronounced in surface waters of the tropical and Northern Hemisphere subtropical regions (IPCC 2013). In the deeper ocean (i.e., depth 1,000 m) the warming is projected to be between  $0.3$  and  $0.6\text{ }^{\circ}\text{C}$  by 2100 (IPCC 2013). The salinity of sea surface is predicted to decrease in the Pacific with regional differences relating to changes in rainfall (BOM and CSIRO 2011). This declining salinity, coupled with the projected increase in water temperature is likely to drive further stratification between the surface and deep ocean, inhibiting mixing and reducing the supply of nutrients from the deep ocean received by surface waters (BOM and CSIRO 2011).

The impacts of sea-level rise on coastal areas and islands include physical impacts, such as inundation of low-lying areas and coastal erosion; and ecological impacts such as salinization of soils and groundwater making them unsuitable for agriculture (BOM and CSIRO 2011, Duce et al. 2010). The countries of SAO were found to be among the most exposed to sea-level rise impacts based on various indicators (Figure 7), and various impacts can be identified within different nations in this region. For example:

- Soil salinity can increase due to the inundation of the land by sea water caused by both extreme (e.g., cyclone and storm surge) and chronic events (e.g., sea-level rise) (Rabbani et al. 2013). Combined with urbanization and industrialization, salinization presents an

additional pressure to land available and suitable for agricultural production. Salt intrusion can substantially impact crop yields and the viability for agricultural production with ensuing economic consequences (Warner et al. 2012; Rabbani et al. 2013).

- Mangroves provide an important land use buffer to the risks from cyclone activity, as well as a unique natural habitat. Shearman et al. (2013) used remote sensing to assess changes in some of SAO's major mangrove deltaic systems: the Fly and Kikori-Purari (Papua New Guinea), Irrawaddy (Myanmar) and Mekong (Vietnam). The study found an overall net loss of mangroves across the region with considerable variation within individual systems. The greatest decline was found to have occurred in the Papuan deltas which experience the least anthropogenic activity and where sediment load could be expected to increase due to deforestation and mining within the catchments. Shearman et al. (2013) speculate that this could be a result of eustatic sea-level rise in the area and perhaps associated with, but hard to quantify, increases in wave activity.
- Groundwater is a dependency for many small island states for agriculture, livestock and domestic supply (Falkland 1991; Barnett and Campbell 2010). Groundwater in small island states often exists as a "lens" of less dense freshwater floating on more dense saltwater (Ketabachi et al. 2013; Robins 2013). Groundwater modelling studies have shown that sea-level rise leading to increased land surface inundation will lead to increased saltwater intrusion and therefore a decrease in available freshwater on many small island states (Ketabachi et al. 2013; Robins 2013), impacting communities and ecosystems dependent on groundwater.
- Storm frequency coupled with increased sea-level rise could pose a substantial risk to coastal zones and islands in SAO (BOM and CSIRO 2011; Hay 2013). Brecht et al. (2012) identified considerable asymmetry in the exposure of countries to large storm surges with Manila in the Philippines exhibiting the greatest coastal population at risk (Brecht et al. 2012). The recent devastation caused by Typhoon Haiyan in the Philippines potentially provides grounding to validate this assertion, but Brecht et al. (2012) noted the lack of a global database on coastal-zone management and shoreline protection – a considerable limitation to such studies.

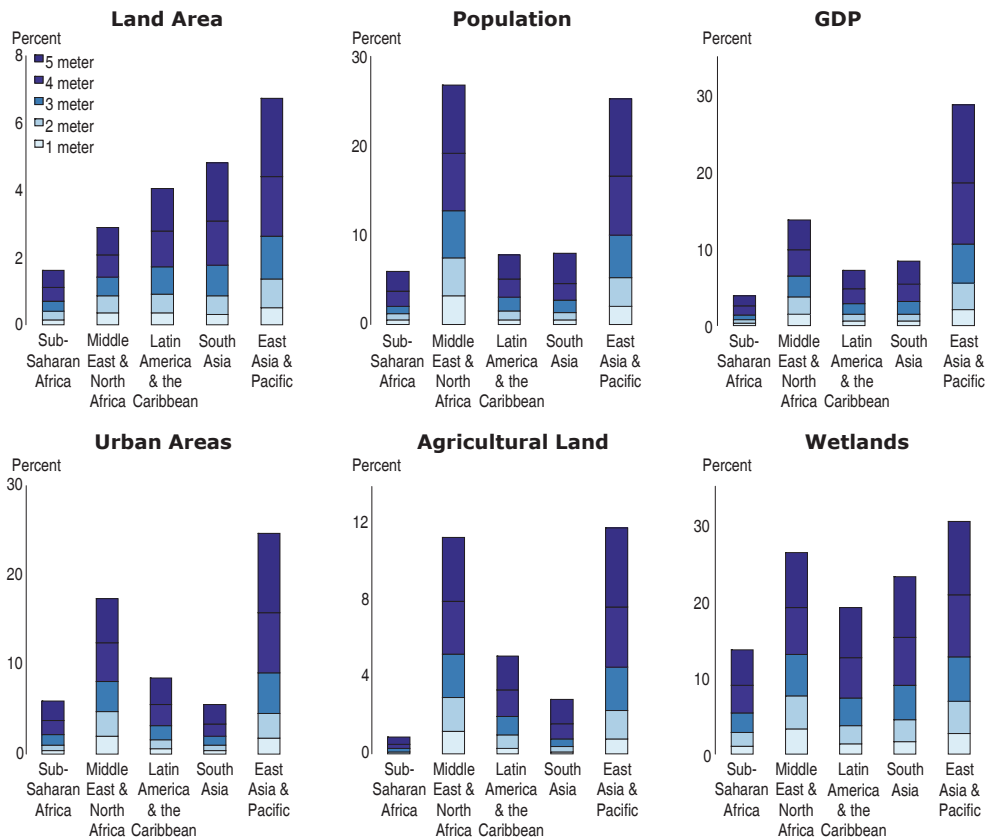


Figure 7. Regional impacts of sea-level rise for each indicator. The two columns to the right represent the SAO region of interest in this paper (Source: Dasgupta et al. 2009).

## 1.5 Ocean Acidification

Atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased to the highest rates in 800,000 years; 40, 150 and 20% higher, respectively, than pre-industrial levels (IPCC 2013). A proportion of these emissions has been absorbed by the oceans leading to a decrease in pH in the process of ocean acidification (refer to Figure 8) (IPCC 2013). By 2100 a decrease in surface ocean pH of 0.06 to 0.32 is predicted. The east coast of Australia is projected to be one of the most rapidly acidifying regions (Figure 9). This acidification is associated with a decrease in the amount of carbonate minerals available in seawater to be secreted as shells and skeletal material by many key species. Reef building corals precipitate calcium carbonate in the form of aragonite and require an optimal aragonite saturation rate of four or higher. Since 1990, there has been a decline in aragonite saturation throughout the Pacific Ocean (BOM and CSIRO 2011). Future changes indicate aragonite saturation rates are predicted to fall below 3.5 in many regions of the Pacific (BOM and CSIRO 2011). The recent IPCC report (2013) projects that surface waters will become seasonally corrosive to aragonite in some coastal upwelling systems within a decade, and in parts of the Southern Ocean within one to three decades under most scenarios.

Societies within the SAO region which are heavily reliant upon coral reef and other marine ecosystems for subsistence fishing, tourism and/or exports will likely be negatively impacted by ocean acidification. More broadly, oceanic climate change impacts may result in the extinction of numerous local marine fish and invertebrate species in tropical areas (Cheung et al. 2009) by 2050. Approximately 30 million people worldwide depend heavily on fish as a primary source of protein (Bell et al. 2011). Coastal and island nations, provided for by predominantly small-scale

fisheries, have the highest per capita seafood consumption rates in the world (Huelsenbeck 2012). In assessing the vulnerability of national economies to climate change impacts on fisheries, Allison et al. (2009) found Cambodia to be one of the most vulnerable countries in the SAO region.

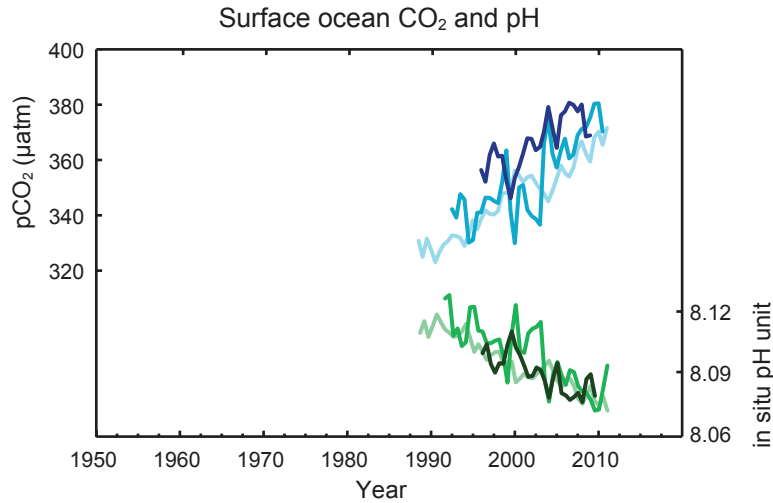


Figure 8. Partial pressure of dissolved CO<sub>2</sub> at the ocean surface (blue curve) and in situ pH (green curves). The light blue and light green curves are based on measurements from the Pacific Ocean (22 45°N, 158 00°W) and the other curves are from the Atlantic Ocean (Source: IPCC 2013).

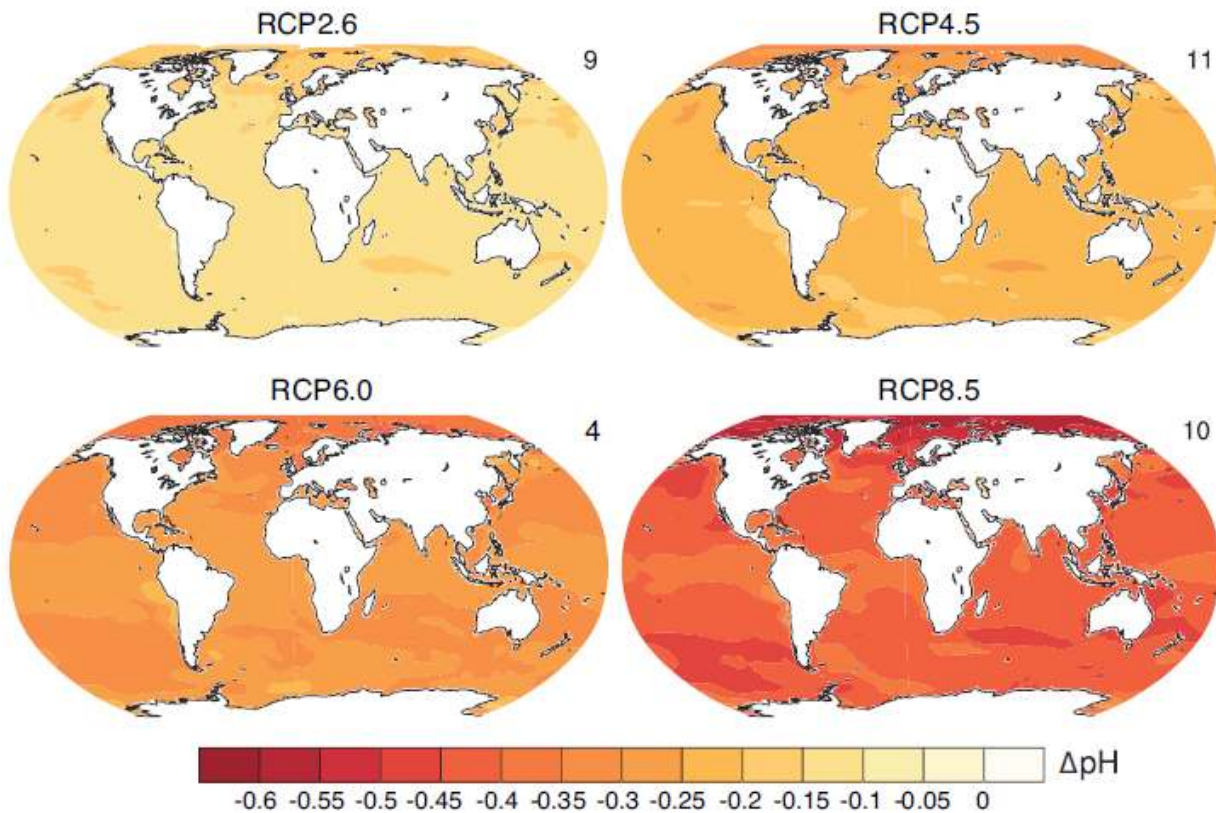


Figure 9. Changes in global surface pH in 2081-2100 relative to 1986-2005. The number of CMIP5 models to calculate the multi-model mean is shown in the top right corner of each panel (Source: IPCC 2013).

## 1.6 Biodiversity

The SAO region supports areas of significant biodiversity, endemic wildlife and a major proportion of the world's threatened species. Altogether nine of the 34 international biodiversity hot spots identified by Conservation International are within the SAO region. These include East Melanesian Islands, Indo-Burma, New Caledonia, New Zealand, Philippines, Polynesia-Micronesia, southwest Australia, Sundaland and Wallacea. The scale of development and infrastructural expansion associated with rapid economic advancement within the region and its neighboring countries has resulted in regional decline in biodiversity. Human-induced disturbance of natural ecosystems can alter species composition and ecological processes. The main drivers of biodiversity loss in the SAO region include invasive species, deforestation, timber and biofuel monocultures, land use and water use change, habitat fragmentation, agricultural expansion and intensification, unsustainable harvesting of timber and non-timber forest products (e.g., over-hunting of game species), over-fishing, urban expansion, pollution and climate change (Gardner et al. 2010).

Increasing global demand for food, biofuel and other commodities has resulted in the expansion of oil palm and paper-and-pulp industries at the expense of lowland dipterocarp forests in Southeast Asia (Sodhi et al. 2010). Medicinal plants also face a high risk of extinction in regions where there is continuing dependence on wild collection (UNEP 2010). Those most affected by loss of biodiversity and associated decline in ecosystem services are communities whose lives are closely linked with the environment, and who are often most impoverished and marginalized (Fuentes et al. 2012). Maintaining functional connectivity across multiple-use landscapes and protection of species-rich habitats, including traditional agroforestry systems and secondary regrowth, are fundamental to long-term ecological resilience (Tabarelli et al. 2010). In this region of high cultural diversity in which community livelihoods are dependent on human-environment interactions, traditional ecological knowledge has an important role in biodiversity conservation.

## 1.7 Pollution

### 1.7.1 Agricultural

There has been an 800% increase in nitrogen applications to farmlands in the last 50 years; agriculture is now the largest source of nitrogen and phosphorus in water bodies, and of the nitrogen fertilizer applied to croplands only 30-50% is utilized by crops (Tilman et al. 2002; Foley et al. 2005, 2011). The resultant excessive nutrient loading of water bodies facilitates eutrophication, toxic algal blooms, disturbance of species composition, anoxic conditions that deplete fish stocks, degradation of coastal ecosystems and subsequent health impacts from poor-quality drinking water (Tilman et al. 2002; Carpenter et al. 2010; Wiener et al. 2010). This highlights that agriculture can lead to decline in both water availability, through irrigation extraction greater than renewable limits, and water quality; this often has downstream impacts (Wiener et al. 2010). A global analysis revealed that developed countries are able to limit threats to biodiversity whilst maintaining water security, an option not always available to developing countries (Figure 10) (Vörösmarty et al. 2010). This suggests that under current water use practices and governance structures there will be a trade-off between increasing calls to meet biodiversity and conservation goals and the need to provide water security to approximately one seventh of the world's population.

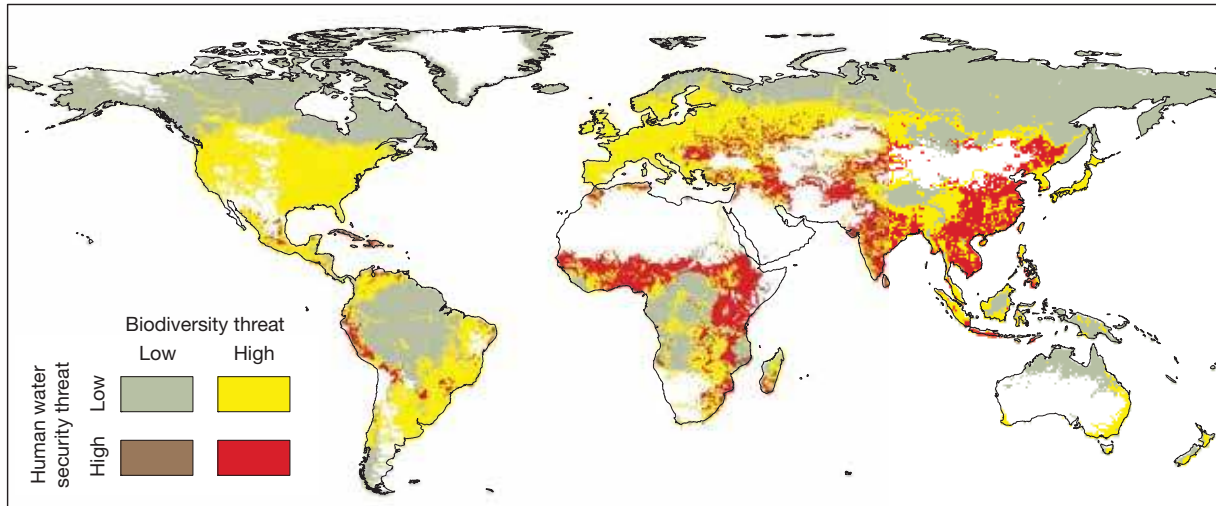


Figure 10. Adjusted human water security threat is contrasted against incidental biodiversity threat (Source: Adapted from Vörösmarty et al. 2010).

### 1.7.2 Marine

Coastal habitat degradation and marine pollution are the two main pressures in marine environments. Despite international conventions and regional efforts focused on controlling marine pollution, there has been continued increase in environmental damage caused by debris in the Asia-Pacific oceans (UNEP 2005; McIlgorm et al. 2009). The economic impact of marine debris to fishing, transportation, tourism and insurance industries in the SAO region is estimated to be US\$1.265 billion across the 21 APEC economies (McIlgorm et al. 2009). Additional, less economically quantifiable costs include impact to coastal habitats, loss of local livelihoods and lost capital-investment opportunities. It is estimated that, globally, approximately 80% of marine debris comes from land-based sources, entering ocean environments directly (deliberate or unintended) or indirectly via runoff, rivers, sewers, stormwater or wind (UNEP 2005). Plastics comprise approximately 60-80% of marine debris (Allsopp et al. 2006) and are potentially the most preventable form (Derraik 2002). Current understanding of the oceans' accommodative capacity for land-based wastes is limited due to the difficulty in quantifying decomposition rates of inorganic marine debris. In reducing the stock of marine debris, the benefit-cost ratios are greater for preventive measures than clean-up activities, suggesting efforts should be concentrated on reducing debris entering coastal waterways and controlling waste practices (McIlgorm et al. 2009). The dispersal of pollutants and marine organisms impacted by toxic contaminants (such as heavy metals and dioxins) is influenced by ocean currents. Due to the interconnectivity of marine systems, regional influences on waste regulation can impact localized pollutant concentrations. Both land- and ocean-based waste practices have important consequences for fisheries-related food security, particularly in communities reliant on coastal fisheries for local livelihood.

## 2. VULNERABILITIES AND PRESSURES

### 2.1 Demographic Transitions

The SAO region contains some of the largest and smallest national populations on the planet (UNFPA 2013). Populations are disproportionately distributed in the region, resulting in widely varying population densities (Waggener and Lane 1997). Accompanying this diversity are demographic trends characterized by lower overall fertility and mortality rates, as well as rapid urbanization and migration flows within and out of the region (UNFPA 2013). Some countries in the region are faced with a “youth bulge”, which presents opportunities to accelerate development, while others are ageing rapidly, making the provision of adequate healthcare and other services imperative (UNFPA 2013). CEPAR (2013) state that significant change will occur in the Asian region’s age structure; half of the projected increase in the one billion Asian population by 2040 will be over 65 and the ratio of older (65+) to working-age population (15-64) will more than triple in many East and Southeast Asian countries. This demographic transition is being driven by increases in life expectancy and decreases in fertility (CEPAR 2013).

#### 2.1.1 Migration

Migration is also an important population issue in the region. SAO is the origin of 40% of all international migrants globally and there are even more people moving within their own countries (UNFPA 2013). Rapid economic growth, the slowing of domestic population and the growth of the labor force due to fertility reduction have resulted in countries such as Singapore opening its doors to in-migration of foreigners for employment, with the option of permanent settlement for the highly skilled (Chongsuvivatwong et al. 2011). The Philippines, Indonesia and Vietnam are major labor-exporters, whereas Malaysia and Thailand both receive and send nationals abroad (both within and outside the SAO region) (Chongsuvivatwong et al. 2011). There is also significant undocumented or illegal migration and movement of displaced people in the region - groups that are particularly vulnerable since they are disproportionately more exposed to health risks and are often left out of assistance programs in times of disasters and emergencies (Chavez 2007).

#### 2.1.2 Urbanization

Currently, two out of every five persons in the region live in urban areas, but this ratio is expected to increase significantly in the next two decades as millions move from the countryside to towns and cities in search of employment and better opportunities (UNFPA 2013). Even a slowing urbanization growth rate in China is still expected to add hundreds of millions to Asia’s urban population in the next 20 years (CEPAR 2013).

### 2.2 Social and Cultural Factors

Demographic shifts in terms of an ageing population and increasing urbanization are not unrelated, as urban centers not only boast better job opportunities and higher incomes but also allow greater access to health services, education, and social networks – factors known to be associated with longer lives (CEPAR 2013). Accompanying these demographic shifts are social trends and changes, particularly in relation to family structure. For example, Asians are now marrying less, translating to fewer children and affecting the pattern of family formation, which can undermine traditional sources of support (CEPAR 2013). Such trends and changes in society can result in vulnerability

to particular communities or individuals, which may either impact upon or be inherently rooted within cultural values.

### 2.2.1 Ethnicity

One example of vulnerability to the population, which arises as a consequence of sociocultural factors, is the marginalization of a particular ethnic minority or indigenous groups by the dominant ethnic groups in a country, often as a result of historical power shifts (e.g., Duncan [ed.] 2004). In Mainland Southeast Asia, ethnic minority groups have been pushed into ecologically marginal and vulnerable spaces, often in mountainous border regions (such as the so-called hill tribes of North Thailand or the indigenous Kh'mu in northern Lao PDR) or in fragile coastal and island locations (e.g., the so-called 'sea gypsies' in southern Thailand and Myanmar and in some provinces of Malaysia and Indonesia). Many of these groups tend to be regarded as either economically and culturally backward or environmentally destructive (or both) by mainstream society (Duncan 2004; Forsyth and Walker 2008). To empower ethnic minority and indigenous groups, and to validate their rich local knowledge and cultural practices, several NGOs and indigenous associations have been established in Asia, such as the Thailand-based Asia Indigenous Peoples' Pact (<http://aippnet.org>) and Indigenous Peoples' International Centre for Policy Research and Education (<http://www.tebtebba.org>), based in the Philippines.

### 2.2.2 Gender

Gender is another major social factor of vulnerability. Gender can be conceptualized as "the rules, customs and practices by which biological differences are translated into social differences between men and women" (Sullivan et al. 2012). Statistics which are not gender-disaggregated mask inequality and the feminization of poverty (Chant 2006). Gender disparities persist across the board and women are yet to reach equity with men (Okali 2011; World Economic Forum 2013). Although culturally diverse, the SAO region is predominantly characterized by entrenched patriarchal traditions. These are arguably more evident in Southern Asia (where a strong son-preference still prevails) than in the small island nations of the Pacific which tend to exhibit a more fluid appreciation of gender roles (as exemplified by the Fa'afafine of Samoa). Women in many rural societies in SAO do not have equal access to land, water and other natural resources and are rarely landholders in their own right as their male peers. Women's rights to agricultural and forestland are often fragile and they face risks of being excluded in state-led land reform processes and community forestry initiatives.

In Nepal, for instance, where community forest user groups (CFUG) cover more than 22% of the country's forest area, the majority of CFUG members are male, and wealthier upper-caste men tend to dominate major decisions with regard to forest control and use, although women spend much of their time and energy gathering forestry products (Acharya 2005; Larson et al. 2010). Women in most small island states of the South Pacific are also disadvantaged in terms of access to land. With the exception of French Polynesia and the Cook Islands, where women enjoy the same land rights as their male peers, Pacific Island women are mostly excluded from the right of inheritance, both in patrilineal societies (e.g., Fiji, Tonga) and in matrilineal societies (e.g., Marshall Islands, Palau, Nauru as well as some parts of Papua New Guinea, the Solomon Islands and Vanuatu) (IPS-USP 1986). In some places, perceptions of the status and entitlements of women are slowly changing, and higher education, the gradual shift from communal to individually held land, and the expansion of freehold land markets have opened some opportunities for women to own land, thereby reducing their economic vulnerability in some places (Ward and Kingdon 1995).



## 2.3 Political and Institutional Factors

Political and institutional factors of vulnerability have received less attention from scholarly research than ecological, economic and social factors. Yet, in many countries of the SAO region, controversial government policies have had a major impact on the sustainability of rural livelihoods. All too often, governments mistakenly believe they can control resources ‘for the public good’ most effectively. They tend to ignore the possibility that a communal property regime and community self-governance – when recognized and supported by the government – could provide greater protection and more effective use of the resources under many circumstances. One of the consequences of this misconception was the declaration of state-controlled protected areas, the majority of which have been established on indigenous and ethnic minority peoples’ lands without their consent. In 1999, it was estimated that about 80-100 million people in Southeast Asia lived in national parks, wildlife sanctuaries, forest reserves and other protected areas, most of them without a legal basis on their land and continuously threatened by expulsion (Poffenberger 1999). This number has likely increased since then, as several countries, most notably Thailand and Vietnam, have since expanded their national protected areas (Neef et al. 2003; Dahal et al. 2011).

### 2.3.1 Land tenure

In Thailand, communal management of forests still has no legal basis despite the constitutional rights of local communities to actively participate in the management of natural resources. In the Thai uplands, the failure to recognize communities’ rights and to delineate boundaries for community forests has left local people’s hands tied in protecting their communal resources against encroachers and outside investors. In Lao PDR, Cambodia, Malaysia and Indonesia large concession projects that promote agro-industrial plantations and commercial timber extraction frequently come into conflict with indigenous approaches to forest management, despite the official recognition of community forestry in these countries (e.g., Kenney-Lazar 2012; Neef et al. 2013; Eilenberg 2014). The only country in Southeast Asia that has formally adopted community-based forest management as a national strategy to achieve sustainable forestry is the Philippines. It is also the ASEAN country that is most progressive in terms of acknowledging indigenous peoples’ territorial rights. The Indigenous People’s Rights Act (IPRA) provides the legal basis of giving indigenous communities titled tenure rights on their ancestral domains. Legal ambiguities remain a problem, however, as many ancestral domains overlap with mining land, traditionally owned by the State (Llanto and Ballasteros 2003). Another problem is that jurisdiction over IPRA was recently shifted from the Office of the President to the Department of Environment and Natural Resources (DENR) which does not see the advancement of indigenous domains as a major priority (Dahal et al. 2011).

### 2.3.2 Displacement

Due to high population densities, rapid urbanization processes and a strong focus on quantitative economic growth, Asia is home to the world’s largest displaced population. Development-Induced Displacement and Resettlement (DIDR) has gained increasing attention by media, development circles, civil society, donor countries and national policymakers throughout Asia, particularly triggered by well-publicized cases of civil resistance (e.g., to the Sardar Sarovar Dam in India; Maitra 2009) and to the Monywa Copper Mine in Myanmar (Zerrouk and Neef 2014)), by the enormous scale of environmental and socioeconomic disruption, for example, that posed by the Three Gorges Dam in China (Wilmsen et al. 2011; Wang et al. 2013) and by politically charged transboundary controversies and conflicts (e.g., over the impacts of dam construction in the

Mekong River Basin; Tilt et al. 2009; Middleton et al. 2009; Zhang et al. 2013). In the Pacific region, mining, tourism and logging are among the major factors that have caused involuntary resettlement and dispossession of community land (e.g., Banks et al. 2013 for the case of the mining sector in Papua New Guinea; Wittersheim 2011 for the case of tourism in Vanuatu; Hameiri 2012 for the case of large-scale logging in the Solomon Islands). There is substantial empirical evidence that development-induced displacement exacerbates vulnerabilities among already marginalized, poor and vulnerable social groups, such as women, ethnic minorities, the urban poor, and land-poor subsistence farmers depending on access to communally held natural resources (e.g., Vandergeest et al. 2006; Bisht 2009; Bui et al. 2013; Quetulio-Navarra 2014).

## 2.4 Geographic Location

Turvey (2007) defines geographic vulnerability from a developing perspective as a country's susceptibility to physical and human pressures, risks and hazards, in spatiotemporal contexts. Small island developing states (SIDS) vary enormously according to distinct biophysical, sociocultural and economic characteristics (FAO 1999). However, Mercer et al. (2007) report common challenges are shared, including small populations, limited resources, excessive dependence on international trade, vulnerability to global developments and a susceptibility to environmental hazards. Briguglio (1995) argued many SIDS face special disadvantages associated with small size, insularity, remoteness and proneness to natural disasters rendering their economies highly vulnerable and threatening their economic viability. The geography of the region, Pacific islands in particular, also means that many nations are physically isolated from global markets and their economies are narrowly based (ADB 2013a).

## 2.5 Natural Resource Economies

The SAO region, particularly the Pacific nations, is characterized by a fragile economic structure, largely dependent on natural resources, which heightens its vulnerability to climate change (ADB 2013a). Economies in SAO reflect the great natural resource diversity (Table 1) but poverty rates still remain high throughout much of the region (ADB 2013a). Agriculture, industry and tourism are the primary economic contributors to GDP in the region with relative importance varying considerably between nations. The agriculture sector, including cropping and fisheries, is economically important and also extremely significant for food security in SAO. The agriculture sector in many nations is under pressure from limited arable land, and increasing population and urbanization, with climatic change adding additional pressure (ADB 2013a). Even the industrial sectors of many Pacific nations are dependent on natural resources such as pearls, shells and wood, making them exposed to climate change (ADB 2013a). Most nations in SAO experienced growth in GDP between 2000 and 2012, the highest being in East Asia which had an average annual increase of 7% over the period (Figure 11). However, the Pacific region experienced the lowest overall growth at <1% GDP (ADB 2013a).

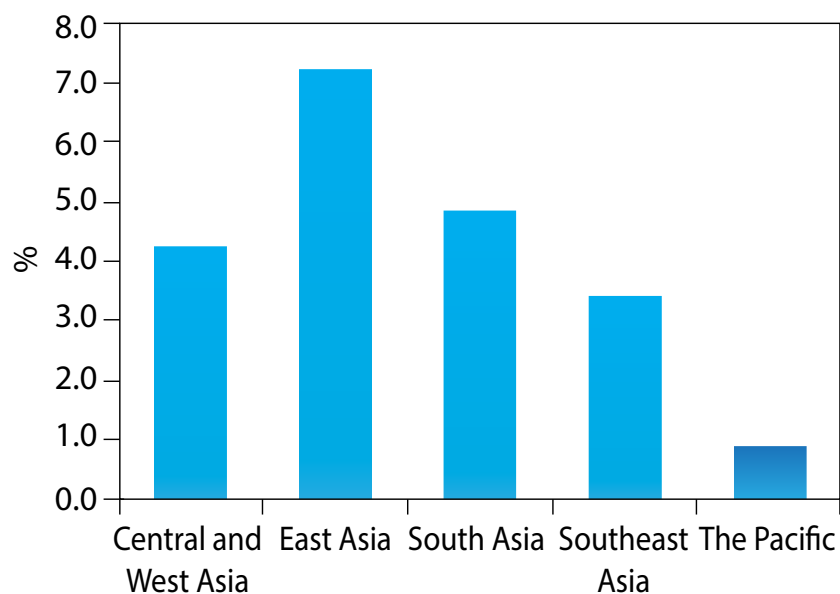


Figure 11. Average annual growth in real Gross Domestic Product (GDP) per capita, 2000-2012 (%) (Source: ADB 2013a).

Table 1. Share of Pacific economies dependent on natural resources (GDP share by sector, %) (Source: ADB 2013a).

Economic indicators	Cook island	Fiji	Kiribati	RMI	FSM	Palau	PNG	Samoa	Timor-Leste	Tonga	Vanuatu
Agriculture	4.6	12.1	26.3	15.0	27.8	5.5	29.1	9.8	3.3	18.8	23.9
Industry	9.0	22.0	8.2	13.1	9.1	8.4	44.2	27.9	85.6	21.1	10.1
Services of which international tourism receipt	86.4	65.9	65.5	72.0	63.2	86.1	26.7	62.3	11.1	60.1	66.0
	44.4	23.4	2.9	2.0	8.4	56.0	0.03	20.2	2.6	5.8	34.1
Tourism plus agriculture	49.0	35.5	29.2	17.0	36.2	61.5	29.1	30.0	5.9	24.6	58.0
Employment in agriculture	4.3	1.3	2.8	12.0	52.2	7.8	72.3	35.4	50.8	27.9	60.5

Note: GDP data is for 2011 except for Palau, PNG, Samoa, Tonga and Tuvalu, which is 2012 data is based on most recent year available. Tourism data is for the year 2010 except for Kiribati and Tonga (2005). Nauru and Tuvalu are not included in the table owing to the absence of tourism data. Solomon islands lacks GDP shares data.

The economies of the Pacific region, in particular the SIDS, rely heavily on tourism which accounts for up to 56% (Palau) of GDP in the nations (Table 1). Aside from direct physical impacts of climate change on the tourism industries (i.e., coastal erosion, decline of coral reefs), Scheyvens and Momsen (2008) argue that the conceptualization of these islands as extremely geographically vulnerable to climate change could present a barrier to sustainable tourism development and, in turn, economic development overall. Farbotko and Lazrus (2012) also provide evidence of this negative conceptualization manifesting in economic loss for SIDS. They contest the concept of “Climate Refugees” being produced on small island states due to their high vulnerability to climate changes, with particular reference to sea-level rise. The authors state that migration has been a key part of Tuvaluan life long before climate change was recognized as a threat and argue that labeling migrants as climate refugees is politically charged and disempowering to the communities concerned. Connell (2013) provides a useful review of the dialogue surrounding climate change and migration in the Pacific Region.

## 2.6 Climate Change Adaptation

Climate change represents a significant threat to resources critical to ensuring security across the nexus sectors, and will amplify current worrying trajectories in resource use. Warming temperatures and extreme heat events are likely to negatively impact cereal crop production (Deryng et al. 2014; Gourджи et al. 2013; Challinor et al. 2014; Rosenzweig et al. 2014). It is likely that warming temperatures will also impact crop water productivity (Döll 2002) and availability of water for irrigation (Elliott et al. 2014). Climate change will also impact the energy sector, warming temperatures will reduce the efficiency of water used in cooling systems in thermal power plants, rising sea levels could threaten coastal energy infrastructures (e.g., tidal power, coastal power plants) and droughts and erratic precipitation could impact hydropower (Rodriguez et al. 2013). Global Hydrological Models (GHM) indicate human extraction of freshwater has a negative impact on runoff in all basins compared to a natural hydrological cycle (Haddeland et al. 2013). Population increases and growing water demand will further exacerbate scarcity (Chatres and Sood 2013). However, projected changes in runoff under climate change (RCP 8.5) will have differing impacts in basins across the globe; in some basins, climate change will increase runoff cancelling out human extraction impacts (e.g., Nile Basin) and in others it will exacerbate the impacts of human extraction (i.e., increase runoff deficit from a natural hydrological cycle) (Haddeland et al. 2013).

The political situation and decision-making capacity of a nation affect their level of environmental vulnerability and their ability to adapt to climate change successfully. Kelly and Adger (2000) argue that institutional constraints are a key determinant of vulnerability by controlling the access to resources, influencing resilience and constraining or enabling adaptation. The dissemination of knowledge facilitating climate-change adaptation has typically followed a top-down approach (McNamara 2013). However, it has been asserted, for example by Garnaut (2008), that climate change adaptation is likely to be most successful when bottom-up. McNamara (2013) reviewed the success of community-based climate-change adaptation projects throughout the Pacific. The author concluded that limited progress has been made to address climate-change impacts at a community level and recognized the need for broad enhancement of sustainable livelihood resources as part of project development and implementation. Hay and Mimura (2013) reviewed vulnerability, risk and adaptation mechanisms and actions employed across Pacific Island Communities (PIC). They document a shift from country-wide approaches towards those with a single-sector focus and identify the need for vulnerability assessments to be context-specific for the Pacific, allow for planned rather than reactive adaptation, need strong government support and require more sufficient evaluation, monitoring and reporting on adaptation initiatives.

## 2.7 Socioecological Resilience

The concept of vulnerability is a common gateway to defining resilience. Social vulnerability, the exposure of groups or individuals to stress as a result of the impacts of environmental change, in general, encompasses disruption to livelihoods and loss of security (Adger 2000). Vulnerability for natural ecosystems occurs when individuals or communities of species are stressed, and where thresholds of potentially irreversible changes through environmental adjustments are experienced (Adger 2000). Adger (2000) defines social resilience as the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change, and ecological resilience as the characteristic of ecosystems to maintain themselves in the face of disturbance. There are clear links between social and ecological resilience, particularly for social groups dependent on ecological resources for their livelihoods, as demonstrated by Adger (2000) through the example of the privatization of Vietnam mangroves. The interaction of the

management of the coastal resources with the social system forms a direct coevolving link between ecological and social resilience (Adger 2000). Land reclamation policy directly results in ecosystem change which feeds back to the productivity of the economic activity and the institutional structures which manage them (Adger 2000). Resilience of the management system governing fish extraction from the remaining mangroves depends on resilience to increased fishing pressure of mangrove and fish stocks (Adger 2000).

Furthering the concept of dependency, resource dependency relates to communities and individuals whose social order, livelihood and stability are directly linked to their resource production and localized economy (Machlis et al. 1990). Adger (2000) states the promotion of specialization in economic activities has negative consequences in terms of risk for individuals within communities and for communities themselves. In the context of coastal regions of Southeast Asia, individuals may not necessarily rely on a single crop or fish stock, but may be dependent on an integrated ecosystem or a whole ecosystem (Bailey and Pomeroy 1996; Adger 2000). However, Bailey and Pomeroy (1996) argue social systems dependent on coastal resources are inherently resilient, despite their single ecosystem dependence, because of reduced vulnerability to sudden economic misfortune and community instability associated with the complexity of tropical coastal resource systems. Conversely, research in Malaysia by Dow (1999) has shown that major impacts can be experienced from events such as oil spills for those parts of coastal communities directly dependent on fishing. But the notion of complexity adding to increased resilience is again emphasized by Costanza et al. (1995). They report that the resilience of coastal and estuarine systems may be high due to the diversity of functions which they perform, such as rapid self-regulation and regeneration; thus the resilience of coastal communities is enhanced by the regenerating and absorptive capacity of the coastal ecosystems itself (Adger 2000).

### 2.7.1 Planetary boundaries

Given societal reliance on environmental services and the pressure humanity is placing on the planet with worrying trajectories in key environmental processes key thresholds in the Earth system have been identified which if exceeded could harm human well-being (Rockström et al. 2009a). This analysis suggested that humanity has already exceeded planetary boundaries for climate change, rate of biodiversity loss and the nitrogen cycle; boundaries are yet to be determined for atmospheric aerosol loading and chemical pollution (Table 2). A key message to take from the 'planetary boundaries' analysis is that human well-being, at a range of scales, is linked to Earth system functioning at a range of scales. This is based on the premise that unique environmental conditions during the Holocene provided the opportunity for human societal development and through current anthropogenic activities (often activities within water, energy and food systems), we are altering the state of the environment (Rockström et al. 2009a). For livelihoods to be secure, and be sustained in a state of security, good environmental and resource governance should not only focus on the immediate 'local' environment but also address 'global' issues and consider cross-scale feedbacks (Gerst et al. 2014; Tittonell 2014). This is where 'resilience thinking' or 'systems' approaches to managing livelihoods-environment linkages (aka socioecological systems) can help address the complexities inherent to water, energy and food security (Hoff 2011). Such 'systems' approaches will not necessarily set a list of management goals (e.g., halving hunger by 2015), rather they will seek to build processes and functioning that continually link resources to positive results (e.g., a sustainable functioning food system) (Mitchell 2013; Matyas and Pelling 2012; Gerst et al. 2014). Identifying these 'processes' will be important for managing the nexus in the future to promote environmental well-being and sustainable livelihoods simultaneously.

Table 2. The planetary boundaries (Source: Rockström et al. 2009a).

Planetary boundaries				
Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) change in radiative forcing (watts per metres squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1-1
Nitrogen cycles (part of a boundary with the phosphorous cycles)	Amount of N <sub>2</sub> removed from the atmosphere for human use (millions of tons per year)	35	121	0
Phosphorous cycles (part of a boundary with the nitrogen cycles)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5-9.5	-1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km <sup>3</sup> per year)	4000	2600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis	To be determined		
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in the global environment, or the effects on ecosystems and functioning of Earth system thereof	To be determined		

Currently, human activities and extraction of resources are threatening to undermine our resource base on a global scale, and have already done so in isolated circumstances at a local scale (Rockström et al. 2009a; Gerst et al. 2014). This suggests we are extracting huge amounts of natural capital, yet over a billion people are food, water or energy insecure; these people do not realize the benefits of the extraction of this natural capital or do not have the capabilities to utilize it in a positive manner. Research looking at the planetary boundaries and the environmental ceiling (thresholds) of localized systems is emerging to better quantify environmental impact and resilience at a regional scale (e.g., case studies in China presented in Dearing et al. 2014). Such research is advocating the better management of links between natural resources and development to enable a concurrent reduction of our pressure on the Earth system whilst simultaneously boosting livelihoods. There still remains a question as to whether the concept of planetary boundaries can be, or needs to be, operationalized or governed at the regional or local level. There may be scope to include planetary boundaries concepts, such as the threats of tipping points or the

careful consideration of safe operating spaces, to attain water-food-energy security, particularly given the synergy of both concepts to natural resource use. Scale becomes an important factor in decision-making here, and monitoring system change needs careful scale consideration.

### 2.7.2 Tipping points and safe operating spaces

Where systems are complex and contain nonlinear relationships between variables, processes or actors it is likely there are multiple potential states the system can occupy (Gallopín 2006). Closely linked to systems approaches, and inherent to the idea of planetary boundaries is an awareness that thresholds exist in system functioning, which if passed, would have negative environmental and societal outcomes; the point at which a system shifts from one state to another is termed a threshold and the system is said to have undergone a regime change (Scheffer et al. 2001; Scheffer and Carpenter 2003; Gallopín 2006; Eakin et al. 2012). When the resilience in a system is eroded it can shift from one state to another (potentially undesirable state), in a gradual, nonlinear or a more catastrophic manner (e.g., a tipping point) (Scheffer et al. 2001; Scheffer and Carpenter 2003). Before reaching a tipping point, the system may enter into a state termed as an unsafe space (Rockström et al. 2009a, b; Hughes et al. 2013a, b). Often, returning to a prior state, or a desired state, will not be as simple as reversing a development trajectory (Tittonell 2014). In this context, a loss of resilience implies increasing likelihood for the system to undergo a threshold change; often, this threshold change can be triggered by an extreme event (Eakin et al. 2012), which within the SAO region could be anything previously referred to from a catastrophic cyclone to political unrest.

### 2.7.3 Environmental carrying capacity

Explicit to the planetary boundaries framework is that the boundaries are interlinked (Rockström et al. 2009a), which is indicative of a systemic approach where change in one subsystem or system driver can impact others thus altering the state of the larger system. Regarding water, energy and food security a lack of systems thinking may allow unsustainable resource use in one's sector (e.g., excessive groundwater extraction) which may push the entire system closer to critical, harmful thresholds, undermining water, energy and food security (alongside the environmental resource base). The concept of thresholds and planetary boundaries suggests a limit or carrying capacity defined by environmental systems of varying scales for different human systems. However, due to complexity, cross-scale linkages and feedbacks and shifts in human perceptions and scientific capabilities the locations of Earth system thresholds will constantly change. Given the close integration of humans into environmental system functioning, humans now have the capacity to 'determine' our carrying capacity through innovative and effective management (Gerst et al. 2014).

Given that thresholds are dynamic, to promote sustainable livelihoods and environmental functioning simultaneously management should seek to move beyond quantifying a threshold (e.g., amount of renewable water available). A more effective management strategy, and better suited to cope with inherent environmental complexities, would be to build management and livelihoods structures which have an in-built resilience to passing thresholds of harm or undergoing catastrophic collapses (Adger et al. 2005; Hoff 2011; Matyas and Pelling 2012; Carpenter et al. 2012a, b). This is often specified as 'general resilience' whereby a system has redundancy and diversity (so it can cope with a shock without collapse); flexibility and adaptive learning (so it maintains an inherent capability to re-orientate itself to utilize resources for development and resilience to a changing set of stresses, shocks and demands), leadership and polycentric governance (governance and programming in narrow silos can undermine overall system

resilience; for example, often food security can be undermined by poor water quality) (Walker et al. 2010; Carpenter et al. 2012a, b; Biggs et al. 2012; Mitchell 2013; Tiftonell 2014). The important feature of 'general resilience' is that it does not specify the stress, shock or risk landscape but seeks to better enable a system, and the actors within it, to be prepared for an uncertain future. Such sustainability within a system can be defined using the overarching concept of the environment nexus.

Given that traditional governance structures have not led to environmental sustainability or sustainable human development, Upreti (2013) advocates a new governance approach. This approach directly links sustainable development and the management of environmental resources; it is holistic rather than sectoral-specific, and is decentralized and not just focused on delivering outcomes (e.g., production) but on delivering stewardship and learning processes (Upreti 2013). Upreti (2013) calls for iterative social learning where governance is built upon accumulated knowledge and also collective management of resources and adaptive governance with inherent flexibility to cope with future surprises. This approach to management fits with the Sustainable Livelihoods Framework which identifies the need to transform governance structures so poor and marginalized people can have a voice in constructing the policies and institutions which determine their access to resources and livelihood outcomes (DFID 2001b). Adaptive learning and flexibility are also considered crucial components of generalized resilient systems (Carpenter et al. 2012a, b).



### 3. THE ENVIRONMENT NEXUS

The water-energy-food nexus seeks to optimize efficiencies in food, energy and water systems through integrated and adaptive management approaches which recognize interdependencies between the systems. At the same time, such integrated and adaptive management should aim to reduce pressure on ecosystems, reduce negative externalities (e.g., GHG emissions which could have negative global consequences, downstream consequences of upstream land uses), and foster positive human development trajectories (i.e., the ‘security’ aspect of the nexus) (Hoff 2011). The nexus approach incorporates food security, water security and energy security into one framework (e.g., Figures 12 and 13). Nexus frameworks have varied from water-centric (e.g., Hoff 2011) to more recent resource-centric approaches which link more effectively to environmental sustainability (e.g., Ringler et al. 2013). The use of the term ‘security’ can be ambiguous (this is further defined in Part II) as it has connotations to the security of the nation state and militaristic strength (Floyd 2008). However, a nexus perspective takes a more holistic and individual view of security; ‘security’ implies an individual has access and the capacity to utilize resources for their well-being without fear of harm, concerns over the stability of supply and without impacting future ‘securities’ for themselves or others. Viewing the nexus through an environmental lens, one would consider ‘security’ to be achieved when the unit of analysis (nation to individual) has the capabilities and assets to utilize environmental resources in a sustainable manner to support and further their well-being. In this paper, we include climate within our nexus approach, given its inextricable link to attaining a secure and sustainable livelihood throughout many communities of the SAO region. We term this quadrilateral mutualism the ‘Environment Nexus’, a concept which can be used to denote food, water and energy security under a changing climate to achieve sustainable development.

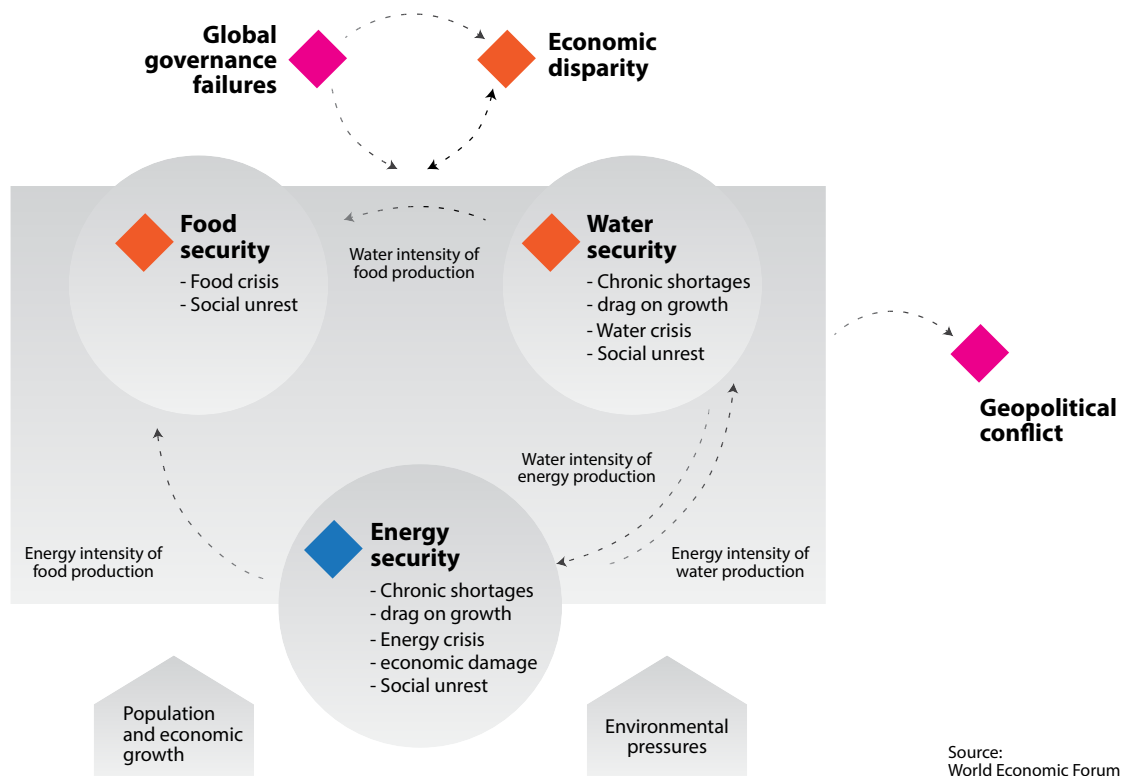


Figure 12. The Water-Food-Energy nexus according to the World Economic Forum; the founders of the nexus concept (Source: WEF 2011).

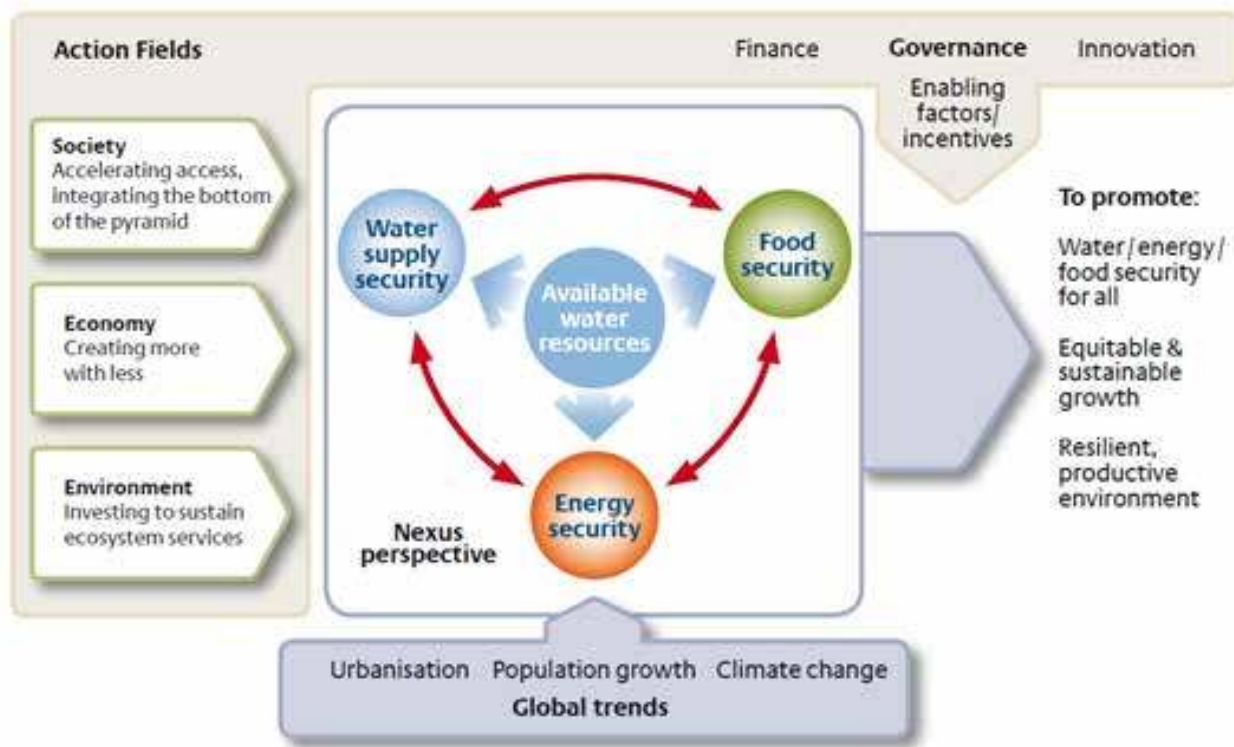


Figure 13. The Water-Food-Energy nexus according to the Bonn 2011 Conference and providing solutions for the green economy (Source: Hoff 2011).

### 3.1 Food Security

*"[Food security] A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Based on this definition, four food security dimensions can be identified: food availability, economic and physical access to food, food utilization and stability over time."*

FAO-IFAD (2013: 50)

Food security is determined by a complex interaction of factors (or production), conceptualized as a dynamic outcome of a food system comprising various factors which determine availability of, access to, the stability of, and the capacity to utilize, food and nutrition (Ericksen 2008). Indicators can characterize physical access to food, economic access to food, the capacity to utilize food which is often interlinked with good health and clean water, persistent vulnerability and exposure to shocks (to capture a more holistic picture of the dynamics which determine food security) (FAO-IFAD 2013). Scale is very important to be considered here, as food availability at the macro-level does not necessarily translate to food security at the micro-level, with the latter relating to Sen's (1981) theory of entitlement and is highly important to achieving equitable livelihood security. During times of famine, priority leans towards preserving productive assets to protect livelihoods rather than meeting immediate food needs (Maxwell and Frankenberger 1992). Associated with food security, food sovereignty refers to the right to define food systems and food policy. Food sovereignty first came to prominence at the UN World Food Summit in 1996 and has grown into

a significant grass roots movement spearheaded by the Via Campesina movement (Patel 2009; Oswald Spring et al. 2009).

Globally, 12% of the world's population are deemed food-insecure, with 98% of this food insecurity concentrated in developing countries (FAO-IFAD 2013). The Millennium Development Goal (MDG) of halving the proportion of hungry people by 2015 has been met in East and Southeast Asia; between 1990-92 and 2011-13 the proportion of undernourished in Southeast Asia declined from 31.1 to 10.7%. Despite declines in undernourishment, currently 65 million and 167 million are undernourished in Southeast and Eastern Asia (FAO-IFAD 2013). In the FAO defined Asia-Pacific region (which includes South Asia, a major food insecurity hot spot) 528.7 million people are undernourished (FAO-IFAD 2013).

One of the key challenges is to ensure sustainable zero-hunger in SAO countries whilst guaranteeing that there is no regress in progress made since 1990-92. This issue is pertinent given that agricultural legacies over the past 40-50 years (post-Green Revolution), whilst increasing production, have also caused severe environmental stress undermining further productivity gains. For example, in China, cropland area has recently declined, and 23% of irrigated lands are now saline (Thenkabail et al. 2010; UNESCAP 2013). Any increases in agricultural production in SAO will have to be reconciled with increasing requirements for environmental sustainability and competition from other nexus sectors (Hoff 2011; UNESCAP 2013; Godfray and Garnett 2014). Population growth up until 2050 is likely to result in two to three billion extra mouths to feed (Foley 2011) which will require an increase in food production of 100-110% (Tilman et al. 2011). This is problematic considering the signs that existing food systems are stagnating and productivity is slowing, and that there are concerns over the sustainability of irrigation resources and degraded croplands increasingly being left fallow, e.g., 10 million ha of cropland are lost each year due to salinity (Thenkabail et al. 2010; Hanjra and Qureshi 2010). Current rates of increase in crop yield fall well short of what is required to meet the increased demand from population growth (Ray et al. 2013). Improving efficiencies within food system activities, such as increasing equitable access to food, will reduce the need to produce more food. This will further reduce agriculture's impact on resource use (e.g., land and water) freeing up resources for other nexus sectors or conservation gains.

Increased income in SAO countries will result in dietary shifts towards increased consumption of meat and dairy. With projected increases in population and income changing demand, agriculture will need an extra 5,600 km<sup>3</sup> of water per year; 800 km<sup>3</sup> are available from 'blue water' sources suggesting agricultural systems will need to find an extra 4,800 km<sup>3</sup> per year (Hanjra and Qureshi 2010). The need for extra grazing land to meet this demand will squeeze existing croplands, shift more cereal crops towards livestock feed, threaten expansion into tropical forests and natural grasslands, increase GHG emissions, and increase water consumption (The Royal Society 2009; Foresight: Final Project Report 2011; Foley 2011). Concurrently, the increased pressure to meet food demand will place added pressure on already stressed water resources, which will be particularly problematic in areas where water quality and quantity are already compromised, e.g., saline water intrusion and drought-prone regions (as discussed in Part I). The converse is also true, in that competition within the nexus for water demand could impact food security. For example, hydropower construction plans in basins across Asia may have significant impacts on the productivity of deltaic and lowland rice bowls; in the Greater Mekong, 12 hydropower dams are planned to be built between 2011 and 2025 which will impact the water and hydrological systems in lowland rice croplands (UNESCAP 2013).

### 3.2 Water Security

*“[Water security is]...the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments, and economies.”*

Grey and Sadoff (2007: 547-548)

The World Water Council (2000) elaborates key water security challenges as meeting basic human needs, securing the food supply, protecting ecosystems, sharing water resources, managing risks, valuing water and governing water wisely (World Water Council 2000; Oswald Spring and Brauch 2009; Bogardi et al. 2012; Bogardiet al. 2015).

Currently 2.8 billion people live in areas of high water stress and 1.2 billion live in areas with absolute physical water scarcity (Rodriguez et al. 2013). Water scarcity can be defined as when water availability is inadequate per person (Falkenmark 1986); either when water resources development and extraction have reached sustainable limits (physical scarcity), or when human, social, economic or political factors inhibit appropriation of available water for human purposes (economic scarcity) (ADB 2013b). In SAO physical water scarcity has occurred in regions where groundwater and renewable water resources have been mined for irrigation (ADB 2013b). This has been attributed to business and governance models which regard water as a largely unlimited resource; to address these issues a restructuring of economic and political frameworks will be required (ADB 2013b). Watersheds in parts of Australia, Philippines and Indonesia pose high risk levels for physical water availability (Gassert et al. 2013) (Figure 14). Hotspots for economic water scarcity in the SAO region occur in Vietnam, Lao PDR and Myanmar (ADB 2013b). It is important to note that water scarcity varies spatially, from basin to basin, and in Asia climate change will have uneven impacts on basin-level water availability (Haddeland et al. 2013; Macquarrie and Wolf 2013; Gassert et al. 2013; Lankford et al. 2013).

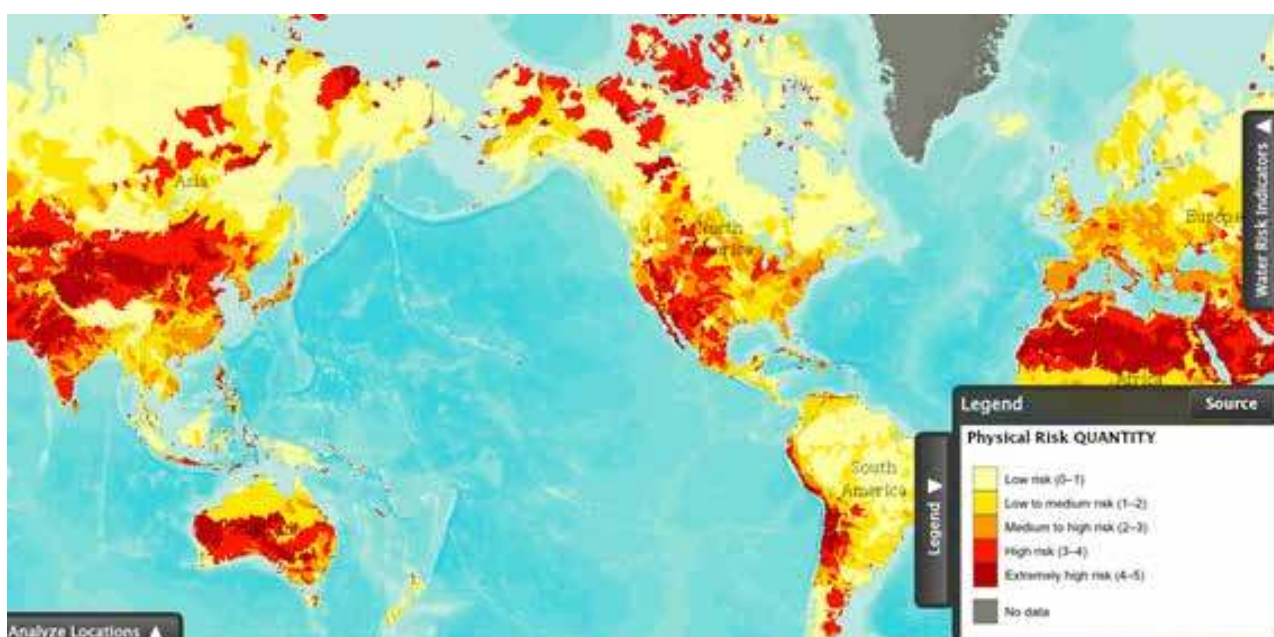


Figure 14. Water quantity physical risk in global river basin, World Resources Institute (Source: Gassert et al. 2013).

### 3.2.1 Water demand

Demand for water comes from numerous sectors, chiefly agriculture, energy, industry, and drinking water (Molden 2007; Wiener et al. 2010). Agriculture currently constitutes approximately 80% of water use; 65% of this water is used for rain-fed cropping with the remaining 35% used for irrigation (Wiener et al. 2010; Thenkabail et al. 2010). It is important to note there are large uncertainties in estimating agricultural water use at a global scale; various studies put annual agricultural consumption of water between 6,685 km<sup>3</sup> per year to 7,500 km<sup>3</sup> per year (Postel 1998; Thenkabail et al. 2010; Siebert and Döll 2010). It has been computed that, on average, a human being requires 50 liters of water a day for basic needs such as washing and drinking; this is expanded to 2,700 liters when water costs in food production are taken into account (Macquarrie and Wolf 2013). Per capita, per day water needs will vary with diet; one m<sup>3</sup> of water is required to produce a kilogram of grain whereas 13.5 m<sup>3</sup> are required to produce 1 kg of meat (Macquarrie and Wolf 2013). Therefore, per capita daily water use and requirements will vary in space, and often with income, as wealthier households and states have a meat-based diet (Wiener et al. 2010; Foley 2011). As a global level it is likely there will be a 40% gap between the sustainable supply of water and demand for water by 2030 (ADB 2013b). Currently, industry accounts for 16% of water withdrawals, and this will grow to 22% by 2030 with China accounting for 40% of this growth (ADB 2013b). Energy generation (from a range of sources) also requires water; and often competes with agriculture for water use.

### 3.2.2 Water management

Globally, there are 276 transboundary water basins (Macquarrie and Wolf 2013). This highlights the need for an integrated approach to managing water resources, which brings together nation states and various sectors with a vested interest in water use, firstly to maximize sustainable water use and secondly, to avoid potential water-fueled conflict (Bogardi et al. 2012; Macquarrie and Wolf 2013). The transboundary nature of water sources and fluxes within the hydrological cycle indicate why tenets of Integrated Water Resources Management (IWRM) have been subsumed into wider nexus thinking, despite the failure of IWRM to gain traction in applied governance (Bogardi et al. 2012; Lawford et al. 2013). 1.2 billion people live in areas of water scarcity (Rodriguez et al. 2013). It is noted in Biggs et al. (2013) where, using Nepal as a case study, IWRM and equitable access to water resources are limited by a lack of political infrastructure.

### 3.2.3 Water quality

Alongside having sufficient access to water, the water quantity, availability or scarcity aspects of water security, water quality is also a vital component of water security. Poor water quality impacts a range of sectors, at a range of spatial scales, ranging from an individual's health to agricultural production in fields and fish stocks (Wiener et al. 2010). The MDG target 7C aimed to halve the proportion of the population without sustainable access to safe drinking water and basic sanitation. Since 1990, 2.1 billion people have gained access to improved drinking water sources; currently, 89% of the global population have access to improved water sources compared to 76% in 1990 (United Nations 2013). In East Asia, 92% of the population have access to improved water sources; in Oceania, this ratio stands at 56% (United Nations 2013). There has been less progress in achieving the MDG of halving the proportion of people without access to a latrine, flush toilet or improved sanitation at a global level; an extra 1 billion people need access to improved sanitation to meet the 2015 target (United Nations 2013). However, considerable progress has been made in East Asia where, in 2011, 67% of the population had access to improved sanitation compared to 27% in 1990.

Despite progress towards MDGs for water there are still significant proportions of the world's population whose development and livelihoods are limited by lack of access to water or water of sufficient quality. For example, 636 million of the 768 million people who did not have access to improved drinking sources in 2011 were in rural areas highlighting a rural-urban disparity in water security (United Nations 2013). Despite halving the proportion of people without access to safe drinking water since 1999, between two and six million people die annually due to water-related diseases (Wiener et al. 2010). This highlights the importance of improving access to piped drinking water in homes as only 38% of the global population with access to improved water sources have piped water to their homesteads (United Nations 2013). There is also a need to address gendered variability in access to water; women in Asia, on average, walk 6 km a day to obtain water (Wiener et al. 2010).

#### 3.2.4 Access to water

It has been noted that the MDG of halving the proportion of people without access to safe drinking water and sanitation does not sit easily with the premise that water security is a basic human right for all (Bogardi et al. 2012). In Asia, recent advances in poverty alleviation may be undermined by pressures on water resources; to safeguard development and development trajectories it is crucial to shift governance perspectives away from viewing water as an 'unlimited resource' and for water-scarce regions to preemptively introduce water management reforms to either 'import' water or secure innovative private investment in water systems (ADB 2013b). Investing in water security has wider economic and development co-benefits; for example, a 10% decrease in global diarrhea yields a \$7.3 billion yearly avoidance in health costs and \$750 million gain in working days (Wiener et al. 2010).

#### 3.2.5 Water infrastructure

Investment in water infrastructure and good governance of water resources is crucial to maintaining current levels of development and alleviating poverty through providing income opportunities and improving the livelihoods of the poorest (Wiener et al. 2010; ADB 2013b). Women are disproportionately represented in the ranks of the poor. Domestic water supply is generally cast as women's business but the role of women in the productive use and community management of water is slowly gaining recognition along with the increasing feminization of agriculture (Moser 1993; Lastarria-Cornhiel 2006). In water and other key development sectors practitioners are upping the ante on gender mainstreaming and moving to a gender transformative approach to represent and reflect the requirements, knowledge and skills of female water users that are still largely absent in governing institutions. Here, governance can be understood in the broader sense that it spans civil society, political society, government, bureaucracy, economic society and the judiciary (ODI 2006). Here the intersection of gender and governance is evident as females continue to be systematically excluded from leadership and decision-making positions in both formal and informal institutions.

### 3.3 Energy Security

*"[Energy security is] access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses" (UN) and as "uninterrupted physical availability [of energy] at a price which is affordable, while respecting environment concerns."*

International Energy Agency (2014)

Winzer (2012) highlights that energy security has been defined as making the poorest segments of society resilient to fluctuations in the price of energy and also as the ability of the nation state to secure energy independence. However, there is no simple way to measure and define energy security; energy security will be a different reality for individuals in different geographical settings and that energy security needs to be addressed at multiple, interlinked, spatial scales, whilst considering the risks, threats and impacts of energy security (Winzer 2012). Consequently, energy security should be viewed through a lens which can incorporate complexity and interdependencies (i.e., a nexus approach) to highlight suitable management of resources to provide energy security to all in a sustainable manner. Winzer's (2012) review of the broad concept of energy security has several overlaps with conventional approaches to assessing the resilience of socioecological systems (e.g., recognizing both slow and fast processes) which underpin nexus thinking (Folke 2006; Jacoby 2009; Hoff 2011; Mitchell 2013).

Energy security, or access to energy is a requirement for water use and food production in many situations; for example, electricity is required for pumping of groundwater for irrigation and energy is required in manufacture of fertilizers and post-harvest food system activities (Ringler et al. 2013; ADB 2013b). At the same time water is a vital requirement for energy generation; water is used for hydropower and is also used intensively in cooling systems of thermal power plants (e.g., coal, geothermal and nuclear) (Rodriguez et al. 2013). At a global scale, there are concerns about the future of energy security given that currently one billion do not have access to modern sources of energy (Hoff 2011), 1.3 billion are without electricity (with high concentrations in sub-Saharan Africa and East Asia) (Rodriguez et al. 2013), and projections suggest that by 2030 demand will increase by 50% (Poppy et al. 2014) with a tripling of electricity production in Asia by 2050 (Rodriguez et al. 2013).

### 3.4 Climate and the Nexus

Under current management practices, ensuring people have water, energy and food security places increasing pressure on environmental resources. An increased demand, for a limited supply of resources, is being exacerbated by population and income growth, coupled with pressures from changing climatic conditions. It is likely crop production will be negatively impacted by warming temperatures whilst also requiring more water per unit yield produced as climate change simultaneously impacts water resource availability (Döll 2002; Challinor et al. 2014). Under a changing climate, a significant challenge will arise for food, water and energy planning, especially in addressing increasing pressure on resources, whilst simultaneously securing provisions for the bottom 'billion' [of the population] and implementation of poverty alleviation schemes (Hoff 2011; Rodriguez et al. 2013). Major climate challenges facing humanity include:

- Approximately 842 million people are undernourished, alongside a projected population growth of 2 billion by 2050 (Foley 2011; FAO-IFAD 2013). Cropped lands for human consumption are stagnating or decreasing, the best farm land on the planet is already exhausted and in some cases has been degraded by anthropogenic use reducing production capabilities (Thenkabail et al. 2010; Foley et al. 2011; Ray et al. 2013).
- There is a net redistribution of croplands towards the tropics where the negative impacts of climate change on agriculture are most exaggerated (Foley et al. 2011).
- Limited water resources are facing growing pressure from urbanization, industry, irrigation and energy sectors (Wiener et al. 2010; Hanjra and Qureshi 2010).

- Warming global temperatures will reduce the productivity of water use (i.e., fewer crops grown per unit water due to increased ET) (Döll 2002).

The multi-scale focus of the nexus approach captures the global-scale issue of climate change without neglecting its location-specific impacts. A nexus perspective seeks to optimize these spatial differences (through a range of locally appropriate schemes such as virtual water trade, interbasin transfers, integrated technical advances) to enhance overall system productivity and deliver food-energy-water security to all at minimal environmental costs (Hoff 2011). It is increasingly recognized that future water scarcity, which will be exacerbated by climate change, and increasing competition for limited water resources will threaten future energy security (Rodriguez et al. 2013). Given the close interdependencies between water and energy, and that these interdependencies will be heightened in the future due to simultaneously increasing demand and pressure on resources, there is a need for integrated planning. This is emphasized in the World Bank's 'Thirsty Energy' initiative, which highlights that integrated, cross-sectoral energy and water planning will increase opportunities to capture synergies and improve efficiencies in tapping into water and energy resources; such integration can be institutional (e.g., reorganization of the energy and water planning sectors; improving modelling tools) and technical (technological efficiency within the nexus)(Rodriguez et al. 2013).

### 3.5 Operationalizing the Nexus

There are close linkages between effective management of the water-energy-food nexus, and resilience to passing harmful thresholds in human-environment system functioning. Over recent decades human extraction of natural resources has not led to equitable socioeconomic development; instead, often there have been increases in inequality, further marginalization of the poorest and degradation of natural resource bases (Hoff 2011). This situation has pushed human-environment systems close to a number of societal and environmental thresholds, which if transgressed, could have negative impacts for all with the effects most acutely felt by the poor (Rockström et al. 2009a, b; Gerst et al. 2014). Various 'securities' (Brauch et al. 2008, 2009, 2011) are key components of resilient national, community and household systems that have simultaneously enabled development (Mitchell 2013). At the household-level food and physical security are prominent factors, and at the national level territorial, economic, ecological and energy security are identified as components of resilience (Mitchell 2013). The link between security and resilience is clear, as resilience is often undermined by slow processes (e.g., resource extraction, long-term buildup of fertilizer application) and achieving security is often closely linked with access to resources, capabilities, entitlements and inclusive governance systems (Gallopín 2006; Ericksen 2008; Walker et al. 2012; Pritchard et al. 2013).

The nexus approach is necessarily holistic and can be interpreted and applied in numerous ways given the unit of analysis and the perspective of the stakeholder. Therefore, a full review of all issues of relevance to water-energy-food nexus is not possible. More prudent is providing a multi-scalar example that cuts across the food, energy and water sectors, which is globally connected and complex, and useable to highlight where nexus thinking would complement management of resources. A range of studies have explored water-food and land linkages, sometimes coming from IWRM perspective, yet less work has been done on exploring energy linkages with food, water and land systems (Ringler et al. 2013). The example used here to highlight the benefits of nexus components is biofuels which have direct energy linkages; biofuels are of contemporary importance in current debates surrounding land use, water use, energy security, sustainability and climate change and trade-offs with food security.



## Case Study: Biofuels

Obtaining energy from biofuel combustion can reduce net GHG emissions as through biomass generation biofuels sequester CO<sub>2</sub> from the atmosphere and thus do not use up fossil carbon stores. First-generation biofuels refer to bioethanol (alcohol produced by fermentation of sugar or starch in biomass) or biodiesel made from vegetable oil crops (e.g., soybean, rapeseed, palm oil) (ADB 2013b). Second-generation biofuels refer to energy generated from cellulosic ethanol produced from lignocellulose which can be found in wood, algae, perennial crops, and crop residue (Fraiture et al. 2008; Water in the West 2013; ADB 2013b).

Conversion of lands for biofuels and the use of biofuels for energy exemplify the trade-offs and synergies that cut across the energy, food and water sectors. Countries have turned to biofuels, often used for transport, in a desire to seek energy independency, reduce demand on fossil fuels and reduce GHG emissions (Water in the West 2013; ADB 2013b). However, conversion of croplands to biofuels reduces land available to generate feedstocks for people or livestock, competes for water resources which could be used for agriculture or encroaches on forests and grasslands (Tilman et al. 2009; Foley et al. 2011). In the SAO region biofuels are largely produced from conversion of peat lands and tropical forests to palm oil for biodiesel (Fargione et al. 2008). Cropping for biofuels in SAO contributes a small proportion globally, yet the region will still be impacted by biofuels cropping across the globe; as more land is set aside for biofuels food prices will rise (ADB 2013b). Due to globally interconnected markets this will impact all countries; especially the poorest segments of society (Hajkovicz et al. 2012).

Projections suggest that as demand for energy grows, alongside a need to secure rural employment and development and seek cleaner forms of energy, biofuels will constitute an increasing proportion of cropping (Fraiture et al. 2008). Amongst others, nexus thinking would encourage:

- Integrated planning across agriculture, water and energy sectors when implementing biofuels policy.
- Enhance opportunities to minimize trade-offs and optimize synergies in resource use across sectors. This resonates with the World Bank's 'Thirsty Energy' initiative which seeks to break down barriers between independent water and energy management to enhance simultaneous water and energy sustainability (Rodriguez et al. 2013).
- A full and comprehensive life-cycle assessment and account for long-term payback periods of planning and allocating land-conversions to biofuels cropping, e.g., paying off the carbon debt from conversion of peatland rainforests to palm-oil plantations in Indonesia/Malaysia would take over 400 years and the carbon debt from conversion of lowland rainforests would take 86 years (Fargione et al. 2008).
- Knowledge on the water footprints of biofuel crops can be used to inform land management practices. The water footprint of crops grown for biofuels varies with crop type, agroclimatic conditions and whether the crop is irrigated or rain-fed (Fraiture et al. 2008).
- Land quality and water availability can be considered for selecting crops type; soybean and rapeseed oil crops grown for biodiesel have a lower water productivity than cereal crops grown for bioethanol (Water in the West 2013).

- Trade-offs between using first- and second-generations can be assessed relative to water availability, e.g., agricultural waste products used in generating second-generation biofuels do not require additional water (Water in the West 2013).
- Build flexibility in management of polluted and/or degraded lands can be restored and harmful decisions can be reversed.
- An integrated approach to agriculture and energy policy, sensitive to global-scale teleconnections, may reveal some of the unforeseen and spatially distinct impacts of policy drawn up in narrow ‘programming silos’ (Mitchell 2013).
- More implicit management to decrease volatility of food prices; learning lessons from past malpractices, such as subsidies for biofuels contributing largely to the global food price spike in 2008 (Hajkowicz et al. 2012).

### 3.6 Governing the Nexus

In the interdisciplinary field of development and environmental change, concerns such as accountability, legitimacy, participation, decision-making, institutions and policymaking are increasingly being looked at together under the overarching umbrella term ‘governance’. Broadly speaking, governance refers to the way rules are formulated and implemented by state or society actors in the public realm (Hoon and Hyden 2003). Rules however, as Hoon and Hyden (2003) note, are neither created nor managed in a power vacuum; they reflect the relative power and influence of contending social forces. Government refers to organizations which provide the provision for governance, whereby governance is a set of social functions which can be performed by governments as well as by other organizations, networks and institutions, where decision-making processes are undertaken in silos or collectively (Robinson 2009). Bevir (2013: 2) notes that governance refers to “all processes of governing, whether undertaken by a government, market or network, whether over a family, tribe, formal or informal organization or territory and whether through laws, norms, power or language.” It thereby centers on the management of complex interdependencies among actors, who are engaged in interactive decision making and, therefore, taking actions that affect each other’s welfare (Young 1996; Robinson 2009). Governance also serves to shape power relations and set direction (Graham et al. 2003; Robinson 2009).

In recent years, many countries in both the Global North and the Global South have experienced a formal shift from command-and-control and prescriptive governance of natural resources towards policymaking and planning processes that build on collaboration, negotiation and deliberation among policymakers, scientists and local stakeholders (Bouwen and Tallieu 2004; Warner 2006; Neef 2009). This “deliberative turn in natural resources management”, as Parkins and Mitchell (2005) have coined it, signified a shift from the emphasis on outcomes to a stronger focus on processes of collaborative resource governance. Ansell and Gash (2008: 544) define collaborative governance as “a governing arrangement where one or more public agencies directly engage non-state stakeholders in a collective decision-making process that is formal, consensus-oriented, and deliberative and that aims to make or implement public policy or manage public programs or assets.” They suggest four critical variables notably (i) starting conditions, (ii) institutional designs, (iii) leadership, and (iv) collaborative process, with the latter as the core

of the model while the other variables are “either critical contributions to, or context for, the collaborative process” (Ansell and Gash 2008: 550). The starting conditions that are most critical for collaborative governance processes are power/resource imbalances, incentives to participate, and the history of antagonism and cooperation among the stakeholders involved (Ansell and Gash 2008).

A case study illustrating the governance, gender inclusion and water security is provided by the management of a new water resource found in Cambodia’s CAM Tonle Sap Rural Water Supply and Sanitation Sector Project, where a formal gender analysis that preceded the project found that women and children were responsible for carrying water in 75% of the local households and could spend up to three hours a day engaged in this activity (ADB 2009). The vast majority of hygiene and sanitation responsibilities were also tasked to women. Due to the incorporation of activation strategies in the project design, women’s participation has been high and they have constituted 55.6% of participants in village-level meetings on community management of ponds and piped water supply systems, and community-managed rainwater tank construction. In practice, although these women may now divert their labor into other livelihood activities, the gendering of responsibility for sustainable use of the water resource is unlikely to be redistributed. In contrast, it is interesting to note that men form the majority in the governance structures that oversee the project. Furthermore, it cannot be assured that any improvements in livelihood returns arising from the new water resource (for example, through increased agricultural production) will be equitably distributed along the lines of gender.



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**PART II:  
CONCEPTUALIZING  
'ENVIRONMENTAL LIVELIHOOD SECURITY'**

## 4. ENVIRONMENTAL SECURITY

Broadly speaking environmental security is a concept linking human well-being to the state of the environment, and is considered as security from environmental shocks or stresses, thus linking societal well-being to environmental functioning (Falkenmark 2001; MA 2005). The human-environment link has been documented throughout history; for example, Malthus' theory suggested that population growth and food demand would exceed agricultural production (Thenkabail et al. 2010; Floyd and Matthew 2013). Most recently, reports such as the Millennium Ecosystem Assessment (MA), the IPCC Assessment Reports, UK Government Office for Science Foresight reports, the Planetary Boundaries concept and planning documents for the post-2015 Sustainable Development Goals agenda have highlighted humanity's dependence on functioning ecosystems (MA 2005; Rockström et al. 2009b; Foresight: Final Project Report 2011; Floyd and Matthew 2013; IPCC 2013; Adger and Pulhin 2014). However, it is difficult to pin down exactly what environmental security constitutes; the concept is interpreted in different ways dependent upon discipline, background and vested interests (Brauch 2005; Floyd 2008; Dalby et al. 2009; Floyd and Matthew 2013). It is important to discuss the development of security theory before we attempt to define environmental livelihood security as a concept.

### 4.1 The Origins of 'Security'

Brauch (2005) conceptualizes security using three perspectives whereby firstly, power is key to obtaining security, secondly international law and human rights lead to security, and thirdly cooperation determines security. Additionally, the geographical context is important for assessing a state of security, i.e., whether focus is on the nation state, an individual or an environmental or ecological unit (Brauch 2005; Floyd 2008; Brauch et al. 2008, 2009, 2011) (Table 3). The 1945 United Nations Charter focused on a nation-centric approach to international security; and, throughout the cold war period security was largely formalized in policy as providing state-level self-defence and freedom from conflict or war (Brauch 2005; Floyd and Matthew 2013). However, the environmental movement of the 1970s began to highlight links between humans and the environment as the foundation of a functioning society (Floyd and Matthew 2013) as discussed in the seminal piece 'The Limits to Growth' (Meadows et al. 1972). This focus on the environment leads to policy and institutional change. For example, in 1972, the US government set up the Environmental Protection Agency and the UN established the UN Environment Programme (Floyd and Matthew 2013).

However, in the post-cold war era, there was a widening of the security concept beyond 'militaristic' and 'nation-state' centred approaches to recognize that there are multiple threats to individuals, communities and society as a whole, and often these threats do not respect national boundaries (Brauch 2005; Floyd and Matthew 2013). The UN, and other organizations, increasingly focus on the concept of 'human security' as opposed to 'state-security' identifying that a range of stresses and shocks can harm livelihoods and impede development (Brauch 2005, 2009a, b). Environmental factors are often mentioned as stresses or shocks which can undermine human security. For example, the 2004 'Report of the Secretary General's High-level Panel on Threats, Challenges and Change' identified that threats recognize 'no national boundaries', suggested that a state-centered approach is not adequate to address the causes of, and threats to, human insecurity, and listed environmental degradation, infectious disease and poverty as threats to security alongside traditional threats such as conflict and terrorism (Brauch 2005; von Einsiedel et al. 2008). Reflecting a commitment to address environmental impacts on human security the United Nations

University Institute on Environment and Human Security was established in 2003 (Brauch 2005). Further highlighting the growing awareness and formalization of links between environmental and security issues, the latest IPCC Assessment Report (AR5) released in 2013/2014 included a chapter on 'Human Security' (Adger and Pulhin 2013).

Table 3. Summary of the range of units which can be assessed for security and potential threats to their security (Source: Brauch 2005).

	<b>Reference object (security of whom?)</b>	<b>Value at risk (security of what?)</b>	<b>Source(s) of threat (security from whom or what?)</b>
<b>National security</b> [political, military dimension]	The State	Sovereignty, territorial integrity	Other states terrorism (substate actors)
Societal security	Nations, societal groups	National unity, identity	(States) Nations, migrants, alien cultures
<b>Human security</b>	<b>Individuals humankind</b>	<b>Survival, quality of life</b>	<b>State, globalisation, GEC, nature, terrorism</b>
<b>Environmental security</b>	<b>Ecosystem</b>	<b>Sustainability</b>	<b>Humankind</b>
Gender security	Gender relations, indigenous people minorities	Equality, identity solidarity	Patriarchy, totalitarian institutions (governments, religions, elites, culture), intolerance

## 4.2 Human Security

The 1994 Human Development Report included a chapter on human security stating that security was previously defined with a narrow mandate focusing only on military aggression and the security of the nation state; this report advocates a shift in focus for security to 'ordinary people who sought security in their daily lives' and not from fear of a 'cataclysmic world event' (UNDP 1994: 22). Thus, according to the UNDP (1994), human security focuses on the 'worries' people experience in their daily lives and safety from both chronic stress such as hunger and sudden shocks to the system. Some key components of human security conceptualize that it is a people-centric, universal and holistic concept applicable to both developed and developing contexts even though the nature of stresses may vary, and the components of human security are interrelated such that if individuals in one locale are insecure this will have external ramifications (UNDP 1994). Broadly, human security can be broken down into the following areas (UNDP 1994; Brauch 2005, 2009a, b; Floyd 2008):

- Freedom from want which implies resource access or availability and links human insecurity to levels of vulnerability.

- Freedom from fear implies that people should be free from worries that their daily lives maybe harmed by a myriad of context-specific, potential shocks and stresses. Achieving this suggests removing the root causes of human insecurity, not merely addressing the outcomes as could be implied by achieving freedom from want; ‘human security is easier to ensure through early prevention’ (UNDP 1994: 22; Brauch 2005).
- Freedom from hazard impacts (Bogardi and Brauch 2005) highlights the vulnerability of communities to natural or human-induced hazards. The interaction of climate change, human management of natural resources and population growth in ‘high-risk’ areas suggests that natural disasters may undermine human development or entrench low levels of human security over the coming decades (Shepherd et al. 2013).
- Freedom of future generations to inhabit a healthy environment; this resonates closely with the sustainable development agenda and suggests that attempts to ensure human security today should not be at the expense of future security. There has been an intensive regional debate on human security in Southeast Asia (Wungaeo 2004; Othman 2009) that took environmental security considerations into account.

### 4.3 Environmental Resources

Academic debates have also questioned whether scarcity of environmental resources could be a driver of conflict and therefore of human insecurity. When the scarcity of renewable resources co-occurs with challenging social conditions there is propensity for local conflict (Floyd 2008). However, the environmental/resource scarcity-conflict linkage has drawn numerous criticisms with little empirical evidence of resource scarcity causing conflict (Brauch 2005; Floyd 2008). For example, Macquarrie and Wolf (2013) highlight that in many transboundary basins, with uneven levels of water scarcity, there have been few documented cases of water disputes. In reality, it has been suggested that environmental resource scarcity encourages cooperation instead of conflict, e.g., the Mekong Committee (now The Mekong River Commission) (Floyd 2008; Macquarrie and Wolf 2013). Other criticisms of the environmental resource scarcity-conflict concept suggest that it neglects the political ecology of resource availability and does not give sufficient consideration to factors which mediate access (Floyd 2008).

Related to environmental resources are the stresses placed on the environment and the stresses the environment places upon humanity. The drivers and outcomes of environmental stress are mediated by a myriad of complex, interrelated social, economic and political processes, institutions and governance structures often operating at multiple hierarchical levels (Figure 15) (DFID 2001b; Brauch 2005). Brauch’s (2005) concept of environmental stress resonates with aspects of human security and the environment nexus. The concept also reflects the widening of the security concept in the governance arena, with various UN bodies and other international organizations using terms such as ‘livelihoods security’, ‘water security’, ‘food security’, ‘energy security’, ‘human security’ and ‘environmental security’ (World Food Summit 1996; Brauch 2005, 2008; International Energy Agency 2014).



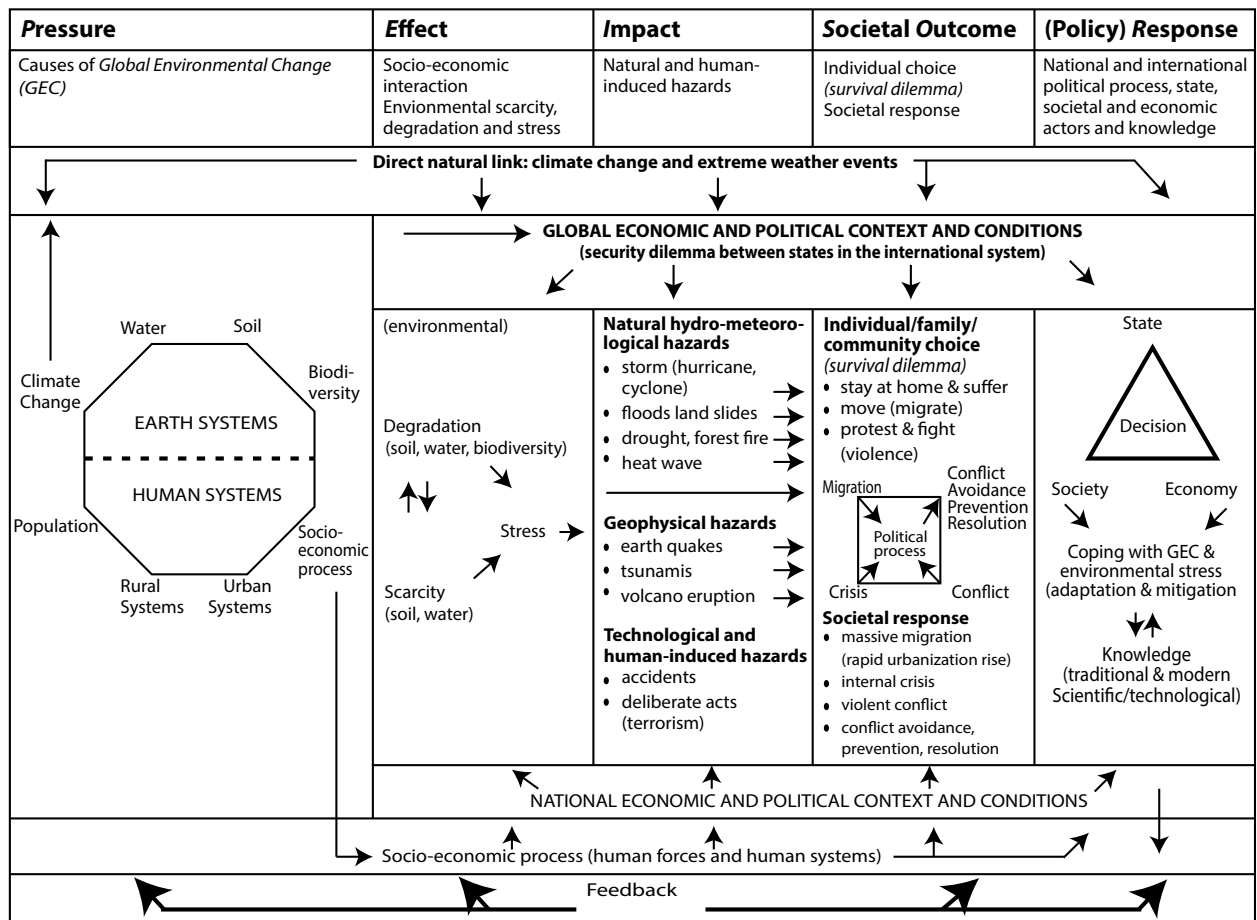


Figure 15. Causes and outcomes of environmental stress (Source: Brauch and Oswald Spring 2009).

#### 4.4 Environmental Security

With regard to environmental security there is debate whether it is security or well-being of the environmental unit (e.g., the atmosphere, climate, land and water, etc.) which should be the focus, or the security of societies and humans (inter)dependent on the environment. Early discussions of environmental security had a militaristic focus; either focusing on the impact of militaries on the environment (e.g., the use of Agent Orange in Vietnam) or on restructuring of Government defence institutions to encompass environmental issues (Floyd 2008; Dalby et al. 2009; Floyd and Matthew 2013). More recently, the environment has been closely linked with the human security concept; UNDP (1994) specifically states environmental and food security as components of human security. The UN also highlights environmental degradation, poverty and infectious disease amongst threats to human security (Brauch 2005, 2008, 2009a, b). This reflects human security encompassing a range of stresses including those directly and indirectly related to the environment. For example, food security would be threatened by environmental degradation (availability of food), poverty (access to food) and infectious disease (utilization of food) (Ericksen 2008; FAO-IFAD 2013). More recently the IPCC 5th Assessment Report includes a chapter on climate change impacts on human security (Adger and Pulhin 2014); this reflects the situation where humans are often a cause and victim of environmental threats (Brauch 2005, 2009a, b). Threats to human security include chronic stresses and short-term shocks, and thus, human insecurity can manifest slowly over time or appear rapidly following a disaster (UNDP 1994).

Environmental insecurity has been linked to social, economic and political factors which determine access to, and the ability to utilize, resources rather than merely environmental scarcity (Pritchard et al. 2013). For example, famines can be prevented through focus on economic power and the substantive freedom of individuals and families to obtain food rather than merely on levels of production (Sen 1999). Gender relations and ethnic and religious divisions can also see a particular segment of society more susceptible to environmental insecurity (Oswald Spring et al. 2009). In reality, there are often cyclical links between socioeconomic conditions which make people more vulnerable to environmental threats and environmental conditions and natural disasters which can undermine development, creating situations of transient or chronic insecurity and further increasing vulnerability (Shepherd et al. 2013). Bogardi et al. (2012: 41) highlight that 'political stability, economic equity and social solidarity are easier to maintain with good water management and governance'. Such 'political stability' will likely make it easier to deliver integrated management across the water-energy-food security nexus to deliver co-benefits of human and environmental well-being.

Environmental security has obvious significance with understanding the resilience of socioecological systems, with a focus on identifying and managing slowly-changing factors which erode a system's resilience (Scheffer et al. 2001; Gallopín 2006). Also, there are a range of environmental threats to human security which can include 'slow' environmental degradation undermining resource bases upon which societies rely (e.g., long-term climate change impacts, salinization of agricultural land or environmental shocks which can rapidly lead to disasters such as tropical cyclones and floods) (Webster 2008; Hanjra and Qureshi 2010; Dalby 2013). Differential impacts on women's and men's security due to sociocultural gender norms are rarely considered (Ariyabandu and Fonseka 2009; Detraz 2009). However, awareness and recognition of environmental threats to human security have not been consistent. For example, the 2002 World Summit on Sustainable Development only mentioned 'food security' but did not mention 'environmental security' and the Commission on Human Security appointed by the UN Secretary General and financially supported by Japan released a final report in 2003 highlighting 10 policy conclusions in areas which impact human security without specifically mentioning the environment (Brauch 2005).

The environmental component of human security reflects the fact that threats to human security do not always respect national boundaries and that the state is an inadequate unit to manage and capture the threats to society and individuals (Brauch 2008, 2009a, b; Dalby 2013). Environmental threats often operate within or across state boundaries (e.g., river basins) and many environmental systems upon which humans rely are global or regional in nature (e.g., the hydrological cycle) thus requiring global governance of environmental resources to ensure human well-being (Vörösmarty et al. 2013; Macquarrie and Wolf 2013). Often, activities within one nation state can have external impacts on others through environmental system linkages. Burning of biomass in North India can disrupt monsoonal circulation thus perturbing a key water source for energy generation and rain-fed agriculture across South Asia (Zickfeld et al. 2005; Ramanathan and Carmichael 2008). Low-lying Pacific islands and deltaic countries such as Bangladesh are most vulnerable to sea-level rise largely driven by GHGs emitted from the industrialization of the developed world (Woodruff et al. 2013; Dalby 2013). These countries cannot address this threat with a state-centered, military response synonymous with traditional definitions of security, nor would such an approach work (Dalby 2013). Differing perceptions of environmental threats to human security determine the nature of response (Dalby 2013); the question being when does an environmental threat require a humanitarian response given a state's failure to address a human security issue? (Dalby 2013).

## 4.5 Links to Development

The concept of human security was advocated by UNDP to provide enabling conditions for development (Dalby 2013). Economic development is viewed as part of the process of human development, that threats to human security should be addressed by long-term development rather than by short-term humanitarian assistance, and that human development should be sustainable (UNDP 1994). The important components of human security are building systems which empower people to ‘take charge of their lives’, which give people the ‘building blocks of survival, dignity and livelihood’, ‘developing norms, processes and institutions that systematically address insecurities’, and empowering people to be involved in their own decision-making processes (CHS 2003; Brauch 2005). This is echoed in the Sustainable Livelihoods Approach (SLA) which is people-centric, ‘supporting people to achieve their own livelihood goals’ aiming to transform policies, institutions and processes such that people can utilize or gain access to assets to support their livelihood outcomes (DFID 2001b). The framework for the SLA identifies food security as a desired livelihood outcome, whereas UNDP (1994) suggests human security is an enabling condition for development (UNDP 1994; DFID 2001b; Dalby 2013). In reality, they are interdependent in that security is an outcome of development and yet a state of security creates conditions conducive to equitable development. The same is true for linkages between the environment and sustainable development; and that a community or people-centric approach to managing environmental resources is key for sustainable development (Upreti 2013).

*“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”*

Brundtland Commission (1987)

Given that dependence of human beings on a well-functioning environment and its component ecosystems, sustainable development is closely linked to environmental issues (Upreti 2013). Sustainable development is underpinned by human security, which in turn relies on conditions of food, water and energy security, which are all vulnerable to climate change. It is also noted that the poorest members of society often live in the marginal environments, either on fragmented or poor-quality landholdings in rural settings or in informal settlements in urban areas and are often directly dependent upon the environment for survival through subsistence agriculture (Upreti 2013). This implies that for sustainable development to occur, people must be free from environmental threats and new governance models are required for environmental management (Upreti 2013). Environmental issues have been recognized in development agendas and in environment goal setting, e.g., Goal 7 of the MDG is aimed at ensuring environmental sustainability (Upreti 2013; United Nations 2013).

Economic-centered development has not led to sustainable management of environmental resources. Due to human impacts, many of the Earth’s environmental systems have been pushed to dangerous limits as articulated by the planetary boundaries concept and is most obvious in the ongoing threat of climate change (Rockström et al. 2009; Hoff 2011). Simultaneously, a development model centered on economic development has not led to equity in the benefits of natural resource extraction; despite producing more food than is necessary per-capita, 842 million people remain undernourished (FAO-IFAD 2013). Therefore, it is argued that there is a need for a more holistic concept of sustainable development and new approaches to managing

development and environmental resources (Upreti 2013). Similarly Costanza (2014) has advocated a need to 'move beyond' GDP and develop a more integrated measure of sustainable well-being and development that better reflects the threats society faces today. One of the criticisms of human security is that it is too broad a concept to be of relevance to applied policymaking (Dalby 2013). However, at the same time it is not possible to properly address human security issues and their root causes or perform vulnerability analyses within simple frameworks (Dalby 2013). The water-energy-food nexus has begun to conceptually address this challenge (Hoff 2011), yet it has some way to go as a framework to enable explicit considerations for sustainable development at a livelihood-level.

## 5. SUSTAINABLE LIVELIHOODS

*“A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for making a living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base.”*

Carney (1998)

Before we draw together the literature on environmental security, sustainable development, the environment nexus and livelihoods, it is first necessary to provide some background on the concept of sustainable livelihoods.

### 5.1 The Roots of Sustainable Livelihoods

The concept of ‘livelihoods’ surfaced in the international development literature in the early 1990s, largely in response to the publication of Chambers and Conway (1992), who are generally credited with introducing the highly contested term ‘sustainable livelihoods’ (Solesbury 2003; Hilson and Banchirigah 2009). The term questioned whether concepts found within the development literature are useful both analytically, to generate insight and hypotheses for research, and practically, as a tool for decision making (Chambers and Conway 1992). Sustainable livelihoods challenged the evolution of conceptualizing development, from modernization of nations (Scoones 2009; Morse 2013), to neoliberalism enforcing free market philosophies (which saw the rise of non-governmental organizations as key players) (Scoones 2009; Morse 2013), to actor-orientated approaches which drew attention to poverty, vulnerability and marginalization (de Haan and Zoomers 2005). Sustainable livelihoods as a concept then evolved from changing perspectives on poverty, individual and community participation and sustainable development (Sen 1981; Chambers and Conway 1992).

In 1987, the World Commission on Environment and Development used the term ‘sustainable livelihoods’ in discussions on resource ownership, basic needs, and rural livelihood security (WCED 1987; Conroy and Litvinoff 1988). The 1992 UN Conference on Environment and Development located sustainable livelihoods as a means of linking socioeconomic and environmental concerns (Brocklesby and Fisher 2003). Both forums were important in steering concern for the environment towards a focus on people and their livelihood activities, and placing these concerns within a policy framework for sustainable development. To this end, a sustainable livelihoods approach is a holistic method of addressing development through the establishment of development objectives that focus on people’s livelihoods, while providing an analytical tool for understanding the factors influencing a community’s ability to enhance livelihoods and eradicating poverty (FAO 2002). ‘Sustainable livelihoods’ as a theory integrates three key concepts of capability, equity and sustainability (Chambers and Conway 1992).

#### 5.1.1 Capability

The notion of capability is derived from Amartya Sen who identified the importance of ‘capability’ within the development process (Sen 1984, 1987; Dreze and Sen 1989). Sen (1984) defined development in terms of the availability of options and essential choices open to people allowing

for a long and healthy life, to acquire knowledge, and to have access to resources needed for a decent standard of living. Within Sen's use of capability, a subset of livelihood capabilities includes the ability to cope with stresses and shocks, and the ability to make use of livelihood opportunities (Chambers and Conway 1992). An increase in 'capability' can occur in many ways, for example, by an improvement in educational opportunity or the quality or quantity of resources (natural, social or otherwise). There are obvious overlaps with sustainable development and its emphasis on provision for future generations and increased resilience to shocks (e.g., environmental; economic) with a diverse livelihood base. Indeed, one of the first steps taken in a livelihood analysis is a consideration of the assets open to an individual, household or a community.

### 5.1.2 Equity

Chambers and Conway (1992) use the term 'equity' broadly to imply progress towards a more equal distribution of assets, capabilities and opportunities, and enhancement of these for those most deprived, including an end to discrimination against women and minorities. In the environmental security context, this concept would acknowledge that natural resources are particularly important for the poorest and most vulnerable communities who have limited access to external services (IISD 2003). Gender inequalities across disparate outcomes in health, education and bargaining power tend to be larger in countries with low GDP per capita (Jayachandran 2014). Ellis (1999) notes that gendered differences in assets, and access to resources and opportunities are widespread across global rural development contexts (e.g., landownership amongst women is rare; access to education is more difficult for women due to gender discrimination). In combination, these conditions can work to undermine equal access to the potential for diversification of women's economic activities towards achieving livelihood security. Over the last two decades development policy and programs have become increasingly cognisant of the need to reflect gender equity. For example, Meinzen-Dick et al. (2011) examine assets and livelihoods from a gendered perspective with a specific focus on planning for agricultural development. However, Harcourt and Stremmelaar (2012) observe that achieving gender equity has been recently obscured by the emergence of a discourse that privileges environmentally sustainable livelihood practices but places an uneven share of the responsibility for achieving these upon the production/reproduction and consumption activities of women.

### 5.1.3 Sustainability

In the livelihood context, sustainability is a function of how assets and capabilities are utilized, maintained and enhanced to preserve life (Chambers and Conway 1992). Key challenges are whether livelihoods are sustainable environmentally and socially, through limiting impacts on other resources and providing coping mechanisms (Chambers and Conway 1992). "Environmental sustainability concerns the external impact of livelihoods on other livelihoods" (Chambers and Conway 1992: 9). At the local level, environmental sustainability reflects livelihood activities which maintain and enhance, rather than deplete and degrade (e.g., desertification, deforestation, soil erosion), the local natural resource base. At the global level, the question is whether, environmentally, livelihood activities make a net positive or negative contribution to the long-term environmental sustainability of other livelihoods (Chambers and Conway 1992). In terms of equity, the environmental sustainability of livelihoods is to be complemented by the social sustainability of all livelihoods, whereby "Social sustainability concerns the internal capacity to withstand outside pressures" (Chambers and Conway 1992). Social sustainability refers to whether a human unit (individual or household) can not only gain but also maintain an adequate and decent quality

of life. Here, there is a negative dimension where individuals and communities react to, or cope with, stresses and shocks; and a positive dimension which enhances capacities to adapt, exploiting change, and assuring continuity (Chambers and Conway 1992).

## 5.2 The Sustainable Livelihoods Approach

The Sustainable Livelihoods Approach (SLA) gained acceptance amongst development scholars and practitioners as a set of principles guiding development intervention, as an analytical framework to help identify intervention strategies, and as an overall development objective. Large development institutions have adopted the SLA (e.g., DFID, FAO, UNDP, Oxfam, CARE International) (Scoones 2009; Carney et al. 1999), and the concept has been applied across multiple sectors including water (Nicol 2000), forestry (Warner 2000), natural resources management (Pound 2003), animal genetic resources (Anderson 2003), agriculture (Carswell 1997), urban development (Farrington et al. 2002), river basin management (Clever and Franks 2005) and fisheries (Allison and Ellis 2001). Conceptualized by Chambers and Conway (1992), the SLA has experienced wide use. Not without critique, the SLA emerged at a time when neoliberal ideologies dominated development thinking resulting in the imposition of free market principles on developing nations. In opposition, and armed with an understanding that poverty reduction could only be eradicated by addressing individual and community livelihoods, the SLA became the dominant development paradigm of its time. The SLA is based on four main concepts: (i) a vulnerability context, (ii) an asset base, (iii) livelihood strategies and outcomes, and (iv) policies and institutions which shape access to assets (Brocklesby and Fisher 2003). However, the literature demonstrates variations in the basic approach (Swift 1989; Chambers and Conway 1992; Scoones 1998; Arce 2003; Davies et al. 2013). Development of the Sustainable Livelihoods Approach has included the creation of a number of frameworks (e.g., Scoones 1998; Ellis, 2000; DFID 2001) that conceptually identify the key components of livelihoods and their interactions (Robinson and Fuller 2010). For example, DFID's framework is illustrated in Figure 16 and Scoones' in Figure 17. Central to all of these frameworks are a strong asset base for achieving sustainable livelihoods, a vulnerability context, policy and institutional processes, and livelihood strategies and outcomes.

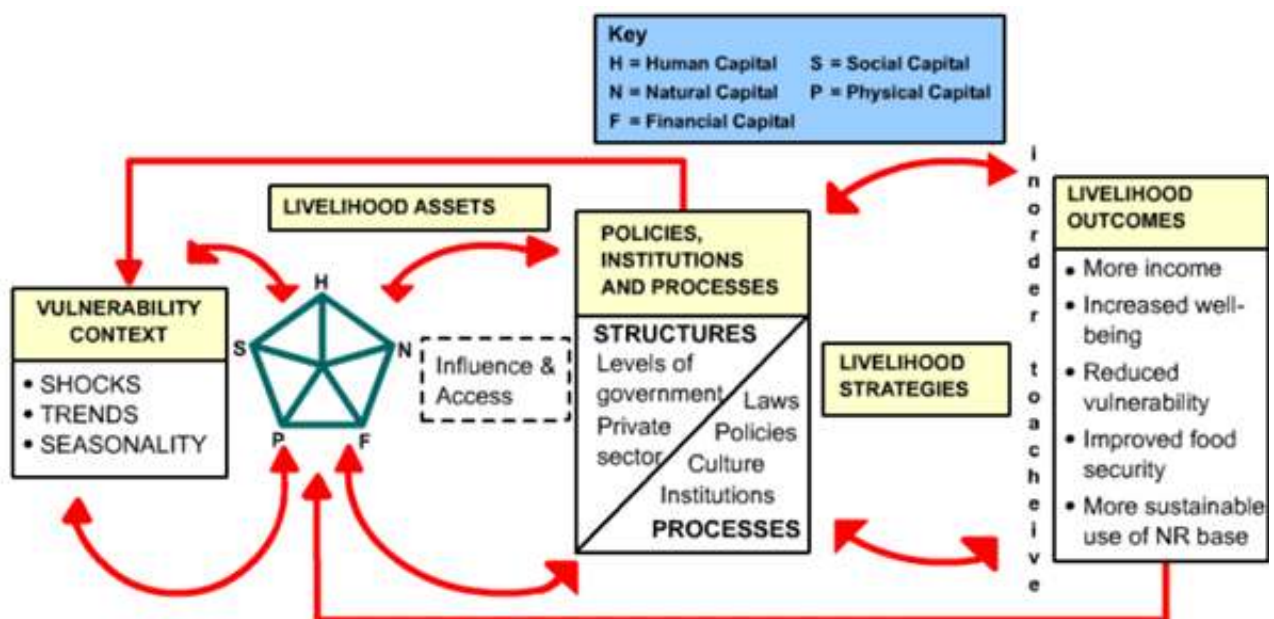


Figure 16. The sustainable livelihoods framework (Source: DFID 1999).

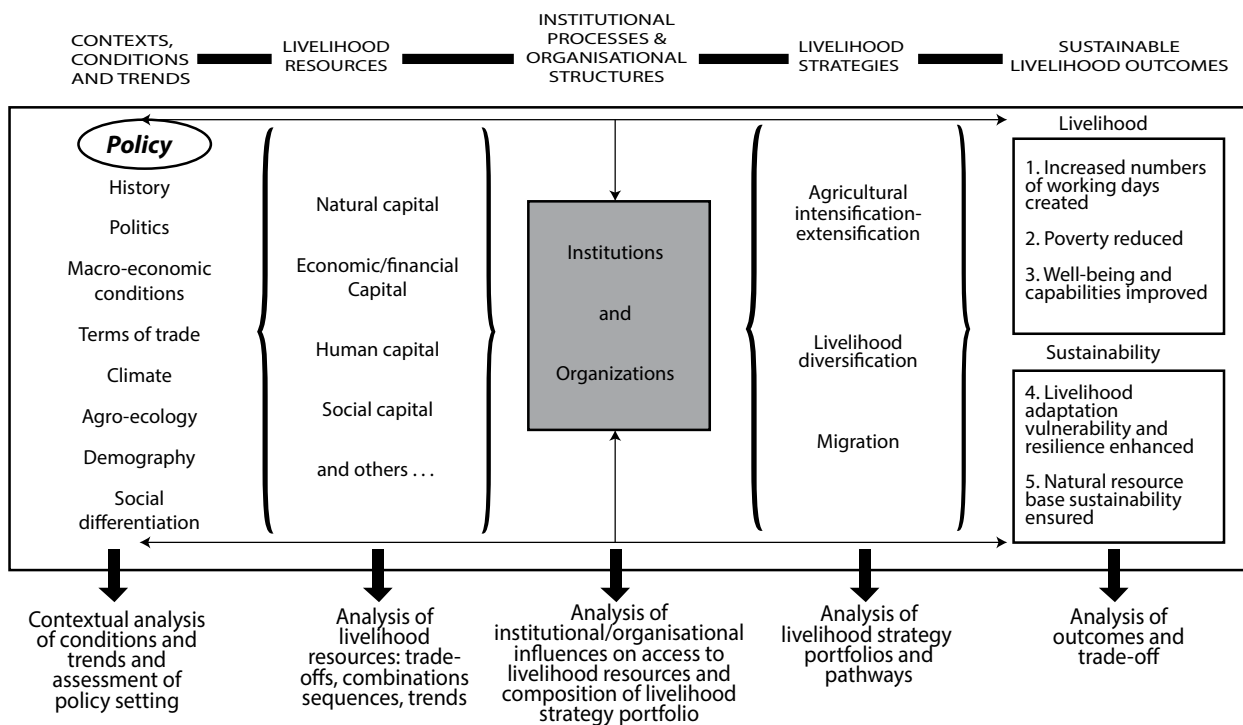


Figure 17. Sustainable rural livelihoods: A framework for analysis (Source: Scoones 1998).

### 5.2.1 The vulnerability context

Humans and their livelihoods are vulnerable to stresses and shocks (Chambers and Conway 1992). According to Chambers and Conway (1992: 10), vulnerability in the SLA has two aspects: “external, the stresses and shocks to which they are subject; and internal, the capacity to cope”. Stresses are pressures which are typically chronic and cumulative, predictable and distressing such as seasonal shortages, declining resources and overpopulation, while shocks are impacts which are typically sudden, unpredictable and traumatic such as fires, floods and epidemics (Chambers and Conway 1992). Examples of livelihood stresses which build up over time include declining yields on degraded soils; diminished water tables; decreasing rainfall; and low bioeconomic productivity (Chambers and Conway 1992). Long-term changes to the climate may further exacerbate chronic stressors as identified in Part I of this paper. Seasonal stresses are often more significant than chronic stressors as they can manifest during already stressful times of the year (Chen 1991; Chambers and Conway 1992). Examples of acute shocks to the livelihood system include storms, floods, fires, famines, landslips, epidemics of crop pests or human or animal illnesses (Chambers and Conway 1992). Reducing vulnerability, from a sustainable livelihoods perspective, can be achieved externally through public action, and internally through private action.

### 5.2.2 Livelihood assets

Underlying the SLA is the theory that people draw on a range of capital assets to further their livelihood objectives (DFID 1999; FAO 2002). Assets are categorized as social (social networks and relationships of trust), human (skills, knowledge, labor), natural (natural resource stocks), physical (transport, shelter, water, energy, communications) and financial (savings, income, credit) (e.g., Figure 18), and may serve as both inputs and outcomes (Baumann and Sinha 2001; FAO 2002).



Various vulnerability factors (such as environmental stresses and shocks) can impact these assets (FAO 2002) which are often filtered through policies, institutions and processes that affect the degree to which livelihood objectives are realized (FAO 2002). Increasingly, it is being recognized that in addition to the traditional five asset categories, political capital (an individual's stock of political capital) determines one's ability to influence policy and government processes (Bauman 2000; FAO 2008). DFID (1999) notes that a single physical asset can generate multiple benefits; if some people have secure access to land (natural capital) they may also be well-endowed with financial capital, as they are able to use the land not only for direct productive activities but also as collateral for loans. Similarly, livestock may generate social capital (prestige and connectedness to the community) for owners while at the same time being used as productive physical capital (think of animal traction) and remaining, in itself, as natural capital. In order to develop an understanding of these complex relationships it is necessary to look beyond the assets themselves, to think about prevailing cultural practices and the types of structures and processes that 'transform' assets into livelihood outcomes (DFID 1999). The more assets a household has access to, and the more diversified those assets, the stronger the livelihood security, and the higher the coping capacity of the household in the face of threats to security (Chambers 1995).

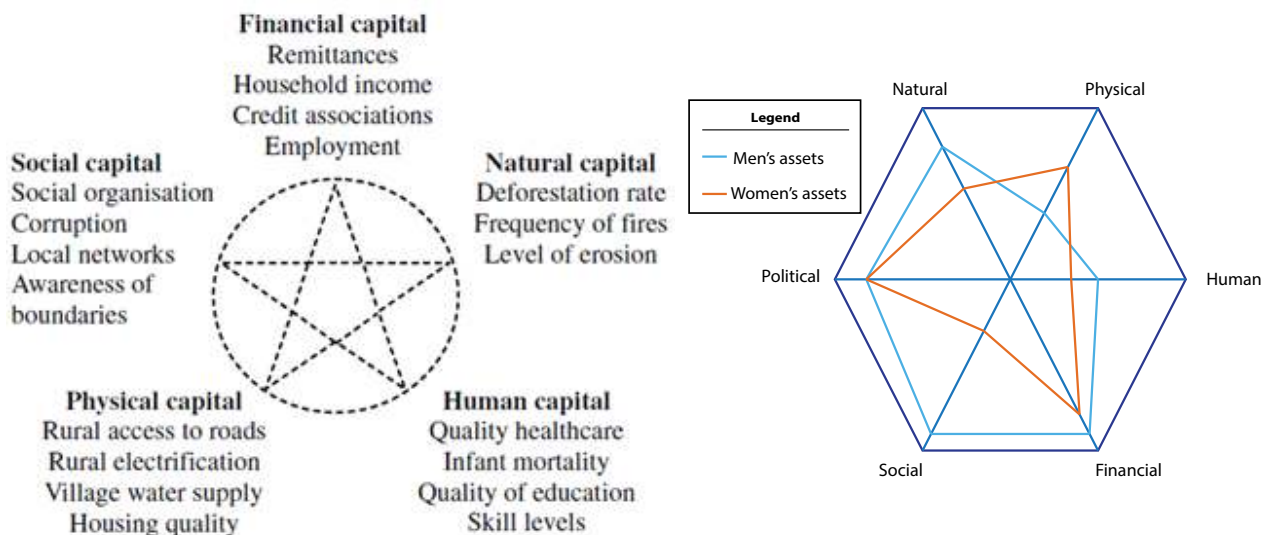


Figure 18. The five capital assets(left) modified by Bebbington (1999). By displaying each asset as a point, an individual's access to capitals can be graphed where the center point of the pentagon, represents zero access to assets while the outer perimeter represents maximum access. On this basis, different shaped pentagons can be drawn for different communities or social groups within communities (Source: Sayer et al. 2006). Some researchers have also included political capital (e.g. Bauman 2000; Meizen-Dick et al. 2011) to form an assets hexagon (right) (Meizen-Dick et al. 2011).

### 5.2.3 Policy and institutional processes

Policies and institutions represent an important set of external factors that influence the livelihoods of people, through influencing access to assets; and reducing vulnerability to shocks, positive livelihood outcomes can be produced (FAO 2008). Examples of institutions that influence livelihood outcomes include formal membership organizations (cooperatives and registered groups), informal organizations (exchange labor groups or rotating savings groups), political institutions (parliament, law and order or political parties), economic institutions (markets, private companies, banks, land rights or the tax system), and sociocultural institutions (kinship, marriage, inheritance or religion) (FAO 2008). Understanding the structures and processes that mediate the process of achieving a sustainable livelihood is critical, in particular, identification of processes which are enabling for sustainable livelihoods, social processes which promote livelihood sustainability and approaches which address the complexity of institutions relative to the livelihood context (Scoones 1998). Without an understanding the structures and processes that create positive livelihood outcomes it becomes increasingly difficult to inform and drive policy necessary to enact real change.

### 5.2.4 Livelihood strategies and outcomes

The most basic livelihood outcomes relate to satisfaction of elementary human needs, such as food, water, energy, shelter, clothing, sanitation, and healthcare among others (FAO 2008). The ultimate outcome is to achieve preservation of the household and to provide the next generation with a desirable quality of life (FAO 2008). People tend to develop the most appropriate livelihood strategies necessary to reach a desired outcome. Scoones (1998) identified three broad clusters of livelihood strategies in the sustainable livelihoods framework. These include: agricultural intensification/ extensification, livelihood diversification, and migration. Options for rural people are either to gain more livelihood activities from agriculture through processes of intensification (more output per unit area through capital investment or increases in labor inputs) and extensification (more land under cultivation), to diversify to a range of off-farm income earning activities, to move away and seek a livelihood either temporarily or permanently elsewhere, or more commonly, a combination of strategies together or in sequence (Scoones 1998). Unfavorable or unsatisfactory livelihood outcomes maybe the result of several factors which often interact, including low level of livelihood assets, high degree of vulnerability to external shocks, and insufficient livelihood support from surrounding institutions (FAO 2008). It is not only the total number of sustainable livelihoods created that is important, but also the level of livelihood intensity (Chambers 1987; Scoones 1998). Thus investigating the multiplier effects (both positive and negative) of particular livelihood activities on others and the environment, both now and in the future is important (Scoones 1998). In the SLA, livelihoods are evaluated on the basis of “sustainability” of resource use. The focus on the non-income aspects of livelihoods, such as reduced vulnerability, makes outcomes difficult to measure (Ashley and Carney 1999).

### 5.2.5 Critiques of the SLA

The SLA can be considered as a set of principles guiding development intervention (which needs to be evidence-based and community-informed), an analytical framework to understand the current state and what could enhance livelihood sustainability, and an overall development objective (e.g., to reduce the vulnerability; improving institutions) (Farrington 2001; Morse et al. 2009). These principles are deemed to explain the popularity of the SLA given their compatibility with a range of frameworks on poverty alleviation and capacity-building (both in rural and urban contexts),

but like all initiatives in development, the SLA did not materialize from a vacuum but from the evolution of several older trends and ideas (Morse et al. 2009).

Farrington (2001) identified some shortcomings of the SLA such as projects needing government endorsement, concepts which are not universally understood, costs in scaling-up interventions, a need for full administrative and financial flexibility and also having the potential to dismiss intra-household interactions and wider social networks. Morse et al. (2009) highlight a number of criticisms of the SLA, stating that the approach can be too quantitative, there is ambiguity in selecting and measuring assets, a lack of trust with participants can prevail, power to locally transform outcomes to interventions may be insufficient, accounting for shocks at a macro-scale is unpredictable, and the various frameworks over simply the complexity inherent in people's livelihoods. Scoones (2009) also identifies four recurrent failings of the SLA that are likely attributed to its decline in prominence: (i) an inability to deal with big shifts in the state of global markets and politics; (ii) power and politics lack focus with livelihoods and governance debates not linked to development; (iii) lacks rigor in deadline with long-term large-scale environmental change; and (iv) failure in relating to debates regarding rural economies and agrarian change. Scoones (2009) also notes that livelihood approaches have been accused of being good methods in search of a theory (O'Laughlin 2004). However, he suggests that although more explicit attention to the theorization of concepts is warranted, a more pluralist, hybrid vision is probably more appropriate if a solid, field-based, grounded empirical stance is to remain at the core (Scoones 2009).

However, the evidence-based approach of the SLA is one of its core positive attributes according to Morse et al. (2009). They note that the focus on households, livelihoods and sustainability is not new but the synergy of these concepts within a single framework is the progress made by the SLA. The SLA helped establish the principle that successful development intervention, even if led internally, must begin with a reflective process of deriving evidence. In this sense, Morse et al. (2009) noted that there is a deep resonance of SLA with the broad field of 'evidence-based' intervention and policy. A further attraction of the SLA is that it is people-centric, and depends on the involvement of those meant to be helped by the change. As a result, the SLA builds upon the long history of the participatory movement in development, and techniques and methods honed over years of application in stakeholder participation can be used within SLA (Morse et al. 2009). The SLA represents an acceptance that multiple sectors (social, economic and natural) have to be considered which mirrors the values of sustainable development and integrated rural development. Additionally, it recognizes that livelihoods are dynamic and provide objectives for intervention to follow (Morse et al. 2009) which is essential for capacity building.

There have also been attempts to link SLA with operational indicators (Hoon et al. 1997), monitoring and evaluation (Adato and Meinzen-Dick 2002), sector strategies (Gilling et al. 2001) and poverty reduction strategies (Norton and Foster 2001). One of the claims of the livelihoods perspectives is that they link the micro with the macro but, according to Scoones (2009), this has more often been an ambition than a reality. One of the persistent failures of livelihood approaches has been a failure to address wider global processes and their impingement on livelihood concerns at the local level. For example, he poses that a central future challenge must be integrating livelihoods thinking and understandings of local contexts and responses with concerns for global environmental change (Scoones 2009). A more geographic perspective could be of assistance here, linking a solid place-based analysis with broader-scale spatiotemporal patterns.

### 5.3 Alternative Livelihood Frameworks

The Sustainable Livelihoods Approach has evolved into a holistic and transdisciplinary entity that encompasses both an approach to development policy and practice, and a conceptual framework (Allison and Horemans 2006). Given its breadth, rather than elaborating exclusive ‘alternatives’ to the SLA, several authors have described how the SLA could address key criticisms through integration with other approaches and frameworks that link poverty alleviation with environmental resources. For example, Fisher et al. (2013) provide a useful overview of nine conceptual frameworks used to link ecosystem services and poverty alleviation (of which SLA is one); Small (2007) outlines attempts to integrate SLA with rights-based and actor-oriented approaches; Kumar et al. (2011) describe a framework which draws on the SLA and MA to show interlinks between poverty alleviation and wetlands use; and Schreckenberg et al. (2010) consider how the key concepts of SLA have influenced approaches to social impact assessment. Some of the most commonly invoked ‘alternatives’ or complementary approaches to SLA are discussed here.

#### 5.3.1 Environmental frameworks

The Environmental Entitlements framework (Leach et al. 1999) highlights the role of institutions in mediating environment-society relationships, particularly in terms of access to resources. Under this framework, the community is disaggregated in recognition of the endowments (rights and resources) and entitlements (legitimate, effective command over commodities) that are available to differently positioned social actors. With its recognition of relative poverty, intra-community and intra-household differentiation in access to resources, the environmental entitlements framework explicitly addresses political economy and power relationships; the SLA has been criticized for relatively weak consideration of these factors (Carney 2002). The environmental entitlements framework bears similarities with ‘rights-based’ approaches to development (e.g., Cornwall and Nyamu-Musembi 2006). According to Farrington (2001), the main difference between the two approaches is that rights-based approaches focus on what people’s entitlements are (or should be), and the SLA assesses the impact that the presence or absence of particular entitlements has on livelihoods (Farrington, 2001:3). Environmental entitlements and SLA developed in parallel in the 1990s (Scoones 2009), and there are analytical overlaps between the two approaches (Fisher et al. 2013). Some authors have suggested that rights-based approaches and SLA approaches can be combined to help address the shortcomings of both (Farrington 2001; Carney 2002).

#### 5.3.2 Social frameworks

Alternative frameworks used for social assessment have built upon the core concepts of the SLA. Adaptive Social Protection (ASP) (Davies et al. 2013) is broadly derived from the SLA, and integrates elements of social protection, disaster risk reduction, and climate change adaptation. ASP explicitly incorporates vulnerability, but considers vulnerability to result not only from risks and shocks, but also from the preexisting socio-institutional context. A key point of departure from the SLA is that a lack of means to cope with risk and vulnerability is in itself seen as a cause of persistent poverty and poverty traps (Davies et al. 2013). ASP advocates a ‘rights-based approach’ to empower people and reduce vulnerability. Schreckenberg et al. (2010) stop short of defining a new method of social assessment, but instead present a modified version of the SLA that incorporates political and legal assets alongside the five livelihood capitals of the SLA (referred to as assets in this context). Furthermore, Schreckenberg et al.’s (2010) Social Assessment of Protected Areas framework incorporates the MA (MA 2005) definition of ecosystem services, with three categories (provisioning, regulating, and supporting services)

included under natural assets and the fourth category (cultural services) included within social assets (Figure 19). Kumar et al. (2011) also utilized the MA (2005) concept whereby ecosystem services (of wetlands) are considered to partially constitute natural capital, and through transforming structures and processes, ecosystem services can contribute to all capitals. An understanding of these interactions rationalizes the extent to which ecosystems can contribute to poverty reduction for a given livelihood system (Kumar et al. 2011).



Figure 19. Modified sustainable livelihoods framework (Source: Schreckenberg et al. 2010).

### 5.3.3 Social-ecological frameworks

Adaptive comanagement is a contemporary approach to natural resources management that links learning and collaboration to facilitate effective governance of complex social-ecological systems (Armitage et al. 2009). This approach draws on resilience theory (derived from ecological principles) and the idea of coevolving systems of humans and nature (social-ecological systems or SES), where delineation of social systems and ecological systems is seen as artificial. Local environmental knowledge is seen as holding a critical role in buffering and adapting to change (Olsson and Folke 2001). Key concepts within the adaptive comanagement and SES sphere include adaptability, vulnerability, and the capacity for systems to be resilient in the face of change – either through absorbing shocks, or through renewal, reorganization and development (Folke 2006).

Resilience-based approaches have been criticized for being relatively apolitical and not prioritizing human agency (Fisher et al. 2013). Adaptive comanagement builds on this by explicitly including consideration of institutions, governance, horizontal and vertical linkages, power asymmetries and links to policy (Armitage et al. 2009). While bearing some commonalities with the SLA, adaptive comanagement has a stronger focus on ecosystem management than on livelihoods, and considers livelihoods through the lens of resilience, as exhibiting multiple dynamic equilibria for a given set of circumstances (Armitage 2007). Recently, scholars including Ostrom (2009) have sought to develop a framework for understanding complex SES that explicitly includes a number of variables related to social, economic and political settings (including governance systems). The social-ecological system framework was developed to enable researchers from diverse disciplines to share a common vocabulary and analytical framework (Ostrom 2009; McGinnis and Ostrom 2014).

## 5.4 Governing Livelihoods

Given the frameworks presented here to look at livelihood security and future sustainability, it is important to discuss how livelihoods are generally governed; this is particularly pertinent for the transforming processes component identified by sustainable livelihood frameworks. Building on the work of 2009 Nobel Prize Winner for Economics, Elinor Ostrom, on the governance of the commons (e.g. Ostrom 1990, 2009), Agrawal and Ribot (1999) and Agrawal (2001) have analyzed the trend of decentralization of government and role of community in sustainable governance of resources and have identified a number of issues with regard to identifying and empowering the community and their (in)ability to self-organize in certain conditions.

### 5.4.1 Empowerment

Hoon and Hyden (2003) argue that the sustainable livelihoods approach has evolved as possibly the most useful conceptual derivative of sustainable development by recognizing the linkages between micro action and macro conditions and policies. It starts from the premise that individuals must empower themselves but any such effort must take advantage of local assets and strengths (whether entailed in knowledge systems or strategies for coping with or adapt to changing conditions). The capacity to cope with stress and shocks, however, cannot succeed without access to supplementary resources from outside the local context or community (Hoon and Hyden 2003). Nor will it succeed without recognition of the cross-sectoral and cross-scalar nature of the sustainable development enterprise. While community-based institutions may be well suited to manage natural resources confined to a small locality with well-defined boundaries, the interconnectedness of communities and stakeholders in a larger regional context calls for approaches that extend beyond the scale of village territories, district boundaries and sometimes even national borders (Warner 2006). A major question is then how far more institutionalized and multi-layered forms of public participation in environmental governance integrate the various types of community-based natural resources management or whether they create a parallel universe, thereby undermining local communities' or resource management groups' efforts to manage and protect natural resources (cf. Neef 2008). Gender is also an important consideration for empowering individuals and communities (see sections 2.2.2, 3.6 and 5.1.2 for examples).

### 5.4.2 Participatory processes

*“Participatory research is a collection of approaches that enable participants to develop their own understanding of and control over processes and events being investigated” and “Participatory development is defined as a process in which people enjoy active and influential participation in all decisions that have an impact on their lives.”*

(BMZ 1999: 2; Ashby 2003: 10)

Neef et al. (2013) note that participatory approaches to agricultural research, natural resources management and rural development have been widely discussed and promoted since the early 1980s (Figure 20; Table 4)(e.g., Chambers 1983, 1994; Ashby 1986; Pretty 1995; Pound et al. 2003). These approaches originally emerged as a response to the lengthy and top-down planning processes used in rural development projects and the failure of the transfer-of-technology model which had predominated between the 1960s and early 1980s. Forerunners to these approaches were the forebears of Rapid Rural Appraisal (RRA), a method which later evolved into the more democratic Participatory Rural Appraisal (PRA) approach, described by Chambers (1994: 953) as “a growing body of approaches and methods [used] to enable local people to share, enhance, and analyze their knowledge of life and conditions, to plan and to act.” RRA and PRA were developed through the merging of several research approaches and techniques, such as participatory action research, agroecosystem analysis, applied anthropology and farming systems research (Campbell 2001). The increasing interest in participatory approaches within national and international environmental systems has been linked to the limited outreach of conventional, station-based research approaches in more difficult environments. Whereas the Green Revolution, with its focus on technological packages, was successful to a certain degree in high-potential areas, it was almost a complete failure in highly heterogeneous and marginal areas, such as mountainous or rain-fed semiarid regions (Neef et al. 2013). The more recent blue revolution seeks to overcome these and other failings from a more holistic perspective in particular linking land and water use (Calder 2005).

Hoon and Hyden (2003) identify two types of principal contributions generated by interest in sustainable livelihoods that have been instrumental in changing perceptions in the policy arena: (i) the first consists of those like Chambers and Conway (1992), Davies (1993), and Singh and Titi (1994) who have focused on developing participatory methodologies that may facilitate the enabling sustainable livelihoods. This “bottom”-up approach places the individual actor on center stage. The assumption is that empowering the poor through participatory methods is the key to success. They note that the institutional or structural constraints are, if not overlooked, often underestimated in this approach; (ii) the second approach has focused on the systems level and pointed to the disjuncture between the way natural and human systems are managed. Literature on multistakeholder participation has pointed out the importance of making values explicit in participatory processes (Checkland and Scholes 1990; Robinson and Fuller 2010). Robinson (2009) notes how in practice there is still much to learn about how to make values explicit in participatory processes and how to use such processes to arrive at collective expressions of value. The question of how to articulate, communicate and negotiate diverse types and combinations of values amongst various stakeholders is part of the challenge of governance (Robinson and Fuller 2010). Robinson and Fuller (2010) note that while much attention has been given to implementing the SLA in a participatory way at the local level (e.g., Ashley and Hussain 2000; DFID 2001; Farrington et al. 2002; Westley and Mikhalev 2002) despite the approach making no explicit reference to

participation, the implications of sustainable livelihoods for the scaling-up of participation have yet to be fully explored.

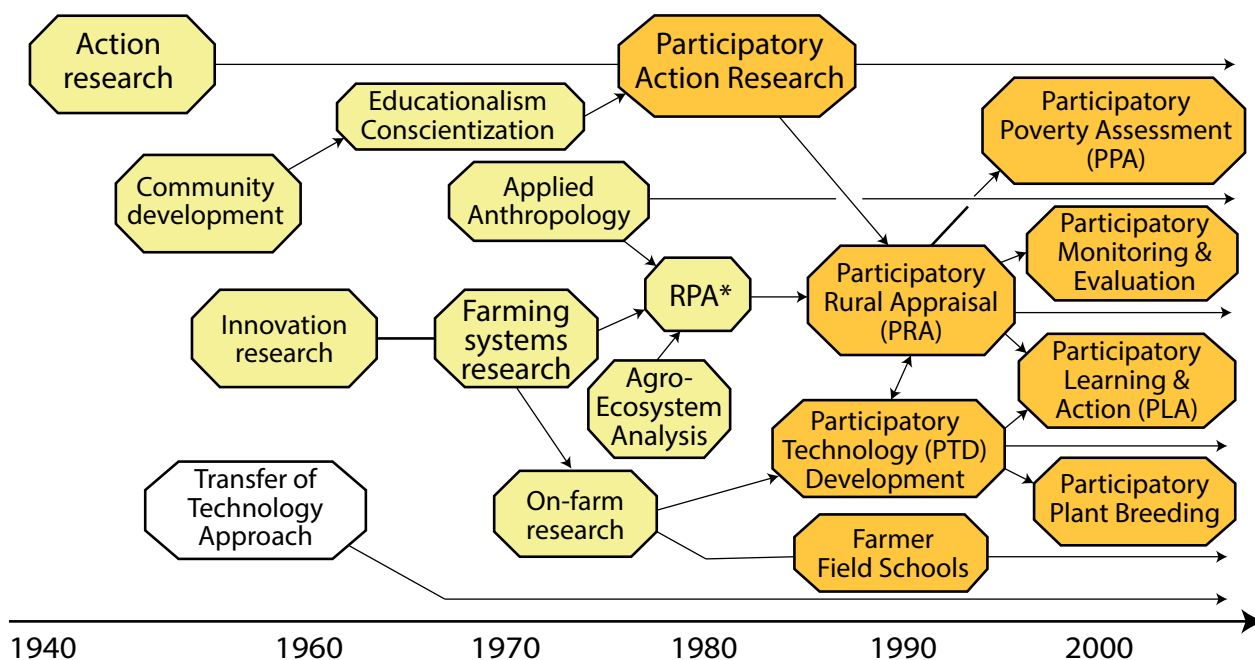


Figure 20. A selective evolutionary history of participatory approaches to research and development (Source: Neef et al. 2013).

Table 4. Features of the most popular participatory approaches to research and development (compiled by A. Neef).

Approach	Features
<b>Rapid Rural Appraisal (RRA)</b>	A package of tools developed in the 1980s to enable interdisciplinary teams of development experts and researchers to get a quick and holistic overview of major characteristics of rural communities and their resource use.
<b>Participatory Rural Appraisal (PRA)</b>	A set of interactive methods and tools developed to help rural people make their own knowledge and understanding of their socioecological environment and economic reality more explicit in collaboration with development practitioners and/or researchers (emerged from RRA).
<b>Participatory Action Research (PAR)</b>	Evolved from Lewin’s notion of action research and is based on the belief that research should be conducted in a collaborative way and should contribute to changing people’s lives rather than just producing academic outcomes.
<b>Participatory Technology Development (PTD)</b>	Developed as an alternative to linear innovation diffusion models that emphasize a transfer to technology from science via the agricultural extension service to farmers; PTD put strong emphasis on collaborative forms of technology development by integrating local knowledge.
<b>Farmer Field School (FFS)</b>	A group-based learning process emphasizing experiential education of farmers and farmer-to-farmer exchange; major activities include field observations, small experiments and group-based analysis; mainly used to promote Integrated Pest Management (IPM) strategies.

(Continued)



Table 4. Features of the most popular participatory approaches to research and development (compiled by A. Neef). (Continued)

Approach	Features
<b>Participatory Plant Breeding (PPB)</b>	A particular form of PTD popularized by international research centers to develop plant breeding programs in collaboration between plant breeders and farmers; this collaborative process of crop genetic improvement can also include processors, traders, consumers and policymakers.
<b>Participatory Poverty Assessment (PPA)</b>	A participatory research approach that seeks to understand poverty in its local context and social, institutional and political dimensions by incorporating the perspectives of various local stakeholders and involving them actively in follow-up activities; popularized by the World Bank.
<b>Participatory Monitoring &amp; Evaluation (PM&amp;E)</b>	A process that involves a range of local stakeholders in monitoring and evaluating a particular development project, program or policy; thereby it is intended to share control over the M&E activity and engage local people in identifying adjustment of goals and corrective actions.
<b>Participatory Learning and Action (PLA)</b>	Participatory Learning and Action (PLA) is an extension of PRA and emphasizes learning about, and engaging with, communities. The approach combines a range of participatory, visual and interactive methods and tools with natural interviewing techniques and intends to facilitate a process of collective analysis and learning.

### 5.4.3 Traditional ecological knowledge

The role of traditional ecological knowledge (TEK) in addressing decline in ecosystems services, adaptive comanagement of natural resources and building resilience in social-ecological systems is gaining increased recognition in the context of global change (Butler et al. 2012; Gomez-Baggethun et al. 2013). For example, Turnhout et al. (2012) argue for the inclusion of a broader range of ecological knowledge and stakeholders if the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) is to be effective in reducing biodiversity loss at multiple scales. Under changing climatic regimes, incorporation of TEK is important in any analysis of the livelihood security of communities dependent on environmental resources. Establishing a singular definition for TEK appropriate for all stakeholders and contexts is inherently ambiguous (Whyte 2013). Berkes (1999: 5) defines TEK to incorporate the broader concepts of landscape and adaptive practices relevant to the issues of both sustainable livelihoods and environmental frameworks: TEK constitutes “a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and their environment.” An important aspect of TEK is that it is both cumulative and dynamic, building upon experience and adapting to challenges (Berkes 1999). Combining TEK with science and management knowledge (SMK) provides the diversity and depth of knowledge for problem-solving needed to enhance social-ecological resilience to environmental stressors (Butler et al. 2012). TEK often provides place-specific, contextual and finer-scale spatiotemporal information (Moller et al. 2004; Butler et al. 2012) that offers insight on localized system response to management practices or altered environmental conditions.

#### 5.4.4 Enabling technologies

Governance is one, but by no means the only, tool to enhance sustainable livelihoods; science and technology are other important factors (Hoon and Hyden 2003; Juma 2001). Hoon and Hyden's (2003) paper is devoted to a discussion on how governance may be operationalized to serve the implementation of sustainable livelihoods. They suggest a four-pronged approach that takes into consideration that changes in power relations are typically the result of leadership interventions from above as well as citizen demands from below. The four aspects they cover are: articulation; mobilization; distribution and confirmation. They conceive an operationalization of governance built around the implementation of sustainable livelihoods in specific programmatic and institutional contexts where particular principles and objectives become important (e.g., access; civic engagement; rights). Recent increase in the accessibility of spatially enabling technologies has allowed communities to engage in the geographical representation of TEK through platforms such as volunteered geographic information (VGI) (discussed further in Part III). Existing quantitative spatial methods for assessing livelihood vulnerability to environmental change across multiple spatiotemporal scales can be strengthened through incorporation of TEK. However, in translating local knowledge for inclusion in spatial-based methods, consideration needs to be given to the characteristics of indigenous thinking to avoid important meaning being lost in cartographic translation. These include a cyclical concept of time, recognition of fluid and flexible boundaries, non-anthropocentricity, nonbinary thinking and the idea that facts cannot be dissociated from values (Rundstrom 1995).

## 6. ENVIRONMENTAL LIVELIHOOD SECURITY

As identified so far in this paper, there are strong parallels between the concepts of the environment nexus, environmental security and sustainable livelihoods. The fundamental issue identified is that attaining ‘sustainable livelihood security’ leads us to conceptualize a term ‘environmental livelihood security’ (ELS), which combines the strengths of the nexus approach with the sustainable livelihoods approach. As stated in the foreword of this paper, our definition of the concept is as follows: “Environmental livelihood security refers to the challenges of maintaining global food security and universal access to freshwater and energy to sustain livelihoods and promote inclusive economic growth, whilst sustaining key environmental systems functionality, particularly under variable climatic regimes.” Scale is a crucial consideration for operationalizing a nexus-livelihoods approach, as this will determine characteristics such as suitable methods for monitoring change in ELS and appropriate governance tools for achieving/retaining sustainability in the environment-livelihoods system. The concept is discussed further in this section and the importance of the term for providing a theoretical grounding for spatially assessing change at multiple scales is introduced.

### 6.1 Livelihoods and the Nexus

The SLA is an integrating transdisciplinary approach that encourages the use of the perspective of the rural household and its livelihood, rather than the boundaries of an academic discipline or government-defined sector, to identify relevant variables that describe the system. In this way, the SLA is not simply about using a systems perspective to identify relevant factors and the causal linkages between them, but it can be integrated with other approaches such as those identifying the influence of food, water and energy nexus on human security (Hoff 2011) and the relationship between human security and livelihoods (Khagram et al. 2003). The SLA can be used not only to organize information but also to help its users to restructure information and knowledge and to see the world through different lenses. In this sense, it can also be used as a framework for knowledge integration assessment (Knutsson 2006). The various SLA frameworks in use recognize that livelihoods are created from diverse assets and diverse activities. Analyzing livelihood assets and activities at the household level can contribute to an understanding of livelihood dynamics that transcends both disciplinary boundaries and outdated paradigms (Robinson and Fuller 2010).

The Brundtland Report (Brundtland Commission 1987) is credited with signalling the change in emphasis from market liberalization to poverty alleviation and the environment (and thus sustainable livelihoods) as priorities for international development agencies (Solesbury 2003); but it is Chambers and Conway’s (1992) paper that is the foundation of sustainable livelihoods work. This paper approached “sustainable livelihoods” as an integrating concept, bringing together Sen’s (1984) concepts of capability with notions of equity and long-term environmental sustainability, in direct opposition to development thinking that revolved around production, employment, and poverty (Small 2007). Alternately constructed as a way of thinking, a set of principles, and a framework for analysis (Farrington 2001), the approach draws together several major popular ideas in international development thought. As such it represents a paradigm shift in international development thinking but is not sufficiently developed to be considered a paradigm in itself (Solesbury 2003). Accordingly, integration of the SLA with other constructs has merit (Small 2007). Referring to the frameworks of the SLA and sustainability science, for example, Khagram et al. (2003) note that each clearly demonstrates the intricate interconnectivities of human, social and environmental systems – action on one invariably affects the other. One notable empirical study aimed at integrating the SLA constructs with ecosystem health was pursued by the Canadian

International Development Agency (CIDA) (Connell 2010). Small (2007) notes that what ecosystem health approaches offer to the SLA is legitimization for scaling up the SLA, placing the household and its assets within the context of complex systems, thus addressing not only the poor but all system elements, particularly the natural resource context (Waltner-Toews et al. 2004; Robinson and Fuller 2010). More recently there have been approaches to integrate the SLA with constructs relevant to the water-energy-food nexus (e.g., Kemp-Benedict et al. 2009).

## 6.2 Environmental Livelihood Security

According to Khagram et al. (2003), conceptual and practical frameworks should virtually always link security and development. In practice this means that communities concerned with each of these must be in deep dialogue and continual engagement. In this respect, the capacity sustainable livelihoods to be integrated with other constructs in sustainable development may be of particular use for analysis and practical applications in vulnerable areas where natural disasters or ecological considerations are of primary importance, such as those identified in SAO. Given the concepts discussed in Part II of this paper, we propose that the sustainable livelihoods approach (e.g., DFID 1999) could be combined with nexus-thinking (e.g., Hoff 2011), as per the conceptual representation in Figure 21, for use in adopting a framework to spatially examine the geography of environmental livelihood security. This conceptual framework for investigating environmental livelihood security (ELS) has the capacity to integrate the livelihood capitals into the water-energy-food-climate nexus. In this theoretical construct, in order to achieve environmental livelihood security there needs to be a sustainable balance between human demand and natural supply. This requires equilibrium between both livelihood and environmental pressures whereby livelihoods can place pressure on the environment and the environment can place pressure on livelihoods. The environment system is viewed through a nexus lens, incorporating the environmental security concepts of food, water, energy and climate securities. The livelihood system is viewed through an asset lens, incorporating the concepts of 'sustainable livelihood security' as analyzed by Bohle (2009: 521) who argued that "sustainable livelihood security... can be identified and targeted, how pro-poor interventions can be planned, and how policy-relevant analysis on local levels can guide research on vulnerability, poverty and development." Furthermore, he stated that "sustainable livelihood security is closely connected with the concept of human security, putting people at the center and taking equity, human rights, capabilities and sustainability as its normative basis". Both the environment and livelihood systems retain the synergies and strengths of their conceptual informants, namely the ultimate goal of achieving sustainable development and additionally, long-term sustainability. The ELS concept is designed to be versatile enough to be applicable across spatial scales and at multilevel institutional scales.

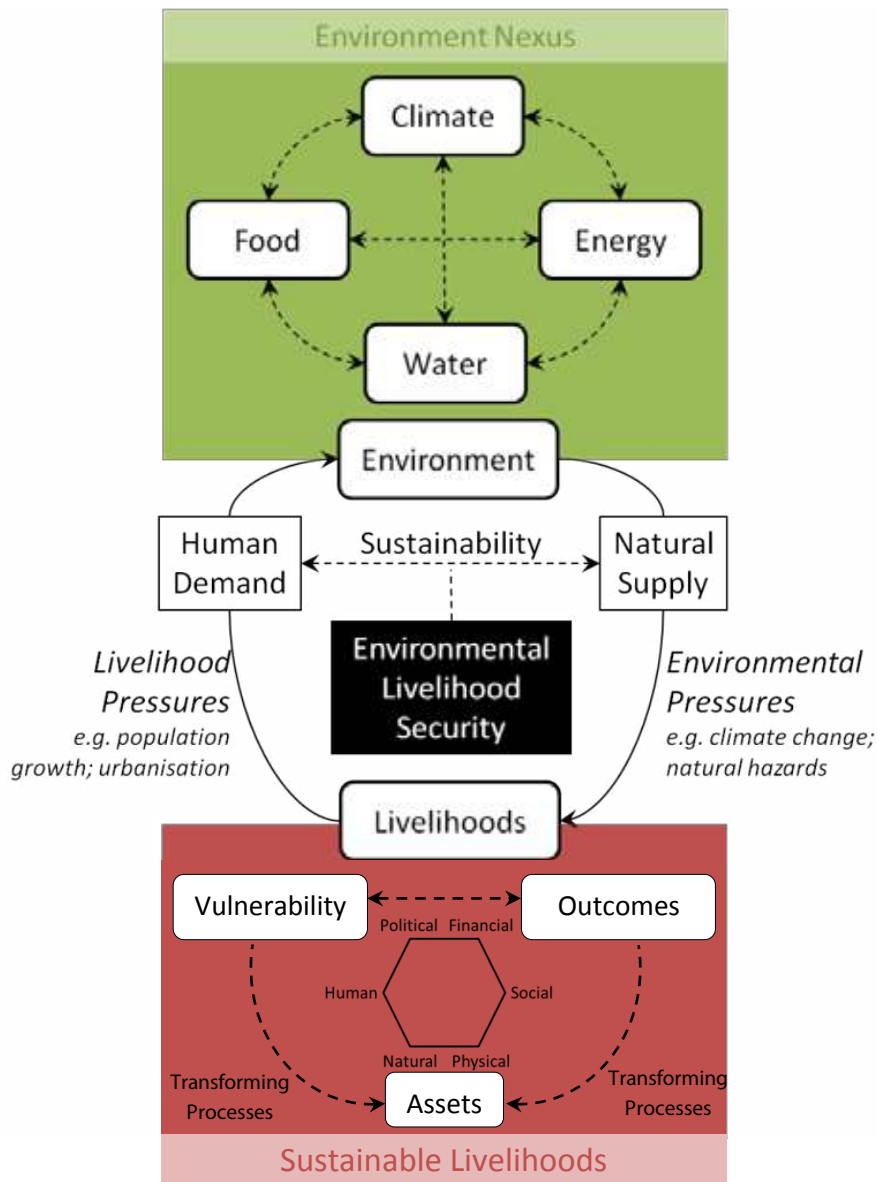


Figure 21. Conceptual framework for investigating environmental livelihood security (ELS); combines concepts of the water-energy-food-climate nexus with the livelihood capitals of the sustainable livelihoods framework.

### 6.3 Assessing the Geography of Environmental Livelihood Security

Currently, many 'security' assessments are still constrained by national boundaries such as reporting on the progress of the Millennium Development Goals (United Nations 2013), the state of food security (FAO-IFAD 2013), the IFPRI Global Hunger Index; while some reports address water security with basin-level assessments such as the World Resources Institute Aquaduct tool (Gassert et al. 2013) or the groundwater footprints assessment (Gleeson et al. 2012). However, these assessments often mask vast levels of intranation or intrabasin insecurity and gradients in environmental stresses and conditions. A first step for environmental livelihood security assessments is to move away from state-centered assessments of environmental threats; increasing fine-spatial resolution datasets are being generated which can contribute to this need e.g., WorldPop (<http://www.worldpop.org.uk/>); FAO AquaMap (<http://www.fao.org/nr/water/aquamaps/#map>).

A recurrent theme in the literature is that the root causes of environmental degradation, environmental insecurity, environmental disasters and human insecurity are due to institutional and governance frameworks not providing people with freedom to access resources in order to secure favorable livelihoods outcomes. Current security assessments are often outcome-orientated such as maps of food security or water scarcity (FAO-IFAD 2013; Gassert et al. 2013). In constructing indices, often, a range of indicators are now used reflecting complex social and environmental determinants of development or security; however, these indicators are still often outcomes of institutional structures, policies and governance processes. There is scope to develop methods, frameworks and indicators to assess the performance of policy, the role of institutions, the presence of governance processes, and the different impacts on women and men which would contribute to environmental livelihoods security. A recent example would be the work of Tall et al. (2013) which developed a set of indicators to assess national disaster management policy in terms of whether it proactively implemented disaster risk reduction measures to safeguard development from hydrometeorological hazards. However, this work was limited to assessing only one environmental threat; it did not assess how policy actually played out on the ground (the difference between policy intention and action), it was limited to the national level and did not assess informal governance structures and institutions (Lowe and Schilderman 2001).

There is a need for research to focus on exploring rapid mapping of thematic disaster impacts on livelihoods, not just delineating affected areas. Such an informational gain will improve the efforts of stakeholders, charged with disaster relief and recovery operations, in ensuring that disasters have minimal impacts on the positive development trajectories of poor and vulnerable rural communities. This advance would ensure that operational disaster response is not distinct from achievement of wider development goals and climate change resilience.

As demonstrated in this paper, the social-ecological environments in which women and men live and create their livelihoods are characterized by multiple lines of cause and effect, positive and negative feedback loops, unpredictability, and influences that operate across scales. For any given social-ecological system various valid “maps” are possible, and therefore matters of deciding which data are relevant and of interpreting them are problematic (Robinson and Fuller 2010). Multiple theories may be devised that attempt to explain some aspects of complex systems such as: identifying food webs; succession patterns; energy flows; capital circuits; patterns of political power; social, political or ecological feedback loops and cause-effect patterns, and so on, but each of these would only be describing a subsystem (Robinson and Fuller 2010). No theory can encompass all possibly relevant aspects of the whole system; for any given social-ecological system various valid “maps” are possible, depending on data selected.

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**PART III:  
GEOSPATIAL INFORMATION FOR  
ASSESSING ENVIRONMENTAL LIVELIHOOD  
SECURITY IN SOUTHEAST ASIA AND OCEANIA**

## 7. IDENTIFYING INDICATORS

Before our notion of ELS can be measured to identify change and provide potential solutions for increased sustainable livelihoods, it is first required to identify what change has actually occurred. Indicators provide a way to identify variables of socioecological systems. Conceptual frameworks for indicators (also termed variables, parameters, measures, statistical measures, proxy measures and subindices; Veleva and Ellenbecker (2001) provide focus and clarify what to measure, what to expect from measurement and what kinds of indicators to use. Diversity of core values, indicator processes and development theories have resulted in the advancement and application of a variety of different development-focused frameworks. The main differences among them are the ways in which they conceptualize the key dimensions of development, levels of attention to gender and disaggregation of data by sex, the interlinkages among the dimensions, the way each groups the issues to be measured and the concepts by which each justifies the selection and aggregation of indicators. Several approaches to indicator frameworks exist (UNDESA 2007), such as (i) driving force-state-response, (ii) issues or themes relating to sustainable development or sustainability, (iii) capital frameworks which evaluate national wealth as a function of different factors (e.g., finance; institutions), and (iv) accounting frameworks which pull indicators from a single database. However, while there is evidence that macro-indicator systems such as those that exist for aggregate economies, environments and societies are somewhat useful for informing broader policy controversies, there is increasing consensus that more subtle disaggregated indices are needed to reflect key realities on the ground, and that macro-indicators do not necessarily reflect the status or priorities of communities located at various scales or in different contexts (Khagram et al. 2003).

Morse (2013) notes the creation and use of development indicators are related to differing theories of what development means. Development indicators were traditionally centered on economic growth (income per capita) given that development was initially synonymous with economic growth (Morse 2013). Indicators for development have since moved through several transitions to focus less on the economy and more on livelihoods and promoting sustainability. Scoones (1998) notes that no neat, simple algorithm for objectively measuring sustainable livelihoods emerges from the various definitions; indicators range from very precise measures amenable to quantitative assessment to broad and diffuse indicators requiring more qualitative techniques for assessment. In any particular case, there will always need to be negotiations and trade-offs as to what is actually valued. Scale and perspective can also be determined through identifying the boundaries of the system (Connell 2010). Selecting variables and indicators effectively defines what is included as elements in the system and what is outside the system. Likewise, the unit of analysis, variables, and indicators define what is relevant to the observer, which may differ across approaches, and the unit also defines the scale of the system (e.g., landscape; biome; household; nation) with influence occurring across scales (Scoones 1998; Connell 2010). Involving participatory approaches can aid in determining the boundaries of a system (e.g., Table 5); this provides synergies with the planetary boundaries concept and resonates with the same issues regarding scale as discussed in section 2.7.1. As an example of indicator selection, Sayer et al. (2006) use indicators within a sustainable livelihood framework in the context of wider ecosystems based upon the capital framework approach (Table 6).



Table 5. Guiding questions applied to the mountain pine beetle epidemic case (Source: Connell 2010).

<b>Ecosystem Health (ecological systems)</b>		<b>Sustainable Livelihoods (social systems)</b>
System thinking	Worldview	System thinking
Complex adaptive systems	Theoretical framework(s)	Complex adaptive systems
Impacts of the mountain pine beetle epidemic on the forest	Primary issues/context	Expected loss of employment and income from forest sector
Social well-being, ecological integrity	Guiding principles	Economic well-being, economic diversification
Forest as a resource	Goals	Maximize economic benefits of forests, minimize economic impact of epidemic
Health	Concepts	Livelihoods
Lodgepole pine forest ecosystems	Unit(s) of analysis	Timber supply areas
Functionality	Variables	Commercial value, forest income dependency, amenity values
Area of land infested, volume of trees (red and gray attack), species composition, age, class, structure, wildlife habitat fragmentation, hydrology	Indicators	Timber value, timber volume, annual allowable cut, jobs, income, recreational access, visual quality

Table 6. Trial indicators chosen for the capital assets for the three field sites (Source: Sayer et al. 2006).

<b>Chefchaoen livelihood indicators</b>	<b>Bayanga livelihood Indicators</b>	<b>E Usambara Mts Indicators</b>
<b><i>Natural capital</i></b>		
Forest reserves available to village	Deforestation rate	Village forest reserves
Level of erosion	Frequency and size of fires	Water riparian strips protected
Quality of soils for agricultural production	Extent of certified forests	Enhancing/encouraging natural regeneration in corridors
	Quality of land available for agricultural production	Presence or trees in gaps (corridors)
		Native species planted in corridors
<b><i>Physical capital</i></b>		
Rural access roads	Number of manioc mills per inhabitant	Quality of housing
Mechanisation (number of mechanised (farm implements)	Housing quality	Water supply
Housing quality	Number of kiosks selling basic products	Electricity
Existence of rural electrification	Sources of drinking water	Road/accessibility
Quality of village water supply	Village accessibility	Telecommunication
<b><i>Financial capital</i></b>		
Household income	Formal sector employment	Total household income
Income from agricultural production	Household income	Income from tree products (on farm)
Employment front crafts	Changes in price of basic products	Number of livestock
Employment from tourism	Number of local credit associations (known as "Tontines" in much of Francophone Africa)	Income from non-timber forest products (e.g., butterfly farming)
<b><i>Social capital</i></b>		
Community NRM institutions active	Community-based initiatives, e.g., Community Based Natural Resource Management operating	Village environmental or natural resources committees functioning
Local networks operating amongst the communities in the landscape	Stage agencies effective	Village participation in landscape level initiatives
Level of awareness/transparency of boundaries/zones	Traditional governance effective dispute resolution mechanisms in place community rules operating	Joint Forest Management operating
Co-operation between local institutions and forestry department	Perceptions-levels of corruption of government officials	Awareness of zones/boundaries
	Local NGO and informal associations active	Capacity to manage village finances

Discrete indicators may not be the most appropriate method for encapsulating the inherent complexity in socioecological systems. Modelling approaches which use statistical structures can help address issues of variability, diversity and uncertainty within a system. As an example, Kemp-Benedict et al. (2009) use the SLA to assess water-related poverty, and the model structure they define, as well as links between the indicators and the model, which are specific to the community. However, water can be seen as flowing through three interlinked systems of hydrology, food production and livelihoods (Cook and Gichukli 2006; Kemp-Benedict et al. 2009). In linking livelihood assets to indicators, they elaborate their conceptual framework into a quantitative model, with each node (such as natural assets) in the SLF potentially becoming a variable. They note the nodes in the conceptual framework are better characterized as ranges or distributions of values; that is, 'fuzzy' rather than as a single value. They achieve this using Bayesian modelling which relates variables to one another using conditional probabilities (Jensen 1996; Pearl 2001)

## 8. MONITORING THE ENVIRONMENT

This section explores how the environment can be monitored spatially in relation to water, energy and food security under a changing climate. As previously noted, spatial analysis presents a way to implement the concepts of ELS at multiscales and multilevels. Through using spatial datasets to measure potential indicators of ELS, change can be monitored and assessed through a nexus-livelihoods approach. The core environment nexus elements of water-energy-food-climate constitute the basis for assessing change spatially for enabling that balance between natural supply and human demand to ensure both environmental and livelihood security. Here we discuss available spatial data and methodologies for potential indicators in the context of the SAO region.

### 8.1 Earth Observation

Satellite systems provide a unique opportunity to continuously monitor the Earth at regular intervals, with satellite-based information greatly enhancing our knowledge and understanding of the processes and dynamics within Earth systems (Thies and Bendix 2011). Satellite-based observations exploit geostationary and low-Earth-orbiting satellite systems, providing data at different spatial and temporal resolutions (Thies and Bendix 2011). Satellite imagery are increasingly utilized with climate models for simulation of climate system dynamics and to improve climate projections (Yang et al. 2013). By quantifying processes and spatiotemporal states of the atmosphere, land and oceans, remote sensing satellites provide major advances in understanding the climate system and its changes (Yang et al. 2013). For example, satellite remote sensing has allowed for better understanding of the interactions between cloud, aerosols and precipitation. Remotely sensed satellite data have also played a crucial role in monitoring dynamics of snow and ice cover extents, and satellite altimetry observations have been combined with in situ or tide-gauge measurements to reconstruct long-term sea-level time series (Yang et al. 2013).

Alongside these advances are a number of important challenges. The short duration of observation series and their uncertainties limit the capture of robust long-term trends of many climate variables (Yang et al. 2013). Yang et al. (2013) outline three recurring limitations of satellite data: short data spans or records, biases associated with instruments, and uncertainties in retrieval algorithms. If satellite observations lack long-term continuity, consistency and homogeneity, challenges will arise in separating long-term trends from interannual and decadal variability (Yang et al. 2013). An example of this is provided in estimates of global mean SLR made from satellite data. These estimates have been much higher than those calculated from tide-gauge data; however, owing to the short data span (~2 decades) of satellite altimetry, the higher rate could be influenced by interannual or longer oceanic variations, and cannot be necessarily attributed to accelerated sea-level rise (SLR) (Yang et al. 2013). Biases exist in the coarse-resolution sensors carried by some satellites unable to capture climate processes occurring at finer spatial scales due to their original design for meteorological observations (Yang et al. 2013). For example, as noted by Brecht et al. (2012), the spatial resolution of remote sensing elevation data from the Shuttle Radar Topography Mission (SRTM) means that small island nations are not included in these datasets. Uncertainty in retrieval algorithms used in converting electromagnetic signals from satellite sensors into measurements of climate variability may introduce uncertainty in the magnitude of detected trends (Yang et al. 2013). Yang et al. (2013) express a pressing need for more global reference networks for collaborating satellite data and validating data products.

Several studies have sought to detail the current state of knowledge and research on the application of remote sensing technologies for monitoring Earth's climate and natural hazard systems (see Joyce et al. 2009; Thies and Bendix 2011; Yang et al. 2013). To date, research has tended to focus on Earth observation technologies for measuring, observing and monitoring physical events or processes, such as the extent of flood (see Joyce et al. 2011) or changes in mean sea-level rise (see Yang et al. 2013). There is a need for further research into spatial support systems and Earth observation data and techniques for monitoring socioecological vulnerabilities.

## 8.2 Geospatial Data

Freely available geospatial data for the SAO region are available from various sources. AVISO+ is a website run by the Centre National d'Etudes Spatiales (CNES) and Center for Topographic studies of the Ocean and Hydrosphere (CTOH), which provides a portal to access global satellite altimetry data through four key themes: ocean, coast, hydrology and ice (AVISO+, 2014). Useful datasets include global sea level, wave height, wind speed and more. Outreach material and other prepared maps are also available. The Australian Government Bureau of Meteorology (BOM) website provides weather data from stations across Australia and tidal predictions for Australia, the South Pacific and Antarctica. The BOM also provides yearly (from 2005 to the present) and monthly (from 1999 to the present) data reports on sea level and related parameters collected as part of the Australian Baseline Sea Level Monitoring Project ([http://www.bom.gov.au/oceanography/projects/abslmp/abslmp\\_reports.shtml](http://www.bom.gov.au/oceanography/projects/abslmp/abslmp_reports.shtml)). They also provide monthly (from 2006 to present) data and reports on sea level and related parameters for 14 countries in the South Pacific region as part of the South Pacific Sea Level and Climate Monitoring Project ([http://www.bom.gov.au/oceanography/projects/spslcmp/spslcmp\\_reports.shtml](http://www.bom.gov.au/oceanography/projects/spslcmp/spslcmp_reports.shtml)). The Pacific Rainfall Database (PACRAIN) provides 24-hour rain gauge observations (<http://pacrain.evac.ou.edu/>). The University of Oxford School of Geography and Environment provides a database of climate change reports, observed and model data for 61 countries including Cambodia, Indonesia and Vietnam (<http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/>).

## 8.3 Monitoring Water Security

Various variables constitute important indicators for water security which signify both water quantity and water quality. Remotely-sensed products which indicate water quality have not really evolved due to inherent scale issues with monitoring water quality (e.g., pollution is largely localized to river systems, or specific wells and has a very important location context which is not currently captured in the resolution of remotely-sensed data products). Two variables which can provide valuable spatial information from Earth observation data are temperature and precipitation. From these variables, evapotranspiration can be calculated which has a strong influence on water balance in environmental systems.

### 8.3.1 Evapotranspiration

Evapotranspiration (ET) can be estimated from remote sensing data: using statistical models (which use remote-sensing-derived vegetation indices with in-situ measurements), surface-energy-balance (SEB) methods (which use thermal band in remotely-sensed products), or physical models (which use remote sensing data). A notable ET product is the MODIS-derived 1 km spatial resolution global product (derived using physical Penman-Monteith model)(Mu et al. 2011). The global and repeat coverage (every 8 days) of this product and its significant local detail make it a

valuable dataset for answering many complex problems inherent within the water-energy-food nexus. Remote sensing measures of ET can be used in water productivity assessments to assess availability of water resources and also to inform planning on more efficient use of water (Platanov et al. 2008; Wiener et al. 2010). Such planning is crucial as global and national demand for available water resources are placed under increasing pressure from numerous stresses (e.g., population growth, industry, agriculture) (Hanjra and Qureshi 2010). Using remote sensing to identify locations of inefficient water use (e.g., low crop water productivity) can contribute to targeting agricultural innovations to improve the water productivity of the landscape (in agricultural terms creating more food from the same water input) and free up more water to meet external demand (e.g., utilizing the theory of climate-smart agriculture). Other studies have used Landsat remote sensing data with a 'finer' 30 m spatial resolution to map ET using a SEB model approach at a farm-level to highlight local differences in water productivity between fields and crop types (Platanov et al. 2008). However, Landsat use is reliant upon cloud-free coverage on multiple dates throughout the growing season, so is not upscalable; but this does highlight how remote sensing could be used to target local-level water productivity improvements.

Limitations of ET products provide scope for future geospatial analysis to improve accuracy and coverage of ET estimates. For example, the MODIS ET product is useful for global- or national-scale analysis. However, it is suboptimal for understanding household-, farm- or community-level dynamics in water productivity; which is often where the impacts of water scarcity are most acute and small gains in improved water use efficiency could have a big positive impact on livelihoods. Further work could explore how fusions of MODIS and Landsat data could be used to generate local-level estimates of ET. This could inform on more water efficient crop types/cropping practices for agriculture in water-stressed locations.

### 8.3.2 Precipitation

Precipitation can be estimated using satellite products. The NASA-JAXA produced Tropical Rainfall Measuring Mission (TRMM) precipitation datasets are the dominant satellite-derived precipitation observations (<http://pmm.nasa.gov/node/158>) with a spatial resolution of 0.25° and precipitation estimated every 3-hours. The TRMM specifically monitors tropical precipitation (35° N/S), and other climatic variables including SST, ocean surface wind speed, columnar water vapor and cloud liquid water (<http://www.remss.com/missions/tmi>). Following the TRMM, the Global Precipitation Mission (GPM) core observatory satellite was launched in 2014 to provide 3 hourly global measurements of snow and precipitation. The GPM methodology will allow continuation of the TRMM methodology enabling an extended time series; however, it has advanced the TRMM method to detect light rain and snow which are more important at higher latitudes ([http://www.nasa.gov/mission\\_pages/GPM/overview/index.html#.U0pEoPmSw6s](http://www.nasa.gov/mission_pages/GPM/overview/index.html#.U0pEoPmSw6s)).

The focus of TRMM is on furthering understanding of the hydrological cycle and atmospheric processes but there has been less focus on understanding how the huge quantities of data generated can be better utilized to provide tangible benefits to large numbers of poor, and water-stressed agricultural communities. There is potential here, as many of the world's poorest subsistence farmers, whose livelihoods are closely tied to reliable water availability to support agricultural production, are located in the tropics (and subtropics), the focal regions for the TRMM satellite. The wide spatial coverage of TRMM, its temporal detail and ever-growing temporal coverage (~15 years) mean that it now constitutes a detailed dataset of extreme and variable precipitation events covering the majority of the world's subsistence farming landscapes. Exploring what the impact of these extreme events was for communities in a range of agroecosystems, and also on

other sectors such as hydropower, would provide useful analogues and planning tools to help prepare for projected precipitation uncertainty under a changing climate. Also, the TRMM dataset could be used to identify agricultural locations where precipitation is delivered in intense pulses, interspersed with dry spells or damaging for crop production. Such locations could be targeted with local-level water-harvesting capacities enhancing resilience to climate stresses.

## 8.4 Monitoring Food Security

Accurate maps of croplands are important to supplement agricultural statistics and crop acreage estimates in data-poor regions, to improve the spatial resolution and reduce the error of crop production and crop water productivity estimates (Funk and Budde 2009; Thenkabail et al. 2010; Rembold et al. 2013; Atzberger 2013). A global perspective to mapping croplands is important given the global interconnections within the hydrological cycle, food and virtual water trade, a global squeeze on available cropland and global-level feedbacks between land use, irrigation and climate (Rockström et al. 2009a, b; Thenkabail et al. 2010; Foley et al. 2011). The key challenges of using Earth observation data for assessing food security are capturing details of smallholder cropping systems with fine-enough remotely sensed resolution data, as it is at this scale where food and livelihoods have strong associations. It is also important to ensure trade-offs with water and energy use can be monitored as well as the potential impacts of changing climate. There is vast potential in remote sensing data to offer spatially explicit and timely data on croplands to help balance competing needs and reduce negative externalities between nexus linkages.

### 8.4.1 Cropland maps

Numerous global land use land cover (LULC) mapping products over the past 25 years have included agricultural and cultivated lands as a single class, or sometimes separating irrigated and agricultural lands. Even the most recent global LULC mapping products do not provide much thematic detail on agricultural landscapes. For example, Globcover 2009 generated by ESA from MERIS data has 22 land cover classes following the UN Land Cover Classification System (LCCS) at a 300 m spatial resolution (Bontemps et al. 2011). The Globcover 2009 product includes one water body class and four classes related to agriculture (two mixed vegetation-cropland classes, rain-fed croplands and flooded or irrigated land). The operational MODIS land-cover product (MCD12Q1) generates an annual global land-cover map with five different classifications schemes (Friedl et al. 2010). The MCD12Q1 product does not discriminate between crop types, though the plant functional traits classification scheme includes a cereal croplands class (Friedl et al. 2010). Unlike Globcover 2009 or MCD12Q1 global land cover products, there are several specific global cropland maps (produced for 2000) (Figure 22). These maps were generated using a range of methodologies and a combination of remote sensing, agricultural census and GIS approaches to map global croplands (Table 7) with cropland area to be between 1.3 and 1.53 billion ha around the year 2000 (Thenkabail et al. 2010).

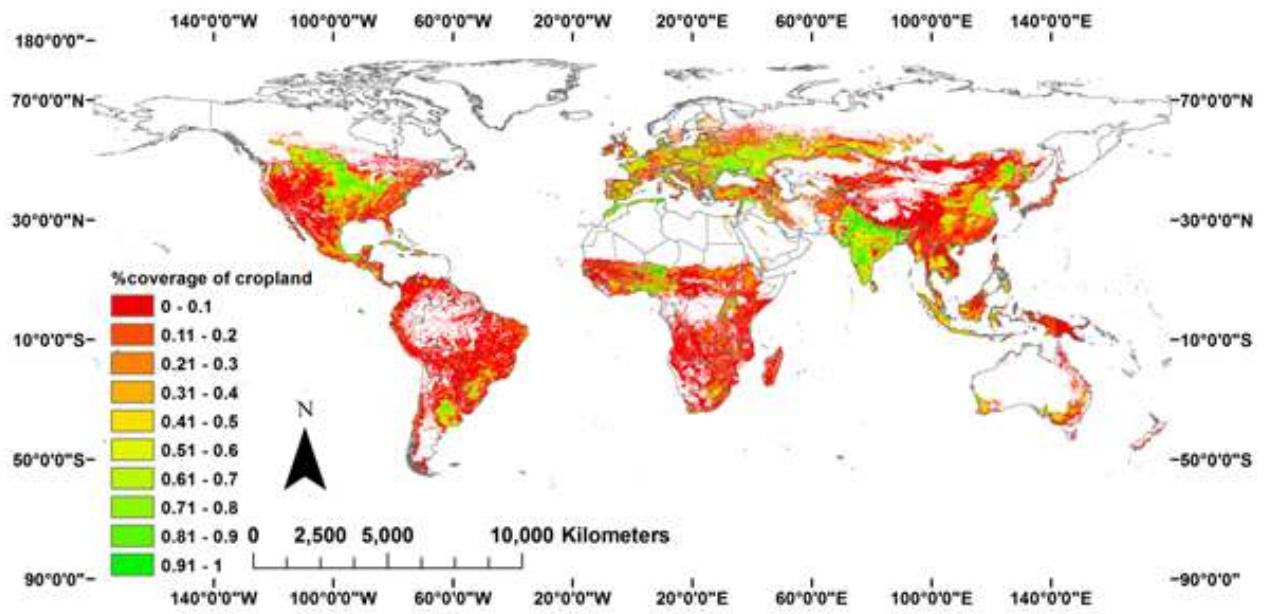


Figure 22. Global Croplands Map (circa 2000) (Source: Ramankutty et al. 2008).



Table 7. Characteristics of different global cropland maps.

Map	Method	Resolution	Class Information
Global Irrigated Area Maps (IWMI) (Thenkabail et al. 2009)	Dominant remote-sensing-based methodology – Decision tree, unsupervised classification, spectral-time series analysis (spectral matching techniques) and ancillary data (elevation, precipitation, forest).	10 km	Cropping intensity (single, double, continuous cropping). Irrigation type (major irrigation or minor irrigation). Mixture of crop types. Total area available for irrigation and annual irrigated area. Estimates of subpixel fractions of irrigated area provided.
Global Cropland Map (Ramankutty et al. 2008)	Integration of remote sensing land cover datasets (MODIS MCD12Q1 and SPOT derived GLC2000) with agricultural census information.	5 minutes (~10 km)	Proportion of cropland within each 5 minute grid cell.  A separate global pasture dataset also generated.
Monthly Irrigated and Rain-fed Crop Areas (MIRCA 2000) (Portmann et al. 2010)	Integrating national and subnational census statistics for area of crop harvested and cropping calendars, climatic and topographic data and then downscaled onto existing irrigated area and cropland maps.	5 minutes	26 rain-fed and 26 irrigated cropland classes.  Monthly growing area for each crop.  Maximum monthly growing area for each grid cell.  Cropping period for each crop.  Cropping intensity.
Global map of harvested area and yields for 175 crops (Monfreda et al. 2008)	National and subnational statistics of cropped area and yields were spatially distributed onto a gridded global map of croplands (Ramankutty et al. 2008).	5 minutes (~10 km)	Proportion of 5 minute grid cell harvested for one or more of 175 crops (Total area harvested per year).  Yield within 5 minute grid cell for one or more 175 crops.
Global map of irrigation areas (V5) (Siebert et al. 2013)	Irrigation statistics for subnational units closest to year 2005 collected from a range of sources and integrated with geospatial information on position and extent of irrigation schemes to generate irrigation intensity grid at 0.01° resolution for each country which was upscaled to 5 minute resolution in the global dataset.	5 minutes	Proportion of 5 minute grid cell equipped for irrigation (irrigation density). Percentage of area equipped for irrigation that is actually used for irrigation. Irrigation source: groundwater, surface water, nonconventional water sources.

(Continued)

Table 7. Characteristics of different global cropland maps. (Continued)

Map	Method	Resolution	Class Information
Global Spatial Production Allocation Model (SPAM) (You et al. 2014)	Integrates multiple input datasets (e.g., remote-sensing-derived land cover, rural population and agricultural census statistics) to weight allocation of crop area and production to a 5 minute grid cell.	5 minutes	Area and production of 20 major food crops within 5 minute grid cells. Area and production estimates for cropping systems (irrigated, high input rain-fed, low input rain-fed and subsistence).

The coarse spatial resolution of the global cropland maps is suboptimal for capturing cropland areas in fragmented or heterogeneous agricultural landscapes. With global cropland maps generated at a 5 minute spatial resolution there is considerable uncertainty where, and in what configuration, cropland extent, crop type, cropping intensities, and irrigation source exist within a pixel (Thenkabail et al. 2009; Thenkabail et al. 2010). This issue will be particularly pertinent over fragmented, smallholder and subsistence farming landscapes where there is a greater heterogeneity in livelihoods activities, and cropping seasons, and where farm sizes are often far smaller than 10 km pixels.

There have been several regional and continental-scale cropland mapping projects at finer spatial resolutions than the global cropland maps discussed above. Xiao et al. (2006) and Gumma et al. (2011) utilize phenological details contained in MODIS data to map rice croplands across all of south and Southeast Asia at a 500 m spatial resolution. Thenkabail et al. (2005) used MODIS data to map a range of crop types and cropping intensity at a 500 m spatial resolution across North India. However, even the 250-500 m footprint of a MODIS pixel can contain a mixture of land cover types and so remain suboptimal (Bolton and Friedl 2013). Therefore, again there is potential to blend Landsat data with MODIS imager to encapsulate more detail regarding agricultural production.

Some of the uncertainty in estimates of cropland area (e.g., mixed-pixel effects) will be reduced by improving the spatial resolution of cropland maps to better represent the cultivated footprint. Also, finer spatial resolution cropland maps will enable discrimination of thematic variation across cultivated lands (e.g., differences in crop types, irrigation sources, gradients of land-use with distance from the homestead) which are masked at coarse spatial resolutions. It is worth noting that accurate cropland maps, with sufficient thematic resolution, provide the building blocks for spatially distributed estimates of crop production and crop water use (Funk and Budde 2009; Thenkabail et al. 2010; Rembold et al. 2013; Atzberger 2013; Bolton and Friedl 2013). Given pressure to expand croplands to increase production to meet demands for a growing population, issues of cropland conversion to biofuel crops rather than to consumption, competition of cropland with grazing land as income levels increase and diets shift and the negative externalities of expanding croplands onto natural ecosystems (Foley 2011; Foley et al. 2011), accurate monitoring of interannual cropland dynamics is crucial. It is likely that advances in remote sensing technologies and methodologies will contribute to addressing these needs as currently maps are generally temporarily static (Thenkabail and Wu 2012).

### 8.4.2 Monitoring crop phenology

Methodologies, and toolboxes such as TIMESAT (Jonsson and Eklundh 2004), already exist to process time series (remote sensing data) generated from MODIS, and other sensors with high frequency repeat coverage (e.g., SPOT-VGT), and to obtain phenology parameters over croplands (Jonsson and Eklundh 2004; Chen et al. 2004; Dash et al. 2010). A global, annual, MODIS phenology product is available but this is applicable to all land covers and is not yet tailored towards croplands (Ganguly et al. 2010). However, progress is being made in other areas, such as the automated cropland classification algorithm (ACCA) which generates outputs of crop type, irrigation or rain-fed, and cropping intensity (Thenkabail and Wu 2012). The ACCA algorithm might reveal local-level untapped opportunities for increased intensification, diversification or temporal shifts in cropland cover (e.g., towards biofuel crops) which could have complex ramifications across multiple spatial scales (Fargione et al. 2008; Galford et al. 2008; Hoff 2011; You et al. 2014). Like cropland phenology, the ACCA needs proper validation in the most challenging landscapes, e.g., fragmented smallholder farming regions of sub-Saharan Africa before widespread operationalization. However, open-source and crowd-source data represent a novel way to continually validate cropland maps; recent initiatives include 'cropland capture' and geowiki (Atzberger 2013). Reducing uncertainty in monitoring of crop phenology will enhance the capability of discriminating specific crop types, provide greater spatial detail on the timing and duration of cropped areas improving accuracy of estimates of crop water use and detection of crop-specific development stages, and enable improved crop-yield monitoring and monitoring of crop sensitivity to extreme heat events (Wardlow et al. 2007; Funk and Budde 2009; Thenkabail et al. 2010; Lobell et al. 2012; Bolton and Friedl 2013).

Complementing the ACCA, the launch of the Sentinel-2 constellation satellites will provide multispectral imaging of the Earth's surface at a 10 m spatial resolution every 5 days (ESA 2010), effectively combining the benefits of MODIS and Landsat. This will enhance the level of detail (i.e., intra-farm or individual field) which can be gleaned from remote sensing data and enable monitoring of crop phenology with reduced mixed pixel effects. This will result in more accurate monitoring of conditions in specific fields and reduce error in propagating into subsequent modelling where cropland cover is one input. This will increase the applied value of using remote sensing data to monitor crop production accurately in fragmented farming landscapes. New methodologies should be developed now to take advantage of the enhanced capabilities of the Sentinel-2 satellites to monitor croplands echoing the long and successful planning prior to the launch of the TERRA and AQUA satellites carrying the MODIS sensor.

### 8.4.3 Crop yield

Crop yield is determined by physiological processes (largely photosynthesis) at certain crop development stages, which are correlated with spectral reflectance values, prior to harvest date (Tucker 1979; Pinter et al. 1981). Often, crop yield and vegetative activity, in general, are associated with spectral reflectance in the red and near-infrared wave bands which are used as inputs into most vegetation indices (VI) such as the enhanced vegetation index (EVI) or the normalized difference vegetation index (NDVI). Therefore, VIs derived from remote sensing data have been used as inputs into most regression models predicting crop yield (Rojas 2007; Funk and Budde 2009; Rojas et al. 2011; Bolton and Friedl 2013; Rembold et al. 2013). The correlation between VI values and final crop yield varies during a growing season, and will vary spatially due to different planting dates (Pinter et al. 1981; Bolton and Friedl 2013). For most cereal crops, crop yield has the strongest correlation with VI during the crop reproductive or grain filling (early senescence)

phases (Pinter et al. 1981; Sakmoto et al. 2005; Funk and Budde 2009; Huang et al. 2013). From a spatial perspective, studies have used remote sensing, or quasi-remote sensing-agricultural census databases to highlight existent crop ‘yield gaps’ pinpointing large portions of China where maize and rice croplands are underperforming relative to their climatic potential (Licker et al. 2010). Other studies have highlighted water productivity gaps where there is potential to enhance the efficiency of crop water use (Brauman et al. 2013). Studies such as these are useful as they highlight where existing technologies can be targeted to increase resource use efficiency, without expansion of croplands.

#### 8.4.4 Crop productivity

Remote sensing information can improve estimates of crop yield when updating crop simulation models or using Monteith’s efficiency equation (Lobell 2003; Rembold et al. 2013). Monteith’s efficiency equation requires measures of the amount of photosynthetically active radiation (PAR) absorbed by the crop canopy (APAR) and is estimated as the sum of incremental products of PAR and the fraction of absorbed photosynthetically active radiation (fAPAR) (Bastiaanssen and Ali 2003; Lobell 2003). VI can be used to estimate fAPAR over a growing season as they are both influenced by leaf area index (LAI) (Hatfield et al. 1984; Rembold et al. 2013).

#### 8.4.5 Crop simulation models

Observed data, often derived from satellite sensor observations, can be assimilated into crop simulation models to correct model error and improve model performance (Hoefsloot et al. 2012). Satellite observations can be used to parameterize or initialize model parameters prior to simulation of crop growth (Rembold et al. 2013). As satellite observations are accumulated over a growing season state variables within a crop simulation model (e.g., LAI) can be updated via a range of techniques (e.g., re-calibration or reparameterization, reinitialization, forcing and updating) (Hoefsloot et al. 2012; Rembold et al. 2013). Doraiswamy et al. (2004) used MODIS NIR reflectance as an input into an inversion of the Scattering by Arbitrary Inclined Leaves (SAIL) radiative transfer model to estimate crop LAI through a growing season. The MODIS-simulated LAI were then used to adjust the timing of phenological stages within a crop simulation model and fit crop model LAI (Doraiswamy et al. 2004).

### 8.5 Monitoring Vulnerability and Pressures

Remote sensing is a valuable source of spatial information for Earth observation with its utility proven on many occasions, particularly for the various hazards and natural disasters experienced worldwide on an annual basis (Joyce et al. 2009). Remote sensing within this domain has become increasingly common with increased awareness of environmental issues and a simultaneous increase in geospatial technologies and the opportunity to distribute up-to-date imagery to the public through media and the Internet (Joyce et al. 2009). Remote sensing solutions are varied but generally have a role to play in all phases of the disaster management cycle (prevention, preparation, response, recovery) (Joyce et al. 2009). Comprehensive reviews of remote sensing for hazards and natural disaster events are offered by Tralli et al. (2005), Gillespie et al. (2005) and Joyce et al. (2009), providing both examples of the application of remote sensing for natural disaster mapping, and the limitations to its use, including associated difficulties of rapid data acquisition, provision of a robust product to end users, and visibility of features obstructed by vegetation canopy or cloud cover. In contributing to disaster management, remote sensing offers the advantage

of the availability of many orbiting and geostationary satellite services, and coverage of almost any part of the world at timescales ranging from hours to days (Joyce et al. 2009). In addition, Joyce et al. (2009) report the scale of events roughly matches the resolution of satellite imagery, and some imagery is relatively cheap or freely available.

### 8.5.1 Natural disasters

The most common and operational use of remote sensing satellites has been the weather satellites for cyclones, storms, and flash flood events (Joyce et al. 2009). Flooding is apparent in both optical and satellite aperture radar (SAR) data (Joyce et al. 2009), which appear ideal for detection of extensive floods since the backscatter signature of water is so distinct from vegetation, providing for accurate extent mapping (Lewis et al. 1998). Combining SAR with other geospatial data, such as digital elevation models, provides opportunity to estimate water depth of flooded regions (Joyce et al. 2009).

For disaster events, commercial satellite services can be tasked to collect data, and there are at present a number of systems and databases in place around the world, both commercial and otherwise, to utilize satellite data in these instances (Joyce et al. 2009). The Global Observing Systems Information Centre, the Global Geodetic Observing System and the Global Earth Observation System of Systems have been implemented to provide spatial-decision-support and to coordinate efforts to produce and disseminate high-quality satellite and climate data (Yang et al. 2013). The US Geological Survey hosts a Hazards Data Distribution System for downloading pre- and post-event hazard imagery, and Geoscience Australia has a hot spot identifying geographical information system (GIS) interface based on MODIS and AVHRR thermal imagery for Australia, New Zealand, and the South Pacific (Joyce et al. 2009). The Pacific Disaster Centre ([www.pdc.org](http://www.pdc.org)) states its objective as using information, science and technology to inform decision making in disaster response and to prevent hazards becoming a crisis. It has an emphasis on observation systems, modelling, and information communication to empower a range of stakeholders in disaster management. Sentinel Asia ([http://www.aprsaf.org/initiatives/sentinel\\_asia/](http://www.aprsaf.org/initiatives/sentinel_asia/)) is an on-demand network of information delivery websites developed to provide online information in the Asia/Pacific region from satellites in near-real-time, and contains information on various events such as cyclones and flooding in Myanmar and earthquake damage in China (Joyce et al. 2009).

The International Charter 'Space and Major Disasters' came into existence in 2000 after its conception at UNISPACE III and originally provided support for signatory space agencies and organizations. However, currently any national government can request the charter to be activated and receive support in disaster situations. Aiming to provide remotely sensed imagery and data to countries affected by disasters, the International Charter has membership of several international space agencies (Joyce et al. 2009). Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property (International Charter 2014; <http://www.disasterscharter.org/home>).

### 8.5.2 Recovery and response

Often, operational use of Earth observation in a disasters' context has a focus on initial damage mapping (e.g., inundation or damage to structures), as evident in responses to the activation of the International Charter after one of the biggest recent disasters in the SAO region, Typhoon Haiyan. Much of the thematic detail in post-disaster mapping focused on structural damage and shelter, not on damage to croplands and grazing lands which support livelihoods on a day-to-day basis and will

provide crucial assets to enable long-term recovery. Given that natural disasters are closely linked to poverty and maldevelopment, there should be a focus on protecting and restoring livelihoods in the long term after disasters as well as just saving lives in the immediate aftermath (Shepherd et al. 2013; World Bank 2013). There is potential to utilize available remote sensing products to generate greater levels of thematic detail regarding disaster impacts on cropping and rural livelihoods at fine spatial resolutions. Remote-sensing-based approaches for cropland mapping and crop yield estimates (Funk and Budde 2009; Bolton and Friedl 2013) demonstrate the contribution of these monitoring platforms and the importance of finer-scale mapping capabilities. There is a need for research to focus on exploring rapid mapping of thematic disaster impacts on livelihoods, not just delineating affected areas. Such an informational gain will improve the efforts of stakeholders, charged with disaster relief and recovery operations, in ensuring that disasters have minimal impacts on the positive development trajectories of poor and vulnerable rural communities.

## 8.6 Volunteered Geographic Information

The emerging field of Volunteered Geographic Information (VGI), described here as the widespread engagement of large numbers of people from the general public creating and sharing geographic information (Goodchild 2007; Elwood et al. 2012), provides new opportunities for increased community participation and utilization of important local information and/or traditional knowledge in development strategies. Recently emerged spatially enabling technologies including Web 2.0, georeferencing, geotags, global positioning systems and broadband communication have enabled mass proliferation of geographic user-generated content via the Internet (Goodchild 2007). Furthermore, the development of smartphones equipped with location and data recording sensors has resulted in near-instant geospatial data collection and dissemination using mobile platforms (see Raento et al. 2009; Lane et al. 2010). Sources of VGI include social media platforms such as Facebook and Twitter, photo and video-sharing websites such as Flickr or YouTube, and online map-making software such as OpenStreetMap or Wikimapia. Inclusion of the geographical component in user-generated data can assist in discriminating between reports based on location and facilitates more targeted initiatives and improved spatial planning.

In the context of sustainable environmental livelihoods in the SAO region, VGI offers the opportunity for intelligent observers with diverse local knowledge to contribute reports in near-real time in-situ, without the disadvantages of other forms of technology, such as the costs associated with satellite or aerial imagery, issues of scale, or the impacts of cloud cover or weather and satellite imagery (see Triglav-Čekada and Radovan 2013). In the case of natural disasters, VGI provides a timely and cost-effective method for creating and disseminating relevant geographic information through two-way communication mechanisms facilitated between individuals, communities and authorities (see Goodchild and Glennon 2010; McDougall 2011). Increasing climate and environmental pressures in the region (see section 2 of this document) will further highlight the importance and value of VGI for understanding and addressing local risk, vulnerabilities and impacts. Furthermore, in preparing and planning community development initiatives, VGI technologies can facilitate increased input from local communities and individuals to foster greater participation in 'bottom-up' approaches and act as a mechanism to sidestep traditional or dated 'top-down' approaches.

There are important challenges to consider with the use of VGI, including issues of data quality, accuracy and reliability, trust and reliability of data and data sources, security and liability, bias in reports, data management, and the notion of the digital divide, or those without means or access

to technologies potentially being excluded or marginalized (see Chinn and Fairlie 2007; Flanagan and Metzger 2008; Goodchild and Glennon, 2010; Zook et al. 2010; Ostermann and Spinsanti 2011; Gao et al. 2011; Purves 2011; Elwood et al. 2012; Goodchild and Li 2012; Triglav-Čekada and Radovan 2013; Scassa 2013). But overall, with these considerations in mind, VGI provides an exciting opportunity to harness the existing dense network of observers and local knowledge to address a range of questions and issues across the environmental livelihoods sphere, and further research is needed to understand and detail potential applications and impacts (both positive and negative).

## 9. MONITORING LIVELIHOODS

The value of Earth observation and remotely sensed satellite data is intrinsically of great value in monitoring environmental change. However, such technologies and broad-scale data products are of limited use to monitoring socioeconomic conditions. This section discusses tools available for monitoring livelihoods to achieve sustainable outcomes.

### 9.1 Tools for Implementing the SLA

Various frameworks have been devised which conceptualize the SLA for different contexts, and various methodologies have been developed to allow implementation of the frameworks to produce interventions for development. De Haan et al. (2002) look at methods for understanding urban poverty and livelihoods, and note that in the livelihoods approach, knowledge is needed about the situation and strategies adopted by poor households, in relation to both their characteristics and external opportunities and constraints. The methodological approach in such data collection and analysis is first, contextual and, second, participatory. Qualitative and in-depth data need to be complemented by large-scale data collection and quantitative analysis, in order to reveal the characteristics of the context, the overall dimensions of trends in poverty, and the extent to which household characteristics revealed in relatively small-scale studies are 'typical.'

DFID has issued a series of 'guidance sheets' on implementing the SLA which summarizes and shares emerging thinking on the sustainable livelihoods approach. It does not offer definitive methodology, instead it is intended to stimulate readers to reflect on the approach and make their own contributions to its further development (<http://www.eldis.org/vfile/upload/1/document/0901/section2.pdf>.) Examples of specific implementation techniques include LAT and CVA as detailed here.

#### 9.1.1 Designing an SLA framework

Closely linked to theory which was discussed in Part II, before a method can be developed a framework for establishing the SLA needs to be constructed to identify important factors and indicators for the context being studied. We have already introduced a couple of examples in Part II, but in terms of framework design a further example is provided here. Bebbington (1999) argues we can conceptualize sustainable rural livelihoods in terms of debates on access to resources (Berry 1989; Blaikie 1989), asset vulnerability (Moser 1998), and entitlements (Sen 1981). The suggestion is that one part of a useful heuristic framework for doing this is one that conceives of livelihoods and the enhancement of human well-being in terms of different types of capital (natural, produced, human, social and cultural) that are at once the resources (or inputs) that make livelihood strategies possible, the assets that give people capability, and the outputs that make livelihoods meaningful and viable. The second part of their framework focuses on household and intra-household forms of engagement with markets, the state and civil society, and the implications of these engagements for the distribution and transformation of assets. Malleon et al. (2008) adopted a hierarchical sampling scheme to select the population and regions for implementing livelihoods research. They used participant observation and participatory exercises (e.g., wealth ranking; household census). An example from Ashley and Hussein (2000) at livelihood impact assessment through livelihood strategies and stakeholder groups is given in Figure 23. Brock (1999) highlighted that ensuring field-level experience in the broader context of the relationship between research and policy, is particularly important in terms of the exchange and flow of information between different stakeholders in the policy development process (Figure 24).



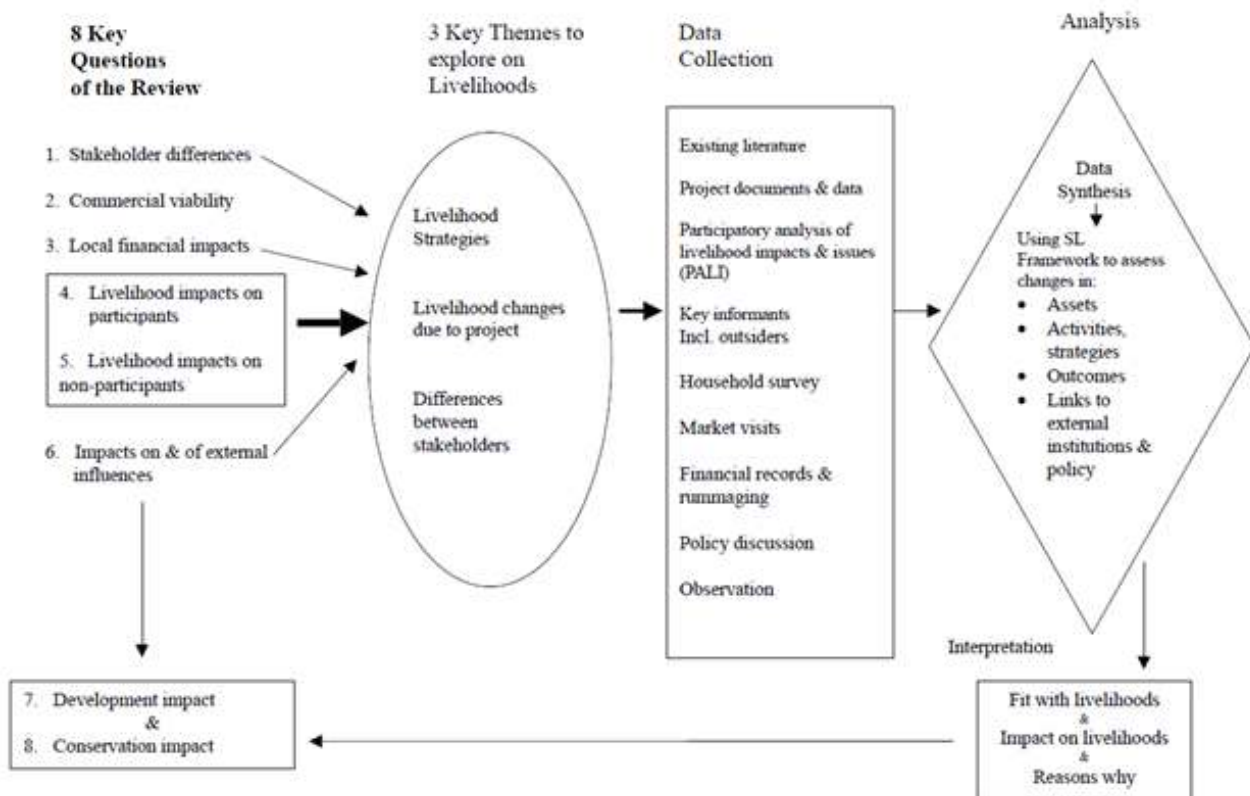


Figure 23. Summary of the process of livelihood impact analysis (Source: Ashley and Hussein 2000).

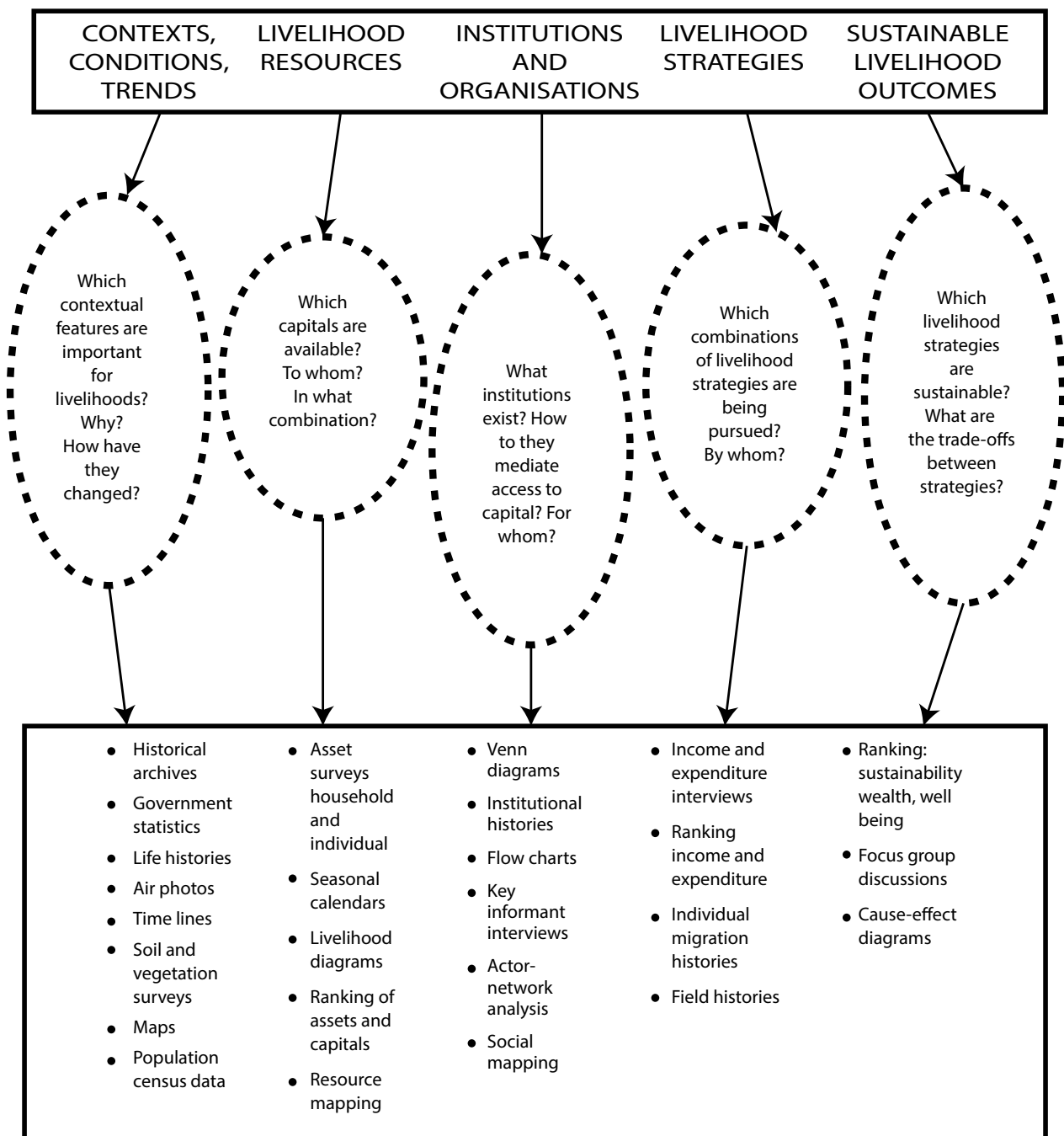


Figure 24. Range of methods to implement a Sustainable Livelihoods framework (Source: Brock 1999). See also DFID (2001) for further methods of implementation.

### 9.1.2 The livelihood assessment toolkit (LAT)

The Livelihood Assessment Toolkit (LAT) (FAO 2008) process consists of three interrelated elements: (i) a livelihood baseline which provides a picture of ‘normal’ livelihood patterns in areas at risk from natural hazards together with an indication of likely impact of hazards, key response priorities and institutions likely to be involved in recovery; (ii) an initial livelihood impact appraisal which provides an initial assessment of impact of disaster on livelihoods at local level; and (iii) a

detailed livelihood assessment which provides an assessment of impact of disaster on livelihoods and opportunities, capacities and needs for recovery at household, community and local economy levels. As currently designed, the LAT is aimed at sudden onset of natural disasters. However, it is planned to extend the coverage of the LAT to other types of emergency. Each of the three parts of the LAT serves different but related functions in the assessment process.

### 9.1.3 Capabilities and vulnerability analysis (CVA)

Cannon et al. (2008) note that key components of the SLA are contained within the Capacities and Vulnerabilities Analysis (CVA) which looks at the vulnerabilities and capacities to physical/natural, social/organizational and motivational/attitudinal change. What might be termed as social, physical, financial, human and natural capital and the vulnerability context, have always been stressed as fundamental building blocks to understanding vulnerability and capacity in the CVA. They note, however, that a consideration of transforming processes and structures has yet to make its way into the assessment in any real sense. The integration of the livelihoods approach with the CVA tool could be used to identify vulnerable groups, relationships between actors in social networks, important capacity-building initiatives for risk mitigation and disaster preparedness, and the relationship between disaster and development.

## 9.2 Monitoring Sustainable Development

The field of sustainable development has been fundamental in capturing the emergent scientific and social understanding of the intimate coupling of nature and society: efforts to protect nature will fail unless they simultaneously advance the cause of human betterment; efforts to better the lives of people will fail if they fail to conserve, if not enhance, essential resources and life support systems (Khagram et al. 2003: 289). The sustainable livelihoods approach has a normative aspect to it which goes beyond people's own objectives or definition of poverty (DFID 1999). Livelihood outcomes should incorporate the dimensions of sustainability. This implies a need to investigate the effect of people's livelihood strategies and the outcomes that guide them on social, institutional, environmental and economic factors (and subsequently to promote positive directions of change). Both material and nonmaterial outcomes for certain groups may be challenged by others and therefore be nonsustainable. Or else the achievement of a given outcome may be at the expense of severe environmental degradation.

Khagram et al. (2003: 299) state that the normative, analytic and practical space in which the questions of 'what is to be sustained' and 'what is to be developed' are debated is actually the essence of the field of 'sustainable development.' There is no consensus in the field of a narrow or precise definition of sustainable development but debate has certainly moved beyond a global aggregate of balancing of the world economy and the global environment. Alternative framings in terms of disaggregated interests – developing individuals and communities, sustaining particular species and places are growing in strength. It is now increasingly understood that analysis of sustainable development requires understanding of complex trans-scale linkages and relationships. But, they argue, it does seem that crucial threats and vulnerabilities to sustainable development converge at meso-scales in critical regions, often ecologically defined (Kasperson et al. 1999: Khagram et al. 2003). Khagram et al. (2003) suggest it is probable that relatively too much activity is directed at local and global levels to the neglect of intermediate and intermediating geographical scales. Specifically referring to the frameworks of sustainability science and sustainable livelihoods, they note that both of these frameworks have much in common that could guide sustainable

security and development (Khagram et al. 2003). Both frameworks provide a distinct awareness of the systematic, multifaceted and diverse characteristics of human and environment systems. Yet both offer a means by which to focus the analysis and practice on particular vulnerabilities in specific temporal and spatial contexts – a good tool to use in prioritizing people’s development and security.

## 10. CONCLUDING REMARKS

This paper has presented a baseline report for (i) environmental conditions in Southeast Asia and Oceania, (ii) a full conceptualization of the term environmental livelihood security, and (iii) an assessment of potential geospatial data and methodologies which could be integrated to monitor changes in ELS in SAO. Given the information provided in this paper, researchers can now formulate approaches for expanding our concept of ELS and consider methods for spatially monitoring and assessing changes in ELS.

### 10.1 Assessing Environmental Livelihood Security

Further research conceptualizing and quantifying the relationship between food-water-energy security and sustainable livelihoods, using a spatiotemporal approach, would advance conceptual and practical frameworks, linking security and development at intermediating geographical scales. The work by Kemp-Benedict et al. (2009) on assessing water-related poverty using the sustainable livelihoods framework is a promising step forward in this regard. Further focus on reducing vulnerabilities of poor communities to withstand the impacts of climate change will improve their security: the extent to which they can live their lives and conduct their livelihoods free from threats (IISD 2003). The literature reviewed provides support that livelihoods need to be better encompassed within nexus thinking to ensure environmental securities are applicable at multiple scales for enabling sustainable livelihoods, and not only sustainable development. There is scope to investigate ELS throughout the SAO region in detail, looking at both natural supply and human demand to push forward with sustainable solutions. Issues of scale need careful consideration when developing a framework to assess ELS and time provides an important dimension, i.e., achieving long-term sustainability.

### 10.2 Aligning with Post-2015 Agenda

Environmental issues provide an entry point for individuals and communities to participate in decisions about their own security and development, even in the most restrictive political regimes (Khagram et al. 2003). Through the development of the ELS concept we feel that livelihoods can now be better encapsulated within nexus-thinking, and that our theorization goes some way to providing conceptual grounding for looking at the natural supply and human demand of a system and maintaining socioecological resilience under the increasing threat of climate change. Environmental livelihood security aligns itself well to ongoing discussions surrounding the post-2015 agenda and the development of the Sustainable Development Goals (SDGs).<sup>1</sup> The research presented here communicates with several outcomes of the Rio+20 meeting such as “focus on priority areas for the achievement of sustainable development” and “address and incorporate in a balanced way all three dimensions of sustainable development and their interlinkages.” We believe, that with further work, which this consortium of researchers has underway, our discussions within this paper can assist in providing action-orientated research and concise methods for assessing environmental livelihood security in SAO. The multiscale and multilevel approach to our research will ensure that such methods can assist in providing appropriate means of monitoring progress in sustainability with more informed solutions. Such outcomes were not emphasized within the MDG, as progress was only monitored at a national level. We are interested in the day-to-day

<sup>1</sup> See <http://sustainabledevelopment.un.org/owg.html> for emerging dialogue.

lives of people not only to enable them to live more sustainably but also to improve their general living standard. In this respect, we feel the dialogue on ELS presented here will provide valuable insight for informing monitoring of the SDG process and ensuring focused and coherent action on sustainable development.

## REFERENCES

- Acharya, K.P. 2005. *Improving the effectiveness of collective action: Sharing experiences from community forestry in Nepal*. CAPRI Working Paper No. 54. Washington, DC: International Food Policy Research Institute (IFPRI).
- Adato, M.; Meinzen-Dick. 2002. *Assessing the impact of agricultural research on poverty using the sustainable livelihoods framework*. Environment and Production Technology Division Discussion Paper No. 89. Washington, DC: IFPRI.
- ADB (Asian Development Bank). 2009. *Cambodia: Rural water and sanitation - Can a gender action plan make a difference?* Gender and Development. Mandaluyong City, Philippines: ADB.
- ADB. 2013a. *The economics of climate change in the Pacific*. Mandaluyong City, Philippines: ADB.
- ADB. 2013b. *Thinking about water differently: Managing the water-food-energy nexus*. Manila, Philippines: ADB.
- Adger, W.N. 2000. Social and ecological resilience: Are they related? *Progress in Human Geography* 24: 347-364.
- Adger, W.N.; Hughes, T.P.; Folke, C.; Carpenter, S.R.; Rockström, J. 2005. Social-ecological resilience to coastal disasters. *Science (New York, N. Y.)* 309: 1036-9.
- Adger, W.N.; Pulhin, J. 2014. Human security. In *Climate change 2013: The physical science basis*. Contribution of Working Group 2 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: International Panel on Climate Change.
- Agrawal, A.; Ribot, J. 1999. Accountability in decentralisation: A framework with South Asian and West African cases. *The Journal of Developing Areas* 33: 473-502.
- Agrawal, A., 2001. The regulatory community: Decentralization and the environment in the van panchayats (forest councils) of Kumaon, India. *Mountain Research and Development* 21: 208-211.
- Allison, E.; Ellis, F. 2001. The livelihoods approach and management of small-scale fisheries. *Marine Policy* 25: 377-88.
- Allison, E.H.; Horemans, B. 2006. Putting the principles of the sustainable livelihoods approach into fisheries development policy and practice. *Marine Policy* 30: 757-766.
- Allison, E.H.; Perry, A.L.; Badjeck, M.C.; Adger, N.W.; Brown, K.; Conway, D.; Halls, A.S.; Pilling, G.M.; Reynolds, J.D.; Andrew, N.L.; Dulvy, N.K. 2009. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries* 10: 173-196.
- Allsopp, M.; Walters, A.; Santillo, D.; Johnston, P. 2006. Plastic debris in the world's oceans. *Greenpeace International* 43p.
- Anderson, S. 2003. Animal genetic resources and sustainable livelihoods. *Ecological Economics* 45: 331-9.
- Ansell, C.; Gash, A. 2008. Collaborative governance in theory and practice. *Journal of Public Administration Research and Theory* 18: 543-571.
- Arce, A. 2003. Value contestations in development interventions: Community development and sustainable livelihoods approaches. *Community Development Journal* 38: 199-212.
- Ariyabandu, M.M.; Fonseka, D. 2009. Do disasters discriminate? A human security analysis of the impact of the Tsunami in India, Sri Lanka and of the Kashmir earthquake in Pakistan. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, Ú.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera, N. Chadha; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H., pp. 1215-1226. Berlin - Heidelberg - New York: Springer-Verlag.
- Armitage, D. 2007. Building resilient livelihoods through adaptive co-management: The role of adaptive capacity. Chapter 4 in *Adaptive co-management: Collaboration, learning and multi-level governance*. 2007, (ed.), Berkes, F.; Armitage, D.R.; Doubleday, N. Vancouver: UBC Press.
- Armitage, D.R.; Plummer, T.; Berkes, F.; Arthur, R.I.; Charles, A.T.; Davidson-Hunt, I.J.; Diduck, A.P.; Doubleday, N.C.; Johnson, D.S.; Marschke, M.; McConney, P.; Pinkerton, E.W.; Wollenberg, E.K. 2009. Adaptive co-management for social-ecological complexity. *Frontiers in Ecology and Environment* 7: 95-102.
- Ashby, J.A. 1986. Methodology for participation of small farmers in the design of on-farm trials. *Agric Adm* 22: 1-19.

- Ashby, J.A. 2003. Introduction: Uniting science and participation in the process of innovation – research for development. In *Managing natural resources for sustainable livelihoods: Uniting science and participation*, ed., Pound, B.; Snapp, S.; McDougall, C.; Braun, A., pp. 1–19. London: Earthscan.
- Ashley, C.; Carney, D. 1999. *Sustainable livelihoods: Lessons from early experience*. London: Department for International Development.
- Ashley, C.; Hussein, K. 2000. *Developing methodologies for livelihood impact assessment: Experience of the African Wildlife Foundation in East Africa*. ODI Working Paper 129. London: Overseas Development Institute (ODI).
- Atzberger, C. 2013. Advances in remote sensing of agriculture: Context description, existing operational monitoring systems and major information needs. *Remote Sensing* 5: 949–981.
- AVISO+, 2014. AVISO+ Satellite Altimetry Data [Online]. CNES. <http://www.aviso.altimetry.fr/en/data.html> (accessed April, 2014).
- Bailey, C.; Pomeroy, C. 1996. Resource dependency and development options in coastal South East Asia. *Society and Natural Resources* 9: 191–99.
- Banks, G.; Kuir-Ayius, D.; Kombako, D.; Sagir, B. 2013. Conceptualizing mining impacts, livelihoods and corporate community development in Melanesia. *Community Development Journal* 48: 484-500.
- Barnett, J.; Campbell, J. 2010. *Climate change and small island states: Power, knowledge, and the South Pacific*. London: Earthscan.
- Bastiaanssen, W.G.M.; Ali, S. 2003. A new crop yield forecasting model based on satellite measurements applied across the Indus Basin, Pakistan. *Agriculture, Ecosystems and Environment* 94: 321–340.
- Bauman, P. 2000. *Sustainable livelihoods and political capital: Arguments and evidence from decentralisation and natural resource management in India*. ODI Working Paper 136. UK: ODI.
- Bauman, P.; Sinha, S. 2001. *Linking development with democratic processes in India: Political capital and sustainable livelihoods analysis*. ODI Natural Resource Perspectives, Number 68. UK: ODI.
- Bebbington, A. 1999. Capital and capabilities: A framework for analysing peasant viability, rural livelihoods and poverty. *World Development* 27: 2021-44.
- Bell, J.D.; Johnson, J.E.; Hobday, A.J. 2011. *Vulnerability of tropical Pacific fisheries and aquaculture to climate change*. Noumea: Secretariat of the Pacific Community.
- Berkes, F. 1999. *Sacred ecology: Traditional ecological knowledge and resource management*. Philadelphia, Pennsylvania, USA: Taylor and Francis.
- Berry, S. 1989. Social institutions and access to resources. *Africa* 59: 41-55.
- Bevir, M. 2013. *Governance: A very short introduction*. Oxford, UK: Oxford University Press.
- Biggs, E.M.; Duncan, J.M.A.; Atkinson, P.M.; Dash, J. 2013. Plenty of water, not enough strategy. *Environmental Science and Policy* 33: 388–394.
- Biggs, R.; Schlüter, M.; Biggs, D.; Bohensky, E.L.; Burnsilver, S.; Cundill, G.; Dakos, V.; Daw, T.; Evans, L.S.; Kotschy, K.; Leitch, A.M.; Meek, C.; Quinlan, A.; Raudsepp-Hearne, C.; Robards, M.D.; Schoon, M.L.; Schultz, L.; West, P.C. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37: 421–448.
- Bisht, T.C. 2009. Development-induced displacement and women: The case of the Tehri Dam, India. *The Asia Pacific Journal of Anthropology* 10(4): 301-317.
- Blaikie, P. 1989. Environment and access to resources in Africa. *Africa* 59(1): 18-40.
- BMZ (Federal Ministry for Economic Cooperation and Development). 1999. *Cross-sectoral strategy: Participatory development cooperation*. Bonn/Berlin: BMZ.
- Bogardi, J.J.; Brauch, H.G. 2005. Global environmental change: A challenge for human security – Defining and conceptualising the environmental dimension of human security. In *UNEO – Towards an International Environment Organization – Approaches to a sustainable reform of global environmental governance*, ed., Rechkemmer, A. pp. 85-109. Baden-Baden: Nomos.



- Bogardi, J.J.; Dudgeon, D.; Lawford, R.; Flinkerbusch, E.; Meyn, A.; Pahl-Wostl, C.; Vielhauer, K.; Vörösmarty, C. 2012. Water security for a planet under pressure: Interconnected challenges of a changing world call for sustainable solutions. *Current Opinion in Environmental Sustainability* 4: 35–43.
- Bogardi, J.J.; Oswald Spring, Ú.; Brauch, H.G. 2015. Water security: Past, present and future of a controversial concept. In *Handbook on water security*, ed., Pahl-Wostl, Claudia; Bhaduri, Anik; Gupta, Joyeeta. Cheltenham - Northampton, MA: Edward Elgar.
- Bohle, H.G. 2009. Sustainable livelihood security. Evolution and application. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, Ú.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera, N. Chadha; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H., pp. 521-528. Berlin – Heidelberg – New York: Springer-Verlag.
- Bolton, D.K.; Friedl, M.A. 2013. Forecasting crop yield using remotely sensed vegetation indices and crop phenology metrics. *Agricultural and Forest Meteorology* 173: 74–84.
- BOM (Australian Bureau of Meteorology); CSIRO (Commonwealth Scientific and Industrial Research Organization). 2011. Climate change in the Pacific: Scientific assessment and new research, Volume 1: Regional Overview. Online <http://www.pacificclimatechangescience.org/wp-content/uploads/2013/08/Climate-Change-in-the-Pacific.-Scientific-Assessment-and-New-Research-Volume-1.-Regional-Overview.pdf> (accessed October 2014).
- Bontemps, S.; Defourny, P.; Bogaert, E.; Arino, O.; Kalogirou, V.; Perez, J.; 2011. *GLOBCOVER 2009 Products description and validation report*. [http://due.esrin.esa.int/globcover/LandCover2009/GLOBCOVER2009\\_Validation\\_Report\\_2.2.pdf](http://due.esrin.esa.int/globcover/LandCover2009/GLOBCOVER2009_Validation_Report_2.2.pdf); (accessed 30-10-2014).
- Bouwen, R.; Taillieu, T. 2004. Multi-party collaboration as social learning for interdependence: Developing relational knowing for sustainable natural resource management. *Journal of Community and Applied Social Psychology* 14: 137-153.
- Brauch, H.G. 2005. *Environment and human security: Towards freedom from hazard impacts*. Bonn: United Nations University – Institute for Environment and Human Security.
- Brauch, H.G. 2008. Conceptualising the environmental dimension of human security in the UN. *International Social Science Journal (Special Issue). Rethinking Human Security* (September): 19-48.
- Brauch, H.G. 2009a. Securitized global environmental change. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, Ú.; Grin, J.; Mesjasz, C.; Kameri-Mbote, P.; Behera, N. Chadha; Chourou, B.; Krummenacher, H., pp. 65-102. Berlin – Heidelberg – New York: Springer-Verlag.
- Brauch, H.G. 2009b. Human security concepts in policy and science. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, Ú.; Grin, J.; Mesjasz, C.; Kameri-Mbote, P.; Behera, N. Chadha; Chourou, B.; Krummenacher, H., pp. 965-990. Berlin – Heidelberg – New York: Springer-Verlag.
- Brauch, H.G.; Oswald Spring, Ú. 2009. *Securitizing the ground-grounding security*. Bonn: United Nations Convention to Combat Desertification.
- Brauch, H.G.; Oswald Spring, Ú.; Grin, J.; Mesjasz, C.; Kameri-Mbote, P.; Behera, N. Chadha; Chourou, B.; Krummenacher, H., eds. 2009. *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*. Berlin – Heidelberg – New York: Springer-Verlag.
- Brauch, H.G.; Oswald Spring, Ú.; Grin, J.; Scheffran, J., eds. 2016. *Sustainability transition and sustainable peace handbook*. Cham - Heidelberg – New York – Dordrecht – London: Springer-Verlag.
- Brauch, H.G., Oswald Spring, Ú.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera, N. Chadha; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H., eds. 2008. *Globalization and environmental challenges: Reconceptualizing security in the 21st century*. Berlin – Heidelberg – New York: Springer-Verlag.
- Brauch, H.G.; Oswald Spring, Ú.; Mesjasz, C.; Grin, J.; Kameri-Mbote, P.; Chourou, B.; Dunay, P.; Birkmann, J., eds. 2011. *Coping with global environmental change, disasters and security – threats, challenges, vulnerabilities and risks*. Berlin – Heidelberg – New York: Springer-Verlag.
- Brauman, K.A.; Siebert, S.; Foley, J. 2013. Improvements in crop water productivity increase water sustainability and food security—a global analysis. *Environmental Research Letters* 8: 2-7.

- Brecht, H.; Dasgupta, S.; Laplante, B.; Murray, S.; Wheeler, D. 2012. Sea-level rise and storm surges: High stakes for a small number of developing countries. *Journal of Environment and Development* 21: 120-138.
- Briguglio, L. 1995. Small-island developing states and their economic vulnerabilities. *World Development* 23: 1615-32.
- Brock, K. 1999. *Sustainable livelihoods in Mali*. Research Report 35. UK: Institute of Development Studies.
- Brocklesby, M.; Fisher, E. 2003. Community development in sustainable livelihoods approaches – an introduction. *Community Development Journal* 38: 185-198.
- Brundtland Commission. 1987. *Our common future*. Oxford: The World Commission on Environment and Development; New York: Oxford University Press.
- Bui, T.M.H.; Schreinemachers, P.; Berger, T. 2013. Hydropower development in Vietnam: Involuntary resettlement and factors enabling rehabilitation. *Land Use Policy* 31: 536-544.
- Butler, J.R.A.; Tawake, A.; Skewes, T.; Tawake, L.; McGrath, V. 2012. Integrating traditional ecological knowledge and fisheries management in the Torres Strait, Australia: The catalytic role of turtles and dugong as cultural keystone species. *Ecology and Society* 17: 34.
- Calder, I. 2005. *Blue revolution: Integrated land and water resource management*. London: Earthscan.
- Camargo, S.J.; Emanuel, K.A.; Sobel, A.H. 2007. Use of a genesis potential index to diagnose ENSO effects on tropical cyclone genesis. *Journal of Climate* 20: 4819-4834.
- Campbell, J.R. 2001. Participatory Rural Appraisal as qualitative research: Distinguishing methodological issues from participatory claims. *Hum Organ* 60: 380-389.
- Cannon, T.; Twigg, J.; Rowell, J. 2008. *Social vulnerability, sustainable livelihoods and disasters*. Kent: Benfield Hazard Research Centre.
- Carney, D. 1998. *Sustainable rural livelihoods: What contribution can we make? Proceedings of the Department for International Development's Natural Resources Advisors' Conference*. London: Department for International Development (DFID).
- Carney, D. 2002. *Sustainable livelihoods approaches: Progress and possibilities for change*. London: DFID.
- Carney, D.; Drinkwater, M.; Rusinow, T.; Neefjes, N.; Wanmali, S.; Singh, N. 1999. *Livelihoods approaches compared. A brief comparison of the livelihoods approaches of the UK Department for International Development (DFID), Cooperative for Assistance and Relief, Oxfam and the United Nations Development Programme (UNDP)*. London: DFID Publication.
- Carpenter, S.R.; Caraco, N.F.; Correll, D.L.; Howarth, R.W.; Sharpley, A.N.; Smith, V.H. 2010. Nonpoint pollution for surface water with phosphorus and nitrogen. *Ecological Applications* 8: 559-568.
- Carpenter, S.; Biggs, R.; Brock, W.; Crépin, A.-S.; Engström, G.; Folke, C.; Hughes, T.; Kautsky, N.; Li, Chuan-Zhong; McCarney, G.; Meng, K.; Mäler, K.-G.; Polasky, S.; Scheffer, M.; Shogren, J.; Sterner, T.; Vincent, J.; Walker, B.; Xepapadeas, A.; Zeeuw, A. 2012a. General resilience to cope with extreme events. *Sustainability* 4: 3248-3259.
- Carpenter, S.R.; Brock, W.A.; Cole, J.J.; Pace, M.L. 2012b. A new approach for rapid detection of nearby thresholds in ecosystem time series. *Oikos* 290-297.
- Carswell, G. 1997. *Agricultural intensification and rural sustainable livelihoods*. IDS Working Paper 64. Brighton: Institute of Development Studies.
- CEPAR (Center of Excellence in Population Ageing Research). 2013. *Asia in the ageing century: Part 1 – population trends*. CEPAR Research Briefs. Kensington: Australian School of Business.
- Challinor, A.J.; Watson, J.; Lobell, D.B.; Howden, S.M.; Smith, D.R.; Chhetri, N. 2014. A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change* 1-5.
- Chambers, R. 1983. *Rural development: Putting the last first*. London: Routledge.
- Chambers, R. 1987. *Sustainable livelihoods, environment and development: Putting poor rural people first*. IDS Discussion Paper 240. Brighton: Institute of Development Studies.
- Chambers, R. 1994. The origins and practice of participatory rural appraisal. *World Development* 22: 953-969.
- Chambers, R. 1995. Poverty and livelihoods: Whose reality counts? *Environment and Urbanization* 7: 173-204.

- Chambers, R.; Conway, G.R. 1992. *Sustainable rural livelihoods: Practical concepts for the 21st century*. IDS Discussion Paper No. 296. Brighton: Institute of Development Studies.
- Chant, S. 2006. Rethinking the “Feminization of Poverty” in relation to aggregate indices. *Journal of Human Development* 7: 201-220.
- Chartres, C.; Sood, A. 2013. The water for food paradox. *Aquatic Procedia* 1: 3-19.
- Chavez, J. 2007. Social policy in ASEAN: The prospects for integrating migrant labour rights and protection. *GlobSoc Policy* 7: 378.
- Checkland, P.B.; Scholes, J. 1990. *Soft systems methodology in action*. New York: John Wiley & Sons.
- Chen, M. 1991. *Coping with seasonality and drought*. New Delhi, California and London: Sage Publications.
- Chen, J.; Jonsson, P.; Tamura, M.; Gu, Z.; Matsushita, B.; Eklundh, L. 2004. A simple method for reconstructing a high-quality NDVI time-series data set based on the Savitzky – Golay filter. *Remote Sensing of Environment* 91: 332–344.
- Cheng, H.; Zhang, P.Z.; Spotl, C.; Edwards, R.L.; Cai, Y.J.; Zhang, D.Z.; Sang, W.C.; Tan, M.; An, Z.S. 2012. The climatic cyclicity in semiarid-arid central Asia over the past 500,000 years. *Geophysical Research Letters* 39.
- Cheung, W.W.L.; Lam, V.W.Y.; Sarmiento, J.L.; Kearney, K.; Watson, R.; Pauly, D. 2009. Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* 10: 235-251.
- Chinn, M.; Fairlie, R. 2007. The determinants of the global digital divide: A cross-country analysis of computer and internet penetration. *Oxford Economic Papers* 59: 16–44.
- Choi, G.; Collins, D.; Ren, G.; Trewin, B.; Baldi, M.; Fukuda, Y.; Afzaal, M.; Pianmana, T.; Gomboluudev, P.; Huong, P.T.T.; Lias, N.; Kwon, W.T.; Boo, K.O.; Cha, K.M.; Zhou, Y. 2009. Changes in means and extreme events of temperature and precipitation in the Asia-Pacific network region, 1955-2007. *Int. Journal of Climatology* 29: 1906-1925.
- Chongsuvivatwong, V.; Phua, K.H.; Yap, M.T.; Pocock, N.S.; Hashim, J.H.; Chhem, R.; Wilopo, S.A.; Lopez, A.D. 2011. Health and health-care systems in Southeast Asia: Diversity and transitions. *The Lancet* 377: 429-437.
- CHS (Commission on Human Security). 2003. *Human security now*. New York.
- Cleaver, F.; Franks, T. 2005. How institutions elude design: River basin management and sustainable livelihoods. *Alternative Water Forum*. Bradford: Bradford Centre for International Development.
- Collins, M.; An, S.I.; Cai, W.J.; Ganachaud, A.; Guilyardi, E.; Jin, F.F.; Jochum, M.; Lengaigne, M.; Power, S.; Timmermann, A.; Vecchi, G.; Wittenberg, A. 2010. The impact of global warming on the tropical Pacific Ocean and El Niño. *Nature Geoscience* 3: 391-397.
- Connell, D. 2010. Sustainable livelihoods and ecosystem health: Exploring methodological relations as a source of synergy. *EcoHealth*. Published online 23 November 2010. International Association for Energy and Health.
- Connell, J. 2013. Soothing breezes? Island perspectives on climate change and migration. *Australian Geographer* 44: 465-480.
- Conroy, C.; Litvinoff, M., eds. 1988. *The greening of aid: Sustainable livelihoods in practice*. London: Earthscan.
- Cook, S.; Gichuki, F. 2006. *Mapping water poverty: Water, agriculture and poverty linkages*. BFP Working Paper 3. Challenge Program on Water and Food. Colombo, Sri Lanka: International Water Management Institute.
- Cornwall, A.; Nyamu-Musembi, C. 2006. Putting the ‘rights-based approach’ to development into perspective. *Third World Quarterly* 25: 1415-1437.
- Costanza, R. 2014. Time to leave GDP behind. *Nature* 505: 283–285.
- Costanza, R.; Kemp, M.; Boynton, W. 1995. Scale and biodiversity in estuarine ecosystems. In *Biodiversity loss: Economic and ecological issues*, ed., Perrings, C.; Mäler, K.G.; Folke, C.; Holling, C.S.; Jansson, B.O., pp. 84–125. Cambridge: Cambridge University Press.
- CSIRO (Commonwealth Scientific and Industrial Research Organisation); BOM (Bureau of Meteorology), eds. 2011. *Climate change in the Pacific: Scientific assessment and new research*. Canberra, Australia.
- Dahal, G.R.; Atkinson, J.; Bampton, J. 2011. *Forest tenure in Asia: Status and trends*. Kuala Lumpur: EU FLEGT Facility.
- Dalby, S. 2013. Environmental dimensions of human security. In *Environmental security approaches and issues*, ed., Floyd, R.; Matthew, R.A., pp. 121–138. Oxford: Routledge.

- Dalby, S.; Brauch, H.G.; Oswald Spring, Ú. 2009. Environmental security concepts revisited during the first three phases (1983-2006). In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, Ú.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera, N. Chadha; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H., pp. 781-790. Berlin – Heidelberg – New York: Springer-Verlag.
- Dasgupta, S.; Laplante, B.; Meisner, C.; Wheeler, D.; Yan, J. 2009. The impact of sea level rise on developing countries: A comparative analysis. *Climatic Change* 93: 379-388.
- Dash, J.; Jeganathan, C.; Atkinson, P.M. 2010. Remote sensing of environment. The use of MERIS Terrestrial Chlorophyll Index to study spatiotemporal variation in vegetation phenology over India. *Remote Sensing of Environment* 114: 1388–1402.
- Davies, M.; Béné, C.; Arnall, A.; Tanner, T.; Newsham, A.; Coirolo, C. 2013. Promoting resilient livelihoods through adaptive social protection: Lessons from 124 programmes in South Asia. *Development Policy Review* 31: 27-58.
- Davies, S. 1993. *Versatile livelihoods: Strategic adaptation to food security in the Malian Sahel*. IDS Discussion Paper No. 304. Sussex: Falmer.
- Dearing, J.A.; Wang, R.; Zhang, K.; Dyke, J.G.; Haberl, H.; Hossain, S.; Langdon, P.G.; Lenton, T.M.; Raworth, K.; Brown, S.; Carstensen, J.; Cole, M.J.; Cornell, S.E.; Dawson, T.P.; Doncaster, P.; Eigenbrod, F.; Flörken, M.; Jefferso, E.; Mackay, A.W.; Nykvist, B.; Poppy, G.M. 2014. Safe and just operating spaces for regional social-ecological systems. *Global Environmental Change* 28: 227–238.
- de Haan, L.; Drinkwater, M.; Rakodi, C.; Westley, K. 2002. *Methods for understanding urban poverty and livelihoods sustainable development*. Working Paper. UK: DFID.
- de Haan, L.; Zoomers, A. 2005. Exploring the frontiers of livelihoods research. *Development and Change* 36: 27-47.
- Deo, R. 2011. On meteorological droughts in tropical Pacific Islands: Time-series analysis of observed rainfall using Fiji as a case study. *Meteorological Applications* 18: 171–180.
- Derraik, J.G.B. 2002. The pollution of the marine environment by plastic debris: A review. *Marine Pollution Bulletin* 44: 842–852.
- Deryng, D.; Conway, D.; Ramankutty, N.; Price, J.; Warren, R. 2014. Global crop yield response to extreme heat stress under multiple climate change futures. *Environmental Research Letters* 9: 1-13.
- Detraz, N. 2009. Environmental security and gender: Necessary shifts in an evolving debate. *Security Studies* 18: 345-369.
- DFID (Department for International Development). 1999. Sustainable livelihoods and poverty elimination. London.
- DFID. 2001a. *Sustainable livelihoods – current thinking and practice*. London.
- DFID. 2001b. *Sustainable livelihoods guidance sheets*. London.
- Döll, P. 2002. Impact of climate change and vulnerability on irrigation requirements: A global perspective. *Climatic Change* 54: 269–293.
- Doraiswamy, P.C.; Hatfield, J.L.; Jackson, T.J.; Akhmendov, B.; Prueger, J.; Stern, A. 2004. Crop condition and yield simulations using Landsat and MODIS. *Remote Sensing of Environment* 92: 548–559.
- Dow, K. 1999. The extraordinary and the everyday in explanations of vulnerability to oil spill. *Geographical Review* 89: 74-93.
- Dreze, J.; Sen, A. 1989. *Public action for social security: Foundations and strategy*. London: Development Economics Research Programme No. 20.
- Duce, S.J.; Parnell, K.E.; Smithers, S.G.; McNamara, K.E. 2010. A synthesis of climate change and coastal science to support adaptation in the communities of the Torres Strait. Synthesis Report prepared for the Marine and Tropical Science Research Facility. Cairns: Reef and Rainforest Research Centre Ltd.
- Duncan, C.R. 2004. *Civilizing the margins: Southeast Asian Government policies for the development of minorities*. Ithaca and London: Cornell University Press.
- Eakin, H.; Benessaiah, K.; Barrera, J.F.; Cruz-Bello, G.M.; Morales, H. 2012. Livelihoods and landscapes at the threshold of change: Disaster and resilience in a Chiapas coffee community. *Regional Environmental Change* 12: 475–488.

- Eilenberg, M. 2014. Frontier constellations: Agrarian expansion and sovereignty on the Indonesian-Malaysian border. *The Journal of Peasant Studies* 41: 157-182.
- Einsiedel, S. von; Nitzschke, H.; Chhabra, T. 2008. Evolution of the United Nations security concept: Role of the high-level panel on threats, challenges, and change. In *Globalization and environmental challenges: Reconceptualizing security in the 21st century*, ed., Brauch, H.G.; Oswald Spring, U.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera, N. Chadha; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H., pp. 621-636. Berlin – Heidelberg – New York: Springer-Verlag.
- Elliott, J.; Deryng, D.; Müller, C.; Rieler, K.; Konzmann, M.; Gerten, D.; Glotter, M.; Flörke, M.; Wada, Y.; Best, N.; Eisner, S.; Fekete, B.M.; Folberth, C.; Foster, I.; Gosling, N.; Haddeland, I.; Khabarov, N.; Ludwig, F.; Masaki, Y.; Olin, S.; Rosenzweig, C.; Ruane, A.C.; Satoh, Y.; Schmid, E.; Stacke, T.; Tang, Q.; Wisser, D. 2014. Constraints and potentials of future irrigation water availability on agricultural production under climate change. *Proceedings of the National Academy of Sciences of the United States of America* 111: 3239-44.
- Ellis, F. 1999. *Rural livelihood diversity in developing countries: Evidence and policy implications*. Natural Resources Perspectives no. 40. London: ODI.
- Ellis, F. 2000. *Mixing it: Rural livelihoods and diversity in developing countries*. Oxford: Oxford University Press.
- Elwood, S.; Goodchild, M.F.; Sui, D. 2012. Researching volunteered geographic information: Spatial data, geographic research, and new social practice. *Annals of the Association of American Geographers* 102: 571-590.
- Ericksen, P.J. 2008. Conceptualizing food systems for global environmental change research. *Global Environmental Change* 18: 234-245.
- ESA (European Space Agency). 2010. *GEMS Sentinel-2 Mission Documentation*. Paris: ESA.
- Falkenmark, M. 1986. Fresh waters as a factor in strategic policy and action. In *Global resources and international conflict: Environmental factors in strategic policy and action*, ed., Westing, A.H., 85-113. New York: Oxford University Press.
- Falkenmark, M. 2001. The greatest water problem: The inability to link environmental security, water security and food security. *International Journal of Water Resources Development* 17(4): 539-554.
- Falkland, A. 1991. *Hydrology and water resources of small islands: A practical guide*. Paris: UNESCO Press.
- FAO (Food and Agriculture Organization of the United Nations). 1999. Environment and natural resources in small island developing states. Special Ministerial Conference on Agriculture in Small Island Developing States, Rome, Italy. <http://www.fao.org/docrep/meeting/x1011e.htm> (accessed on 28 April 2014).
- FAO. 2002. *Analytical framework: Sustainable livelihoods*. <http://fao.org/docrep/007/j2602e02.htm> (accessed on 17 March 2014).
- FAO. 2008. *The livelihood assessment tool-kit: Analysing and responding to the impact of disasters on the livelihoods of people*. Rome.
- FAO. 2011. *Climate-smart agriculture managing ecosystems for sustainable livelihoods*. Rome.
- FAO-IFAD (International Fund for Agricultural Development). 2013. *The state of food insecurity in the world. The multiple dimensions of food security*. Rome.
- Farbotko, C.; Lazrus, H. 2012. The first climate refugees? Contesting global narratives of climate change in Tuvalu. *Global Environmental Change* 22: 382-390.
- Fargione, J.; Hill, J.; Tilman, D.; Polasky, S.; Hawthorne, P. 2008. Land clearing and the biofuel carbon debt. *Science* 319: 1235-8.
- Farrington, J. 2001. Sustainable livelihoods, rights and the new architecture of aid. *Natural Resource Perspectives* 69. London: ODI.
- Fisher, J.A.; Patenaude, G.; Meir, P.; Nightingale, A.J.; Rounsevell, M.D.A.; Williams, M.; Woodhouse, I.H. 2013. Strengthening conceptual foundations: Analysing frameworks for ecosystem services and poverty alleviation research. *Global Environmental Change* 23: 1098-1111.
- Farrington, J.; Ramasut, T.; Walker, J. 2002. *Sustainable livelihoods approaches in urban areas: General lessons, with illustrations from Indian cases*. Working Paper no. 162. London: ODI.
- Flanagin, A.; Metzger, M. 2008. The credibility of volunteered geographic information. *GeoJournal* 72: 137-148.

- Floyd, R. 2008. The environmental security debate and its significance for climate change. *The International Spectator* 43: 51–65.
- Floyd, R.; Matthew, R.A. 2013. Environmental security studies: An introduction. In *Environmental security approaches and issues*, ed., Floyd, R.; Matthew, R.A., pp. 21–35. Oxford: Routledge.
- Foley, J.A. 2011. Can we feed the world and sustain the planet? *Scientific American* 305(5): 60–5.
- Foley, J.A.; Defries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.C.; Coe, M.C.; Daily, G.C.; Gibbs, H.K.; Helkowski, J.H.; Holloway, T.; Howard, E.A.; Kucharik, C.J.; Monfreda, C.; Patz, J.A.; Prentice, I.C.; Ramankutty, N.; Snyder, P.K. 2005. Global consequences of land use. *Science (New York, N.Y.)* 309: 570–4.
- Foley, J.A.; Ramankutty, N.; Brauman, K.A.; Cassidy, E.S.; Gerber, J.S.; Johnston, M.; Mueller, N.D.; O'Connell, R.; West, P.C.; Balzer, C.; Bennett, E.M.; Carpenter, S.R.; Hill, J.; Monfreda, C.; Polasky, S.; Rockström, J.; Sheehan, J.; Siebert, S.; Tilman, D.; Zaks, D.P.M. 2011. Solutions for a cultivated planet. *Nature* 478: 337–42.
- Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16: 253–267.
- Foresight: Final Project Report. 2011. *The future of food and farming: Challenges and choices for global sustainability*. London.
- Forsyth, T.; Walker, A. 2008. *Forest guardians, forest destroyers: The politics of environmental knowledge in Northern Thailand*. Seattle, WA: University of Washington Press.
- Fraiture, C.; De Giordano, M.; Liao, Y. 2008. Biofuels and implications for agricultural water use: Blue impacts of green energy. *Water Policy* 10: 67.
- Friedl, M.A.; Sulla-Menashe, D.; Tan, B.; Schneider, A.; Ramankutty, N.; Sibley, A.; Huang, X. 2010. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. *Remote Sensing of Environment* 114: 168–182.
- Fuentes, R.U.; Inciong, R.; Jose-Castillo, L.A. 2012. Biodiversity outlook in the Southeast Asia: Challenges and prospects for the next decade. In *The Biodiversity Observation Network in the Asia-Pacific Region Ecological Research Monographs*, ed. Nakano, S.; Yahara, T.; Tohru, N., pp. 21–25. Japan: Springer.
- Funk, C.; Budde, M.E. 2009. Phenologically-tuned MODIS NDVI-based production anomaly estimates for Zimbabwe. *Remote Sensing of Environment* 113: 115–125.
- Galford, G.L.; Mustard, J.F.; Melillio, J.; Gendrin, A.; Cerri, C.C.; Cerri, C.E.P. 2008. Wavelet analysis of MODIS time series to detect expansion and intensification of row-crop agriculture in Brazil. *Remote Sensing of Environment* 112: 576–587.
- Gallopin, G.C. 2006. Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change* 16: 293–303.
- Ganguly, S.; Friedl, M.A.; Tan, B.; Zhang, X.; Verma, M. 2010. Land surface phenology from MODIS: Characterization of the Collection 5 global land cover dynamics product. *Remote Sensing of Environment* 114: 1805–1816.
- Gao, H.; Barbier, G.; Goolsby, R. 2011. Harnessing the crowdsourcing power of social media for disaster relief. *IEEE Intelligent Systems* 26 (3): 10–14.
- Gardner, T.A.; Barlow, J.; Sodhi, N.S.; Peres, C.A. 2010. A multi-region assessment of tropical forest biodiversity in a human-modified world. *Biological Conservation* 143: 2293–2300.
- Garnaut, R. 2008. *The Garnaut climate change review: Final report*. Melbourne, Australia: Cambridge University Press.
- Gassert, F.; Landis, M.; Luck, M.; Reig, P.; Shiao, T. 2013. *Aqueduct Global Maps 2.0*.
- Gerst, M.D.; Rashkin, P.D.; Rockström, J. 2014. Contours of a resilient global future. *Sustainability* 6: 123–135.
- Gillespie, T.W.; Chu, J.; Frankenberg, E.; Thomas, D. 2007. Assessment and prediction of natural hazards from satellite imagery. *Progress in Physical Geography* 31: 459–70.
- Gilling, J.; Jones, S.; Duncan, A. 2001. Sector approaches, sustainable livelihoods and rural poverty reduction. *Development Policy Review* 19: 303–19.
- Gleeson, T.; Yoshihide, W.; Bierkens, M.F.P.; van Beek, L.P.H. 2012. Water balance of global aquifers revealed by groundwater footprint. *Nature* 488: 197–200.

- Godfray, C.H.J.; Garnett, T. 2014. Food security and sustainable intensification. *Philosophical Transactions of the Royal Society* B369: 1-10.
- Gómez-Baggethun, E.; Corbera, E.; Reyes-García, V. 2013. Traditional ecological knowledge and global environmental change: Research findings and policy implications. *Ecology and Society* 18: 72.
- Goodchild, M.F. 2007. Citizens as sensors: The world of volunteered geography. *GeoJournal* 69 (4): 211–221.
- Goodchild, M.F.; Glennon, J.A. 2010. Crowdsourcing geographic information for disaster response: A research frontier. *International Journal of Digital Earth* 3: 231-241.
- Goodchild, M.F.; Li, L. 2012. Assuring the quality of volunteered geographic information. *Spatial Statistics* 1: 110–120.
- Gourdji, S.M.; Sibley, A.M.; Lobell, D.B. 2013. Global crop exposure to critical high temperatures in the reproductive period: Historical trends and future projections. *Environmental Research Letters* 8: 024041.
- Graham, J.; Amos, B.; Plumpre, T. 2003. Governance principles for protected areas in the 21st century. *Report prepared for the Vth World Parks Congress, Durban, South Africa*. Ottawa: Institute on Governance.
- Grey, D.; Sadoff, C. 2007. Sink or swim? Water security for growth and development. *Water Policy* 9 (6): 545-571.
- Griffiths, G.M.; Chambers, L.E.; Haylock, M.R.; Manton, M.J.; Nicholls, N.; Baek, H.J.; Choi, Y.; Della-Marta, P.M.; Gosai, A.; Iga, N.; Lata, R.; Laurent, V.; Maitrepierre, L.; Nakamigawa, H.; Ouprasitwong, N.; Solofa, D.; Tahani, L.; Thuy, D.T.; Tibig, L.; Trewin, B.; VEDIAPAN, K.; Zhai, P. 2005. Change in mean temperature as a predictor of extreme temperature change in the Asia-Pacific region. *International Journal of Climatology* 25: 1301-1330.
- Gumma, M.K.; Nelson, A.; Thenkabail, P.S.; Singh, A.N. 2011. Mapping rice areas of South Asia using MODIS multitemporal data. *Journal of Applied Remote Sensing* 5: 053547.
- Haddeland, I.; Heinke, J.; Eisner, S.; Flörke, M.; Hanasaki, N.; Konzmann, M.; Ludwig, F.; Masaki, Y.; Schewe, J.; Stacke, T.; Tessler, Z.D.; Wada, Y.; Wisser, D. 2013. Global water resources affected by human interventions and climate change. *Proceedings of the National Academy of Sciences of the United States of America* 11: 3251-3259.
- Hajkowicz, S.; Negra, C.; Barnett, P.; Clark, M.; Harch, B.; Keating, B. 2012. Food price volatility and hunger alleviation – Can Cannes work? *Agriculture and Food Security* 1: 8.
- Hameiri, S. 2012. Mitigating the risk to primitive accumulation: State-building and the logging boom in Solomon Islands. *Journal of Contemporary Asia* 42: 405–426.
- Hanjra, M.A.; Qureshi, M.E. 2010. Global water crisis and future food security in an era of climate change. *Food Policy* 35: 365–377.
- Harcourt, W.; Stremmelaar, J. 2012. Women reclaiming sustainable livelihoods: An introduction. In *Women reclaiming sustainable livelihoods: Spaces lost, spaces gained*, ed., Harcourt, W. pp. 1-11. UK: Palgrave Macmillan.
- Hatfield, J.; Asrar, G.; Kanemasu, E. 1984. Intercepted photosynthetically active radiation estimated by spectral reflectance. *Remote Sensing of Environment* 14: 65–75.
- Hay, J.E. 2013. Small island developing states: Coastal systems, global change and sustainability. *Sustainability Science* 8: 309-326.
- Hay, J.E.; Mimura, N. 2013. Vulnerability, risk and adaptation assessment methods in the Pacific Islands Region: Past approaches, and considerations for the future. *Sustainability Science* 8: 391-405.
- Hilson, G.; Banchirigah, S. 2009. Are alternative livelihood projects alleviating poverty in mining communities? Experiences from Ghana. *Journal of Development Studies* 45: 172-196.
- Hoefsloot, P.; Ines, A.; Dam, J.V.; Duveiller, G.; Kayitakire, F.; Hansen, J. 2012. *Combining crop models and remote sensing for yield prediction: Concepts, applications and challenges for heterogeneous, smallholder environments*. Italy: ISPRA.
- Hoff, H. 2011. Understanding the nexus. *Background paper for the Bonn 2011 Conference: The water, energy and food security nexus*. Stockholm: Stockholm Environment Institute.
- Hoon, P.; Hyden, G. 2003. Governance and sustainable livelihoods. In *Achieving sustainable development: The challenge of governance across social scales*, ed. Prof. Bressers; Dr. Hans. J.T.A.; Rosenbaum, W.A. London: Praeger.
- Hoon, P.; Singh, N.; Wanmali, S. 1997. Sustainable livelihoods: Concepts, principles and approaches to indicator development. <http://www.sustainable-livelihoods.com/pdf/sustainablelivelihoodssc-1.pdf> (accessed on 17 March 2014).

- Huang, J.; Wang, X.; Li, X.; Tian, H.; Pan, Z. 2013. Remotely sensed rice yield prediction using multi-temporal NDVI data derived from NOAA's-AVHRR. *PLoS one* 8: 70816.
- Huelsenbeck, M. 2012. Ocean-based food security threatened in a high CO<sub>2</sub> world: A ranking of nations' vulnerability to climatic change and ocean acidification. *Oceana* 16.
- Hughes, T.P.; Carpenter, S.; Rockström, J.; Scheffer, M.; Walker, B. 2013a. Multiscale regime shifts and planetary boundaries. *Trends in Ecology and Evolution* 28: 389–95.
- Hughes, T.P.; Linares, C.; Dakos, V.; van de Leemput, I.A.; van Nes, E.H. 2013b. Living dangerously on borrowed time during slow, unrecognized regime shifts. *Trends in Ecology and Evolution* 28:149–55.
- Institute of Development Studies (IDS). 1996. Sustainable rural livelihoods. *A proposal to ESCOR*. Brighton.
- International Charter. 2014. Space and major disasters.[http:// www. disasterscharter. org/home](http://www.disasterscharter.org/home) (accessed on 4 April 2014).
- International Charter Space and Major Disasters. 2000. Charter on cooperation to achieve the coordinated use of space facilities in the event of natural technological disasters Rev.3. United Nations High Commissioner for Refugees. [http:// www.refworld.org/docid/41de7e544.html](http://www.refworld.org/docid/41de7e544.html) (accessed October 2014).
- International Energy Agency. 2014. Energy security. Online: <http://www.iea.org/topics/energysecurity/> (accessed November 2014).
- IISD (International Institute for Sustainable Development). 2003. *Livelihoods and climate change*. Canada.
- IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. In *Contribution of Working Group 1 to the Fifth Assessment of the Intergovernmental Panel on Climate Change*, ed., Stocker, T.F.; Qin, N.D.; Plattner, G.K.; Tignor, M.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P.M. Cambridge, United Kingdom and New York, USA: Cambridge University Press.
- IPS-USP (Institute of Pacific Studies of the University of the South Pacific). 1986. *Land rights of Pacific women*. Suva, Fiji: Institute of Pacific Studies of the University of the South Pacific.
- Jacoby, K.D. 2009. Energy security: Conceptualization of the International Energy Agency (IEA). In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, U.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera, N.C.; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H., pp. 345-354. Berlin – Heidelberg – New York: Springer-Verlag.
- Jayachandran, S. 2014. *The roots of gender inequality in developing countries*. Annual Review of Economics, 7. Submitted. DOI: 10.1146/annurev-economics-080614-115404.
- Jensen, F. 1996. *An introduction to Bayesian networks*. New York: Springer-Verlag.
- Jonsson, P.; Eklundh, L. 2004. TIMESAT — a program for analyzing time-series of satellite sensor data. *Computers and Geosciences* 30: 833–845.
- Joyce, K.E.; Belliss, S.E.; Samsonov, S.V.; McNeill, S.J.; Glassey, P.J. 2009. A review of the status of satellite remote sensing and image processing techniques for mapping natural hazards and disasters. *Progress in Physical Geography* 33: 183-207.
- Juma, C. 2001. The global sustainability challenge: From agreement to action. *International Journal of Global Environmental Issues* 10: 2.
- Kasperson, J.; Kasperson, R.; Turner, B., eds. 1999. *Regions at risk: Comparisons of threatened environments*. Tokyo: UN University Press.
- Katz, R.W.; Brown, B.G. 1992. Extreme events in a changing climate: Variability is more important than averages. *Climatic Change* 21: 289–302.
- Kelly, P.M.; Adger, W.N. 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47: 325-352.
- Kemp-Benedict, E.; Bharwani, S.; de la Rosa, E.; Krittasudthacheewa, C.; Matin, N. 2009. *Assessing water-related poverty using the sustainable livelihoods framework*. Stockholm: Stockholm Environment Institute.
- Kenney-Lazar, M. 2012. Plantation rubber, land grabbing and social-property transformation in southern Laos. *The Journal of Peasant Studies* 39: 1017-1037.



- Ketabchi, H.; Mahmoodzadeh, D.; Ataie-Ashtiani, B.; Werner, A.D.; Simmons, C.T. 2013. Sea-level rise impact on fresh groundwater lenses in two-layer small islands. *Hydrological Processes*. DOI 10.1002/hyp.10059 (accessed October 2014).
- Khagram, S.; Clark, W.; Firas Raad, D. 2003. From the environment and human security to sustainable security and development. *Journal of Human Development* 4: 289-313.
- Knutsson, P. 2006. The sustainable livelihoods approach: A framework for knowledge integration assessment. *Society for Human Ecology* 13: 90-99.
- Kumar, R.; Horwitz, P.; Milton, R.; Sellamuttu, S.S.; Buckton, S.T.; Davidson, N.C.; Pattnaik, A.K.; Zavagli, M.; Baker, C. 2011. Assessing wetland ecosystem services and poverty interlinkages: A general framework and case study. *Hydrological Sciences Journal* 56: 1602-1621.
- Lane, N.; Miluzzo, E.; Lu, H.; Peebles, D.; Chaoudhury, T.; Campbell, A. 2010. A survey of mobile phone sensing. Ad hoc and sensor networks. *IEEE Communications Magazine* 48: 140-150.
- Lankford, B.; Bakker, K.; Zeitoun, M.; Conway, D. 2013. *Water security: Principles, perspectives and practices*. Abingdon: Routledge.
- Larson, A.M.; Barry, D.; Dahal, G.R.; Pierce Golfer, C.J. 2010. *Forests for people: Community rights and forest tenure reform*. London: Earthscan.
- Lastarria-Cornhiel, S. 2006. Feminization of agriculture: Trends and driving forces. Background paper for World Development Report 2008. <https://openknowledge.worldbank.org/handle/10986/9104> (accessed on 12 August 2014).
- Lawford, R.; Bogardi, J.; Marx, S.; Jain, S.; Wostl, C.P.; Knüppe, K.; Ringler, C.; Lansigan, F.; Meza, F. 2013. Basin perspectives on the water-energy-food security nexus. *Current Opinion in Environmental Sustainability* 5: 607-616.
- Leach, M.; Mearns, R.; Scoones, I. 1999. Environmental entitlements: Dynamics and institutions in community-based natural resource management. *World Development* 27: 225-247.
- Lewis, A.J.; Henderson, F.M.; Holcomb, D.W. 1998. Radar fundamentals: The geoscience perspective. In *Principles and applications of imaging radar*, ed., Henderson, F.M.; Lewis, A.J. 131-81. New York: Wiley.
- Licker, R.; Johnston, M.; Foley, J.A.; Barford, C.; Kucharik, C.J.; Monfreda, C.; Ramankutty, N. 2010. Mind the gap: How do climate and agricultural management explain the “yield gap” of croplands around the world? *Global Ecology and Biogeography* 19: 769-782.
- Llanto, G.M.; Ballesteros, M.M. 2003. Land issues in poverty reduction strategies and the development agenda: The Philippines. *Land Reform* (Special Edition on Land Settlement and Cooperatives), 2003/2.
- Lloyd-Hughes, B.; Saunders, M.A. 2002. A drought climatology for Europe. *International Journal of Climatology* 22: 1571-1592.
- Lobell, D.B. 2003. Remote sensing of regional crop production in the Yaqui Valley, Mexico: Estimates and uncertainties. *Agriculture, Ecosystems and Environment* 94: 205-220.
- Lobell, D.B.; Sibley, A.; Ortiz-monasterio, J.I. 2012. Extreme heat effects on wheat senescence in India. *Nature Climate Change* 2(3): 186-189.
- Lowe, L.; Schilderman, T. 2001. *The impact of policies, institutions and processes in urban up-grading*. Regulatory Guidelines for Urban Up-grading Working Paper. Practical Action. [http://practicalaction.org/docs/t4sl/t4sl\\_rguu\\_workingpaper\\_2001.pdf](http://practicalaction.org/docs/t4sl/t4sl_rguu_workingpaper_2001.pdf) (accessed October 2014).
- MA (Millennium Ecosystem Assessment). 2005. *Ecosystems and human well-being*. Washington, DC.
- Machlis, G.E.; Force, J.E.; Burch, W.R. 1990. Timber, minerals and social change: An exploratory test of two resource dependent communities. *Rural Sociology* 55: 411-24
- Macquarrie, P.; Wolf, A.T. 2013. Understanding water security. In *Environmental security approaches and issues*, ed., Floyd, R.; Matthew, R.A., pp. 169-186. Abingdon: Routledge.
- Maitra, S. 2009. Development induced displacement: Issues of compensation and resettlement – Experiences from the Narmada Valley and Sardar Sarovar project. *Japanese Journal of Political Science* 10: 191-211.
- Malleson, R.; Asaha, S.; Sunderland, T.; Burnham, P.; Egot, M.; Obeng-Okrah, K.; Ukpe, I.; Miles, W. 2008. A methodology for assessing rural livelihood strategies in West/Central Africa: Lessons from the field. *Ecological and Environmental Anthropology* (Paper 25) 4: 1-12.

- Matyas, D.; Pelling, M. 2012. Disaster vulnerability and resilience: *Theory, modelling and prospective*. London: Foresight Government Office for Science.
- Maxwell, S.; Frankenberger, T.R. 1992. *Household food security: Concepts, indicators, measurement*. A Technical Review. New York and Rome: International Fund for Agricultural Development (IFAD) and United Nations Children's Fund (UNICEF).
- McDougall, K. 2011. Using voluntary geographic information to map the Queensland floods. *Proceedings of the surveying and spatial sciences biennial conference*. November 2011, Wellington, NZ: Scion.
- McGinnis, M.D.; Ostrom, E. In press. Social-ecological system framework: Initial changes and continuing challenges. *Ecology and Society* 19: 30.
- McIlgorm, A.; Campbell, H.F.; Rule, M.J. 2008. Understanding the economic benefits and costs of controlling marine debris in the APEC region (MRC 02/2007). A report to the Asia-Pacific Economic Cooperation Marine Resource Conservation Working Group by the National Marine Science Centre (University of New England and Southern Cross University), Coffs Harbour, NSW, Australia, December. Coffs Harbour, Australia: National Marine Science Centre.
- McNamara, K.E. 2013. Taking stock of community-based climate-change adaptation projects in the Pacific. *Asia Pacific Viewpoint* 54: 398-405.
- Meadows, D.H.; Meadows, D.L.; Randers, J.; Behrens, III WW. 1972. *The limits to growth*. New York: Signet.
- Meinzen-Dick, R.; Johnson, N.; Quisumbing, A.; Njuki, J.; Behrman, J.; Rubin, D.; Peterman, A.; Waithanji, E. 2011. *Gender, assets and agricultural development programs (GAAP)*. CAPRI Working Paper No. 99. Washington, DC: Systemwide Program on Collective Action and Property Rights.
- Mercer, J.; Dominey-Howes, D.; Kelman, I.; Lloyd, K. 2007. The potential for combining indigenous and western knowledge in reducing vulnerability to environmental hazards in small island developing states. *Environmental Hazards* 7: 245-56.
- Middleton, C.; Garcia, J.; Foran, T. 2009. Old and new hydropower players in the Mekong region: Agendas and strategies. In *Contested waterscapes in the Mekong region*, ed., Molle, F.; Foran, T.; Käkönen, T., pp. 23-54. London: Earthscan.
- Mitchell, A. 2013. *Risk and resilience: From good idea to good practice*. France: Organisation for Economic Cooperation and Development.
- Mitchell, J.F.B.; Manabe, S.; Meleshko, V.; Tokioka, T. 1990. Equilibrium climate change – and its implications for the future. In *Climate change: The IPCC scientific assessment*, ed., Houghton, J.T.; Jenkins, G.J.; Ephraums, J.J., pp. 131-172. Cambridge: Cambridge University Press.
- Molden, D. 2007. *Water for food, water for life: A comprehensive assessment of water management in agriculture*. London: Earthscan and Colombo: International Water Management Institute.
- Moller, H.; Berkes, F.; Lyver, P.O.; Kislalioglu, M. 2004. Combining science and traditional ecological knowledge: Monitoring populations for co-management. *Ecology and Society* 9: 2.
- Monfreda, C.; Ramankutty, N.; Foley, J.A. 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles* 22: 1-19.
- Morse, S. 2013. Indices and indicators in development: *An unhealthy obsession with numbers*. London: Earthscan.
- Morse, S.; McNamara, N.; Acholo, M. 2009. Sustainable livelihood approach: A critical analysis of theory and practice. *Geographical Paper* 189.
- Moser, C. 1993. *Gender planning and development: Theory, practice and training*. London: Routledge.
- Moser, C. 1998. The asset vulnerability framework: Reassessing urban poverty reduction strategies. *World Development* 26: 1-19.
- Mu, Q.; Zhao, M.; Running, S.W. 2011. Improvements to a MODIS global terrestrial evapotranspiration algorithm. *Remote Sensing of Environment* 115: 1781-1800.
- Neef, A. 2008. Lost in translation: The participatory imperative and local water governance in North Thailand and Southwest Germany. *Water Alternatives* 1: 89-110.

- Neef, A. 2009. Transforming rural water governance: Towards deliberative and polycentric models? *Water Alternatives* 2: 53-60.
- Neef, A.; Ekasingh, B.; Friederichsen, R.; Becu, N.; Lippe, M.; Sangkapitux, C.; Fror, O.; Punyawadee, V.; Schad, I.; Williams, P.; Schreinemachers, P.; Neubert, N.; Heidhues, F.; Cadisch, G.; The Dang, N.; Gypmantasiri, P.; Hoffmann, V. 2013. Participatory approaches to research and development in the Southeast Asian uplands: Potential and challenges. In *Sustainable land use and rural development in Southeast Asia: Innovations and policies for mountainous areas*, ed. H.L. Frohlich; Schreinemachers, P.; Stahr, K.; Clemens, G. London: Springer.
- Neef, A.; Onchan, T.; Schwarzmeier, R. 2003. Access to natural resources in Mainland Southeast Asia and implications for sustaining rural livelihoods - The case of Thailand. *Quarterly Journal of International Agriculture* 42: 329-350.
- Nicol, A. 2000. *Adopting a sustainable livelihoods approach to water projects: Implications for policy and practice*. ODI Working Paper 133. London: ODI.
- Nicholls, R. J.; Cazenave, A. 2010. Sea-level rise and its impact on coastal zones. *Science* 328: 1517-1520.
- Norton, A.; Foster, M. 2001. *The potential of using sustainable livelihoods approaches in poverty reduction strategy papers*. London: ODI.
- ODI (Overseas Development Institute). 2006. Governance, development and aid effectiveness: A quick guide to complex relationships. Briefing Paper [www.odi.org/resources/docs/218.pdf](http://www.odi.org/resources/docs/218.pdf) (accessed 6 August 2014).
- Okali, C. 2011. *Searching for new pathways towards achieving gender equity: Beyond Boserup and 'Women's role in economic development'*. ESA Working Paper No 11-09. Rome: FAO.
- O'Laughlin, B. 2004. Book reviews. *Development and Change* 35(2): 385-403.
- Olsson, P.; Folke, C. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken watershed, Sweden. *Ecosystems* 4: 85-104.
- Ostermann, F.; Spinsanti, L. 2011. A conceptual workflow for automatically assessing the quality of volunteered geographic information for crisis management. In *Proceedings of the 14th AGILE International Conference on Geographic Information Science*, 18-22 April. Utrecht, The Netherlands: University of Utrecht.
- Ostrom, E. 1990. *Governing the commons: The evolution of institutions for collective action*. Cambridge: Cambridge University Press.
- Ostrom, E. 2009. A general framework for analysing sustainability of social-ecological systems. *Science* 325: 419-422.
- Oswald Spring, Ú. 2009. Food as a new human and livelihood security issue. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, Ú.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera N. Chadha; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H., pp. 471-500. Berlin - Heidelberg - New York: Springer-Verlag.
- Oswald Spring, Ú.; Brauch, H.G. 2009. Securitizing water. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, Ú.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera, N. Chadha; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H. pp. 175-202. Berlin - Heidelberg - New York: Springer-Verlag.
- Oswald Spring, Ú.; Brauch, H.G.; Dalby, S. 2009. Linking anthropocene, HUGE and HESP: Fourth phase of environmental security research. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, H.G.; Oswald Spring, Ú.; Mesjasz, C.; Grin, J.; Dunay, P.; Behera N. Chadha; Chourou, B.; Kameri-Mbote, P.; Liotta, P.H., pp. 1277-1294. Berlin - Heidelberg - New York: Springer-Verlag.
- Othman, Z. 2009. Human Security Concepts, Approaches and Debates in Southeast Asia. In *Facing global environmental change: Environmental, human, energy, food, health and water security concepts*, ed., Brauch, Hans Günter; Oswald Spring, Úrsula; Grin, John; Mesjasz, Czeslaw; Kameri-Mbote, Patricia; Behera, Navnita Chadha; Chourou, Béchir; Krummenacher, Heinz, pp. 1037-1048. Berlin - Heidelberg - New York: Springer-Verlag.
- Parkins, J.R.; Mitchell, R.E. 2005. Public participation as public debate: A deliberative turn in natural resource management. *Society and Natural Resources* 18: 529-540.
- Patel, R. 2009. Food sovereignty. *The Journal of Peasant Studies* 36: 663-706.
- Pearl, J. 2001. Causal inference in statistics: A gentle introduction. *Computing Science and Statistics, Proceedings of Interface '01* 33. Fairfax, Vermont: Interface Foundation of North America.

- Pinter, P.J.; Jackson, R.D.; Idso, S.B.; Reginato, R.J. 1981. Multidate spectral reflectance as predictors of yield in water stressed wheat and barley. *International Journal of Remote Sensing* 2: 43–48.
- Platanov, A.; Thenkabail, P.S.; Biradar, C.M.; Cai, X.; Gumma, M.K.; Dheeravath, V.; Cohen, Y.; Alchanatis, V.; Goldshlager, N.; Ben-Dor, E.; Vithanage, J.; Manthrithilake, H.; Kendjabev, S.; Isaev, S. 2008. Water productivity mapping (WPM) using Landsat ETM+ Data for the irrigated croplands of the Syrdarya River Basin in Central Asia. *Sensors* 8: 8156–8180.
- Poffenberger, M., ed. 1999. *Communities and forest management in Southeast Asia. A regional profile of the Working Group on Community Involvement in Forest Management (WG-CIFM)*. Berkeley and Gland: Asia Forest Network and The World Conservation Union (IUCN).
- Poppy, G.M.; Chiotha, S.; Eigenbrod, F.; Harvey, C.A.; Honzák, M.; Hudson, M.D.; Jarvis, A.; Madise, N.J.; Schreckenber, K.; Shackleton, C.M.; Villa, F.; Dawson, T.P. 2014. Food security in a perfect storm: Using the ecosystem services framework to increase understanding. *Philosophical Transactions of the Royal Society* B369: 20120288.
- Portmann, F.T.; Siebert, S.; Döll, P. 2010. MIRCA2000 — Global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling. *Global Biogeochemical Cycles* 24: 1–24.
- Postel, S. 1998. Water for food production: Will there be enough in 2025? *Bioscience* 48: 629–637.
- Pound, B.; Snapp, S.; McDougall, C.; Braun, A., eds. 2003. *Managing natural resources for sustainable livelihoods: Uniting science and participation*. London: Routledge.
- Preston, B.; Suppiah, R.; Macadam, I.; Bathols, J. 2006. *Climate change in the Asia/Pacific region: A consultancy report prepared for the climate change and development roundtable*. Victoria, Australia: CSIRO.
- Pretty, J.N. 1995. Participatory learning for sustainable agriculture. *World Development* 23: 1247–1263.
- Pritchard, B.; Rammohan, A.; Sekher, M.; Parasuram, S.; Choithani, C. 2013. *Feeding India: Livelihoods, entitlements and capabilities*. London: Routledge.
- Purves, R. 2011. Answering geographic questions with user generated content: Experiences from the coal face. *SoCG 11 Proceedings of the twenty-seventh annual symposium on computational geometry*, pp. 297–299. New York: Association for Computing Machinery.
- Quetulio-Navarra, M.; Niehof, A.; van der Horst, H.; van der Vaart, W. 2014. Short-term risk experience of involuntary resettled households in the Philippines and Indonesia. *Habitat International* 41: 165–175.
- Rabbani, G.; Rahman, A.; Mainuddin, K. 2013. Salinity-induced loss and damage to farming households in coastal Bangladesh. *International Journal of Global Warming* 5: 400–415.
- Raento, M.; Oulasvirta, A.; Eagle, N. 2009. Smartphones: An emerging tool for social scientists. *Sociological Methods & Research* 37: 426–454.
- Ramanathan, V.; Carmichael, G. 2008. Global and regional climate changes due to black carbon. *Nature Geoscience* 1: 221–227.
- Ramankutty, N.; Evan, T.A.; Monfreda, C.; Foley, J.A. 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. *Global Biogeochemical Cycles* 22.
- Ray, D.K.; Mueller, N.D.; West, P.C.; Foley, J.A. 2013. Yield trends are insufficient to double global crop production by 2050. *PLoS one* 8: e66428.
- Rembold, F.; Atzberger, C.; Savn, I.; Rojas, O. 2013. Using low resolution satellite imagery for yield prediction and yield anomaly detection. *Remote Sensing* 5: 1704–1733.
- Ringler, C.; Bhaduri, A.; Lawford, R. 2013. The nexus across water, energy, land and food (WELF): Potential for improved resource use efficiency? *Current Opinion in Environmental Sustainability* 5: 617–624.
- Robins, N.S. 2013. A review of small island hydrogeology: Progress (and setbacks) during the recent past. *Quarterly Journal of Engineering Geology and Hydrogeology* 46: 157–165.
- Robinson, L.W. 2009. Environmental governance as if values matter: Communities and conservation in Africa. *Protected areas and poverty reduction project paper*. Canada: Vancouver Island University.

- Robinson, L.W.; Fuller, A.M. 2010. Towards an ecosystem approach to policy process: Insights from sustainable livelihoods and ecosystem health approaches. *International Journal of Sustainable Development* 13: 393-411.
- Rockström, J.; Steffen, W.; Noone, K.; Persson, A.; Chapin, F.S.; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; Nykvist, B.; de Wit, C.A.; Hughes, T.; van der Leeuw, S.; Rodhe, H.; Sörlin, S.; Snyder, P.K.; Costanza, R.; Svedin, U.; Falkenmark, M.; Karlberg, L.; Corell, R.; Fabry, V.J.; Hansen, J.; Walker, B.; Liverman, D.; Richardson, K.; Crutzen, P.; Foley, J.A. 2009a. A safe operating space for humanity. *Nature* 461: 472-475.
- Rockström, J.; Steffen, W.; Noone, K.; Persson, A.; Chapin, F.S.; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; Nykvist, B.; de Wit, C.A.; Hughes, T.; van der Leeuw, S.; Rodhe, H.; Sörlin, S.; Snyder, P.K.; Costanza, R.; Svedin, U.; Falkenmark, M.; Karlberg, L.; Corell, R.; Fabry, V.J.; Hansen, J.; Walker, B.; Liverman, D.; Richardson, K.; Crutzen, P.; Foley, J.A. 2009b. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society* 14: 32.
- Rodriguez, D.J.; Delgado, A.; Delaquil, P.; Sohns, A. 2013. *Thirsty energy*. Washington, DC: World Bank.
- Rojas, O. 2007. Operational maize yield model development and validation based on remote sensing and agro-meteorological data in Kenya. *International Journal of Remote Sensing* 28: 3775-3793.
- Rojas, O.; Vrieling, A.; Rembold, F. 2011. Assessing drought probability for agricultural areas in Africa with coarse resolution remote sensing imagery. *Remote Sensing of Environment* 115: 343-352.
- Rosenzweig, C.; Elliott, J.; Deryng, D.; Ruane, A.C.; Müller, C.; Arneth, A.; Boote, K.J.; Folberth, C.; Glotter, M.; Khabarov, N.; Neumann, K.; Piontek, F.; Pugh, T.; Schmid, E.; Stehfest, E.; Yang, H.; Jones, J.W. 2014. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences of the United States of America* 111: 3268-73.
- Rundstrom, R.A. 1995. GIS, indigenous peoples, and epistemological diversity. *Cartography and GIS* 22: 45-57.
- Sakamoto, T.; Yokozawa, M.; Toritani, H.; Shibayama, M.; Ishitsuka, N.; Ohno, H. 2005. A crop phenology detection method using time-series MODIS data. *Remote Sensing of Environment* 96: 366-374.
- Sayer, J.; Campbell, B.; Petheram, L. 2006. Assessing environment and development outcomes in conservation landscapes. *Biodiversity and Conservation* 16: 2677-2694.
- Scassa, T. 2013. Legal issues with volunteered geographic information. *The Canadian Geographer* 57: 1-10.
- Scheffer, M.; Carpenter, S.R. 2003. Catastrophic regime shifts in ecosystems: Linking theory to observation. *Trends in Ecology and Evolution* 18: 648-656.
- Scheffer, M.; Carpenter, S.; Foley, J.A.; Folke, C.; Walker, B. 2001. Catastrophic shifts in ecosystems. *Nature* 413: 591-596.
- Scheffran, J.; Brzoska, M.; Brauch, H.G.; Link, P.M.; Schilling, J., eds. 2012. *Climate change, human security and violent conflict: Challenges for societal stability*. Heidelberg – Dordrecht – London – New York: Springer.
- Scheyvens, R.; Momsen, J. 2008. Tourism in small island states: From vulnerability to strengths. *Journal of Sustainable Tourism* 16.
- Schreckenberg, K.; Camargo, I.; Withnall, K.; Corrigan, C.; Franks, P.; Roe, D.; Scherl, L.M.; Richardson, V. 2010. *Social assessment of conservation initiatives: A review of rapid methodologies*. London: International Institute for Environment and Development.
- Scoones, I. 1998. *Sustainable rural livelihoods: A framework for analysis*. Working Paper 72. Brighton, UK: Institute for Development Studies
- Scoones, I. 2009. Livelihoods perspectives and rural development. *Journal of Peasant Studies* 36: 171-296.
- Sen, A.K. 1981. *Poverty and famines: An essay on entitlement and deprivation*. Oxford: Oxford University Press.
- Sen, A.K. 1984. *Resources, values and development*. Cambridge, Mass: Harvard University Press.
- Sen, A.K. 1987. *The standard of living, the Tanner lectures, Clare Hall Cambridge 1985*. Cambridge: Cambridge University.
- Sen, A.K. 1999. *Development as freedom*. Oxford: Oxford Paperbacks.
- Shearman, P.; Bryan, J.; Walsh, J.P. 2013. Trends in deltaic change over three decades in the Asia-Pacific Region. *Journal of Coastal Research* 290: 1169-1183.

- Shepherd, A.; Mitchell, T.; Lewis, K.; Lenhardt, L.; Jones, L.; Scott, L.; Muir-Wood, R. 2013. *The geography of poverty, disasters and climate extremes in 2030*. UK: ODI.
- Siebert, S.; Döll, P. 2010. Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. *Journal of Hydrology* 384: 198–217.
- Siebert, S.; Henrich, V.; Frenken, K.; Burke Jacob. 2013. *Update of the digital global map of irrigation areas to Version 5*. Bonn: FAO and University of Bonn.
- Singh, N.; Titi. 1994. *Adaptive strategies of the poor in arid and semi-arid lands: In search of sustainable livelihoods*. IISD Working Paper. Winnipeg, Canada: International Institute for Sustainable Development.
- Small, L. 2007. The sustainable rural livelihoods approach: A critical review. *Canadian Journal of Development Studies* 28: 27–38.
- Sodhi, N.S.; Koh, L.P.; Clements, R.; Wanger, T.C. Hill, J.K.; Hamer, K.C.; Clough, Y.; Tschardtke, T.; Posa, M.R.C.; Lee, T.M. 2010. Conserving Southeast Asian forest biodiversity in human-modified landscapes. *Biological Conservation* 143: 2375–2384.
- Solesbury, W. 2003. Sustainable livelihoods: A case study of the evolution of DFID policy. *Overseas Development Institute Working Paper 217*. London: ODI.
- Sullivan, A.; Mwamakamba, S.; Mumba, A.; Hachigonta, S.; Sibanda, M.S. 2012. Climate smart agriculture: More than technologies are needed to move smallholder farmers toward resilient and sustainable livelihoods. *FANRPAN Policy Brief XIII (2)*.
- Swift, J. 1989. Why are rural people vulnerable to famine? *IDS Bulletin* 20: 8–15.
- Tabarelli, M.; Aguiar, A.V.; Ribeiro, M.C.; Metzger, J.P.; Peres, C.A. 2010. Prospects for biodiversity conservation in the Atlantic Forest: Lessons from aging human-modified landscapes. *Biological Conservation* 143: 2328–2340.
- Tall, A.; Patt, A.G.; Fritz, S. 2013. Reducing vulnerability to hydro-meteorological extremes in Africa. A qualitative assessment of national climate disaster management policies: Accounting for heterogeneity. *Weather and Climate Extremes* 1: 4–16.
- The Royal Society. 2009. *Reaping the benefits*. London.
- Thenkabail, P.S.; Wu, Z. 2012. An Automated Cropland Classification Algorithm (ACCA) for Tajikistan by combining Landsat, MODIS, and Secondary Data. *Remote Sensing* 4: 2890–2918.
- Thenkabail, P.S.; Biradar, C.M.; Noojipady, P.; Dheeravath, V.; Li, Y.; Velpuri, M.; Gumma, M.; Gangalakunta, O.R.P.; Turrall, H.; Cai, X.; Vithanage, J.; Schull, M.A.; Dutta, R. 2009. Global irrigated area map (GIAM), derived from remote sensing, for the end of the last millennium. *International Journal of Remote Sensing* 30: 3679–3733.
- Thenkabail, P.S.; Hanjra, M.A.; Dheeravath, V.; Gumma, M.K. 2010. A holistic view of global croplands and their water use for ensuring global food security in the 21st century through advanced remote sensing and non-remote sensing approaches. *Remote Sensing* 2: 211–261.
- Thenkabail, P.S.; Schull, M.A.; Turrall, H. 2005. Ganges and Indus river basin land use/land cover (LULC) and irrigated area mapping using continuous streams of MODIS data. *Remote Sensing of Environment* 95: 317–341.
- Thies, B.; Bendix, J. 2011. Satellite based remote sensing of weather and climate: Recent achievements and future perspectives. *Meteorological Applications* 18: 262–295.
- Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. 2011. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences of the United States of America* 108: 20260–4.
- Tilman, D.; Cassman, K.G.; Matson, P.A.; Naylor, R.; Polasky, S. 2002. Agricultural sustainability and intensive production practices. *Nature* 418: 671–677.
- Tilman, D.; Socolow, R.; Foley, J.A.; Hill, J.; Larson, E.; Lynd, L.; Pacala, S.; Reilly, J.; Searchinger, T. 2009. Beneficial biofuels—The food, energy, and environment trilemma. *Science* 325: 4–5.
- Tilt, B.; Braun, Y.; He, D. 2009. Social impacts of large dam projects: A comparison of international case studies and implications for best practice. *Journal of Environmental Management* 90: 249–257.
- Tittonell, P. 2014. Livelihood strategies, resilience and transformability in Africa. *Agricultural Systems* 126: 3–14.

- Tralli, D.M.; Blom, R.G.; Zlotnicki, V.; Donnellan, A.; Evans, D.L. 2005. Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards. *ISPRS Journal of Photogrammetry and Remote Sensing* 59: 185–98.
- Trenberth, K.E.; Jones, P.D.; Ambernje, R.P.; Bojariu, R.; Easterling, D.; Klein Tank, A.; Parker, D.; Rahimzadeh, F.; Renwick, J.A.; Rusticucci, M.; Soden, B.; Zhai, P. 2007: Observations: Surface and atmospheric climate change. In *Climate change 2007: The physical science basis. Contribution of Working Group to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed., Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; Miller, H.L., pp. 235–336. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Triglav-Čekada, M.; Radovan, D. 2013. Using volunteered geographic information to map the November 2012 floods in Slovenia. *Natural Hazards and Earth System Sciences Discussion* 1: 2859–2881.
- Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment* 150: 127–150.
- Turnhout, E.; Bloomfield, B.; Hulme, M.; Vogel, J.; Wynne, B. 2012. Conservation policy: Listen to the voices of experience. *Nature* 488: 454–455.
- Turvey, R. 2007. Vulnerability assessment of developing countries: The case of small-island developing states. *Development Policy Review* 25: 243–264.
- UNDESA (United Nations Department of Economic and Social Affairs). 2007. *Indicators of sustainable development: Guidelines and methodologies*. 3rd Edition. New York: UNDESA. .
- UNDP (United Nations Development Programme). 1994. *Human development report*. New York.
- UNEP (United Nations Environment Programme). 2005. *Marine litter: An analytical overview*. Kenya: Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization.
- UNEP. 2010. *State of biodiversity in Asia and the Pacific*. Bangkok, Thailand.
- UNESCAP (United Nations Economic and Social Commission for Asia and the Pacific). 2013. *Water, food and energy nexus in Asia and the Pacific*. Thailand.
- UNFPA (United Nations Population Fund). 2013. Linking population, poverty and development. Asia and the Pacific: Population and development. <<http://asiapacific.unfpa.org/public/pid/13193>> (accessed 20 April 2014).
- United Nations. 2013. *The Millennium Development Goals Report*. New York.
- Upreti, B.R. 2013. Environmental security and sustainable development. In *Environmental security approaches and issues*, ed., Floyd, R.; Matthew, R.A., pp. 220–233. Oxford: Routledge.
- Vanderveest, P.; Idahosa, P.; Bose, P.S., eds. 2006. *Development's displacements: Economies, ecologies and cultures at risk*. Vancouver: UBC Press.
- Veleva, V.; Ellenbecker, M. 2001. Indicators of sustainable production: Framework and methodology. *J. Clean. Prod.* 9: 519–549.
- Vörösmarty, C.J.; McIntyre, P.B.; Gessner, M.O.; Dudgeon, D.; Prusevich, A.; Green, P.; Glidden, S.; Bunn, S.E.; Sullivan, C.A.; Liermann, C.R.; Davies, P.M. 2010. Global threats to human water security and river biodiversity. *Nature* 467: 555–61.
- Vörösmarty, C.J.; Pahl-Wostl, C.; Bunn, S.E.; Lawford, R. 2013. Global water, the anthropocene and the transformation of a science. *Current Opinion in Environmental Sustainability* 5: 539–550.
- Waggener, T.R.; Lane, C. 1997. *Pacific rim demand and supply situation, trends and prospects: Implications for forest products trade in the Asia-Pacific region*. Report Prepared for FAO Asia Pacific Forestry Sector Outlook Study. Working Paper APFSOS/WP/02. Seattle, WA: International Forestry Sector Analysis (IFSA).
- Walker, B.H.; Carpenter, S.R.; Rockström, J.; Peterson, G.D. 2012. Drivers, “slow” variables, “fast” variables, shocks, and resilience. *Ecology and Society* 17: 1–4.
- Walker, B.; Sayer, J.; Andrew, N.L.; Campbell, B. 2010. Should enhanced resilience be an objective of natural resource management research for developing countries? *Crop Science* 50.

- Waltner-Toews, D. 2004. *Ecosystem sustainability and health: A practical approach*. Cambridge: Cambridge University Press.
- Waltner-Toews, D.; Kay, J.; Murray, T.; Neudoerffer, C. 2004. Adaptive methodology for ecosystem sustainability and health (AMESH): An introduction. In *Community operational research systems thinking*, ed., Midgley, G.; Ochoa-Arias, A. New York: Springer.
- Wang, P.; Wolf, S.A.; Lassoie, J.; Dong, S. 2013. Compensation policy for displacement caused by dam construction in China: An institutional analysis. *Geoforum* 48: 1-9.
- Ward, R.G; Kingdon, E., eds. 1995. *Land, custom and practice in the South Pacific*. New York: Cambridge University Press.
- Wardlow, B.; Egbert, S.; Kastens, J. 2007. Analysis of time-series MODIS 250 m vegetation index data for crop classification in the U.S. Central Great Plains. *Remote Sensing of Environment* 108: 290–310.
- Warner, J.F. 2006. More sustainable participation? Multi-stakeholder platforms for integrated catchment management. *Water Resources Development* 22: 15-35.
- Warner, K.; van der Geest, K.; Kreft, S.; Huq, S.; Harmeling, S.; Kusters, K.; de Sherbinin, A. 2012. *Evidence from the frontlines of climate change: Loss and damage to communities despite coping and adaptation. Loss and Damage in vulnerable countries initiative*. Policy Report. Bonn: United Nations University Institute for Environment and Human Security (NUN-EHS).
- Water in the West. 2013. *Water and energy nexus: A literature review*. Stanford.
- WCED (World Commission on Environment and Development). 1987. *Our common future*. Oxford.
- Webster, P.J. 2008. Myanmar's deadly daffodil. *Nature Geosciences* 1: 488–490.
- WEF (World Economic Forum). 2011. *Water security: The water-food-energy-climate nexus*. Washington, DC: World Economic Forum.
- WEF. 2013. *Global gender gap report*. Geneva: World Economic Forum.
- Westley, K.; Mikhalev, V. 2002. *The use of participatory methods for livelihood assessment in situations of political instability: A case study from Kosovo*. Working Paper no. 190. London: ODI.
- Whyte, K.P. 2013. On the role of traditional ecological knowledge as a collaborative concept: A philosophical study. *Ecological Processes* 2: 1-12.
- Wiener, T.F.; Thenkabail, P.S.; Montgomery, J.; Pearlman, J.; Lawford, R.; Hanjra, M.A. 2010. *A blueprint for water for the world: Pathway to a blue revolution, IEEE Water for the World, NASA, USGS*. New Jersey: Institute of Electrical and Electronics Engineers.
- Wilmsen, B.; Webber, M.; Duan, Y.F. 2011. Development for whom? Rural to urban resettlement in the Three Gorges Dam, China. *Asian Studies Review* 35: 21-42.
- Winzer, C. 2012. Conceptualizing energy security. *Energy Policy* 46: 36–48.
- Wittersheim, E. 2011. Paradise for sale. The sweet illusions of economic growth in Vanuatu. *Le Journal de la Société des Océanistes* 133: 323-332.
- Woodruff, J.D.; Irish, J.L.; Camargo, S.J. 2013. Coastal flooding by tropical cyclones and sea-level rise. *Nature* 504: 44–52.
- World Bank. 2013. *Building resilience integrating climate and disaster risk into development*. Washington, DC.
- World Food Summit. 1996. *Rome declaration on world food security*. Rome.
- World Water Council. 2000. *Final report. Second world water forum and ministerial conference: From vision to action*. The Hague, Netherlands.
- Wungao, S. 2004. *Human security now: Strengthening policy networks in Southeast Asia*. Bangkok, Thailand: Chulalongkorn University, Center for Social Development Studies.
- Xiao, X.; Boles, S.; Frolking, S.; Li, C.; Babu, J.Y.; Salas, W.; Moore, B. 2006. Mapping paddy rice agriculture in South and Southeast Asia using multi-temporal MODIS images. *Remote Sensing of Environment* 100: 95–113.
- Yang, J.; Gong, P.; Fu, R.; Zhang, R.; Chen, J.; Liang, S.; Xu, B.; Shi, J.; Dickinson, R. 2013. The role of satellite remote



sensing in climate change studies. *Nature Climate Change* 3: 875-883.

You, L.; Wood, S.; Wood-Sichra, U.; Wu, W. 2014. Generating global crop distribution maps: From census to grid. *Agricultural Systems*, in press.

Young, O. 1996. The effectiveness of international governance systems. In *Global environmental change and international governance*, ed., Young, O.; Demko, G.J.; Ramakrishna, K., pp. 1-46. Hanover: Sage.

Zerrouk, E.; Neef, A. 2014. The media discourse of land grabbing and resistance during Myanmar's legal reformation: The Monywa copper mine. *Law and Development Review*. DOI 10.1515/ldr-2014-0008 (accessed in October 2014).

Zhang, Y.; He, D.; Lu, Y.; Feng, Y.; Reznick, J. 2013. The influence of large dams building on resettlement in the Upper Mekong River. *Journal of Geographical Sciences* 23: 947-957.

Zickfeld, K.; Knopf, B.; Petoukhov, V.; Schellnhuber, H.J. 2005. Is the Indian summer monsoon stable against global change? *Geophysical Research Letters* 32: L15707.

Zook, M.; Graham, M.; Shelton, T.; Gorman, S. 2010. Volunteered geographic information and crowdsourcing disaster relief: A case study of the Haitian earthquake. *World Medical and Health Policy* 2: 7-33.



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