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Report

Understanding the effects of resource degradation on socio-economic outcomes in developing countries

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Key messages

The links between the environment and the economy have risen on policy and academic agendas. This paper scopes out the linkages between resource degradation and socio-economic outcomes, focusing on land and water degradation. The socio-economic impact of resource degradation depends on (i) direct transmission mechanisms; and (ii) the ability of producers and consumers to follow mitigation strategies (this could be termed economic, social and governance resilience).

The paper proposes four key elements to consider in such analysis, which can be applied at different scales: (i) **biophysical changes**, i.e. the various types of degradation and their effects on ecosystems; (ii) p**otential socio-economic impacts** of changes in ecosystems, i.e. the various transmission mechanisms to human development, and the degree of socio-economic exposure to these. (iii) the **resilience of socio-economic systems**, i.e. possibilities for mitigation and the constraints and enablers which govern whether or not they can be adopted. and (iv), the **actual socio-economic impacts** resulting from all of the above.

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Executive summary

The links between the environment and the economy have risen on policy and academic agendas. This paper scopes out the linkages between resource degradation and socio-economic outcomes, focusing on land and water degradation. The overall research aims to address some of the shortcomings in existing models and projections of economic growth and resource degradation, which do not incorporate feedback mechanisms related to environmental degradation.

This paper suggests that the socio-economic impact of resource degradation depends on (i) direct transmission mechanisms; and (ii) the ability of producers and consumers to follow mitigation strategies (this could be termed economic, social and governance resilience).

The paper therefore proposes that there are four key elements to consider in such analysis, which can be applied at different scales:

Biophysical changes, i.e. the various types of degradation and their effects on ecosystems.

Potential socio-economic impacts of changes in ecosystems, i.e. the various transmission mechanisms to human development, and the degree of socio-economic exposure to these.

The **resilience of socio-economic systems**, i.e. possibilities for mitigation and the constraints and enablers which govern whether or not they can be adopted.

Finally, the **actual socio-economic impacts** resulting from all of the above.

The direct transmission mechanisms from resource degradation include issues such as the direct (and indirect) dependence on natural resources in production (which tends to be higher in agricultural societies) and consumption (depending on diet composition), the level and quality of natural assets, and the type of agricultural systems being used. However, farmers or consumers might be well placed to mitigate the effects, e.g. by adopting a new production and resource management technology, diversifying into other income generating activities or simply through migration.

In practice, the direct costs of land degradation (on average already worth 1-3% of GDP at present) and water degradation (on average already worth 2-3% of GDP at present) depend on many transmission mechanisms, e.g. the steep topography in Guatemala risking landslides, the overall dependence on agriculture in Ethiopia and irreversible degradation due to pesticide use in Costa Rica.

However, the evidence and debates also suggest that degradation can actually be a source of innovation that is open to some but not others (see e.g. Malthus vs Boserup). In general, the case studies suggest the limited ability of famers to respond, owing to lack of human or physical assets (e.g. in Madagascar). Those that do have such assets can respond to degradation, but the poorest often cannot, which can lead to a poverty trap.

We have identified a range of factors that measure the extent to which land and water degradation affects socio and economic pathways (and we have a database for developing countries). The relationships identified so far are conceptual and qualitative rather than quantitative, however this is something that could be pursued in the future.

1 Introduction

The links between the environment and the economy have risen on policy and academic agendas through various initiatives (e.g. the Economics of Ecosystems and Biodiversity (TEEB), the Green Economy Coalition). In this context, many international fora have argued for the importance of inclusive green growth (e.g. at Rio+20, or the G20). The concept of green growth includes natural capital and environmental considerations into national accounting through into measurement and monitoring. There are several motives for adopting a green growth approach and undertaking proper management of natural capital; they include resource scarcity and security of supply, efficient solutions in land use, benefits to health and quality of life, and the prevention of potentially catastrophic tipping points (CBD, 2010). According to the OECD, "…a declining asset base constitutes a risk to growth" (OECD, 2011).

This paper examines the impact of resource degradation. Resource degradation is the deterioration of the environment through depletion of resources such as air, water and soil, the destruction of ecosystems and the extinction of wildlife. It is defined as any change or disturbance to the environment that is perceived to be deleterious or undesirable. This project scopes out the linkages between resource degradation and socio-economic outcomes, focusing on land and water resources. The overall research aims to address some of the shortcomings in existing models and projections of economic growth and consequential resource degradation that do not incorporate feedback mechanisms related to environmental degradation. In order to incorporate these concerns, however, the pathways between environmental degradation and economic effects need to be mapped.

There is by now significant literature on resource degradation by bodies such as World Bank, UNEP, or ERD2011/2012 (see Box 1). World Bank (2012) argues that damage caused by environmental degradation is costly for an economy and is equivalent to 8%of GDP across a sample of countries representing 40%of the developing world's population. For Ghana, Diao and Sarpong (2007) there are estimates that soil erosion will cost around 5% of total agricultural GDP over the 10 years between 2006 and 2015. Cohen *et al.* (*2*004) estimate that water pollution has been responsible for 1.7 million deaths annually concentrated (90%) amongst children under 5 years old.

Box 1: Links between resource degradation and socio-economic outcomes: Illustrative examples

Degraded rural water supply schemes hit the poorest hardest. Environmental degradation and inappropriate public-sector responses affect the poorest most: between 30% and 60% of existing rural water supply schemes are not working at any given time (Brikké and Bredero, 2003), with the result that the very poorest people, and especially women and girls, end up paying the most for lower quality, less reliable water services.

Environmental degradation and high levels of water-related risk affect social inclusiveness in LICs as it is generally the poor who settle in fragile environments and who are most vulnerable to water-related risks.

Uncontrolled pollution, e.g. by mining companies, but also from fast-growing urban settlements and agriculture, can severely affect both the environment and health of a country. In the Middle East and North Africa (MENA) region, for example, the annual cost of water-related environmental degradation is an estimated 9 billion USD, or between 2.1% and 7.4% of the GDP of MENA countries.

Localised physical water scarcity is occurring in parts of China, India, the Middle East and sub-Saharan Africa. In China, water scarcity costs around 2.3% of GDP (World Bank, 2007).

Not investing in water resource development could involve major future costs: some 2% of Africa's GDP is lost to power cuts, and up to 25% to droughts and floods in affected countries (AfDB, 2009).

It is sometimes possible to bring degraded lands into production, which could have a positive effect on biodiversity (Pehnelt and Vietze, 2010).

Cai et al. (2011) estimate that 320–702 million ha of land could be made available with just the inclusion of abandoned and degraded cropland and mixed-crop and vegetation land, which are usually of low quality. If grasslands, savannahs, and shrub-lands with marginal productivity are considered for planting low-input, high-diversity mixtures of native perennials as energy crops, the total land availability could increase by between 1107 and 1411 million ha.

Source: ERD 2011/2012

However, there is so far little progress in the explicit modelling of resource degradation. Models tend to include a relatively complete picture on the effects of economic activities on the global climate, the state of ecosystems, water supply, and land use change. A challenge however is the conceptualisation, mapping and quantification of feedback mechanisms from environmental change to economic activities (scope, composition, efficiency) and the quality of life (welfare and equity issues, broadly defined). A further challenge is to incorporate such mechanisms into models used for global assessments. For example, how are identifiable effects at the macro-level (industries, sectors; exports, investment etc.) to be balanced with issues that are perhaps more at a micro- or basin level, such as security and access to food, water and energy. Ultimately, this paper will be used to provide information on the feedback linkages to inform model parameters and equations.

The structure of this paper is as follows. Section 2 maps out the general pathways from resource degradation to socio-economic outcomes. Section 3 discusses land and forest degradation and section 4 discusses water degradation. Section 5 concludes.

2 Pathways from resource degradation to socio-economic outcomes

2.1 Patterns and causes of resource degradation

Resource degradation is the outcome of various factors. Nkonya et al. (2011) and Lambin et al (2001) argue that resource degradation often results from immediate causes such as biophysical causes and unsustainable resource management practices, or with underlying causes including population density, poverty, institutional set up, land tenure and access to agriculture extension, infrastructure, opportunities and constraints created by market access as well as policies and general government effectiveness. These underlying causes can be self-perpetuating.

The effects of resource degradation have been analyzed extensively in the relevant literature. Farmers can be caught in resource-based poverty traps in which poor farmers are unable to invest in soil fertility replenishment, due to liquidity constraints in the context of capital and insurance market imperfections. The result is a decrease in crop yields leading to deeper poverty and vicious cycles of poverty and resource degradation. However, poverty does not always lead to resource degradation. Resource degradation can have different socio-economic impacts that vary depending on conditions such as natural and human resource endowments, market integration, and institutional environment. On the one hand, resource degradation can lead to poverty traps, but on the other, e.g. within an appropriate institutional environment, it can foster changes in production technologies and lead to sustainable increases in productivity.

The debates spurred by Malthus and Boserup have dominated the debate over the explanation of the causes and consequences of land degradation (Pascual and Barbier, 2006). The two approaches represent diverging paths regarding assumptions on institutional environments. In the Malthusian approach (Malthus, 1798), increasing pressure on land due to a population increase results in the reduction of fallow periods which prevent replenishment of soil fertility. This in turn results in a vicious cycle between land degradation and poverty. The Malthusian approach is particularly relevant in a world where there are few enablers and many constraints on the adoption of new production and resource management technologies. Facing such constraints, Malthus also suggests that rural, agricultural families can respond to population pressures through out-migration in search of land, which extends the agricultural frontier.

On the other hand, Boserup (1965) suggests that population pressures and declining yields owing to the reduction in fallow periods can actually serve as an incentive for farmers to change production technology. Farmers would intensify land use through the use of inputs - fertilizers, pesticides, and high-yielding varieties – as well as innovative land management techniques aiming at preserving or replenishing soil fertility. Because of such change in technology, farmers will be able to exit the vicious cycle of resource based chronic poverty.

Therefore, the identification of pathways of socio-economic impacts resulting from resource degradation requires an understanding of the incentives and constraints under which producers and consumers are making their investment and production decisions. The understanding of such constraints can then support the formulation of policies to promote resource management. Opportunity cost is an important concept behind the analysis of the decisions of producers and households to adopt certain mitigating strategies. Opportunity cost is the value foregone by employing a resource in one use rather than an alternative one. The opportunity cost of adopting a mitigating strategy over another depends on economic, social and institutional factors, e.g. situations of market imperfections (credit and insurance) that generate inefficiency; imperfect learning and bounded rationality as well as coordination failure and economically dysfunctional institutions (Barrett, 2008; Lambin et al.,2001; Ruij et al 2004; Barbier, 1997).

2.2 General pathways:

Table 1 presents general pathways and broad measures of the impact of resource degradation. In general, the socio-economic impact of resource degradation depends on:

- direct transmission mechanisms; and
- the ability of producers and consumers to follow mitigation strategies (this could be termed economic, social and political resilience).

In subsequent chapters, we will discuss the transmission mechanisms and enabling / constraining factors.

The vulnerability to the economic effects of resource degradation is equal to the direct exposure to the transmission mechanisms *minus* resilience to such exposure (i.e. the ability to mitigate the impact). The direct transmission mechanisms from resource degradation include:

- Direct dependence on natural resources in production (which tends to be higher in agricultural societies) and consumption (depending on tastes); we also include the indirect effects, e.g. if agricultural has permeating effects to other sectors or segments in the value chain.
- The level and quality of natural assets; and
- The type of agricultural systems being used, e.g. the importance of fertility of soil or water for specific agricultural production processes.

However, farmers or consumers might be well placed to mitigate the effects. From the producer’s point of view, we identify three broad types of mitigating strategies:

- Adoption of a new production and resource management technology usually entailing different employment and intensification of one or several production factors;
- Diversification of income generating activities, whether by changing the resource use or by changing activity (from on-farm to off-farm income generating activity);
- Migration. For example, if the country has a high level of natural capital, with large amounts of land or groundwater still available for agricultural production, producers might simply decide to migrate to a location where the resource is available and not yet degraded.

Farmers and consumers are more likely to follow mitigation strategies in the presence of fewer constraints and more enablers. Table 1 highlights five such factors. First, such factors include asset endowments and the level and distribution in natural, human, physical, financial and locational capital. The second set of factors highlights constraints on the access to new technology, the third to other income generating activities and the fourth relates to the availability of substitutable products. Finally, a last set of indicators includes the policy environment and institutions, which we consider exogenous in that they can influence the pathways of socio-economic impact of resource degradation (of course policies can also be a cause of resource degradation).

As argued, resource degradation can be mitigated by following alternative production technologies. The adoption of new production technologies depend on various factors such as the availability of new technologies and many others. But as highlighted by Marenya and Barrett (2006) in Kenya, and Moser and Barrett (2006) in Madagascar, the adoption of new production technologies also depends on the capacity of producers to get access to information about these new technologies, their capacity to adopt it according to their level of education and capacity to mobilize the necessary production factors. In the presence of market failures, poor households who rely on subsistence agriculture can have liquidity constraints that affect their capacity to intensify their use of inputs and labour. Hence, the adoption of a new technology depends on constraints on locational, human and financial capital.

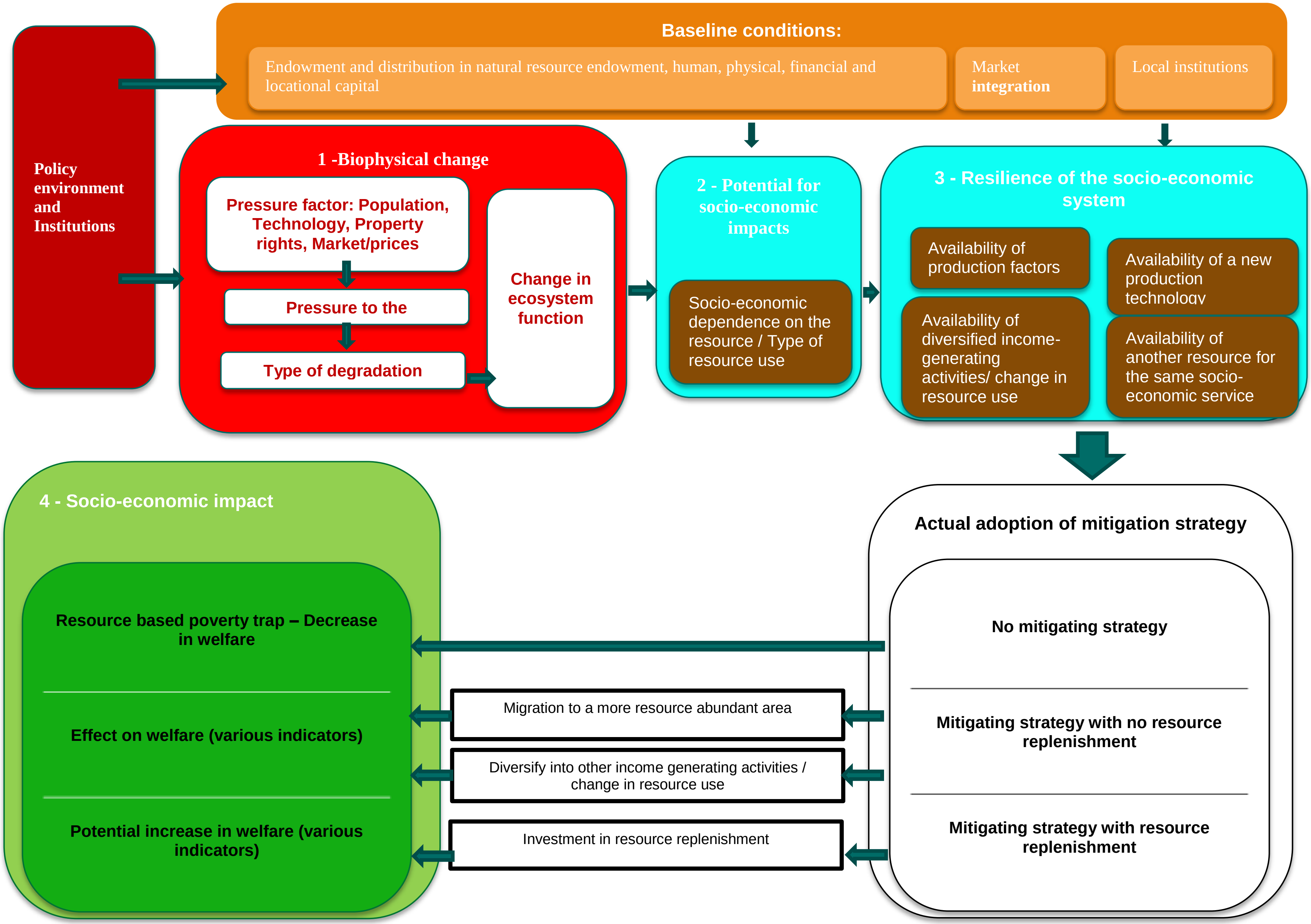
Table 1 summarises the general pathways and Figure 1 illustrates the pathways. We consider four key elements:

1. **Biophysical changes**, i.e. the various types of degradation and their effects on ecosystems.
2. **Potential socio-economic impacts** of changes in ecosystems, i.e. the various transmission mechanisms to human development, and the degree of socio-economic exposure to these.
3. **The resilience of socio-economic systems**, i.e. possibilities for mitigation and the constraints and enablers which govern whether or not they can be adopted.
4. Finally, the **actual socio-economic impacts** resulting from all of the above.

Table 1: General pathways from resource degradation to socio-economic outcomes

Component of pathway	Key elements
1. Biophysical change	Types of degradation
	Changes in ecosystem functions
2.Potential for socio-economic impacts	Transmission mechanisms to human development
	Exposure of human systems
3.Resilience of the socio-economic system	Potential mitigation strategies for socio-economic impacts
	Enablers and constraints for mitigation strategies
4.Socio-economic impacts	Actual impacts will depend on the extent to which mitigation strategies can be adopted.

Figure 1: General pathways of the impact of resource degradation



Mapping the impact of land and forest degradation

3.1 Type of degradation and change in ecosystem function

A first categorisation of the economic impact of land degradation.

The 2011/2012 European Report on Development defines four economic uses of land: i) land for forest; ii) land for biodiversity; iii) land for agriculture; iv) land for human settlement/infrastructure. The pathways to socio-economic impact of land degradation depend first and foremost on its socio-economic use, on the importance of this activity to the economy and on its services to other economic sectors.

Land for forest:

Forests have a direct economic significance through the provision of timber and wood that can be used for the industry but also for the fuel wood and fodder in particular in developing countries where households can depend entirely on wood for their energy.

Forests are also a source of non-timber forest products (NTFP). These include all biological products extracted from forests apart from timber through agro-forestry. According to WWF, the value of non-wood forest product removals was estimated at US$18.5 billion in 2005, with food products accounting for the biggest share. However, agro-forestry covers a large range of activities, from subsistence activities to large palm oil estates. Primary forests are an important provider of biodiversity that can be linked to various economic activities, from the provision of medicinal products to tourism.

Forests provide ecosystems services climate control, pollution abatement. Deforestation is seen as one of the major causes of soil degradation

Therefore, forest degradation can have an impact on populations' livelihoods and income generation through the reduction and loss of direct economic services. But forest degradation can also have an indirect impact through the loss of ecosystems and environmental services.

Land for biodiversity:

The use of land for biodiversity involves placing constraints upon the types of land use and management practices. The economic impact of the degradation of land for diversity necessitates to first assessing the costs of biodiversity loss in terms of the loss in both resilience of the system as a whole and the specific ecosystem services provided. Second, as for forest, land for biodiversity can be linked to various more direct economic activities such as tourism.

Land for human settlement/infrastructure:

If the issue of the degradation of land used for human settlement as in urban areas is not relevant in this analysis, land degradation for human infrastructure can have more important economic impact. Seasonal road degradation due to heavy rains and drought as well as landslides can have a considerable impact on market integration and economic development.

Land for agriculture:

The use of land for agriculture is the focus of the analysis of the main pathways of the socio-economic impact of land degradation developed in the next section. A large majority of developing countries' population relies directly or indirectly on agriculture, through on and off-farm activities. Therefore, degradation of land for agriculture, the partial or complete loss of its economic services, and the consequences on households' livelihood, is identified as the most important in terms of socio-economic impact. The main driver of land for agriculture degradation is the related loss in agricultural productivity and the increase in production costs.

Agricultural land use in developing countries and associated degradation problems

The UN (1997) defines land degradation as the "reduction or loss of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest or woodlands resulting from natural processes, land uses or other human activities and habitation patterns such as land contamination, soil erosion and the destruction of the vegetation cover." The FAO (2001) suggests a simpler definition of soil degradation as the lowering and losing of soil functions. Soil degradation takes various forms and encompasses erosion, desiccation, salinization, and declining fertility.

Deforestation is seen as one of the major causes of soil degradation and the more important types of soil degradation in the world are soil erosion, chemical deterioration and physical degradation. Human causes of land degradation relate to land clearance, such as clear-cutting and deforestation; agricultural depletion of soil nutrients through poor farming practices; livestock including overgrazing and over drafting; inappropriate irrigation and over drafting; monoculture, overuse of inputs destabilizing the local ecosystem.

Soil degradation processes can be due to changes in soil nutrient content, water-holding capacity (WHC), organic matter content (SOM), soil reactivity, topsoil depth, salinity and biomass (Scherr, 1999). Those changes have impacts on the average and variance of yield, and the total factor productivity of agricultural production resulting in loss of income or consumption as well as increased production cost and increased income risks. Table 2 reviews various land types according to resource endowment, and associated pathways in land use and soil degradation.

Table 2: Major pathways of change in agricultural land use in developing countries and associated degradation problems

Land type	Main changes observed in land use	On-site soil degradation	Other resource degradation
Irrigated lands	Increased multiple cropping	Salinization and waterlogging Nutrient constraints under multiple cropping Biological degradation (agrochemicals)	Nutrient pollution in ground/ surface water Pesticide pollution Water-borne disease Water conflicts
High-quality rain-fed lands	Transition from short fallow to continuous cropping High Yielding Varieties Mechanization	Nutrient depletion Soil compaction and physical degradation from over-cultivation, machinery Acidification Removal of natural vegetation, perennials Soil erosion Biological degradation (agrochemicals)	Deforestation of commons
Densely populated marginal lands	Transition from long to short fallows or continuous cropping Cropping in new landscape niches	Soil erosion Soil fertility depletion Removal of natural vegetation, perennials from landscape Soil compaction, physical degradation from over-cultivation Acidification	Loss of biodiversity Watershed degradation
Extensively managed marginal lands	Immigration and land-clearing for low input agriculture	Soil erosion from land-clearing Soil erosion from crop/livestock production Soil nutrient depletion Weed infestation Biological degradation from topsoil removal	Deforestation Loss of biodiversity Watershed degradation
Urban and peri-urban agricultural lands	Rapid urbanization Diversification of urban food markets Rise in urban poverty	Soil erosion from poor agricultural practices Soil contamination from urban pollutants Overgrazing and compaction	Water pollution Air pollution Human disease vectors

Source: Sherr, 1999

There are different types and intensities of resource degradation and this has implications for socio-economic impacts. The socio-economic impacts and mitigating strategies resulting from the degradation of soil organic content due to the overuse of slash and burn agriculture in Madagascar (Moser and Barrett, 2006) will be different in scope and nature from land contamination due to over or misuse of inputs in large commercial agriculture oriented estates in Costa Rica (Thrupp, 1999). The type of land use is an important transmission mechanism of resource degradation, see table 2.

Another issue when examining the degradation is identifying whether the various types of soil degradation are reversible. We need to differentiate biophysical from socio-economic reversibility. From a *biophysical* point of view, some types of land degradation are reversible at low or moderate economic costs relatively to agricultural production and land value (Scherr, 1999). Scherr (1999) highlights that the effects of agrochemical overuse can be reversed at high costs, but in the case of accumulation of toxic substance, costs are so high that degradation is often considered irreversible. For the agricultural producers and employees, the only solution is therefore migration or change in land use out of agricultural production. According to Thrupp (1991) the accumulation of copper-based fungicides in thousands of hectares of land formerly planted in bananas in Costa Rica damaged rendered the soils useless for decades.

However, few types of degradation are truly irreversible. As we highlighted in section 2, the existence of various constraints can prevent producers from conservation and replenishment investments, leading to consider – at least from the producer point of view – such soil degradation as irreversible in specific institutional and socio-economic contexts.

3.2 Potential socio-economic impact of land degradation

Having laid out the different types of land degradation, this section will examine the empirical literature on the impact in more detail. The flowchart in Appendix B (Figure B1) provides a summary of the pathways discussed in this chapter.

Transmission mechanisms for human development

The main analytical framework is to consider the overall impact of land degradation as the direct impact and exposure to land degradation (and there are different types, see 3.1) *minus* the ability of producers and consumer to respond to land degradation.

The *direct impact* can be estimated using several methods. For example, using a production approach, the costs associated with (i) a change in land may take the form of a loss of output, or (ii) an increase in a substitute input in order to maintain the original quantity produced. When the soil is less fertile (through erosion or salinization), a farmer will experience a decline in the quantity of a crop harvested. He or she will then face a choice; he can let the quantity of crops harvested decline, or pay more to invest in fertilizers to maintain his original quantity produced. Either way, he is suffering an economic loss from decreased profits. With decreases in the productivity of land, crop yields decline and with it farmers' net incomes and GDP. In countries that are more dependent on agriculture, GDP would suffer more.

Exposure – Indicators

Following this approach (and highlighted in section 2), table 3 presents various indicators highlighting the country's vulnerability to land degradation and identifying of the potential socio-economic impact.

Table 3: Land degradation and deforestation specific set of indicators

Indicator	Source
Indicator	**Source**
Big picture	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	World Bank
% agriculture in GDP	World Bank
% employment in agriculture (LF in agriculture as % of total LF)	FAO
Political stability and conflict	
CPIA transparency, accountability, and corruption in the public sector rating (1=low to 6=high)	World Bank
Gini Index	World Bank
Agricultural production system and stages in land use: Natural; Frontier clearings; subsistence agriculture and small-scale farms; intensive agriculture; urban areas; protected/ recreational lands	
FAOSTAT Investment: Capital Stock - Land development (gross capital stock and net capital stock) in USD Millions	FAOSTAT
FAOSTAT Investment: Capital Stock - Livestock (fixed assets), (gross capital stock and net capital stock) in USD Millions	FAOSTAT
FAOSTAT Investment: Capital Stock - Machinery and equipment (gross capital stock and net capital stock) in USD Millions	FAOSTAT
FAOSTAT Investment: Capital Stock - Plantation Crops (gross capital stock and net capital stock) in USD Millions	FAOSTAT
FAOSTAT Investment: Capital Stock - Structures for Livestock. (gross capital stock and net capital stock) in USD Millions	FAOSTAT
Yield of stable crop (Hg/Ha) (FAOSTAT)	FAOSTAT
Gini Concentration of Holdings – land tenure, 1981-1990	USAID country profile
Population density (people per sq. km of land area)	World Bank
% Population in Urban/Rural areas	World Bank
Existence of a deforestation pioneer front / frontier clearings	NA
Asset endowment	
Land	
FAOSTAT - Resource: Agricultural area as share of total land area	FAOSTAT
Gini Concentration of Holdings, 1981-1990	USAID country profile
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	World Bank
Labour	
Population density (people per sq. km of land area)	World Bank
% employment in agriculture (LF in agriculture as % of total LF)	FAO
Schooling levels	
a) literacy rate	World Bank
b) Labour force with primary education (% of total)	World Bank
Capital	
FAOSTAT Investment: machinery stock (agricultural tractors, total/per 100 sq. km of arable land)	World Bank
FAOSTAT Investment: Capital Stock (Land development, Livestock (fixed assets), Livestock (Inventory), (Machinery and equipment), Plantation Crops, Structures for Livestock)	see above
Statistics on inputs use (FAOSTAT), Organic, NPK, Pesticides	
a) NPK complex >10kg (consumption in tonnes)	FOASTAT
b)Pesticides (use in tonnes) insecticides + herbicides + fungicides & bactericides + seed treatment + insecticides + rodenticides	FOASTAT
transportation and communication infrastructure	
a) Indicator summarises the quality of trade and transport related infrastructure (e.g. ports, railroads, roads, information technology), on a rating ranging from 1 (very low) to 5 (very high)	World Bank
b) Road density (km of road per 100 sq. km of land area)	World Bank

c) Mobile cellular subscriptions (per 100 people)	World Bank
d) Access to electricity (% of population)	World Bank
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	World Bank
Access to a variety of production technology	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	World Bank
Constraint on access to credit - insurance	see case study
Transport time or average distance to market / Communication infrastructures (roads)	see above
Access to electricity (% of population)	World Bank
Other income generating activities	
Rural Urban connection	
% employment in agriculture (LF in agriculture as % of total LF)	FAO
Unemployment rate	UNDATA
Schooling levels	see above
Availability of substitutable products	
Transport time or average distance to market / Communication infrastructures (roads)	see above
Food imports (% of merchandise imports)	World Bank
land locked or nor (indicator for prices of traded goods due to transaction costs)	
Government policies	
Government expenditure on education (% of GDP)	UNDATA
Government expenditure on health (% of GDP)	World Bank

Source: Authors

3.3 Resilience of the socio-economic systems

Potential mitigation strategies for socio-economic impacts

In many instances, as described in the previous section, land degradation and its impact on agricultural productivity and income can be mitigated. According to constraints on assets, and to the institutional environment, for instance natural or institutional constraints on the availability of new land for agriculture, constraints on human or financial capital etc., agricultural producers will be able to adopt one of following response strategies to avoid a loss of economic activity and income:

- Change production technology: Increase the intensity of the use of production factors: more labour, more capital in the form of inputs or land. Change to an alternative agricultural production less sensitive to the type of land degradation observed.
- Relocate/migrate to an area with more abundant quality land.
- Diversification of income generating activity out of farming.

In terms of impact on land degradation, the mitigation strategies can have different effects, e.g. degrading, neutral or improving. However, it is possible that none of these response strategies can be adopted. In such a case, resource degradation will continue, with a reduction in income and potentially a resource based poverty trap mechanism. For example, the shortage of new land for agriculture in conjunction with the inability of farmers to invest in land rehabilitation technologies may result in the reduction of income and eventually to a decrease in food diversity and availability and therefore in food security. On the other hand, the capacity to adopt new production technologies which allows for the rehabilitation of degraded farmland can result in new income-generating opportunities.

It is also possible that a change in the economic environment will change the opportunity cost of adopting one of those strategies. For instance a change in land tenure allows for better access to new agricultural lands or the construction of a road reduces the costs of adopting new technologies (Jouanjean, 2013).

The indicators suggested in the previous section provide proxies for the determinants of the choice of mitigating strategy: Agricultural production system and stages in land use give information about the actual production systems and therefore about the possible system and technology change (whether the agricultural production is extensive or intensive); asset endowment; access to a variety of production technology; other income generating activities; availability of substitutable products; government policies.

Examples of constraints to the adoption of mitigating strategies are described in the following sections.

Constraints on the choice of mitigation through investment in land improvement and replenishment

As highlighted by the Boseruptian approach, an endogenous process of intensification can be expected under population and market pressure. However, the literature identifies various factors influencing the pace and scale of land transformation (Sheer and Hazell 1994):

- Farmer knowledge about the degradation of the degrading resource
- Incentives for long-term investment
- Capacity to mobilize resources for land investment.
- Level of economic returns to such investment
- Factors affecting the formation and function of local groups to help mobilize resources and coordinate landscape-level change.

Moreover, it identifies various factors influencing the incentives of framers to invest in natural resources:

- Knowledge
- Economic importance of the resource
    - Importance of the related activity to the economy, here farming
    - Importance of the degraded resource
- Willingness to invest for the long-term
    - Subsistence Security
    - Certainty of future returns
    - Secure property rights
- Capacity to mobilize resources
    - Sufficient inputs for investments
    - Flexibility in resource management
- Economic incentives
    - Appropriate technology
    - Supportive Economic Policy
- Local institutional support
    - Developed Institutional support
    - Internalized Externalities

Example of constraints to investment in land improvement and replenishment

Several other factors (enablers and constraints) emerge from the literature on responses to soil degradation. Woelcke (2006) presents the case of Uganda's Lake Victoria Crescent region where agricultural production is characterised by low input–output systems even though the region presents comparative advantages for intensive agricultural production building on high agricultural potential, market access, and high population density. The analysis reveals that farm households would not pursue sustainable intensification under current socio-economic conditions because of high transaction costs (including transport costs), credit market imperfection, lack of agricultural services (ancillary services) and lack of economic incentives to the adoption of environmentally sound production methods. The consequence is the lack of dynamism in agricultural production in a region despite its seeming potential whilst agricultural productivity in Uganda stagnated at the time (APSEC, 2000). Nkonya et al (2011) mention the example of improved access to roads and markets in Machakos, Kenya that led land users to increase investments in soil erosion prevention methods thereby increasing agricultural productivity.

3.4 Socio-economic impact

Relocation/migration to more abundant quality land areas

The presence of other land also helps a response to land degradation. One tendency in many countries in sub-Saharan Africa (SSA) has been for agricultural producers to pursue "shifting cultivation" in response to declining soil fertility.

However, in many areas, this use of land has become impractical as population growth rates accelerated and the arable land frontier is reaching its limits in many areas of SSA. As a consequence, producers intensify their use of land but without providing enough inputs necessary for the replenishment of nutrients through inorganic and organic fertilizers. This situation is resonating with the Malthusian approach to resource degradation.

Potential poverty traps as the result of constraints to investment in land improvement and replenishment

There are several factors (enablers and constraints) that emerge from the literature on *responses to* soil degradation, e.g. capital assets. Indeed, one recurrent theme in the socio-economic literature relating to land degradation is the issue of the link between poverty and land degradation, resource based poverty traps and inequality in access to soil fertility replenishment technologies. Pascual and Barbier (2006) and Barrett (2008) highlight that there are wildly varying responses in producers depending on their assets. The consequence is an increasing divergence between producers able to invest in soil fertility replenishment and poorer producers who are unable or unwilling to make such investments. They are therefore unable to sustain the quality of their farmland and enter a vicious cycle of decreasing productivity and incomes. Madagascar is one prominent example of a countrywide case of a resource based poverty trap. However, such dynamics are usually observed at more disaggregated scales, and usually relate to poorer agricultural producers. (See also Sanchez et al., 2001, Reardon et al., 2001, Barrett et al., 2002 and World Bank, 2003)

The actual socio-economic impacts of land degradation can also be illustrated through a number of case studies, drawn from the World Bank Country Evaluation Analysis and by further literature review.

Case studies using the country evaluation analysis

The World Bank and the Country Evaluation Analysis (CEA) highlight the relationship between deforestation and erosion, and present their costs. They rely on several methods to calculate land degradation for a range of countries. Deforestation and overgrazing of lands often leads to erosion as the natural protection against rain and wind is destroyed. Land degradation is often influenced by naturally occurring factors, which as Table 4 illustrates, is often exacerbated by human intervention.

Table 4 reports on the geographical conditions and human interventions that have led to land degradation in various countries and present the estimated cost in terms of GDP using a range of methods to calculate the costs of land degradation (Soil Erosion and Degradation, Deforestation, and Natural Disasters). One of the main methods of calculating the costs of land degradation is through the Productivity Method as explained above. Another important means for calculating the costs of land degradation is the Benefit Cost Analysis, which includes the costs and benefits of environmental change that are not necessarily reflected in market transactions. This is done by computing the Net Present Value of the change by calculating the sum of the discounted flow of net benefits (benefits minus costs) over time arising from the change. For soil erosion, calculating the Net Present Value, that is the sum of the discounted difference between returns in any given year and the initial returns over a specific time period, can indicate the net costs of land degradation on crop yields. Other methods that are used by CEA when calculating the costs of land degradation include Hedonic Pricing, which can illustrate the costs of land degradation on property values, Travel Costs, which present the decline in travel costs as a result of land degradation as tourism to natural sites reduces, and Contingent Valuation, which calculates an individual’s willingness-to-pay to preserve a natural asset. This method is particularly relevant when discussing the costs of deforestation, especially in country cases like Jordan where deforestation has negatively impacted tourism.

The table suggests that both physical conditions and human action have led to varying costs of land degradation. Overall the costs can be substantial, up to nearly 3% of GDP. Countries like Guatemala that have naturally steep topography are at greater risk of being affected by landslides, while countries like Nigeria with poor soil and periodic droughts are vulnerable to erosion. In these cases, the effects of natural disasters are amplified by environmental degradation and so the costs as a per cent of GDP are greater. Whilst most country reports highlight the presence of pre-existing factors in economies affected by land degradation, they also argue that human intervention has played a significant role in exacerbating naturally occurring deficiencies and contributing more to the cost of land degradation as a per cent of GDP than pre-existing conditions.

Table 4: The cost of land degradation

Country	Cost of Land Degradation as % GDP	Pre-existing conditions	Human Intervention
Jordan	.11	Droughts and periodic earthquakes	Unsound management practices and socioeconomic pressures; growing demand for animal products has led to overgrazing; energy shortages in rural areas
El Salvador	.80	Almost half of the land has slopes greater than 15 per cent and torrential rains are not uncommon	Expansion of the agricultural frontier
Guatemala	2.25	Mountainous terrain with lowlands; high amounts of rainfall	Conversion of forests to unsuitable land uses; frontier migration by subsistence farmers and clearing forested land for cultivation; The combination of high population growth, fragmentation of agricultural plots into economically unviable sizes, and the lack of local alternative sources of employment pushed out-migration from rural areas
Colombia	1.12	Mountainous terrain with lowlands; very high levels of erosion found in regions with low annual precipitation that is concentrated in only a few months of the year	Insufficient drainage and the disposal of garbage in natural channels in most urban areas are important factors contributing to urban flooding; deforestation in Colombia is mainly due to expansion of the agricultural border (mostly for livestock production) and colonization (for cattle raising and small-scale agricultural activities)
Pakistan	1.15	Areas of high aridity that are vulnerable to desertification; naturally saline soils; earthquakes; periodic flooding on the Indus River after heavy rains	Irrigation mismanagement (overwatering); overgrazing
Nigeria	2.70 (soil erosion, flooding, and deforestation, no data on agricultural degradation)	Periodic droughts and flooding; poor water retaining soil	Abandonment by forestry state departments of any form of forestry management for natural forests since the 1970; high population growth rates resulting in the expansion of agriculture, high urban and rural demand for wood and fuel wood, commercial logging
Nepal	No data	Heavy deforestation which has led to erosion	High demand for wood fuel wood; inappropriate infrastructure construction, poor management of wetlands and surrounding areas, and the spread of invasive alien plant species; lack of an overall land use policy has led to more forest and agricultural land being lost to expanding settlements and urbanization; Environmental income makes up over 50% of GDP

Source: World Bank CEA

Further country evidence on land degradation

We present further evidence on impact of land degradation in three countries.

Land degradation and deforestation in Madagascar

Madagascar seems to find itself in a resource based poverty trap. The majority of the farmers experience low and decreasing agricultural yields, however few have made the switch to input intensive farming. As this report with assert, this is because there are constraints on Madagascar's farmers to respond to degradation.

Madagascar has suffered from severe deforestation over the past decades, threatening its biodiversity. Most of the forest clearing is carried out via 'slash and burn', which requires little use of technology and tools. However, whilst there are benefits (including space for new agricultural lands, fertilisation of the new fields by the remaining ashes, etc.), there are also negative consequences. Apart from direct habitat loss, on-going deforestation leads to soil degradation.

When farmers clear their land, they proceed to cultivate it for a couple of years until the soil is exhausted, after which they move on to the next plot, thereby fuelling the deforestation and soil degradation processes. The consequences are manifesting themselves clearly. First of all, it has led to a rise in the number of conflicts between farmers as well as an increase in the cost of fertilisers (Clark, 2012). Furthermore, decreasing yields of rice, Madagascar's staple crop, have been reported. As a direct result, large parts of the population have experienced a threat to their food security. In addition, the productivity losses in rice cultivation have led to lower rural wages and an increase in unemployment (Seagle, 2010).

Mitigating strategies to respond to the land degradation have been seriously hampered by high transaction costs associated with poor communication and transportation networks (see table 5). Moreover, only 19% of the population has access to electricity which hampers the conservation of harvest as well as the use of several agricultural machines.

Furthermore, investments to increase productivity have further been hindered by farmer's lack of liquidity and the underdevelopment or inexistence of financial and insurance markets. Additionally, the investment required to switch to input intensive farming is high relative to most farmers' income. Cadot *et al*. (2006) estimate the entry cost to input intensive farming to be "more than one year of the typical subsistence farmer's output valued at market prices."

As a result, regardless of the expected returns associated with investments in productivity enhancing inputs and technology, farmers might not be able to make lumpy investments due to low liquidity and lack of borrowing options. As the table shows, Madagascar is an extremely poor country, with 81.3% of the population living under the poverty line. A high poverty rate implies that many farmers will face liquidity constraints when trying to make investments. It equally indicates that the number of people that have sufficient funds to lend to farmers within the community might be low.

Moreover, because of such relatively high (fixed) costs of high productivity investments, small scale farmers might still find subsistence farming to be the more attractive option (Barett *et al*, 2001). Furthermore, Moser and Barett (2006) find that education plays an important role in adopting new technologies. This is extremely important in a country with a literacy rate of 64% (note that this is a national average and that amongst more constraint rural households this rate is likely to be much lower).

In contrast, land clearance through 'slash and burn' allows households to escape liquidity and credit constraints when faced with deteriorating soil quality. More precisely, new land is acquired by investing labour time in clearing the plot and as explained above, does not require elaborate techniques or high levels of knowledge (Barett, 1999).

The adoption of new technologies has further been hampered by local norms, values and traditions. For example, Barett (2008) finds that even though farmers claimed that they were financially unable to make the required investments to intensify farming, they were found to spend huge amounts of money on exhuming and re-shrouding dead ancestors every 3-10 years.

In other words, over the past decades, farmers have seen their incomes decrease as a result of a deterioration of land quality. However, intensification has been hampered because of the reasons stated above. This has led many authors to suggest that Madagascar has become stuck in a resource-based poverty trap.

Furthermore, many studies have shown the importance of schooling for diversification strategies. More precisely, with some kind of education, people will find it easier to find non-farm employment. Given the low literacy rate (which is likely to be much lower for rural areas although data is lacking), options to move away from agriculture seem to be limited.

Table 5: Madagascar- Liquidity constraint, inequality and resource based poverty trap

Big picture	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	81.3%
% agriculture in GDP	29%
% employment in agriculture (LF in agriculture as % of total LF)	69.1%
Political stability and conflict	
CPIA transparency, accountability, and corruption in the public sector rating (1=low to 6=high)	2.5
Gini Index	44.1
Agricultural production system	
Indicator for the proportion of landscape under each land use stage	
Stages in land use: Natural; Frontier clearings; subsistence agriculture and small-scale farms; intensive agriculture; urban areas; protected/ recreational lands	
FAOSTAT Investment: Capital Stock - Land development (gross capital stock and net capital stock) in USD Millions	8229./8065.
FAOSTAT Investment: Capital Stock - Livestock (fixed assets), (gross capital stock and net capital stock) in USD Millions	6424./6424.
FAOSTAT Investment: Capital Stock - Machinery and equipment (gross capital stock and net capital stock) in USD Millions	286./251.
FAOSTAT Investment: Capital Stock - Plantation Crops (gross capital stock and net capital stock) in USD Millions	738./705.
FAOSTAT Investment: Capital Stock - Structures for Livestock. (gross capital stock and net capital stock) in USD Millions	875./835.
Yield of stable crop (Hg/Ha) (FAOSTAT)	Here rice: 26615
Gini Concentration of Holdings, 1981-1990	0.80
Population density (people per sq. km of land area)	36
% population in Urban/Rural areas	33%/67%
Land	
FAOSTAT - Resource: Agricultural area as share of total land area	0.71
Gini Concentration of Holdings, 1981-1990	0.8
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	3
Labour	
Population density (people per sq. km of land area)	36
% employment in agriculture (LF in agriculture as % of total LF)	69%
Schooling levels	
a) literacy rate	64%
b) labour force with primary education (% of total)	56% (in 2005)
Capital	
FAOSTAT Investment: machinery stock (agricultural tractors, total/per 100 sq. km of arable land)	550/1.9 (both in 2004)
FAOSTAT Investment: Capital Stock (Land development, Livestock (fixed assets), Livestock (Inventory), (machinery and equipment), Plantation Crops, Structures for Livestock)	see above
Statistics on inputs use (FAOSTAT), Organic, NPK, Pesticides	
a) NPK complex >10kg (consumption in tonnes)	9990
b) Pesticides (use in tonnes) insecticides + herbicides + fungicides & bactericides + seed treatment + insecticides + rodenticides	241.91

transportation and communication infrastructure	
a) Indicator summarises the quality of trade and transport related infrastructure (e.g. ports, railroads, roads, information technology), on a rating ranging from 1 (very low) to 5 (very high)	2.4
b) Road density (km of road per 100 sq. km of land area)	6
c) Mobile cellular subscriptions (per 100 people)	38
d) Access to electricity (% of population)	19%
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	3
Access to a variety of production technology	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	81.3%
Constraint on access to credit - insurance	anecdotal: underdeveloped
Transport time or average distance to market / Communication infrastructures (roads)	see above
Access to electricity (% of population)	19%
Other income generating activities	
Rural Urban connection	indicators see transportation and communication
% employment in agriculture (LF in agriculture as % of total LF)	69.10%
Unemployment rate	2.3% (in 2004)
Schooling levels	see above
Availability of substitutable products	
Transport time or average distance to market / Communication infrastructures (roads)	see above
Food imports (% of merchandise imports)	14%
land locked or nor (indicator for prices of traded goods due to transaction costs)	no
Government policies	
Government expenditure on education (% of GDP)	3%
Government expenditure on health (% of GDP)	2.30%

Land degradation and deforestation in Ethiopia

Over the past decades, Ethiopia has experienced a rapid decline in its forest cover and a serious deterioration of its land quality. One important cause can be found in the demands posed on these resources by increased pressure. Population growth has not only led to land clearance for agricultural purposes, but also to overgrazing (dominant agricultural system is mixed cereal-livestock production (Ehui and Pender ,2005)) as well as increased pressure on existing forests because of increased demand for fodder, fuel wood and building materials (Bishaw, 2001). Deforestation and overgrazing have led to erosion.

For a county like Ethiopia where 83% of the population is directly dependent on agriculture for their livelihood, land quality deterioration is a serious problem (Evans, 2012). On top of that, rural literacy rates are extremely low, implying few opportunities outside the agricultural sector for many farmers. As a result, active mitigation strategies to the benefit of the environment have been scarce.

Over the past two decades, several studies have tried to estimate the actual costs of these degradation processes. Their findings tend to differ due to methodological differences and different underlying assumptions. However, most studies conclude that "the overall cost of land degradation is substantial- probably a few per cent of agricultural GDP per year" (World Bank, 2007). Yesuf et al. (2005) state that the estimate annual cost stemming from land degradation ranges between 2% to 6.75% of agricultural GDP.

At the level of the household level, low yields imply low levels of agricultural income as well as low levels of food for self-consumption. Food insecurity is a huge issue in Ethiopia and a substantial part of this problem can be attributed to land degradation (Ehui and Pender 2005). Evans (2012) cites crop dependent farmers in the highlands (where 90% of the agricultural land can be found) to be one of the groups most at risk of food insecurity.

However, several factors limit the potential for exit, mitigation and intensification strategies. First of all, the existing land and tree tenure system is a source of great insecurity (Bishaw, 2001) and discourages investment in land. As from 1975, all land belongs to the state and as a result all households are users rather than owners. Furthermore, all land sales are prohibited and families that leave their plots lose the right to exploit it. Recently, measures to facilitate transition of land to family members have been taken and attempts to set up long term rental markets have been made. However, permanent transfers of land to people outside the family are exceptional. This tenure system discourages investments in land by farmers and cattle holders and effectively hampers rural-urban migration. Another law in place, which hampers migration within the country, states that families who move to an urban area have to wait six months before they can be registered, implying that during that period, they cannot avail of government amenities /services.

Further disincentives for agricultural intensification are related to high transaction cost, due to limited transportation and communication networks as well as underdeveloped credit, insurance and output markets. Ethiopia scores only 2.22 on 5 on the indicator that summarizes the quality of trade and transport related infrastructure. In 2005, mobile phones and vehicles were almost unknown and government investments in roads have largely focused on connecting urban clusters. The absence of these services has hindered rural-urban migration. Finally, high climatic risks and liquidity constraints further hamper investment in intensification of agricultural production.

Table 6: Ethiopia

Big picture	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	39% (in 2005)
% agriculture in GDP	46%
% employment in agriculture (WDI)	79% (in 2005)
Political stability and conflict	
CPIA transparency, accountability, and corruption in the public sector rating (1=low to 6=high)	3
Gini Index	38.8 (in 2005)
Agricultural production system	
Indicator for the proportion of landscape under each land use stage	
Stages in land use: Natural; Frontier clearings; subsistence agriculture and small-scale farms; intensive agriculture; urban areas; protected/ recreational lands	
FAOSTAT Investment: Capital Stock - Land development (gross capital stock and net capital stock) in USD Millions	2892/2834
FAOSTAT Investment: Capital Stock - Livestock (fixed assets), (gross capital stock and net capital stock) in USD Millions	33806/33806
FAOSTAT Investment: Capital Stock - Machinery and equipment (gross capital stock and net capital stock) in USD Millions	110/963
FAOSTAT Investment: Capital Stock - Plantation Crops (gross capital stock and net capital stock) in USD Millions	589/562
FAOSTAT Investment: Capital Stock - Structures for Livestock. (gross capital stock and net capital stock) in USD Millions	4534/4330
Yields of main crops (Hg/Ha)((FAOSTAT) here cereals/maize/Roots and tubers	13398/24931/72156
Land tenure - Gini coefficient on land distribution	0.541
Population density (people per sq. km of land area)	83
% Population in Urban/Rural areas	17%/83%
Availability of production factors	
Land	
FAOSTAT - Resource: Agricultural area as share of total land area	0.35
Land tenure - Gini coefficient on land distribution	0.54
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	3
Labour	
Population density (people per sq. km of land area)	83
% employment in agriculture (WDI)	79% (in 2005)
Schooling levels	
a) literacy rate urban/rural	70.4%/21.8 %
b) Labour force with primary education (% of total)	20.7 (1999)
Capital	

FAOSTAT Investment: machinery stock (agricultural tractors, total/per 100 sq. km of arable land)	no data
FAOSTAT Investment: Capital Stock (Land development, Livestock (fixed assets), Livestock (Inventory), (machinery and equipment), Plantation Crops, Structures for Livestock.)	see above
Statistics on inputs use (FAOSTAT), Organic, NPK, Pesticides	
a) NPK (consumption in tonnes)	1452 (in 2005)
b) Pesticides (use in tonnes) insecticides + herbicides + fungicides & bactericides + plant growth regulators + rodenticides	612
transportation and communication infrastructure	
a) Indicator summarises the quality of trade and transport related infrastructure (e.g. ports, railroads, roads, information technology), on a rating ranging from 1 (very low) to 5 (very high)	2.22
b) Road density (km of road per 100 sq. km of land area)	4
c) Mobile cellular subscriptions (per 100 people)	17
d) Access to electricity (% of population)	17%
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	3
Access to a variety of production technology	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	39% (in 2005)
Constraint on access to credit - insurance	NA
Transport time or average distance to market / Communication infrastructures (roads)	see above
Access to electricity (% of population)	17%
Other income generating activities	
Rural Urban connection	indicators see transportation and communication
% employment in agriculture (WDI)	79% (in 2005)
Unemployment	20.50%
Schooling levels	see above
Availability of substitutable products	
Transport time or average distance to market / Communication infrastructures (roads)	see above
Food imports (% of merchandise imports)	15%
Land locked or not	yes
Government policies helping to enable mitigation	
Government expenditure on education (% of GDP)	4.7%
Government expenditure on health (% of GDP)	2.6%

Land degradation and deforestation in Costa Rica

Banana production and exports have long played an important role in Costa Rica’s economy. In 1993, bananas represented 25% of the country’s exports and were a source of employment for at least 150,000 people (Chambron, 1999). Multinational companies bought up land from farmers to transform it into large plantations.

Pesticides are a commonly used input. Between 1990 and 1994, the value of Costa Rica's chemical pesticide imports increased by almost 50%. Expansion of banana production was largely responsible for this remarkable increase. However, many of the substances used are dangerous. In 1993, 18% of all pesticides imports were classified by the WHO as extremely hazardous or highly hazardous (Agne and Waibel, 1997). One commonly used and harmful type is copper pesticides. Evidence shows that copper intoxication has long lasting effects on soil quality. Moreover, even low concentration of copper can affect several soil processes and more importantly, in most soils copper residuals are likely to remain indefinitely (Vanzwieten et al, 2004).

The extensive and largely unregulated use of pesticides has had important consequences.

First of all, people that come into contact with these substances are at serious health risk. Cancer, infertility[1], headaches, nausea, skin eruptions and fainting are all reported consequences of exposure to several types of pesticides (Astorga, 1996; Flackman). For households, this might imply serious health care costs and loss in income due to inactivity. At a national scale, costs associated with acute morbidity related to pesticide poisoning have been estimated to range from 0.25% to 0.68% of agricultural GDP (Larson and Perez, 1999). Note however that these estimates exclude economic costs of deaths and other negative externalities.

Furthermore, due to the openness of the banana plantations, pesticides can easily leak into the environment, contaminating water and other natural resources. For example, pesticides stemming from banana cultivation have been reported to have caused massive deaths of fish in the surrounding waters as well as the bleaching of Costa Rica's coral reefs (for example, 90% of the coral reef on the Caribbean Coast of the Limon province has been reported to have died) (Worobetz, 2000).

Finally, in several areas within Costa Rica, soils have become contaminated by the excessive use of several chemicals, to such extent that the damage to the soil has become irreversible (Astorga, 1996). For example, the South pacific region of Costa Rica used to have great agricultural potential. However, after the land abandonment of Chiquita in 1984, the area has now become unsuitable for most agricultural practices. This is important because many households depend directly or indirectly in nearby banana plantations for their livelihoods. After abandonment by the firms, the land that remains cannot be used for subsistence farming. This leaves the laid off workers with little other alternatives.

Chambron (1999) described the evolution of banana production reallocation: "The fear of many in Latin America is that companies will simply leave once the soils are too depleted, leaving them without any alternative for the loss of their main source of revenue and employment. This already happened in the past: banana companies abandoned their plantations in the southern Atlantic zone of Costa Rica when soils became unsuitable for banana plantations, moving production to the Pacific coast. When the soil was exhausted on the Pacific coast, they moved production to the central Atlantic zone." Note that this process of reallocation of production goes hand in hand with deforestation and the taking over of plots of land of small-scale farmers.

Over the years, sectors other than agriculture have become important (see table 7), so that the impact is lower in percentage point than would have been the cases back in the 1990s.

Table 7: Costa Rica-land degradation as a result of pesticide overuse

"Ex-ante" conditions	Big picture	
	GDP per capita in current USD	8647
	Poverty headcount ratio at $1.25 a day (PPP) (% of population)	3.1%
	% Agriculture in GDP	6%
	% employment in agriculture (LF in agriculture as % of total LF)	13.2%
	Political stability and conflict	
	CPIA transparency, accountability, and corruption in the public sector rating (1=low to 6=high)	no data
	Gini Index	50.7
	Agricultural production system	
	Indicator for the proportion of landscape under each land use stage	
	Stages in land use: Natural; Frontier clearings; subsistence agriculture and small-scale farms; intensive agriculture; urban areas; protected/ recreational lands	
	FAOSTAT Investment: Capital Stock - Land development (gross/net) in USD Millions	522/511
	FAOSTAT Investment: Capital Stock - Livestock (fixed assets), (gross/net) in USD Millions	588/588
	FAOSTAT Investment: Capital Stock - Machinery and equipment (gross/net) in USD Millions	235/205
	FAOSTAT Investment: Capital Stock - Plantation Crops (gross/net) in USD Millions	596/569
	FAOSTAT Investment: Capital Stock - Structures for Livestock. (gross/net) in USD Millions	118 /113
	Yield of stable crop (Hg/Ha) (FAOSTAT) here bananas	461043
	Gini Concentration of Holdings	0.82
	Population density (people per sq. km of land area)	9100%
	% Population in Urban/Rural areas	65%/35%
	Availability of production factors	
	Land	
	FAOSTAT - Resource: Agricultural area as share of total land area	0.37
	Gini Concentration of Holdings, 1981-1990	0.82
	CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	no data
	Labour	

Population density (people per sq. km of land area)	9100
% employment in agriculture (LF in agriculture as % of total LF)	13.2%
Schooling levels	
a) literacy rate	0.94
b) Labour force with primary education (% of total)	0.46
Capital	
FAOSTAT Investment: machinery stock (agricultural tractors, total/per 100 sq. km of arable land)	no data
FAOSTAT Investment: Capital Stock (Land development, Livestock (fixed assets), Livestock (Inventory), (machinery and equipment), Plantation Crops, Structures for Livestock)	see above
Statistics on inputs use (FAOSTAT), Organic, NPK, Pesticides	
a) NPK complex (consumption in tonnes)	32220
b)Pesticides (use in tonnes) insecticides + herbicides + fungicides & bactericides + seed treatment + insecticides + rodenticides	14068
transportation and communication infrastructure	
a)Indicator summarises the quality of trade and transport related infrastructure (e.g. ports, railroads, roads, information technology), on a rating ranging from 1 (very low) to 5 (very high)	2.60
b) Road density (km of road per 100 sq. km of land area)	76
c) Mobile cellular subscriptions (per 100 people)	9200%
d) Access to electricity (% of population)	99.3%
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	no data
Access to a variety of production technology	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	3.1%
Constraint on access to credit - insurance	NA
Transport time or average distance to market / Communication infrastructures (roads)	see above
Access to electricity (% of population)	99.3%
Other income generating activities	
Rural Urban connection	see above
% Employment in agriculture (LF in agriculture as % of total LF)	13.2%
Unemployment rate	4.9%
Schooling levels	see above
Availability of substitutable products	
Transport time or average distance to market / Communication infrastructures (roads)	see above
Food imports (% of merchandise imports)	9%
land locked or nor (indicator for prices of traded goods due to transaction costs)	not landlocked
Government policies	
Government expenditure on education (% of GDP)	6.3%

3.5 Conclusions

The overall impact of land degradation depends on the direct impact or and exposure to land degradation *minus* the ability of producers and consumer to respond to land degradation. The section has suggested that there are many different types of land degradation, some of which are close to irreversible in the biophysical sense (e.g. in Costa Rica), and the costs can amount to 1-3% of GDP, owing to physical geographies (e.g. in Nigeria or Guatemala) and other factors. The direct costs will be greater in countries with a greater dependence on the agricultural sector.

This evidence in this section has also suggested that there are various response or mitigation strategies in different countries. Some countries or groups in countries can more easily invest in mitigation strategies than others. For example, a high poverty rate and weak land tenure rights have constrained mitigation strategies in Ethiopia. A weak transportation system and low incomes have constrained investment in high-productivity agricultural methods in Madagascar. The strength of the ability to follow mitigation strategies can be measured and we have suggested various indicators.

4 Mapping the impact of water degradation

4.1Types of degradation, change in ecosystem function and overview of potential socio-economic impacts

There are several types of water degradation. This chapter gives an overview of these and their principal impacts, and then focuses in more detail on one form: groundwater depletion. The main pathways to economic impact are discussed, which are via human health, productivity of agriculture and industry, the cost of water, impact on energy production and damage to infrastructure. We discuss three types of water degradation in this section:

- Surface water depletion and fragmentation;
- Pollution / contamination of surface and groundwater;
- Ground water depletion.

The flowchart in Appendix B (Figure B2) provides a summary of the pathways to be discussed in this chapter.

These are often linked. Contamination of water resources exacerbates scarcity problems, for example, by rendering available water dangerous – and costly – to use. At the same time, over abstraction is also linked to higher levels of contamination due to the reduced ability of wetlands and streams to dilute, filter and buffer pollution. Finally when it comes to aquatic ecosystems, multiple types of degradation will together have the most severe impact. Water degradation is also intimately linked to land degradation discussed in the previous chapter. Many sources of water pollution derive from poor land management practices (e.g. pesticides, fertilisers, leaching of chemicals from industrial waste dumps, erosion), while use of polluted water for irrigation, and poor irrigation management, can degrade land through contamination or salinization.

First a brief note on metrics for measuring the status of water resources. The most commonly used metrics for water scarcity use mean annual river runoff (MARR) as the availability measure, representing the total renewable annual freshwater resources (Taylor, 2009). Vörösmarty et al (2005) define scarcity as a ratio of freshwater demand to availability greater than 0.4. Such measures have been criticised for failing to take into account either soil moisture (a huge contributor to food production, especially in Africa) or groundwater storage (the volumes of which often exceed renewable surface water resources many-fold) (Taylor, 2009). They are also not perfect when it comes to understanding whether surface water systems are degraded, mainly because they tend to emphasise national or basin averages, whereas overuse and degradation may occur more locally, but still with significant effects.

In the sections below, an overview is first given of possible changes to ecosystem functions and potential socio-economic effects due to degradation of surface water systems and groundwater quality degradation. Groundwater depletion is then treated in more depth.

4.1.1 Surface water depletion and fragmentation

UNEP (2008) estimates that over 90% of river flows are in systems which are ‘moderately or highly fragmented’. This means that their flow regime has been altered by a combination of abstraction, diversion and impoundment (dams, whether for storage or hydropower). Changes to the seasonality of river flows may also arise from changes in land use and in particular the loss of wetlands which buffered variations in flow. leading to increases in discharge in the wet season and decreases in the dry season. In extreme cases, river basins become seasonally or permanently 'closed' (unable to meet social and environmental requirements) and may no longer discharge any water to the sea. This is particularly common in arid areas and has happened to the Jordan and Colorado Rivers, for example. Flow reductions and modifications to river hydrology, and reductions in lake levels, may have significant impacts on the functions provided by surface waters, as outlined below.

Reduced water availability downstream for human use
Reductions in surface water flows and stores (e.g. in lakes and wetlands) may ultimately limit the amount which can be abstracted for human use downstream (depending on the availability of alternative sources of water). This could mean affecting drinking water supply for towns, with potential impacts on human health. Water availability for irrigated agriculture and industrial production may also be reduced, with effects on productivity and the quantity and quality of outputs. Such effects may lead to conflicts between upstream and downstream water users.

Reduced fisheries productivity
Reduction in river flows or lake levels can result in reduced productivity of fisheries, both inland and in estuarine and coastal waters which rely on inflow of water and nutrients from rivers to sustain local ecosystems. Dams or periods of low flow also interrupt migration routes for fish, with potentially very serious effects on their populations.

Changes in sediment transport
Reduction in sediment flow can reduce the supply of nutrients to riparian and coastal ecosystems, and may reduce the fertility of floodplain agriculture. Important food production areas in deltas (e.g. around the Nile delta in Egypt) are vulnerable. It can also increase erosion of delta shores (Walling, 2009). Conversely, increased loads (typically resulting from poor watershed management and uncontrolled erosion) can cause sedimentation of reservoirs (reducing their utility) and harm aquatic ecosystems. Sudden releases of accumulated sediment from reservoirs (for periodic clearing) affect downstream fishery production.

Loss of navigation routes
Low flows can make shipping impossible. Last December for example, low flows in the Mississippi river made navigation hazardous, and a complete shipping freeze was threatened.

Reduced ability to absorb pollution
Wetlands play a key role in assimilating human waste products – an ecosystem service worth an estimated USD 400 billion worldwide (Pacific Institute, 2010). And the greater the flow level in a river, the greater its ability to dilute pollution and buffer its effects on river life.

The response options in this situation depend primarily on whether water use is in-stream (fisheries, navigation, hydropower production, ecosystem functions), or out-of-stream (irrigation, drinking, industrial use). Users of water out-of-stream may be able to shift to use of an alternative water source, subject to availability and cost. This is clearly much harder for in-stream uses. Alternatives then are either to shift the location of production (which is not always straightforward), or to invest in restoration efforts such as managing water demand, soil water conservation measures or wetland restoration, or even diverting water from another, more water-abundant area.

4.1.2 Pollution / contamination of surface and groundwater

Various types of pollutants have negative effects on: the health of people using the water for drinking, washing or recreation; the productivity and quality of fisheries/aquaculture, agriculture and industry using the water for production; and the possibility of generating revenues from tourism and recreation. When water is polluted to the extent that it becomes unusable, it becomes essentially a source of scarcity. Groundwater is less vulnerable to pollution than surface water because of the natural filtering ability of soils and rocks through which contaminated surface water (or soil water) passes on its way to aquifers, although persistent chemicals, once they reach groundwater, are extremely difficult to remove.

Microbial pollution

Microbial pollution derives principally from disposal of untreated sewage into watercourses or on to the land, or sometimes runoff from livestock farms. Major types include contamination with faecal coliforms and other bacteria, infectious parasites such as *Giardia* and parasitic worms. All can cause human disease if the water is used untreated for drinking or irrigation of food crops.

Nutrient pollution

Many of the world's water bodies are affected by excessive loads of nutrients, mainly phosphate and nitrogen, deriving from sources including sewage and agricultural runoff (particularly from livestock farms and fertilised fields). Two million tons of human waste (sewage) are disposed of in water courses every day, according to the United Nations World Water Assessment Programme. High nutrient loads lead to eutrophication, algal blooms and oxygen depletion of water bodies. This may result in fish kills, reducing fishery and aquaculture potential, and reduce the appeal of wetlands as tourism or recreational destinations. In some cases toxic algal blooms develop which pose a threat to human health if the water is used for drinking, washing, irrigation or recreation. Nitrate flows to coastal waters also affect important coastal ecosystems, e.g. leading to harmful algal blooms and fish kills there.

Hazardous chemicals

Various organic and inorganic pollutants enter watercourses due to improper disposal of waste from industrial processes, power plants and mine drainage. In developing countries, 70% of industrial wastes are dumped untreated into waterways, according to the World Water Assessment Programme. These include heavy metals, ammonia, acidifying agents (particularly sulphur dioxide), and volatile organic compounds (mainly from industrial solvents). Pesticide use and disposal is also poorly controlled in the developing world, and increasing. At high enough concentrations these pollutants kill aquatic life, make water toxic to drink, and can enter the human food chain via fish or irrigated crops. At intermediate concentrations the yield and quality of both fishery and irrigated production is likely to decline and there may be health consequences from long term chronic exposure.

An analysis from China found that the cost of acute water pollution incidents to commercial fisheries is around 4 billion yuan [630,000 million USD] per year, while irrigation with wastewater costs 7 billion yuan [over 1.1 billion USD] annually due to reduced yields and produce quality, even before the health costs of consuming crops contaminated by heavy metals and other pollutants are considered (World Bank/SEPA, 2007). The quality of industrial output using highly polluted water may also deteriorate – again, in China the use of polluted water has affected the colour and grade of silk production, and has in some cases caused complete stoppages in production (*ibid.*). Effects on human health are harder to quantify due to the many confounding factors, but are likely to be very serious. High rates of cancers in some areas of China are attributed to consumption of (and contact with) polluted waters, for example (ibid).

Hydrocarbons

Petroleum hydrocarbons enter watercourses in runoff from roads and airports. They are therefore particularly prevalent in urban areas. (Urban areas in general tend to act as islands of pollution, releasing large amounts of untreated sewage, solid waste and other pollutants into watercourses or on to the soil, which in turn can lead to leaching of pollutants into groundwater.)

Solid waste
In countries where there are inadequate disposal facilities for solid waste, this often enters waterways, particularly around densely populated urban areas. Persistent materials (e.g. plastics) may harm aquatic life in the river system or may eventually be transported out to sea where they also threaten marine life. They may also interrupt the use of water for socio-economic purposes by clogging pumps/pipes or blocking hydropower turbines. Biodegradable materials (e.g. food waste) in large quantities can cause oxygen depletion and eutrophication when they break down.

Thermal pollution
Discharge of heated cooling water from power generation and industry, even if chemically uncontaminated, can cause dramatic local changes in water temperature in rivers which can kill sensitive fish species.

Groundwater salinization
Poorly managed irrigation, including use of excessive irrigation water, results in salinization of soils (a form of land degradation), which in turn can contaminate shallow groundwater. FAO estimates that 11% of the world's irrigated area is affected by salinity, mostly in Pakistan, China, the USA and India, which reduces yields and may eventually force the abandonment of certain lands (FAO, 2011).

Naturally occurring 'contaminants'
In some regions of the world shallow groundwater systems contain naturally occurring minerals which are dangerous to human health if consumed. An estimated 60 million people in Asia and South Asia face health risks due to high levels of arsenic in groundwater, with 0.7 million affected by arsenicosis (World Bank, 2005, in Giordano, 2009). Although this problem is not a result of human activities, it has been suggested that heavy exploitation of deeper 'fresh' aquifers risks drawing down arsenic-containing water and contaminating these (e.g. Vaidyanathan, 2011).

High fluoride levels, on the other hand, are a problem directly linked to depletion of hard rock aquifers, as this drives the release of fluoride from the surrounding rock. One study estimated that between 10 and 65 million people in India are exposed to excessive levels of fluoride, and that this causes of a loss of 38 disability-adjusted life years (DALYs)[1] per 1000 people affected, as well as a per capita treatment cost of affected populations of around 5000 Rs (90 USD) per year (Krishnan, no date).

The response options when it comes to water pollution all carry significant costs:

- Continue to use polluted water, with negative impacts on productivity and health
- Switch to an alternative water source, if one exists
- Change the mode of production / livelihood to avoid water-dependence (e.g. abandon irrigated agriculture or fishing altogether)
- Remediate waters. This can be achieved with sustained effort in the case of surface waters, as has been demonstrated in many European rivers and other water bodies with the return of fish and invertebrate species. It is much more difficult in the case of groundwater.

[1] The DALY is a widely used metric to understand health impacts on populations. A DALY is equivalent to one lost year of healthy life. DALYs for a disease or condition are calculated as the sum of the years of life lost due to premature mortality in the population, and the years lost due to disability for cases of the health condition (World Health Organization, http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/)

4.1.3 Groundwater depletion

Groundwater depletion has been selected for more in-depth discussion in this paper, due to groundwater's huge economic importance. Groundwater is much more abundant than surface water in terms of total global supply and more reliable as a water source because interannual storage buffers the effect of variations in rainfall. It is also generally higher quality and, unlike surface water, it is highly dispersed in location and, with the exception of areas with extremely deep water tables, is therefore accessible to most people using relatively simple infrastructure. Furthermore, due to its higher quality and reliability it is generally used for higher value uses than surface water (Giordano, 2009). The value of groundwater is likely to increase further if climate change threatens the reliability of surface water systems further (Shah et al, 2007). For these various reasons, groundwater sustains 40% of irrigation water globally, and provides drinking water for nearly half of the world's population, and more than half of the world's cities of over 10 million people (Morris et al, 2003).

Groundwater supports USD 210-230 billion's worth of agricultural production worldwide (Shah et al, 2007). These authors recognise four types of 'groundwater-in-agriculture systems': arid systems entirely dependent on groundwater (e.g. in the Middle East); industrial agricultural systems in the developed world; smallholder farming systems (such as in South Asia and the North China Plains); and groundwater-supported extensive pastoralism (as in much of sub-Saharan Africa and Latin America). In terms of wealth generation and total production values the first two categories are most important, but the latter two categories support billions of poor households. Category three - intensive smallholder farming – underpins food production in some of the most important breadbaskets of Asia: the North China Plain alone supports around 200 million irrigating farmers drawing on a mixture of deep and shallow groundwater. However large areas have seen groundwater levels decline by over 20m since 1960 (Foster & Garduño, 2004). In China as a whole the costs of groundwater depletion, through its impacts on agriculture, industry and drinking water supplies, have been estimated at 50 million yuan (around 8 million US dollars) per year (World Bank/SEPA, 2007).

Measures of groundwater depletion generally define unsustainable abstraction in terms of annual withdrawals which exceed recharge from rainfall (Mason and Calow, 2012). However, the complexity and variability of recharge regimes mean that an annual timescale is not always the most suitable. A recent study of long term groundwater data from an aquifer in central Tanzania found that while annual abstraction to meet the needs of local communities usually exceeds recharge, causing interannual decline in the water table, periodic intense rainfall events associated with El Nino / Southern Oscillation restore the water table and mean that, from a decadal perspective, current levels of abstraction look much more 'sustainable' (Taylor et al, 2012). And in some shallow groundwater systems, intentional overabstraction in the dry season is used to enable greater natural storage of rainwater in the wet season, enhancing local water availability, for example in Bangladesh (Morris et al, 2003). For the purposes of this paper, we therefore define groundwater depletion loosely as the progressive decline of groundwater levels over time periods of several years.

4.2 Potential socio-economic impacts of groundwater depletion

After this extensive discussion on the different types of water degradation, this section will examine the empirical literature on the impact in more detail.

4.2.1Transmission mechanisms to human development

Focusing on the final category of water degradation discussed, i.e. groundwater depletion, falling water tables have four main direct effects, which are all potentially socio-economically important.

1. **Water withdrawals become more limited or impossible using existing equipment**

This: will have an effect on water availability for drinking water systems, leading to health effects if people resort to unsafe sources instead; may reduce yield and quality of irrigated (or previously irrigated) agricultural production,; and may also hinder industrial processes and the generation of energy (power stations require water for cooling). The socio-economic importance of these effects will depend on the contribution of these different sectors to the economy (and to the livelihoods of poor communities). Several of the world's major grain-producing regions are dependent to a large extent on groundwater, and were this production to collapse there could be drastic impacts on food availability, farmer livelihoods, and food prices for consumers.

In some circumstances, and for some users, it may be possible to mitigate these effects by switching to an alternative water source, or spending more money to pump deeper water and continue exploiting the resource. In Dhaka, falling water tables have increased the energy cost of pumping for municipal water supply by 25%, in addition to increasing the capital cost of new (deeper) boreholes (Morris et al, 2003). Alternatively, it may be possible to increase the water-efficiency of production (reducing demand) or for households, businesses or economies to adopt new income-generating strategies that are less water-dependent (e.g. a rural household could move out of agriculture once irrigation becomes non-viable, to ply a different trade or seek employment in a nearby town instead).

Whether or not these opportunities for mitigation exist depend on a range of physical (water resource related), social and economic factors (see table 8 below).

2. **Links with surface water systems are severed, leading to loss of springs, soil moisture and baseflow to rivers and wetlands**

It is critical to recognise the linkages between groundwater and surface water systems. The contribution of groundwater is often vital to maintaining surface water flows in arid and semi-arid zones, particularly during dry seasons and droughts. The effect of lowering the water table may be that perennial rivers become seasonal (leading to all the problems of reduced surface water flow discussed above), and that wetlands may cease to exist. In Jordan, lowering of the water table has led to the disappearance of the Azraq wetlands, affecting the tourism potential of the region (Bergkamp and Cross, 2006). The links between groundwater and soil moisture are not thoroughly understood, but in semi-arid areas without irrigation – including most of Africa – soil moisture is the basis of food production and reductions could be catastrophic. Worldwide, soil moisture provides 80% of water for crops according to the Comprehensive Assessment of Water Management in Agriculture (2007). Springs also provide important water sources for many rural communities across the developing world, and if these become dry – permanently or seasonally – people must travel longer distances for water and suffer both an opportunity cost (time is lost from productive, income-generating activities or from 'reproductive' activities, i.e. caring for family members) and possible health consequences from long or arduous journeys and long working hours.

3. **Depletion leads to drawing in of saline or polluted water (induced pollution)**

Aquifer depletion in coastal areas can lead to ingress of saline water. Salinisation of groundwater is effectively impossible to reverse. The coastal aquifers of Gaza, Gujurat (India), west Java and Mexico among others are permamently salinized (FAO, 2011), while salinization can be a particular challenge in island states. Desalination of the water once abstracted is possible but expensive. It may be necessary where municipal water supplies depend on groundwater, creating a high cost for the water provider and therefore – depending how costs are passed on – to consumers and/or the government which may have to subsidise treatment. Saline water can also corrode pumps, pipes and other equipment, leading to higher repair/replacement costs. Salinisation renders groundwater-based irrigation impossible, taking some coastal areas out of production and forcing populations to move inland. Some pilot projects are experimenting with growing halophyte crops to restore these areas to production (e.g. in Tamil Nadu), and with salt-tolerant rice varieties and aquaculture with salt-tolerant fish (e.g. in Indonesia). In a similar fashion, groundwater overabstraction can draw down polluted surface or subsurface water into deeper aquifers, which again can render supplies unusable or increase the costs of treatment.

4. **Drainage and compacting of sediments causes land subsidence**

Falling water tables where the geology consists of unconsolidated sediments can lead to compaction which causes land subsidence. In urban areas in particular this can cause substantial damage to infrastructure. In Bangkok, groundwater overexploitation was caused by uncontrolled groundwater exploitation for a combination of municipal water supply, small diameter wells serving private apartment blocks, and larger boreholes drilled for industrial and commercial users. Before groundwater use controls were introduced in the 1990s, this led to subsidence rates of more than 10cm per year in some parts of the city (Buapeng and Foster, 2004). This has caused damage to infrastructure including canals, drains, sewers, bridges, roads, railways, levees and buildings. It has also increased the vulnerability of these areas to floods during tidal surges; major floods in 1983, 1995 and 1996 cost billions of baht (equivalent to tens of millions of USD) (UNEP, 2001). In rural areas, subsidence can also cause problems with waterlogging and poor drainage, and can take important productive lands out of production (e.g. in Iran; FAO, 2011). Compaction of shallow sediments also reduces their potential for future water storage.

Morris et al (2003, p.26) provide useful summary tables of the hydrogeological settings in which different impacts of groundwater depletion are likely to occur (adapted as table 7 below), which could be used as indicators of exposure.

Table 8. Susceptibility to side-effects of excessive groundwater abstraction in different hydrogeological settings (adapted from Morris et al., 2003)

Aquifer type	Saline intrusion or upconing	Land subsidence	Induced pollution
Alluvial / coastal plain sediments (coastal)	Major effects	Major effects	Major effects
Alluvial / coastal plain sediments (inland)	Occurrences known	Occurrences known	Major effects
Intermontane valley fill	Major effects where lacustrine deposits are present. Occurrences known elsewhere.	Major effects where lacustrine deposits are present.	Major effects where lacustrine deposits are absent and where permeable lavas/breccas are present. Occurrences known elsewhere.
Glacial deposits	Occurrences known	Occurrences known	Major effects
Loessic plateau deposits	Occurrences known	Occurrences known	Rare / non-existent
Consolidated sedimentary aquifers	Major effects	Occurreneces known where there are overlying compatable aquitards	Occurrences known
Recent coastal calcareous formations	Major effects	Rare / non-existent	Major effects
Extensive volcanic terrains	Major effects	Rare / non-existent	Major effects
Weathered basement complex	Rare / non-existent	Rare / non-existent	Major effects

4.3 Resilience of the socio-economic systems

We now examine two pathways from degradation to economic impact in more detail: via economic uses of water, and via negative effects on health. For each there are various mitigation strategies which may be adopted, but these will depend on whether certain constraints apply.

Impacts via economic uses of water

Most of these different impacts in fact converge on a similar impact pathway when it comes to understanding economic impacts. In most of these examples, the immediate fact is that water becomes less easy to access, which makes economic uses of water difficult and/or costly.

However, the impact can be mitigated when water users (be they households, small farms, large businesses or public providers) 'choose' any of following responses to avoid a loss of economic activity and income:

- Spend more on accessing water (e.g. pumping deeper, treating contaminated water)
- Change to an alternative water source (e.g. relocate boreholes, divert surface water)
- Relocate/migrate to an area with more abundant or higher quality water resources
- Adopt a less water-dependent livelihood/business strategy (e.g. a farming household moves out of agriculture to look for urban jobs)
- A complementary cost-saving strategy is to increase the efficiency of water use, for example by changing irrigation technology, upgrading industrial processes, or reducing leakage.

Clearly the extent to which these responses are possible depends on various contextual factors. For agricultural households affected by falling productivity due to water degradation, the pathways to economic impacts of water degradation are similar to those caused by land degradation, in terms of decreasing farm incomes and increasing costs to consumers. For those farmers who face unmanageable constraints in adopting the above mitigating strategies (e.g. if they have no access to new technologies, live in an area without urban job opportunities, cannot afford to invest in increasing supply or to relocate, or face land or water shortages preventing successful farming in a new location), significant poverty impacts are possible.

Many of the variables and indicators that could explain whether or not households are able to adopt these strategies are similar to those outlined in the section on factors affecting the impacts of land degradation. However, some indicators relate to the nature of water availability (see table 8 below), for example the depth to groundwater (a proxy for the cost of pumping) and the availability of alternative water sources. These indicators are generally national in scale. Of course within a country, there will be households and businesses which can adapt to degradation, and some which cannot. The national indicators are suggested to be useful for global modelling purposes, and to indicate the likely *aggregate* cost of degradation. But it is important to recall that even if many households can successfully adapt, degradation may still have very severe impacts on the poverty and food security of the poorest and most vulnerable within society if they depend on irrigation or fisheries for their livelihoods or to obtain a varied diet. Indeed it is important to note that resource degradation may be seen as likely to increase inequality, because better-off households will be able to invest in coping strategies to maintain production, while poor households may become destitute.

Another important caveat surrounds the indicators related to the availability of alternative water supplies. In the short to medium term these will mitigate the effect of degradation in a specific location, from the perspective of the national economy (as people can move, production can be switched to water-abundant areas, or water diversions can be considered). However, by continuing the exploitation patterns which degraded the resource in one place, it is likely that new resources will in turn become depleted and degraded themselves. It is therefore not appropriate to assume that just because a country currently has a low impact of degradation, it is necessarily on a sustainable path and will not have severe impacts in the future, if there is no long term resource management plan. This depends on the renewability of the resource in question, and the extent to which exploitation of the new resource remains within sustainable limits.

Impacts via health

Reductions in available safe water supply affect health in a number of ways: by forcing people to use poorer quality water, by forcing people to travel further for water (which can involve arduous journeys, undertaken mainly by women and girls including at times when this could be risky, e.g. during pregnancy and old age), or by encouraging people to use less water. In 1984, for example, drought combined with high rates of pumping in eastern India drew down the water table such that thousands of shallow wells used for drinking water became unusable. Poor households were forced to use poor quality, polluted alternative water sources and thousands died from dysentery and other disease (Kahnert & Levine, 1993). When households restrict water use in order to save time, the water use which they typically sacrifice is hygiene (see discussion in Tucker et al, 2013), in spite of the documented links between handwashing and prevention of both waterborne diseases and skin conditions. Impacts on public health are potentially also severe if municipal water supplies in large cities fail or are subject to stoppages/rationing, as disease can spread quickly through dense urban communities if hygiene is poor.

Poor health translates into economic impacts through acute disease episodes, when people have to miss work due to sickness, or cannot work on their own farms. Chronic exposure of people to waterborne disease also contributes to long term physical and cognitive impairment, with impacts on future labour productivity and educational success (Bartram and Cairncross, 2010). The costs of treatment for waterborne diseases are also substantial, to both households and the public purse. The global cost of health impacts due to inadequate drinking water supply and poor hygiene practices has been estimated at around USD 72 billion (Hutton et al, 2007).

In both rural and urban areas, the extent to which health impacts occur as a result of water degradation will depend on the availability and cost of alternative water supplies or water treatment technology. The extent to which health impacts translate into economic impacts will depend on factors including:

- Availability and cost of medical treatment
- Poor nutrition that would compound negative health effects
- Levels of employment (i.e. whether sickness turns into lost income and productivity)

Based on these pathways, the following set of indicators is suggested as relevant for attempting to model the socio-economic impact of groundwater depletion at national level. For factors for which no data exist, such as access to new production technologies, proxies are proposed – in this case measures of rural-urban connectedness and access to electricity and communications.

Table 9: Specific indicators for water degradation

Big picture	**Source**
GDP per capita in current USD	World Bank
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	World Bank
% agriculture in GDP	World Bank
% employment in agriculture (WDI) (LF in agriculture as % of total LF)	World Bank
Political stability and conflict	
CPIA transparency, accountability, and corruption in the public sector rating (1=low to 6=high)	World Bank
Gini Index	World Bank
Agricultural production system	
Indicators of water use in agriculture	
% of total grain production irrigated	AQUASTAT
Total harvested irrigated crop area (as % of total cultivated area, full control irrigation)	AQUASTAT
Area equipped for irrigation (all) (1000ha)	AQUASTAT
Area equipped for power irrigation (1000ha)	AQUASTAT
Area equipped for irrigation from groundwater	AQUASTAT
Agricultural water withdrawal as % of total actual renewable water resources	AQUASTAT
Population density (people per sq. km of land area)	World Bank
% population in urban/rural areas	World Bank
Availability of production factors	
Water	
Total actual renewable water resources per capita (per year)	AQUASTAT
Freshwater withdrawals as % of total actual renewable water resources (%)	AQUASTAT
Total dam capacity (km3)	AQUASTAT
Dam capacity per capita (km3/inhab)	AQUASTAT

Average depth to groundwater (proxy for cost of pumping)	Not freely available but recently mapped by Fan et al (2013)
Price of water for irrigation (to households, businesses, public schemes)?	Not globally available but national data may exist
Water rights regime	Not globally available but national data may exist
Labour	
Population density (people per sq. km of land area)	World Bank
% Employment in agriculture (WDI) (LF in agriculture as % of total LF)	World Bank
Schooling levels	
a) literacy rate total/urban/rural	World Bank/national Demographic and Health Surveys
b) Labour force with primary education (% of total)	Not globally available but national data may exist
Health status of population(life expectancy at birth)	World Health Organisation
Capital	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	
Access to transportation and communication infrastructure (suggested proxies for access to credit)	
a)Indicator summarises the quality of trade and transport related infrastructure (e.g. ports, railroads, roads, information technology), on a rating ranging from 1 (very low) to 5 (very high)	World Bank
b) Road density (km of road per 100 sq. km of land area)	World Bank
c) Mobile cellular subscriptions (per 100 people)	World Bank
d) Access to electricity (% of population)	World Bank
Access to a variety of production technology	
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	World Bank
Access to transport and communication infrastructure (various indicators)	See above
transportation and communication infrastructure	see above
Access to other income-generating activities	
Rural Urban connection	see above
% employment in agriculture (WDI) (LF in agriculture as % of total LF)	World Bank
Schooling rates	see above
Availability of substitutable products	
Access to transport and communication infrastructure (see above)	see above
Food imports (% of merchandise imports)	World Bank
Presence of ports (is the country landlocked)	
Government policies	
Government expenditure on education (% of GDP)	World Bank
Government expenditure on health (% of GDP)	World Bank

4.4 Socio-economic impacts

The actual socio-economic impacts of water degradation are now illustrated through a number of case studies, drawn from the World Bank Country Evaluation Analysis and by further literature review.

Case studies using the country evaluation analysis

The World Bank and the Country Evaluation Analysis (CEA) reports use several different methods to calculate the costs of water degradation

To calculate the human loss due to water degradation, CEA uses Disability Adjusted Life Years (DALYs). DALYs measure the years of healthy life lost to illness and premature mortality, with a weighting function that adjusts for the impacts of death and illness at different ages. To calculate DALYs, the number of years of healthy life lost to illness and years of life with disability are summed. The total number of DALYs can then be converted to a monetary value by transforming a DALY to GDP and thus the cost of illness as a per cent of GDP can be calculated.

For determining the costs of water degradation as a per cent of GDP, these steps are followed using DALYs for waterborne illness such as diarrheal illness. Because cases of diarrheal morbidity are often left untreated, or are treated by private clinics that do not report to public health authorities, a survey of households is often the most telling indicator of diarrheal morbidity prevalence. Additional costs are calculated using the Aversion and Mitigating Behaviour Approach. This approach measures the costs of environmental degradation taking into account the costs that individuals pay in order to avoid or reduce the harmful effects of degradation. In the case of water contamination, costs included are those associated with measures taken to prevent or mitigate the risks of illness, such as visiting the doctor, taking medications, boiling drinking water, investing in water filters, and building public and personal wells to replace those affected by overexploitation.

Where available, the annual costs of agricultural losses due to water quality deterioration, as well as annual losses due to reservoir sedimentation and operating industrial wastewater treatment plants have also been included. Additionally, the CEA report on Jordan highlighted an individual's willingness-to-pay (WTP) for municipal waste collection as a component of water degradation costs. WTP is the amount an individual is willing and able to pay for a reduction in the risk of death or the risk of experiencing illness. In this case, it is the amount that an individual is willing and able to pay to have municipal waste collection in order to reduce the risk of death or illness as a result of water contaminated by waste runoff. Table 9 below offers a comparative glance at the cost of water degradation in the seven countries examined.

Table 10:The costs of water degradation as per cent of GDP

Country	Cost of Water Degradation as % GDP (Poor Water Sanitation and Availability)	Size of Agricultural Sector (as per cent of GDP)	% of Population living in Urban Area	Proportion of total land irrigated (as percentage)
Jordan	0.81	4.5	79	0.92
El Salvador	1.00	10.5	64	2.17
Guatemala	1.60 (waterborne illnesses only)	13.0	49	1.87
Colombia	1.05	6.8	75	0.79

Pakistan	1.84	20.1	36	25.78
Nigeria	1.30	30.9	50	0.32
Nepal	1.20	38.1	24	8.15

There are several factors that have the potential to influence the impact of water degradation on a country's GDP such as the economy's reliance on its agriculture sector, the use of pesticides, and the legal framework surrounding waste dumping. The factors highlighted in Table 7 include the size of the agricultural sector and the per cent of the population living in an urban area. The cost of water degradation appears correlated to these two indicators, particularly the agricultural sector. The total effects are quite substantial, mostly between 1-2% of GDP.

Further country evidence on water degradation

The following case studies illustrate the above pathways and provide evidence on the socio-economic impacts of groundwater degradation. The tables with relevant indicators for each country are presented in appendix A.

India

Over the past four decades, groundwater has become India's most important fresh water source. It plays an extremely important role in providing irrigation for agricultural land in India. Specifically, it is estimated that around 75-80% of irrigated land across the country depends on wells and tube-wells for its water supply (Shah, 2009). Moreover, it is estimated that nowadays, 30 million groundwater constructions are in use (Shah, 2013).

Small-scale farmers and entrepreneurs, encouraged by the easy availability of groundwater, have driven this development by constructing their own wells. Further incentives stemmed from the power subsidies granted to agriculture, making the digging as well as the pumping process relatively cheap (Wyrwoll, 2012). By securing their own water, farmers find it less risky to invest more in the production of their crops (e.g. high-quality seeds, fertilizer), thereby boosting productivity (IWMI, 2002).

This evolution was facilitated by the fact that groundwater exploitation exists almost entirely within the informal and private sector and therefore largely goes unregulated (Shah, 2003). However, this uncontrolled pumping of groundwater for irrigation has led to unsustainable exploitation rates. Almost 60% of all *Indian districts* are facing groundwater problems related to quality and/or quantity, with overdraft concentrated in the west of the country. Recent studies have shown that between 2002 and 2008, India saw a loss in water of about 109 cubic km of water, leading to a decline in water table to the extent of 3-5 cm per annum (Shah, 2013). Subsidence of land resulting from groundwater exploitation has not been widely documented in India, but has been reported in parts of West Bengal and some warnings have been issued for cities including Kolkata (as cities are islands of intensive localised abstraction) (Ganguli, 2011; Sahu and Sikdar, 2011).

These groundwater problems are especially important for the poorer part of the population. The boost in productivity that is associated with the increase in the use of groundwater for irrigation has proportionally benefitted the poor precisely due to the fact that groundwater is easily available and more accessible than large dams and large-scale surface water irrigation projects (IWMI, 2002). Therefore, while groundwater irrigation could serve as a poverty reduction tool when properly managed, its degradation could lead to problems in terms of collapses in yields and harvest for these poor and vulnerable households.

Those who can afford it, continue to dig deeper, thereby contaminating the water with fluoride, arsenic and uranium, (Shah, 2013). However, the majority of the population are losing safe access to groundwater resources for drinking water and irrigation. All over the country, farmers are seeing their agricultural income decrease, along with loss of employment. Some have decided to seek for employment elsewhere. Others end up in debt spirals in a search for water. In some cases, land has been sold in order to survive, increasing inequality in land holdings. Financial stress has ultimately led to large number of farmer suicides (Moench, 2002; Garduño, 2009; Shah et al, 2003).

The experiences in this case suggest that the water degradation can have an important impact on inequality and poverty.

Nigeria

Nigeria is struggling with severe water pollution problems. More precisely, research indicates that the majority of Nigeria's fresh water sources are polluted. Fresh water is reported to contain all kinds of germs, viruses, heavy metals, bacteria and dust particles (Galadima et al, 2011). Part of the pollution can be attributed to household level factors. Because of the poor state of sewage and waste disposal systems, households end up dumping their waste on the streets or in the surrounding area. Another important contributor to the pollution problem, are the local markets. Cans, plastic bags, faeces and other animal waste end up on the side of the road and in the gutters whose final destination are lakes and streams. Oil spill induced pollution is another important problem, if not the most important one, mainly as a result of poorly maintained and monitored pipelines as well as sabotage (Ekubo and Abowei, 2011). Finally, the agricultural sector is adding to water pollution through processes of erosion and chemical runoffs.

All of these factors are both contaminating groundwater and surface water. Given the central role the resource plays in almost every aspect of people's lives (economical as well as private) this is a major threat to human well-being. First of all, polluted water, when consumed directly, increases morbidity. More precisely, people drinking this water are at risk of getting infected with typhoid, dysentery, cholera, hepatitis-E and many other diseases. For example, a recent study found that 19% of Nigeria's population is affected by urinary schistosomiasis with some communities having incidences of 50% (Galadima et al, 2011). Infants and babies share disproportional in the casualties, represented by a high infant annual mortality rate of 78 infants dying per 1000 live births (compared to an average of SSA of 69.3) (World Bank). More precisely, the WHO estimates that diarrheal diseases, which are closely related to poor water, caused the deaths of around 124,400 children under five years old in Nigeria in 2008 (Sanitation and Water for All, 2012). In addition, heavy metal poisoning has been reported to lead to skin rashes, partial parallelization, blindness and death (Galadima et al, 2011). Note that these are only a few examples of the damage that polluted water can cause to people's health. Furthermore, pollution of Nigeria's fresh water resources has also contaminated other resources. More precisely, fisheries and land resources have been affected significantly (WHO/UNEP 1997).

Access to poor water and poor sanitation on a large scale will have economic effects. Simply put, an unhealthy labour force depending on affected inputs (land, water) will have lower productivity rates than a healthy labour force having access to decent inputs. WSP has estimated that poor sanitation costs Nigeria 3 billion USD (=20 USD per person) or 1.3% of the national GDP per year. However, these numbers might be underestimated because, amongst others, costs associated with funerals as well as those related to cognitive underdevelopment of Nigeria's labour force stemming from diarrhea-related undernourishment and stunting, have not been taken into consideration. Furthermore, water pollution related diseases especially the hit hard on poor households, thus increasing inequality.

At the household level, water related productivity decreases lead to food insecurity and poverty. Moreover, because it is reasonable to assume that household members depend on the same water sources, illness is likely to cluster within households. Likewise, because of the limited amount of fresh water sources available, one could say that morbidity is likely to cluster within communities, meaning that it should be treated as a common shock against which insurance is difficult, especially in the absence of developed credit and insurance markets.

4.5 Conclusions

This section has outlined a number of important types of water degradation, including (i) surface water depletion and river fragmentation; (ii) pollution / contamination if surface and groundwater; and (iii) ground water depletion.

Water degradation is a serious and growing concern worldwide. This damage has socio-economic impacts, mediated by through a number of transmission mechanisms, principally:

- Impacts on human health, which reduce the productivity of labour (in agriculture, industry and other sectors), cost households in medical treatment costs and cost national budgets in the cost of healthcare provision.
- Impacts on the productivity (yields and quality) of irrigated crops, industrial products and fisheries and aquaculture, which may be a significant component of national economies and/or may be critical for the livelihoods and food security of poor communities.
- Increased costs of water abstraction and treatment, which are passed on to water users, be they households, farms, businesses or national/municipal governments
- Impacts on energy production, from hydropower but also from other sources which require cooling water, which can raise the cost of electricity (to all users, public and private) and in some cases may cause outages affecting both human safety and productivity.
- Damage to infrastructure, which hinders mobility and production, burdens government, businesses and individuals with the cost of repair/replacement.

However, although it is evident that groundwater depletion can cause significant problems, and has the potential to generate huge costs given the importance of groundwater to global food production, some argue that 'unsustainable' groundwater abstraction might be desirable in the short to medium term. Across much of North Africa and the Arabian Gulf, large fossil aquifers exist which are not receiving contemporary recharge. It has been proposed that exploitation may be societally sustainable as long as investment occurs in long-term substitutes (both alternative water sources, e.g. desalination, and alternative sources of food supply than irrigated production, e.g. imports), so-called 'planned depletion' (Foster et al, 2003).

A similar argument has been made for other large aquifers which contain large volumes of stored water beyond that which recharges annually; over-exploitation may again be societally sustainable if it enables short or medium-term wealth accumulation and a transition to less water-dependent livelihoods (Moench, 2007). However, as Llamas and Martinez-Santos note, "assertive action on the part of governments and thorough stakeholder education is required in order to ensure a mid- or long-term sustainable management of the resource." In contexts such as North China and India with millions of small private groundwater users, however, identifying long term governance solutions which adequately protect the resource, while ensuring livelihoods are protected and poverty does not increase, remains a challenge.

Moreover, the section has argued that various actions can mitigate the impact of water degradation, e.g. when water users respond by (i) spending more on accessing water (e.g. pumping deeper, treating contaminated water); (ii) changing to an alternative water source (e.g. relocate boreholes, divert surface water); (iii) relocating/migrating to an area with more abundant / higher quality water resources; (iii) adopting a less water-dependent livelihood/business strategy (e.g. a farming household moves out of agriculture to look for urban jobs); (iv) increasing the efficiency of water use, for example by changing irrigation technology, upgrading industrial processes, or reducing leakage. We have argued that there are a range of indicators that can be used to measure the ability of water users to engage in such mitigation activities, although equity (*who* is able to mitigate) and the potential for further environmental degradation in another time or place must be considered.

5 Conclusions

This paper has examined the linkages between resource degradation and socio-economic outcomes, focusing on land and water degradation. The overall research aims to address some of the shortcomings in existing models and projections of economic growth and resource degradation which do not incorporate feedback mechanisms related to environmental degradation.

This paper suggests that the socio-economic impact of resource degradation depends on (i) direct transmission mechanisms; and (ii) the ability of producers and consumers to follow mitigation strategies (this could be termed economic, social and governance resilience).

The paper therefore proposes that there are four key elements to consider in such analysis, which can be applied at different scales:

- Biophysical changes, i.e. the various types of degradation and their effects on ecosystems.
- Potential socio-economic impacts of changes in ecosystems, i.e. the various transmission mechanisms to human systems, and the degree of socio-economic exposure to these.
- The resilience of socio-economic systems, i.e. possibilities for mitigation and the constraints and enablers which govern whether or not they can be adopted.
- Finally, the actual socio-economic impacts resulting from all of the above.

This model does not consider all the feedback effects between stages, for example some mitigation strategies may increase the likelihood of further resource degradation in the future.

The direct transmission mechanisms from resource degradation include issues such as the direct (and indirect) dependence on natural resources in production (which tends to be higher in an agricultural society) and consumption (depending on tastes), the level and quality of natural assets; and the type of agricultural systems being used. However, farmers or consumers might be well placed to mitigate the effects, e.g. by adopting a new production and resource management technology, diversifying into other income generating activities or simply through migration.

In practice, the direct costs of land degradation (on average already worth 1-3% of GDP at present) and water degradation (on average already worth 2-3% of GDP at present) depend on many transmission mechanisms, e.g. the steep topography in Guatemala risking landslides, the overall dependence on agriculture in Ethiopia and irreversible degradation due to pesticide use in Costa Rica.

However, the evidence and debates also suggest that degradation can actually be a source of innovation that is open to some but not others (see e.g. Malthus vs. Boserup). In general, the case studies suggest the limited ability of famers to respond, owing to lack of human or physical assets (e.g. in Madagascar). Those that do have such assets can respond to degradation, but the poorest often cannot, thus producing a poverty trap. Resource degradation may be seen as likely to increase inequality, because better-off households will be able to invest in coping strategies to maintain production, while poor households may become destitute.

We have identified a range of factors that measure the extent to which land and water degradation affects socio and economic pathways (and we have a database for developing countries). The relationships identified so far are conceptual and qualitative rather than quantitative, but this is something that could be pursued in the future.

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Appendix A – Factors driving impact

Table A1: Big picture conditions for land degradation

Indicator	Case Study		
	Madagascar	Ethiopia	Costa Rica
Big picture			
GDP per capita in current USD	465	357	8647
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	81.3%	39% (in 2005)	3.1%
% Agriculture in GDP	29%	46%	6%
% employment in agriculture (LF in agriculture as % of total LF)	69.10%	79% (in 2005)	13.2%
Political stability and conflict			
CPIA transparency, accountability, and corruption in the public sector rating (1=low to 6=high)	2.5	3	NA
Gini Index	44.1	38.8 (in 2005)	50.7
Agricultural production system			
Indicator for the proportion of landscape under each land use stage			
FAOSTAT Investment: Capital Stock - Land development (gross/net) in USD Millions	8229.75/8065.16	2892.21/2834.37	522.34/511.89
FAOSTAT Investment: Capital Stock - Livestock (fixed assets), (gross/net) in USD Millions	6424.60/6424.60	33806.96/33806.96	588.64/588.64
FAOSTAT Investment: Capital Stock - Machinery and equipment (gross/net) in USD Millions	286.91/251.05	1101.46/963.78	235.17/205.77
FAOSTAT Investment: Capital Stock - Plantation Crops (gross/net) in USD Millions	738.33/705.11	589.40/562.87	596.58/569.73
FAOSTAT Investment: Capital Stock - Structures for Livestock. (gross/net) in USD Millions	875.32/835.93	4534.84/4330.77	118.87/ 113.52
Yield of stable crop (Hg/Ha) (FAOSTAT)	26615 (rice)	13398/24931/72156 (cereals/maize/ roots and tubers)	461043 (bananas)
Gini Concentration of Holdings	0.80 (1981-1990)	0.541	0.82
Population density (people per sq. km of land area)	36	83	91
% Population in Urban/Rural areas	33%/67%	17%/83%	65%/35%

Table A2: Constraints on mitigating strategies for land degradation (elements having an impact on the opportunity cost of each mitigating strategy identified)

Indicator	Case Study		
	Madagascar	**Ethiopia**	**Costa Rica**
Availability of production factors			
Land			
FAOSTAT - Resource: Agricultural area as share of total land area	0.7118169	0.35683	0.368194281
Utilized agricultural area / Usable farmland (Area suitable for farming)	NA data sources do not distinguish	NA	NA
Gini Concentration of Holdings, 1981-1990	0.80	0.541	0.82
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	3	3	NA
Labour			
Population density (people per sq. km of land area)	36	83	91
% employment in agriculture (LF in agriculture as % of total LF)	69.10%	79% (in 2005)	13.2%
Schooling levels			
a) literacy rate	64%	70.4%/21.8 %	94%
b) Labour force with primary education (% of total)	56% (in 2005)	20.7 (1999)	46%
Capital			
FAOSTAT Investment: machinery stock (agricultural tractors, total/per 100 sq. km of arable land)	550/1.9 (both in 2004)	NA	NA
FAOSTAT Investment: Capital Stock (Land development, Livestock (fixed assets), Livestock (Inventory), (Machinery and equipment), Plantation Crops, Structures for Livestock.)	see above	see above	see above
Statistics on inputs use (FAOSTAT), Organic, NPK, Pesticides			
a) NPK complex >10kg (consumption in tonnes)	9990	1452 (in 2005)	32220
b) Pesticides (use in tonnes) Insecticides + Herbicides + Fungicides & Bactericides + Seed Treatment Insecticides + Rodenticides	241.91	612	14068.06
Transportation and communication infrastructure			
a) Indicator summarises the quality of trade and transport related infrastructure (e.g. ports, railroads, roads, information technology), on a rating ranging from 1 (very low) to 5 (very high)	2.4	2.22	2.60
b) Road density (km of road per 100 sq. km of land area)	6	4	76
c) Mobile cellular subscriptions (per 100 people)	38	17	92
d) Access to electricity (% of population)	19%	17%	99.3%
CPIA property rights and rule-based governance rating (1=low to 6=high) (level of insecurity)	3	3	NA
Access to a variety of production technology			

Poverty headcount ratio at $1.25 a day (PPP) (% of population)	81.3%	39% (in 2005)	3.1%
Constraint on access to credit - insurance	anecdotal: underdeveloped	NA	NA
Transport time or average distance to market / Communication infrastructures (roads)	see above	see above	see above
Access to electricity (% of population)	19%	17%	99.3%
Other income generating activities			
Rural Urban connection	indicators see transportation and communication	indicators see transportation and communication	see above
% employment in agriculture (LF in agriculture as % of total LF)	69.10%	79% (in 2005)	13.2%
Unemployment rate	2.3% (in 2004)	20.50%	4.9%
Schooling levels	see above	see above	see above
Availability of substitutable products			
Transport time or average distance to market / Communication infrastructure (roads)	see above	see above	see above
Food imports (% of merchandise imports)	14%	15%	9%
land locked (indicator for prices of traded goods due to transaction costs)	no	yes	no
Government policies			
Government expenditure on education (% of GDP)	3%	4.7%	6.3%
Government expenditure on health (% of GDP)	2.30%	2.6%	29.00%

Table A3: Big picture conditions for water degradation

Indicator	Case Study	
	India	**Nigeria**
Big picture		
GDP per capita in current USD	1489	1503
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	32.7%	68.0%
% agriculture in GDP	17%	33%
% employment in agriculture (WDI) (LF in agriculture as % of total LF)	53.5%	45% (in 2004)
Political stability and conflict		
CPIA transparency, accountability, and corruption in the public sector rating (1=low to 6=high)	3.5	3
Gini Index	33.4 (in 2005)	48.8
Agricultural production system		
Indicators of water use in agriculture		
% of total grain production irrigated	56%	14.2%
Total harvested irrigated crop area (as % of total cultivated area, full control irrigation)	87259	9.5 (in 1989)
Area equipped for irrigation (all) (1000ha)	66334I	293.2I
Area equipped for power irrigation (1000ha)	51543	128.2
Area equipped for irrigation from groundwater	63.68%	no data
Agricultural water withdrawal as % of total actual renewable water resources	36%	2%
Population density	382 per sq. km	174
% population in urban/rural areas	69%/31%	50%/50%

Table A4: Constraints on mitigating strategies for water degradation

(elements having an impact on the opportunity cost of each mitigating strategy identified)

Indicator	Case Study	
	India	**Nigeria**
Availability of production factors		
Water		
Total actual renewable water resources per capita (per year)	1539	1762
Freshwater withdrawals as % of total actual renewable water resources (%)	33.88%	4.58%
Total dam capacity	224 km3	45.62 km3
Dam capacity per capita (km3/inhabitant)	190.8K	280.8K
Average depth to groundwater (proxy for cost of pumping)	NA	NA
Average distance to surface water (lake/river) - or other measure of whether population concentrations align with surface water availability?	NA	NA
Price of water for irrigation (to households, businesses, public schemes)?	NA	NA
Water rights regime	largely within the informal and private sector and user based	NA
Labour		
Population density	382 per sq. km	174 per sq. km
% Employment in agriculture (WDI) (LF in agriculture as % of total LF)	53.5%	45% (in 2004)
Schooling levels		
a) Literacy rate total/urban/rural	64.8%/79.9%/ 58.7%	61%/70.9%/46.8%
b) Labour force with primary education (% of total)	NA	NA
Capital		
Transportation and communication infrastructure		
a) Indicator summarises the quality of trade and transport related infrastructure (e.g. ports, railroads, roads, information technology), on a rating ranging from 1 (very low) to 5 (very high)	2.87	2.27
b) Road density (km of road per 100 sq. km of land area)	125	21 (in 2004)
c) Mobile cellular subscriptions (per 100 people)	72	58
d) Access to electricity (% of population)	66.3%	50.6%
Access to a variety of production technology		
Poverty headcount ratio at $1.25 a day (PPP) (% of population)	32.7%	68.0%
Constraint on access to credit - insurance	see word doc	NA
Transport time or average distance to market / Communication infrastructures	see above	see above
Other income generating activities		
Rural Urban connection (distance to nearest town / market centre?)	see transportation and communication infrastructure	see above
% Employment in agriculture (WDI) (LF in agriculture as % of total LF)	53.5%	45% (in 2004)
Unemployment rate	4.3% (in 2000)	NA
Schooling levels	see above	see above
Availability of substitutable products		
Transport time or average distance to market / Communication infrastructures (roads)	see above	see above
Food imports (% of merchandise imports)	4%	10%
landlocked or not	no	no
Government policies		
Government expenditure on education (% of GDP)	3.3%	4.7%
Government expenditure on health (% of GDP)	1.2%	1.9%

Appendix B- Flow charts summarising pathways from environmental degradation to socio-economic impacts

Figure B1. Land

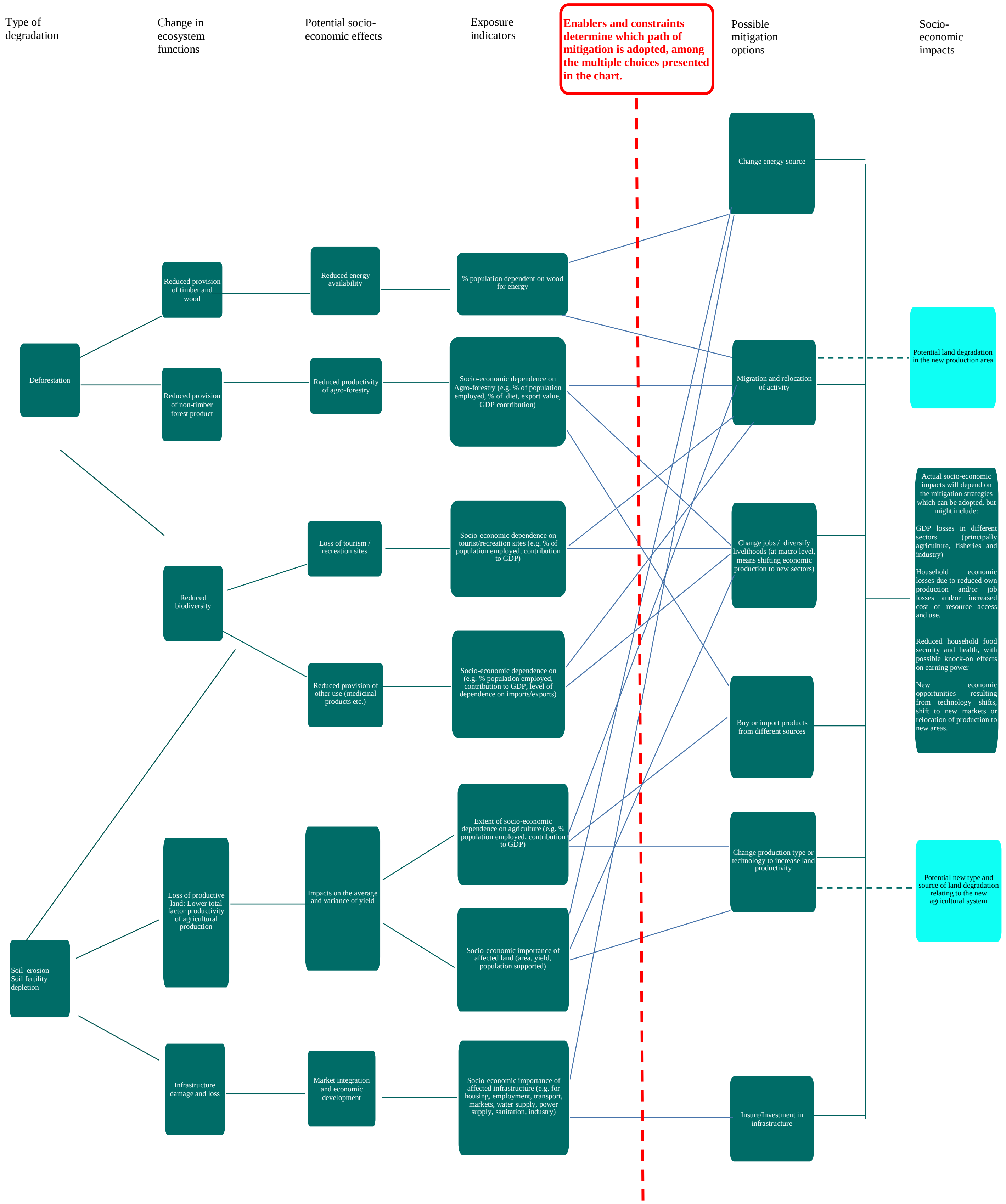
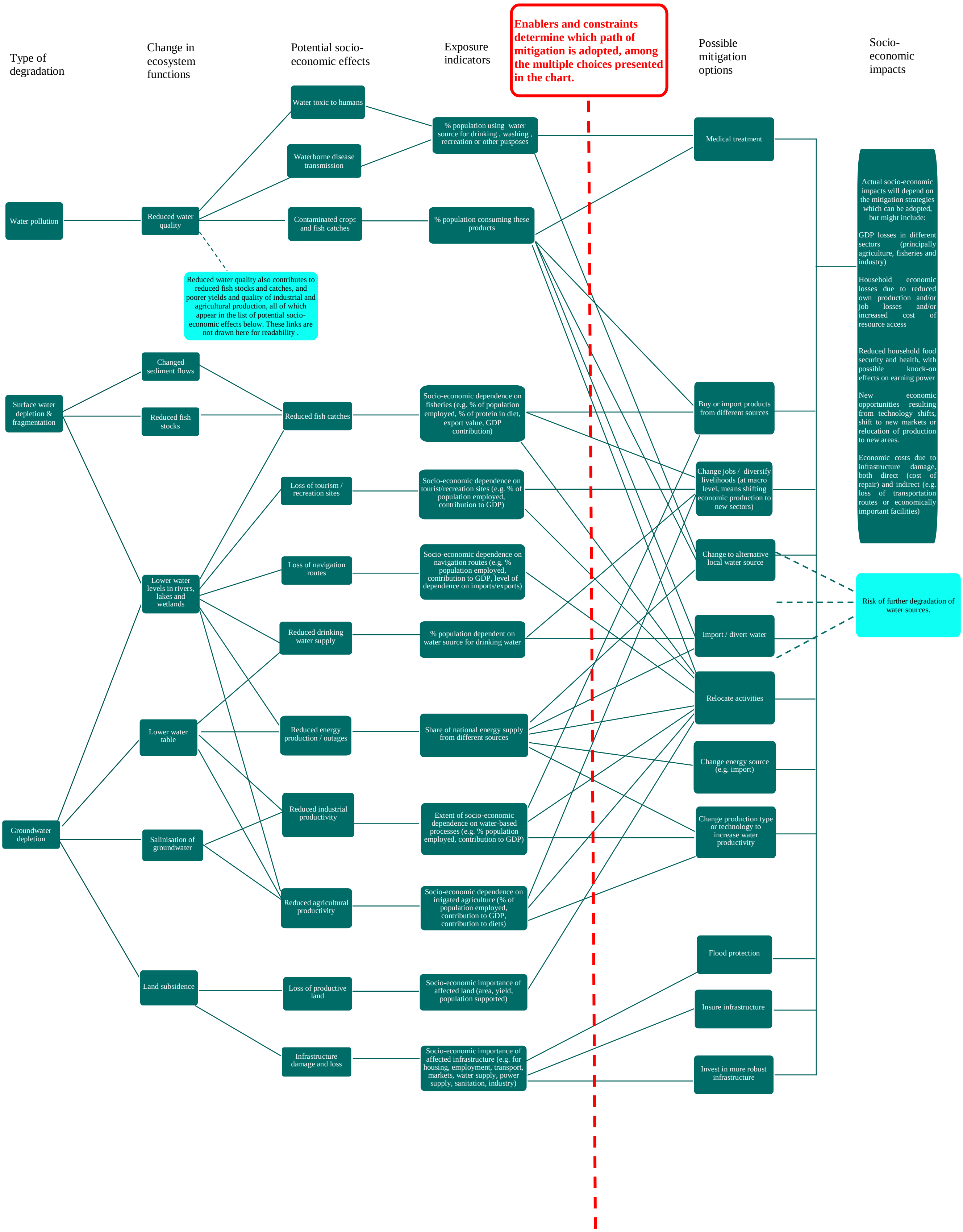


Figure B2. Water



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