Food and Agriculture Organization
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Development of a methodological framework for the State of Land and Water Resources 2021

Driving force-Pressure-State-Impact-Response Framework for land, soil and water resources for agriculture

SOLAW21 Technical background report

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Contents

Figures

Tables

Introduction

Land and water resources are central to agriculture and rural development and they are critical to meeting the global challenges of climate change, food insecurity and poverty. The State of the World's Land and Water Resources for Food and Agriculture (SOLAW), a flagship report of the Food and Agriculture Organization of the United Nations (FAO), which is published every decade, presents comprehensive information and analyses on the current state, trends and challenges related to land and water resources. The first edition of SOLAW was published in 2011.

The major objectives of SOLAW 2011 were to raise awareness of the status of land and water resources, to highlight the risks facing them, to document identified hotspots and identify challenges and opportunities. SOLAW 2011 also emphasized the essential but often understated contribution that appropriate policies, institutions and investments make to ensure equitable access to resources and their sustainable and productive management, while contributing to economic development. The report presented options and strategies for addressing issues such as water scarcity and land degradation.

There have been many important developments since the launch of SOLAW in 2011. The new edition of SOLAW (SOLAW 21) updates the earlier version with a review of status, trends and challenges in land and water resources in light of recent global developments and international commitments. It highlights various opportunities to foster a practical shift toward more sustainable management of land and water resources and provides recommendations for options and actions. SOLAW 21 aims to assist decision-makers, practitioners and the private sector to lead and support a transformative process to move from degradation and vulnerability to sustainability and resilience.
The Driving force-Pressure-State-Impact-Response framework (DPSIR) describes the links and interdependencies between the environment, socioeconomics and sustainable agricultural production systems. While SOLAW 2011 does not explicitly mention the use of DPSIR methodology, its structure broadly followed the DPSIR framework. The preparation of SOLAW 21 made formal use of the framework to build on (and update where needed) the various indicators established by the first SOLAW to identify drivers of change, pressures, impacts and possible response options available to decisionmakers.

This report presents the DPSIR methodological framework used for SOLAW 21 and the indicators used for assessing the state of land and water for agriculture. It identifies the SDG targets relevant to the SOLAW report, and synergies and tradeoffs in the context of sustainable agricultural management.

Background on Driving force-Pressure-State-Impact-Response Framework for land, soil and water resources for agriculture

The assessment of agricultural sustainability is complex, encompassing multifaceted interactions between technology, the environment, natural resources, policy, economics and society. The identification of suitable policy strategies that respond to such dynamic, interacting systems is even more complex. It requires the assessment of sustainable rural livelihoods, emphasizing the social and economic dimensions of sustainable development at a local or micro scale, while assessing the environmental impacts of the use and management of critical resources at global, regional and local scales to ensure effective and efficient response options that are appropriate at different levels.

The DPSIR model evolved from the Pressure-State-Response (PSR) framework, which was devised by the Organisation for Economic Co-operation and Development (OECD) to address the problem of systematic identification of indicators for environmental sustainability for the first time (OECD, 1993). The PSR framework was itself based on the Stress Response framework developed earlier for ecosystems analysis. The PSR framework relies on the simple concept of causality: human activities exert pressure on the environment and change its state. Society responds to these changes with environmental, economic, and other actions and policies. The activities resulting from these actions and policies, in turn, exert pressures of their own, completing the PSR feedback loop. Later, the DPSIR framework was elaborated and adopted by European Environmental Agency to analyse the interacting processes of human environmental systems and capture the cause and effect relationships between social, economic and environmental systems (Burkhard and Müller, 2008; European Environment Agency, 1995; Svarstad *et al.*, 2008).

DPSIR framework has been used in more than 25 countries to analyse the land status and trends at local and national levels. The Land Degradation Assessment in Dryland (LADA)[1] project used the DPSIR framework to describe the interaction between society and the environment with the aim of improving the ability to diagnose land degradation and its impacts.

DPSIR has a simple structure, which allows the capture of complicated relationships and helps in framing policy responses that can mitigate and adapt to direct and indirect impacts; this has led to its widespread adoption (Bunning *et al.*, 2016). However, the framework has certain shortcomings. For example, DPSIR ignores temporal and spatial scale issues; it overlooks social or political aspects and provides limited coverage ecosystem service approaches. Thus, it may be difficult to gather a complete and consistent picture of the operations of the causality chain, particularly in agriculture (Kohsaka, 2010; Rao and Rogers, 2006, Maxim *et al.*, 2009; Potschin, 2009; Spangenberg *et*

[1] The Land Degradation Assessment in Drylands (LADA) was a global project supported by the Global Environment Facility, FAO and the United Nations Environment Programme. LADA developed assessment tools to collect up-to-date information on the status, impact and drivers of land degradation at local, national and global levels. LADA developed a flexible methodological framework involving DPSIR that relies on traditional and digitally assisted methods of data collection, and produced an overview of the global status, pressures and causes of land degradation, indicating hot spots and bright spots. The methodology was tested it in six pilot countries – Argentina, China, Cuba, Senegal, South Africa and Tunisia (Nachtergaele et al. 2008).

al., 2015; Svarstad *et al*., 2008). An additional challenge in the application of DPSIR is the need to develop a common framework that links assessments at different scales.The

causal links between humans, environment, and socioeconomics needs to standardized at the global level assessment, while considering agroecosystems analysis and sustainable livelihoods assessments at more localized and regional levels. Despite such limitations, DPSIR remains a commonly used framework due to its pragmatic structure. For this report, DPSIR was used to enhance the understanding of cause and effect relationships and to assist in developing key policy recommendations to advance the sustainable management of land and water resources. The framework was slightly modified to overcome some limitations, with particular emphasis given to differentiating between global and regional/subregional frameworks.

There are several DPSIR models that address the causal links affecting land, water and soil as individual resources. But given the clear links between the three resources, our intention in this report was to capture the relationships between land, water and soil in agricultural systems.

Driving force-Pressure-State-Impact-Response Framework for the State of Land and Water Resources 2021

This report proposes an adapted DPSIR framework that can generate a picture of the state of the land, vegetation cover, water and soil resources; the direction and nature of changes in the use of these resources; and the effectiveness of technical, institutional and policy responses to mitigate and adapt to land, soil and water degradation.

In the classic DPSIR framework, *drivers* are the factors exogenous to an agricultural system (including land, water and soil) that put the system under stress through increased human activities. The *pressures* are the stresses placed on the system due to the human reactions to the exogenous drivers. The *state* represents the condition of the systems (quality and quantity) over a given period. The state of the system changes over time due to the pressures. The *impact* indicates the influences on flows and services in the ecosystem, agriculture, and economy that are determined by the pressures and state of the systems. The *response* variable in the DPSIR represents the actions taken at different levels to sustain services from the natural systems while minimizing the negative externalities.

The adapted DPSIR framework proposed here will link the three dimensions of sustainability (environmental, economic, and social equity) and the governance and institutions cutting across them. The different elements used in the framework are aligned with SDG targets and goals. The framework is defined on a global scale; however, it could be applied to regional or national contexts with suitable modifications.

The key features of the adapted DPSIR are the following:

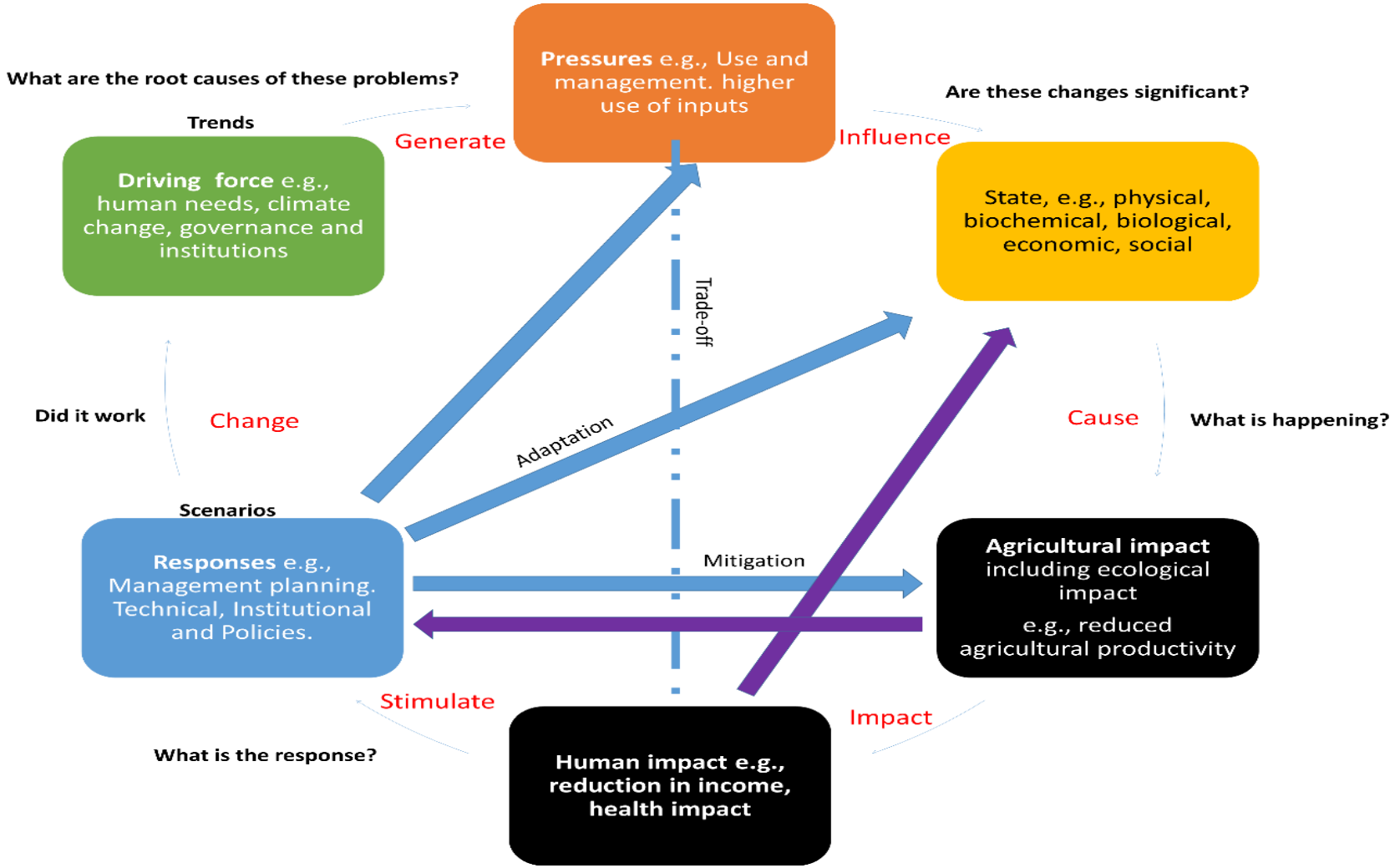
- It provides decision-makers and stakeholders at different levels with information to guide the selection and implementation of appropriate actions to enhance the sustainable management of land and water resources.
- It complements ecosystem and sustainable livelihood frameworks to clarify the impacts of current land uses and management practices on ecosystem goods and services and the livelihoods of local people.
- It links to the global policy agenda, such as the 2030 Agenda for Sustainable Development. It links SDG indicators to several drivers, pressures, state, and impacts while aligning different SDG targets with the responses.
- It follows a dynamic approach and differentiates between state and flow variables. This is useful for understanding long and short term impacts, for formulating policy, technical and institution responses and understanding response variables, which can help achieve resilience.
- It captures the conditions of the land, water and soil in an integrated manner through the state of ecosystem resources, which are defined as assets and services.
- It allows a comparison of the economic benefits (e.g., avoided cost of inaction) and costs of different technical and policy responses, while evaluating institutional

policy, and behavioral responses and the impact of policy options outside the land and water management domain.

- It is expected to support an informed decision-making process on how to prioritize actions. It should also assist in identifying policy misalignments, gaps, overlaps and implementation deficits to provide better guidance on policy options.

The components of the DPSIR framework are defined as follows (see Figure 1):

Figure 1. Interactions in Driving force-Pressure-State-Impact-Response Framework



Source: Authors' own elaboration.

Drivers. In the context of the DPSIR framework, drivers are defined as any natural or human-induced factor that directly or indirectly brings about change in an agricultural system (Hazell and Wood, 2008). The driving forces for SOLAW 21 include market drivers that increase or change consumption, natural drivers and drivers related to changes in governance, institutions and policies. The market driver around consumption reflects the evolving needs of society, for example, the growing demand for food, shelter and water because of population growth, changing employment rates and increasing income. Additional driving force factors include unequal distribution of knowledge and technology application as evidenced by growing knowledge and technology driven agriculture on the one hand, and gaps in knowledge and lower levels of technology deployment to farmers on the other. Agricultural systems can also be affected by rising inequalities in access to land and water, poverty, changing consumption habits, increasing obesity, food waste and changing production technologies. Human-induced climate change and other natural factors affect the sustainability of the land, water and soil, including greenhouse gas (GHG) concentrations, floods and drought events, forest fires, atmospheric transport and deposition, and uneven rainfall distribution. Changing land and water rights, access to agricultural extension services, institutional failures (at different scales) along the value chain leading to postharvest loss, are some governance factors bringing change.

Different international and regional trading agreements, facilitated by organizations such as the World Trade Organization (WTO) affect soil-land-water systems (particularly agricultural production) around the world. For example, in the agriculture sector, international trade has increased by many times over the past few decades. Some countries have taken advantage of this and have increased their exports of non-traditional products, whereas other countries have lost significant market share (Hazell and Wood, 2008).

The drivers in the DPSIR framework can also be characterized at a local level and explained using a sustainable livelihood approach. The drivers can be classified as different forms of capital – social, human, natural, social, financial and physical – that interact with policies, governance and institutions to affect the sustainability of land, water and soil management.

Pressures. The activities provoked by the drivers create pressures by – among other things – changing production systems and the level and type of resource use; bringing about landuse changes; and influencing the movement of soil, contaminants and nutrients, which causes changes in environmental conditions. They include human-induced pressures as well as natural processes and disasters.

The pressures category includes resource use, since the management of land, water and soil exerts pressure on the stock of natural resources. That can lead to continuous cultivation, the intensification of land, water and soil use, the overextraction of groundwater, and the adoption of risky land management practices such as cultivation on slopes, deforestation, overgrazing and land abandonment.

Along the agricultural value chain, pressures manifest in the input sector, where there is evidence of changing dynamics in input use because of changes in fertilizer and energy prices, interdependence of the factors, and market concentration. Pressures also include the intensification of resource use and water pollution due to the intensive use of

agrochemicals, pesticides and fertilizers; the release of contaminated effluents in and near catchments; irrigation with untreated wastewater, livestock waste and greenhouse gases.

States. Agriculture and sustainable resource use are categorized by their: i) physical state, ii) biogeochemical state, iii) biological state, iv) economic state, and v) social state, all of which can be affected by pressures

The physical state captures dynamic physical changes in the soil, land and water, for example, the loss of topsoil, salinization, deforestation, loss of vegetation cover, increased fluctuation of surface water, groundwater depletion, and degree of land degradation, desertification or water scarcity.

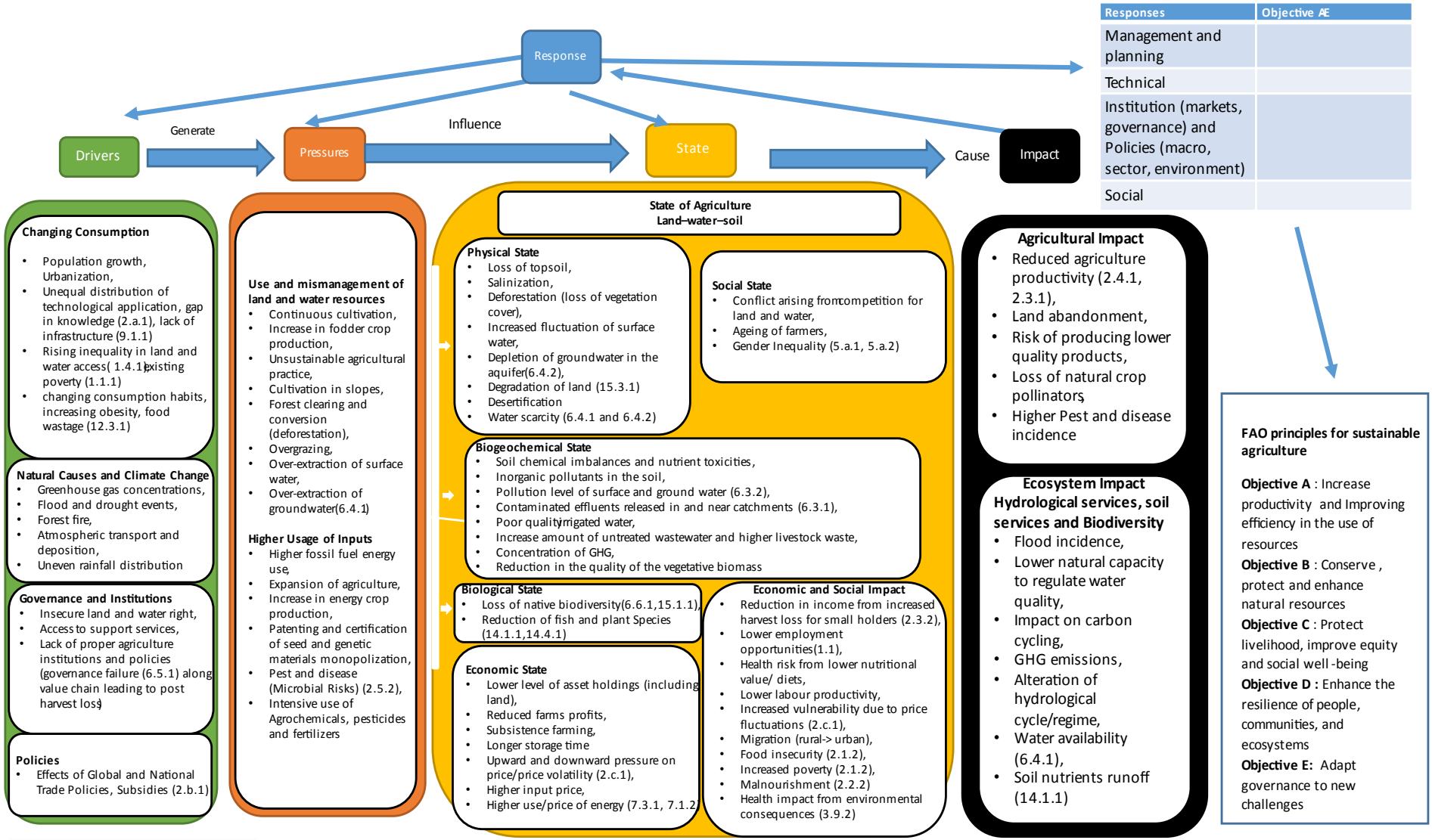
The biogeochemical state includes elements such as soil chemical imbalances and nutrient toxicities, inorganic pollutants in the soil, the pollution of surface and groundwater, and reduction in the quality of the vegetative biomass.

The biological state is defined by the number of fish, animal and plant species and the state of native biodiversity.

The economic state includes the changing market value of agricultural goods due to price volatility and upward and downward pressures on prices, as well as the level of asset holding, inequality, and the income levels of small and marginal farmers.

The social state includes conflicts arising from competition for land and water, migration out of agriculture by young people, and gender inequality.

Figure 2. The Driving force-Pressure-State-Impact-Response framework



Source: Authors' own elaboration.

Impacts. Impacts capture the effect of changes on the functions of the biophysical, socioeconomic and environmental systems.

The adapted DPSIR framework tracks impacts on agricultural productivity, land abandonment, the risk of lower quality products, competition for pollination, higher pest and disease incidence, agricultural efficiency and sustainability.

In addition to direct agricultural impacts, there may be impacts on ecosystem services, which can indirectly affect agricultural productivity. These include flood incidence, decreased natural capacity to regulate water quality, impact on carbon cycling, GHG emissions, alteration of hydrological cycle, reduction in water availability and decline of soil nutrient runoff. These indirect impacts have social and economic consequences, which may include reduced harvests and income loss for smallholders, fewer employment opportunities, health risks from less nutritional diets, lower labor productivity, increased vulnerability due to price fluctuations, a growth in migration to urban areas, increased poverty, malnourishment and health impacts.

Responses. Responses describe the actions and strategies that are available to individuals, groups, communities, businesses and governments to prevent, compensate, ameliorate, mitigate or adapt to the likely changes identified by the DPSIR.

Responses fall into the following categories: i) management and planning, (ii) technical, iii) institutional (markets, governance) and policy (macro, sector and environment), iv) social, and v) other options not related to the direct management of land and water management.

Management and planning responses include resource planning to promote sustainable land, soil and water management. They include gathering the technical and institutional knowledge needed to understand the potential for enhancing agricultural production (vertical as well as horizontal expansion[2]) and productivity in the future under different climate change and projected scenarios, as well as sustainable management approaches to avoid, reduce and reverse degradation, particularly in unique and fragile landscapes.

The technical response category includes techniques that improve agricultural production sustainably, manage soil health and fertility, appropriately source water for irrigated agriculture, and modernize irrigation systems and rainfed agriculture to reduce inefficiencies. It includes water harvesting, techniques for managing wastewater/greywater use and techniques to tackle water pollution in agriculture and to manage pollution related environmental risks. This category may also explore how the use of digital technology (big data, information and communications technology and the internet of things), nature-based solutions and circular economies can influence the state of agricultural systems in the short and long term.

Institutional and policy responses include national strategies and policies that shape sustainable management and secure access to soil, land and water resources. They also include approaches that can strengthen international partnerships and regional alliances, such as initiatives to foster knowledge sharing or policy dialogues on sustainable land and water management.

[2] Vertical expansion allows producers to capture or create more value from products originating from farm commodities, while in horizonal expansion, producer only owned the commodity in its basic form, and then sold it to another firm, which transformed it into another state while sharing no ownership with the producer (Roe 2005)

The sustainable development goals, the paris climate accords, the united nations convention to combat desertification (e.g., land degradation neutrality), the convention on biological diversity (including the aichi targets and the post-2020 global biodiversity framework) and the sendai framework for disaster risk reduction are global responses with regional and local impacts that can influence the sustainable use of resources and create different trade-offs and synergies. in addition, national and regional trade policies, for instance, subsidies, can influence important changes.

Options outside the domain of land and water management may also influence sustainable agriculture. These include the introduction of improved plant varieties (e.g., high yielding crops, seeds that resist diseases, pests, heat, drought and water scarcity, salt-tolerant crops, transgenic crops), crop fortification, and approaches to increasing efficiency in industrial use (e.g., site selection, manufacturing processes that reduce pressure on resources, decrease pollution and contamination). Reducing the cost of energy and promoting the use of renewable sources of energy is considered a very important response in this category.

Pathways to sustainable agriculture depend on many factors, including the behaviour of producers and consumers. Social responses, such as dialogues and awareness actions that can induce behavioural change, are another form of response that can prompt equitable and participatory sustainable land and water management. From a market perspective, dietary patterns not only reflect consumer needs and preferences, but also complex social behaviours. Sustainable choices, such as diets featuring zero kilometre products and efforts to maintain a low water footprint[3] (from the choice of meat to choice of packaging) and to achieve gender balance, also influence agricultural systems and are regarded as a key part of the response function.

Each category of response aligns with FAO's five principles for sustainable food and agriculture (FAO, 2014), which were used to guide policy-makers in framing the food and agriculture actions needed to achieve the Sustainable Development Goals (FAO, 2018). These principles are taken as the objectives for the responses.

Objective A: Increase productivity and improve efficiency in the use of resources.
Objective B: Conserve, protect and enhance natural resources.
Objective C: Protect livelihoods, improve equity and social wellbeing.
Objective D: Enhance the resilience of people, communities and ecosystems.
Objective E: Adapt governance to new challenges.

[3] The water footprint measures the amount of water used to produce each of the goods and services we use.

BOX 1. Classification of Responses according to key objectives. This box lists some of the responses linked to the objectives listed above and indicates the nature of their influence (direct or indirect) on the drivers, pressures, states and impacts identified in the DPSIR framework. The letters indicate the drivers that influence the response and whether that influence is direct or indirect. For example, (R-P) indicates that the response influences pressures while (R-P-S-I) shows that the response influences impact indirectly by influencing pressures and states. The box also indicates the SDG targets aligned to the specific responses.

Objective A: Increase productivity and Improve efficiency in the use of resources.

Improve sustainable agricultural production and facilitate access to productive resources, finance, and services

- Use of improved plant varieties (high-yielding crops; seeds that resist disease, pests, drought, water scarcity, heat; salt-tolerant crops; transgenic crops), fortification, etc.: (R-P), SDG 2.5, 12.2, 6.4
- Investment in mechanization and advanced technologies: (R-P), SDG 2.3,2a, 7b,9b,9c, 17.6 and 17.7, 6.4
- Increasing on-farm water productivity: (R-P) SDG 2.3, SDG 6.4
- Increasing the efficiency of nutrient cycling and applied inputs to maintain and raise soil fertility: (R-P-S), SDG 2.4, SDG 6.5, 9.4, 12.2, 14.1
- Strengthening access to the financial system , risk management instruments and output markets: (R-D-P-S-I), SDG 2.a, 2b, 2c, 9a
- Modernizing irrigation systems: (R-P-S-I), SDG 6.4

Connect smallholders to markets (R-P-S-I)

- A macro-economic framework, including better infrastructure, public goods, regulations and policy, and legal environments: (R-D-P-S-I), SDG 2,7,9-- SDG 2b. 2c,7.1, 7.3, 9.3, 9.1, 17.13
- Improved market information and food safety guidelines, as well a focus on value-added production and marketing: (R-P-S-I), SDG 2, 9c
- Stronger infrastructure for urban-rural integrated development and agricultural connectivity: (R-P-S-I) SDG 2c, 9.1, 9.3, 11a

Objective B: Conserve, protect and enhance natural resources

Enhance soil health and restore land (R-S)

- Soil moisture management for rainfed areas: SDG 2.4,12.4, 15.3, 6.4
- Harmonize data within a common framework and improve information systems for continuous monitoring of soils: SDG 17.19

Protect water and manage scarcity (R-S)

- Sourcing water for irrigated agriculture: SDG 6.4
- Tackling water pollution from agriculture: SDG 3.9, 6.3, 14.1

Objective C: Protect livelihoods, improve equity and social well-being

- Use social protection tools to enhance productivity and income: (R-P), SDG 10.1,10.4, 1.3, 1a
- Promote secure tenure rights: (R-D), SDG 1.4
- Improve nutrition and promote balanced diets: (R-D-S), SDG 2.2,
- Nutritional productivity of water and soil; nutrition-sensitive water and soil management

Objective D: Enhance the resilience of people, communities and ecosystems

Prevent and protect against shocks: enhance resilience: (R-P-S), SDG-1,2, 9, 11,13,14

- Sustainable soil, land and water approaches in view of climate change: SDG 2.4, 13.1, 6.4

Prepare for and respond to shocks (R-P-S)

- Options for the drylands: soil conservation, sustainable land management, water harvesting, wind erosion and control (sand and dust storms): SDG 15.1
- Drought preparedness and management: SDG 15.3

Address and adapt to climate change: (R-D-S)

- Integrated approaches to improving productivity in rainfed systems: SDG 2.4, 6.5
- Strengthen ecosystem resilience: (R-P-S), SDG 13.1

Objective E: Adapt governance to new challenges

Enhance policy dialogue and coordination: (I-R), SDG 1,2, 5,6,7,11 12, 13,14,15,16, 17

- Strengthen international partnerships: SDG 17.16
- Promote social dialogue for equitable and participatory sustainable land and water management
- Encourage regional focus and initiatives to foster knowledge sharing, policy dialogue on regional issue
- Support a global alliance on sustainable land and water management: SDG 17.16
- Engage with the private sector in making the investments and developing the technologies and best practices needed to enhance productivity, efficiency, and sustainability in food value chains.

Strengthen the agricultural market information system (AMIS) to reduce food price volatility: SDG 2b and c

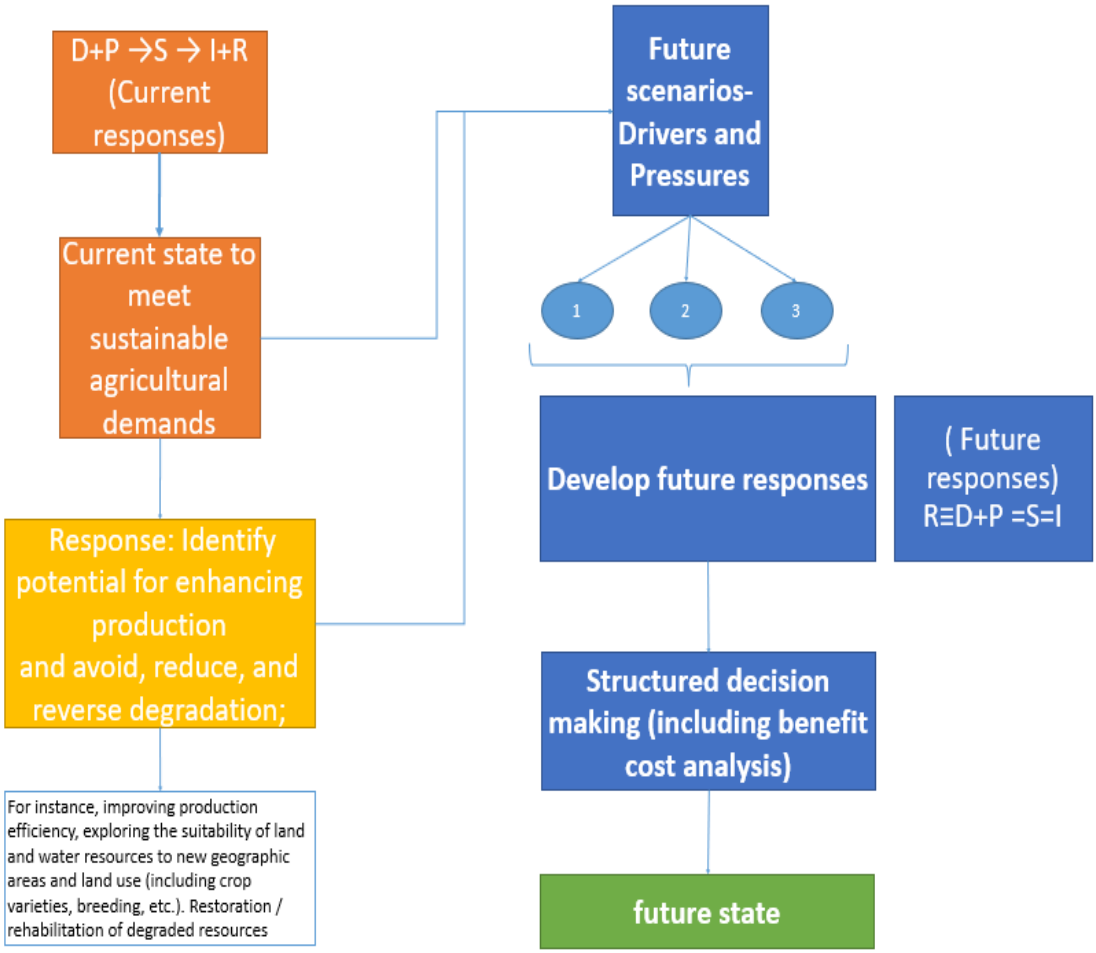
Strengthen innovation systems: (R-P-S)

Adapt and improve investment and finance: (R-P-S-I)

Strengthen the enabling environment and reform the institutional framework: (R-D) and (R-S)

Integrated land and water planning, conflict resolution among competing sectors (trade-offs)

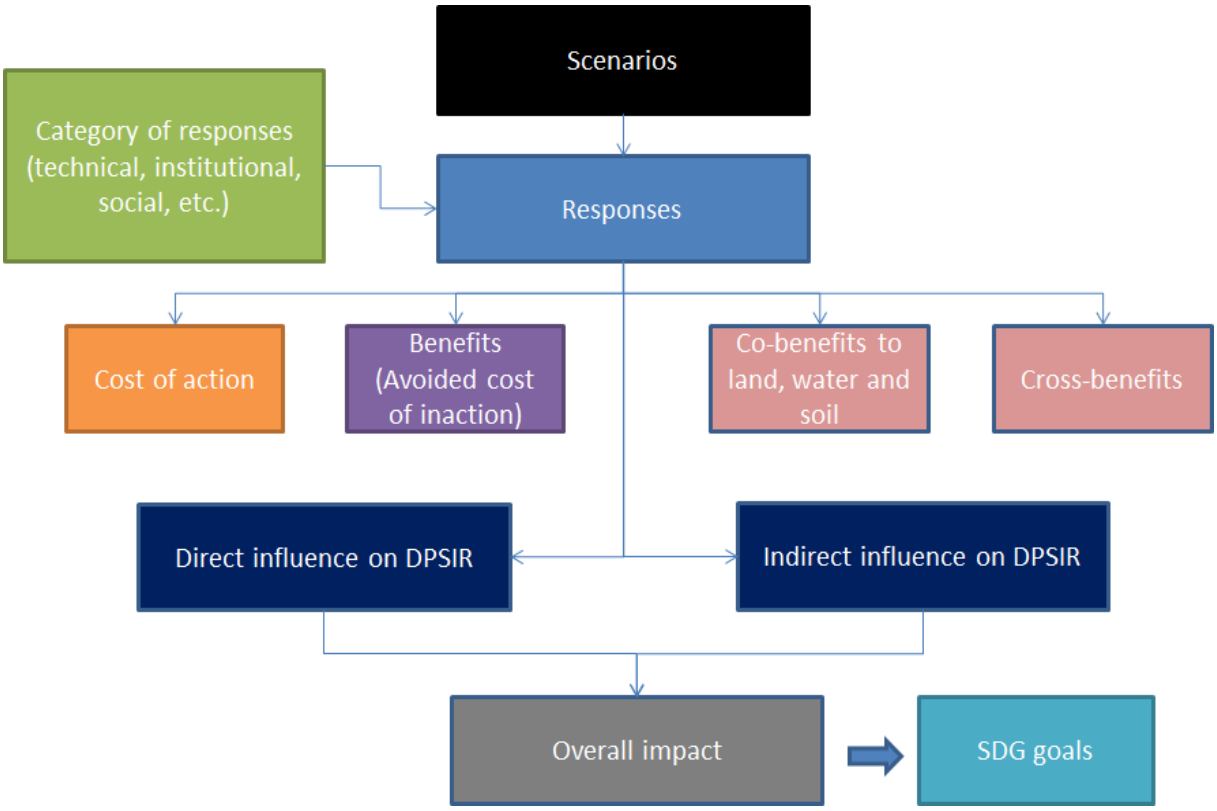
Figure 3. Driving force-Pressure-State-Impact-Response framework with the difference between current and future timeframe



Source: Authors' own elaboration.

Following the approach of Bouma and Montanarella (2016), the DPSIR framework shown in Figure 3 has been separated into current and future timeframes to illustrate the process of sustainable management and restoration .It assumes that current state is influenced by drivers and pressures (past and present), which have created impact and given rise to responses in the current time frame. The responses could have immediate as well as future impacts. As such, future scenarios around drivers and pressures are influenced by past drivers and pressures, as well as by the responses undertaken in the current period. As a result, decision-makers may need to consider multiple scenarios and prepare multiple responses.

Figure 4. Different aspects of responses



Source: Authors' own elaboration.

A comprehensive response assessment framework is used to identify suitable strategies and actions. The response strategies should influence the future state. Some responses (e.g., technical, institutional and policy) can influence decisions around enhancing the sustainable management of land and water resources and combating land degradation. Other responses influence sustainable land productivity and human well being in different ways. It is essential to know the costs and benefits (i.e., avoided costs of inaction) and timeliness implications (i.e., sooner rather than later) of different types of responses, especially if the responses influence the state directly or indirectly through drivers or pressures in the system. Recognizing differences among responses in different scenarios is critical for decision-making and priority-setting. Some responses may also have cross benefits or co benefits for land, water, and soil, and understanding the links between the three resources can help decision makers to better understand synergies and trade offs that could have environment, social and economic costs (see Figure 4).

Key messages

This report presents a framework that can help us to understand the state of land, vegetation cover, water and soil resources, and the changes in the use of these resources since the SOLAW 11 report. While SOLAW 2011 did not explicitly use the DPSIR framework, the process to develop the first report followed a similar approach. The SOLAW 21 process has used the DPSIR framework to describe the interlinkages and interdependencies between environment, socioeconomics and sustainable agricultural production systems (see Appendix A). This has enabled the process to build on (and update as necessary) the various indicators that the first edition of SOLAW established to identify the drivers of change, pressures, impacts and possible response options available to decision-makers (see Appendix B).

In this report, the DPSIR was adapted to enhance the understanding of cause and effect relationships in land and water management and to assist in developing key policy recommendations. The report provides decision-makers and stakeholders at different levels with information to guide the selection and implementation of actions to enhance the sustainable management of land and water resources.

The adapted DPSIR framework links the three dimensions of sustainability (environmental, economic, and social equity) to cross-cutting governance mechanisms. The framework is aligned with SDG targets and goals. The report defines the five elements of DPSIR – driver, pressure, state, impact and responses – in the context of land, water and soil degradation on a global scale.

Drivers are defined as exogenous factors that put agricultural systems under stress. Drivers are any natural- or human-induced element that directly or indirectly brings about change in an agricultural system. They include market drivers, natural drivers and drivers related to changes in governance, institutions and policies.

Pressures are the stresses on agricultural systems that accelerate human activities to meet food demand. They include resource use and management approaches that exert pressure on natural resources. Such pressures lead to continuous cultivation, intensification of land, water and soil, overextraction of groundwater, adoption of practices like tillage practice, cultivation on slopes, deforestation, overgrazing and land abandonment. Pressures cause changes the state of the environment (land-water-soil), characterized by quantity and quality of resources, flora and fauna, and chemical concentrations in water and soil, among others.

The state of agriculture and sustainable use of land, water, and soil are defined by: i) physical state, ii) biogeochemical state, iii) biological state, iv) economic state, and v) social state. Impact captures the influence of pressures and state on flows and services in the ecosystem, agriculture and economy. The responses variable in the DPSIR represents the management, technical and social interventions needed to sustain services from natural systems (land, water and soil) while minimizing negative externalities.

The DPSIR framework relates SDG indicators to a number of drivers, pressures, state and Impacts while aligning different SDG targets with the responses.

The global framework does not capture information about DPSIR linkages within the specific context of individual regions. A complementary report on the regional DPSIR framework provides a quick snapshot of regional challenges in land, water and soil

degradation and identifies potential responses. The report will help to prioritize the drivers, pressures, state and impacts that put stress on agricultural systems at the regional level.

To understand the effectiveness of technical, institutional, and policy responses for mitigating and adapting to land, soil and water degradation, future work may involve developing a comprehensive framework of response assessment that are complementary to DPSIR. The two approaches in combination can help us to better understand links between responses and drivers, pressures, states and impacts.

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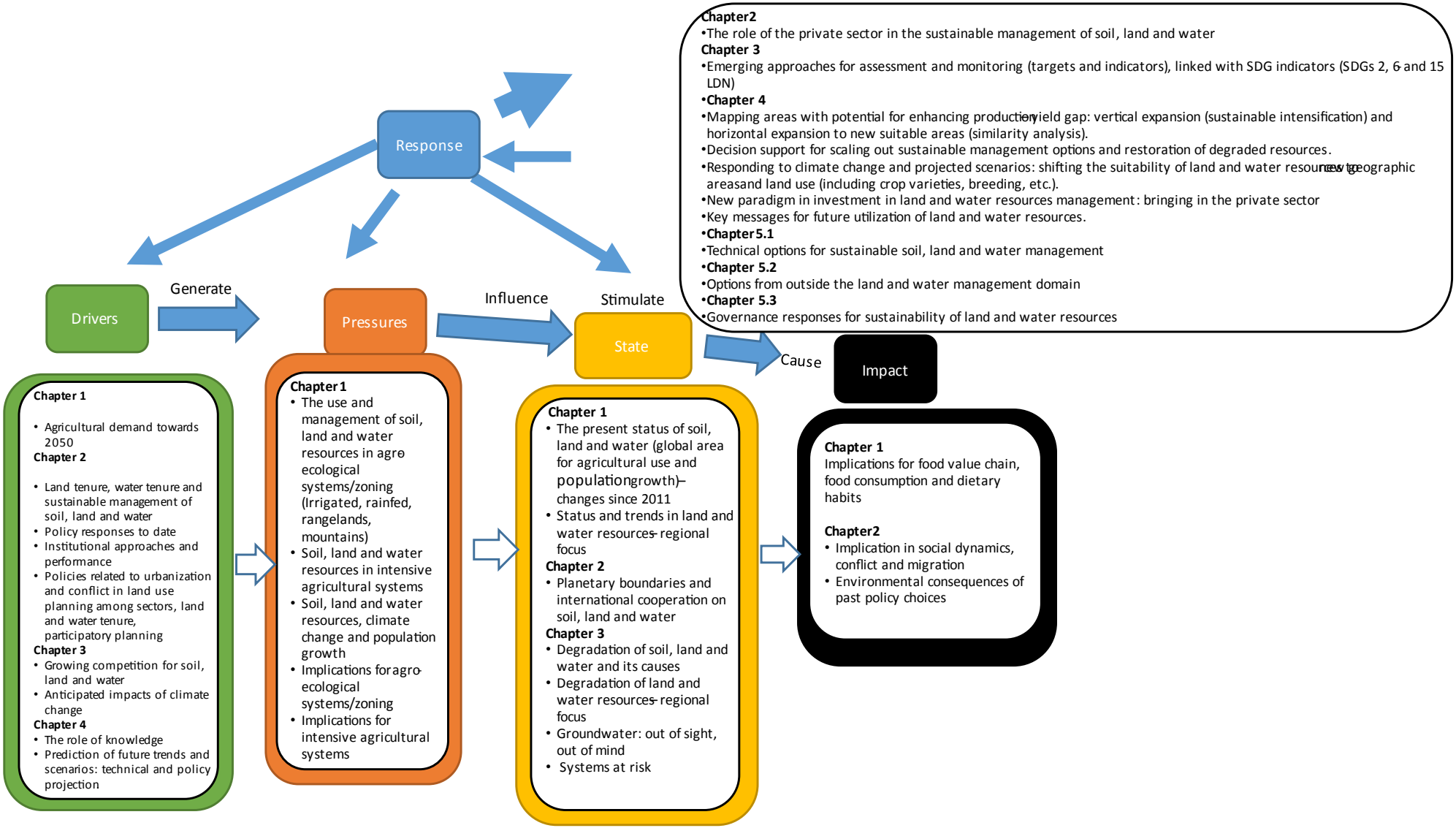
Appendix A: *The linkage of different elements of DPSIR to different chapters and sections of the SOLAW 21 Report*



Source: Authors' own elaboration.

The above figure illustrates

Appendix B. Summary of indicators in the DPSIR framework

Table 1. Description and indicators of direct and indirect drivers

S. No.	Drivers	Description (examples)	Indicators and SDG targets	Source
1	Population growth	Annual population growth in the region over the last decade	Total population growth, national (annual %)	https://data.worldbank.org/indicator?tab=all
2	Urbanization	Urban development and intensification over time	Urban population (annual %); urban population density (per sq. km)	https://data.worldbank.org/indicator?tab=all http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
3	Unequal distribution of technological application and gaps in knowledge	Lack of equitable distribution of technological applications and awareness of such action unable by intended users	Proportion of youth and adults with information and communication technology skills (SDG 4.4.1)	https://unstats.un.org/sdgs/indicators/database/?
			The agriculture orientation index for government expenditures (2.a.1)	http://www.fao.org/sustainable-development-goals/indicators/2a1/en/ https://unstats.un.org/sdgs/indicators/database/

S. No.	Drivers	Description (examples)	Indicators and SDG targets	Source
4	Lack of infrastructure	Inadequate infrastructure, such as roads and information communication technology to support economic development with a focus on equitable access for rural populations	Proportion of the rural population who live within 2 km from an all-season road (also known as the Rural Access Index – RAI) (SDG 9.1.1)	http://www.sum4all.org/gra-tool/country-performance/snapshot https://datacatalog.worldbank.org/dataset/rural-access-index-rai
			Proportion of population covered by at least a 4G mobile network (%) (SDG 9.c.1)	https://unstats.un.org/sdgs/indicators/database/
5	Rising inequality in land and water access	Lack of equity or fair shares of access and formal entitlement to land and water and benefits from land and water use	Proportion of rural population with access to clean water services (SDG 1.4.1)	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
			Proportion of population living in households with access to basic services; proportion of rural population using basic drinking water services (%) (2000-2017)	https://unstats.un.org/sdgs/indicators/database/?

S. No.	Drivers	Description (examples)	Indicators and SDG targets	Source
			Proportion of female with secure tenure rights to land with legal documentation (SDG 1.4.2)	http://www.fao.org/gender-landrights-database/data-map/statistics/en/
6	Existing poverty	The extent of poverty level by headcount ratio (international)	Proportion of population below the international poverty line (%)) (SDG 1.1.1)	https://unstats.un.org/sdgs/indicators/database/?
7	Changing consumption habits	Mean per capita food or nutrient availability	Consumption (kg per capita) and production of meat (in tonnes); share of dietary energy consumption from protein	http://www.fao.org/faostat/en/#search/Protein%20consumption http://www.fao.org/faostat/en/#data/HS
8	Obesity	A condition of overweight as measured by adult Body Mass Index (BMI)	Body mass index >30	https://www.cdc.gov/obesity/adult/defining.html
		Prevalence of malnutrition or overweight among children under 5 years of age	Proportion of children moderately or severely overweight (%)	https://unstats.un.org/sdgs/indicators/database/?
9	Food waste (total supply chain estimate)	Postharvest food loss of unconsumed food products due to decisions and actions by retailers, food service providers, and consumers	Food loss percentage by value of domestic production; proportion of food loss by value of domestic consumption; food waste index: food loss (%) (SDG 12.3.1)	https://unstats.un.org/sdgs/indicators/database/ http://www.fao.org/food-loss-and-food-waste/flw-data/en/

S. No.	Drivers	Description (examples)	Indicators and SDG targets	Source
10	Greenhouse gas concentrations	Accumulation of atmospheric greenhouse gas from various economic activities (e.g., industry, agricultural emissions)	Total greenhouse gas emissions per year from agriculture sector from synthetic fertilizers (total, kilo tonnes (kt) of CO_2 equivalent) (SDG 13.2.2)	http://www.fao.org/faostat/en/#data/GT
11	Flooding and drought events	The occurrence of flood and drought over a period nationally and/or globally	Direct economic loss due to disasters in relation to gross domestic product (GDP) (%) (SGD 11.5.2)	https://www.desinventar.net https://unstats.un.org/sdgs/indicators/database/
12	Forest fires	Forest fires due to natural or involuntary causes	Fire occurrence frequency in countries in the past decade	http://www.fao.org/news/story/en/item/29060/icode/ https://www.ncdc.noaa.gov/societal-impacts/wildfires/
13	Atmospheric transport and deposition	Deposition of atmospheric pollutants in the form of dust or in precipitation that will ultimately enter freshwater systems causing acidification and eutrophication	Deposition of nitrogen (in kg /ha/year) Deposition of phosphorus (in kg/ha/year)	http://www.fao.org/3/CA1328EN/ca1328en.pdf https://stats.oecd.org/Index.aspx

S. No.	Drivers	Description (examples)	Indicators and SDG targets	Source
14	Uneven rainfall distribution	The amount of precipitation over in specific area nationally	A national rainfall index (over the period represents the quality of the crop growing season.	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
15	Insecure land and water rights	Lack of secured rights and ownership to land and water to support rural livelihoods	Share of women among owners or rights-bearers of agricultural land (SDG 1.4.2)	http://www.fao.org/gender-landrights-database/data-map/statistics/en/
16	Access to support services	Official flows of development assistance (e.g., financial, technical and training) to economic sectors	Official flows of development assistance for agriculture (SDG 2.A.2)	http://www.fao.org/faostat/en/#data/EA
17	Lack of proper agricultural institutions and policies	Lack of appropriate government policies for postharvest loss reduction along the supply chain (from harvest until consumption or other end uses)	Food loss index; food loss percentage (%) (SDG 12.3.1)	https://unstats.un.org/sdgs/metadata/
18	Effect of global and national trade policies and subsidies	Subsidies and tariffs measures such as export subsidies, budgetary outlays and quantities as notified by WTO members	Agricultural export subsidies (SDG 2.b.1) See also: Fossil-fuel pre-tax subsidies (consumption and production) as a proportion of total GDP (%) (12.c.1)	https://unstats.un.org/sdgs/indicators/database/

Source: Authors' own elaboration.

Table 2. Description and indicators of pressures

S. No.	Pressures	Description		Source
1	Continuous cultivation	Land area under continuous agricultural production	Land area under permanent agricultural crop production	http://www.fao.org/faostat/en/#data/EL
2	Increase in fodder crop production	Agricultural area indicates increase in fodder production	Proportion of fodder area (fodder crops, grass and permanent grassland and meadows)	https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicators http://www.fao.org/faostat/en/#data/RL
3	Tillage practice	Unsustainable farming practices such as conventional agricultural practice	Conservation agriculture area as % of arable land area (SDG 2.4.1)	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
4	Cultivation on slopes	Cultivation on steep land that is prone to erosion	Proportion of agricultural land area with an average slope of more than 12%, which is approximately equal to 7˚	http://www.fao.org/3/a-bl031e.pdf
5	Deforestation	Loss of natural vegetation cover and land use change	Progress towards sustainable forest management; proportion of forest area with a long-term management plan (%) (SDG 15.2.1)	http://www.fao.org/sustainable-development-goals/indicators/15.2.1/en/ https://unstats.un.org/sdgs/indicators/database/

S. No.	Pressures	Description		Source
6	Overgrazing	Unsustainable use of pastureland for livestock grazing	Land area under permanent meadows and pastures (%)	http://www.fao.org/faostat/en/#data/EK
			Average livestock density in livestock units per agricultural land area	http://www.fao.org/livestock-systems/en/
7	Overextraction of groundwater	Unsustainable extraction of underground water for agricultural use	Change in water-use efficiency over time (SDG 6.4.1) (USD per cubic metre)	https://unstats.un.org/sdgs/indicators/database/
8	Higher input use	Higher level of agricultural input use (e.g., inorganic fertilizers)	Nutrient nitrogen agricultural use (total)	http://www.fao.org/faostat/en/#data/RFN
11	Increase in energy crop production	Intensification of energy crop plantations for biofuel production	Land area used for sorghum (*Sorghum bicolor*) production, (total %); ;yield of sorghum production (tonnes per ha per year) (	http://www.fao.org/faostat/en/#data/QC
13	Pests and diseases (microbial risks)	Crop pests/animal diseases that threaten agricultural production	Proportion of local breeds classified as at risk as a share of local breeds with known level of extinction risk (% (SDG 2.5.2)	http://www.fao.org/dad-is/en/

S. No.	Pressures	Description		Source
14	Intensive use of agrochemicals, pesticides, and fertilizers	Continued use of chemical fertilizers	Ammonium nitrate fertilizer use/consumption, (total in tonnes)	http://www.fao.org/faostat/en/#data/RFN
		The rate of use of pesticides	Level of agricultural pesticide use (total in tonnes)	http://www.fao.org/faostat/en/#data/RFN

Source: Authors' own elaboration.

Table 3. Description and indicators of state

S. No.	State	Description	Indicators	Source
1	Loss of topsoil	Loss of topsoil through erosion from agricultural land	Soil loss due to water erosion (tonnes per hectare per year); proportion of land degraded over total land area (SDG 15.3.1)	http://www.fao.org/3/a-bc595e.pdf https://unstats.un.org/sdgs/indicators/database/
2	Salinization	Irrigated land area affected by salinization due to mineral buildup caused by inadequate drainage	Area salinized by irrigation (1000 ha)	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
			Percentage of area equipped for irrigation salinized	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
3	Deforestation	Loss of natural vegetation cover and land use change	Forest area as a proportion of total land area by region by decade (SDG 15.1.1)	https://unstats.un.org/sdgs/indicators/database/

S. No.	State	Description	Indicators	Source
			Progress towards sustainable forest management: Forest area net change rate SDG 15.2.1	https://unstats.un.org/sdgs/indicators/database/
4	Increased fluctuation of surface water	Surface water level changes over time	Quantity of water use for irrigation (10^9 m3/yr)	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
			Total renewable surface water (10^9 m3/yr) See also water level stress (No. 5)	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
5	Depletion of groundwater in aquifers	Overextraction that leads to reduction in the groundwater table	Level of water stress; freshwater withdrawal as a proportion of available freshwater resources (SDG 6.4.2)	https://unstats.un.org/sdgs/indicators/database/
6	Amount of degraded land	Productive land converted to barren land due to unsustainable land use and management practices	Proportion of land that is degraded over total land area (SDG 15.3.1); \ Barren land area barren) (	http://www.fao.org/faostat/en/#data/LC

S. No.	State	Description	Indicators	Source
7	Desertification	Land area converted to desert due to drought and deforestation	Assessment of NDVI using remote sensing and GIS	https://www.unccd.int/sites/default/files/sessions/documents/ICCD_CSTS-2_INF.1/INF1eng.pdf
8	Water scarcity	Water stress due to unsustainable soil and water resources management	Freshwater withdrawal for agriculture as a proportion of available freshwater resources, expressed as a percentage of the total renewable water resources	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
9	Soil chemical imbalances and nutrient toxicities	Soil chemical imbalances and nutrient toxicities due to the application of inappropriate quantities of chemical fertilizers	Concentration of nitrogen in the topsoil; concentration of phosphate in the topsoil	http://www.fao.org/faostat/en/#data/RFN https://stats.oecd.org/Index.aspx
10	Inorganic pollutants in the soil	Inorganic pollutants enter the soil due to human activities such as agriculture and industries	Proportion of area equipped for irrigation salinized	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

S. No.	State	Description	Indicators	Source
11	Pollution level of surface and groundwater	Changes in water quality due to farming practices (e.g., input use) leading to pollution of surface and groundwater	Proportion of bodies of water with good ambient water quality (%) (SDG 6.3.2)	https://www.sdg6monitoring.org/indicator-632/ https://unstats.un.org/sdgs/indicators/database/?
			Proportion of open water bodies with good ambient water quality (%)	https://unstats.un.org/sdgs/indicators/database/?
12	Contaminated effluents released in and near catchments	Untreated wastewater from point sources entering the surrounding environment	Proportion of domestic and industrial wastewater flows safely treated (SDG 6.3.1)	https://unstats.un.org/sdgs/indicators/database/?
13	Poor quality irrigated water	Application of untreated water for irrigation	Percent of area equipped for irrigation with direct use of non-treated municipal wastewater	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

S. No.	State	Description	Indicators	Source
14	Increased amount of untreated wastewater and higher livestock waste	Increase in the quantity of untreated wastewater discharged without prior treatment	Untreated municipal wastewater released (10^9 m3/year, total)	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
15	Reduction in the quality of vegetative biomass	The density of vegetation cover on a patch of land in decline	Level of greenness of a patch of land based on NDVI	http://www.fao.org/fileadmin/templates/nr/kagera/Documents/LADA_manuals/part2_c.pdf
16	Loss of native biodiversity	Increase in loss of native species, triggering biodiversity conservation efforts	Forest area as a proportion of total land area (%) (SDG 15.1.1) (2000-2015)	http://www.fao.org/faostat/en/#data/EL https://unstats.un.org/sdgs/indicators/database/?

S. No.	State	Description	Indicators	Source
17	Reduction of fish and plant species	Decline in the number of plant and fish species due to overfishing	Proportion of fish stocks within biologically sustainable limits (not harvested) (SDG 14.4.1)	http://www.fao.org/3/i2389e/i2389e00.htm https://unstats.un.org/sdgs/indicators/database/?
18	Reduced level of asset holdings (including land)	Fewer landholders among smallholder farmers	Proportion of people with ownership or secure rights over agricultural land (out of total agricultural population) (SDG 5.a.1)	https://unstats.un.org/sdgs/indicators/database/?
19	Reduced farm profits, subsistence farming	Decline in agricultural production levels and the economic returns for producers	Average income of small-scale food producers, PPP (constant 2011 international USD) (SDG2.3.2)	https://unstats.un.org/sdgs/indicators/database/?
20	Longer storage time	Improved food storage to minimize losses	Investment in food security	http://www.fao.org/fileadmin/templates/ag_portal/docs/i1230e00.pdf

S. No.	State	Description	Indicators	Source
21	Price volatility/upward and downward pressures on prices	Lack of proper functioning of food commodity markets and erratic market prices	Food price anomalies (SDG 2.c.1)	http://www.fao.org/faostat/en/#data/CP https://unstats.un.org/sdgs/indicators/database/?
22	Higher input prices	Increased prices for agricultural inputs	NPK fertilizer import value	http://www.fao.org/faostat/en/#data/RFB
23	Higher use/price of energy	Increasing dependence on clean energy rather than traditional biomass energy	Proportion of population with primary reliance on clean fuels and technology e.g., solar or hydropower (SDG 7.1.2)	https://unstats.un.org/sdgs/indicators/database/?
24	Conflict arising from competition for land and water	Competition for land for livestock feed and food production	Land allocated for production of feedstock as proportion of total agricultural land	http://www.fao.org/nr/solaw/solaw-home/en/
25	Aging of farmers	Productive age group of society	Proportion of population of over 65 years (elderly population)	https://data.oecd.org/pop/working-age-population.htm

S. No.	State	Description	Indicators	Source
26	Gender inequality	Access to productive resources by women, including formal ownership and use rights to land	Share of women among total agricultural population with ownership or secure rights over agricultural land (5.a.1);	https://unstats.un.org/sdgs/indicators/database/?
			Gender inequality index	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

Source: Authors' own elaboration.

Table 4. Description and indicators of impact

S. No.	Impact	Description	Indicators	Source
1	Reduced agriculture productivity	Agricultural crop yield is reduced	Productivity of small-scale food producers (agricultural output per labour day, PPP) (constant 2011 international USD) (SDGs 2.3.1)	https://unstats.un.org/sdgs/indicators/database/?
2	Land abandonment	Land abandoned due to continuous production and loss of fertility	Area of land with temporary fallow (in 1 000 ha, total)	http://www.fao.org/faostat/en/#data/RLf
3	Risk of producing lower quality products	Agricultural production from lower quality farming systems	Proportion of irrigated land area equipped for direct use of untreated municipal wastewater (in 1000 ha)	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
4	Competition for pollination	Lower icrop pollination services by pollinators	Annual value of crop production dependent on pollinator services	http://www.fao.org/3/a-i3991e.pdf
5	Higher pest and disease incidence	Increased economic loss from crop damage and livestock loss	Direct economic loss from crop damage and livestock loss; quantity of livestock lost due to communicable diseases	

S. No.	Impact	Description	Indicators	Source
6	Efficiency and sustainability	Quantity and timing of freshwater flows required to sustain freshwater ecosystems and the human livelihoods and well-being that depend on them	Environmental flow requirements: (10^9 m3/year)	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
			Agricultural water withdrawal as a proportion of total water withdrawal	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
7	Flood incidence	Total number of floods observed in the period 1985-2011		http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
8	Decreased natural capacity to regulate water quality	Reduced water quality regulation services by watershed ecosystems	Degree of implementation of integrated water resources management (IWRM), measured in percent (%)	https://unstats.un.org/sdgs/indicators/database/?

S. No.	Impact	Description	Indicators	Source
9	Impact on carbon cycling	Forest carbon stocks	Amount of forest carbon stocks (carbon stock in living biomass)	http://www.fao.org/fileadmin/user_upload/post-2015/FAO_TI_14_themes_24_06_2014.pdf http://www.fao.org/faostat/en/#data/RL
10	GHG emissions	GHG emissions from agriculture and industries	GHG emissions from industries per year (total) (SDG 13.2.2); agricultural land use total CO2 emissions (per capita, metric tonnes of carbon); manure applied to soils	http://cdiac.ornl.gov/
				http://www.fao.org/faostat/en/#data/EM

S. No.	Impact	Description	Indicators	Source
11	Alteration of hydrological cycle/regime	Changes in natural areas and vegetation cover in mountain areas	Total area of forests (ha)	http://www.fao.org/fileadmin/user_upload/post-2015/FAO_TI_14_themes_24_06_2014.pdf http://www.fao.org/faostat/en/#data/EL
12	Water availability	Total annual actual renewable water resources per inhabitant	Water availability per capita at the national level (m3/inhab/yr) See Table 2, No.7 above	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
13	Decline in soil nutrient runoff	Amount of agricultural nutrients, such as nitrate, phosphate and pesticides, in surface water and groundwater	Index of coastal water eutrophication (SDG 14.1.1)	
			Proportion of land agricultural land area equipped for direct use of treated municipal wastewater	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

S. No.	Impact	Description	Indicators	Source
14	Reduced income due to increased harvest loss for smallholders	Reduction in income from postharvest grain losses due to storage pests of staple food crops like maize	Annual income loss from postharvest losses of crop production due to pests and diseases	http://www.aphlis.net https://www.aphlis.net/en/data/dry-weight-losses/africa/all-countries/all-provinces/maize/all-years?metric=prc#/
15	Lower employment opportunities	Lack of access to high-income jobs and informal employment	Proportion of the population living below USD 1.25 a day; employed population below international poverty line (SDG 1.1)	https://unstats.un.org/sdgs/indicators/database/?

S. No.	Impact	Description	Indicators	Source
16	Health risk from decreased nutritional value in diets	Health issues due to unbalanced diets/calorie intake	Prevalence of anaemia among women and children, proportion	https://www.unccd.int/sites/default/files/sessions/documents/ICCD_CSTS-2_INF.1/INF1eng.pdf https://dhsprogram.com/Topics/Anemia.cfm
17	Lower labour productivity	Farm labour in agricultural sector	Average income of small-scale food producers, PPP (constant 2011 international USD) (SDG 2.3.2)	https://unstats.un.org/sdgs/indicators/database/?
18	Increased vulnerability due to price fluctuations	Lack of proper functioning and stable food commodity markets at the country level	Food price anomalies; consumer food price Index (SDG 2.c.1)	https://unstats.un.org/sdgs/indicators/database/?
19	Increased migration	Increased migration of individuals from rural to urban areas for employment opportunities		https://data.worldbank.org/indicator?tab=all

S. No.	Impact	Description	Indicators	Source
20	Food insecurity	Insufficient food production and lack of reliable employment	Prevalence of moderate or severe food insecurity in the population (%), based on the food insecurity experience scale (FIES) (SDG 2.1.2)	https://unstats.un.org/sdgs/indicators/database/? http://www.fao.org/faostat
21	Increased poverty	Widespread poverty and food insecurity among populations	Prevalence of stunting under five years of age (low height for age); proportion of children moderately or severely stunted (%) (SDG 2.2.1)	https://unstats.un.org/sdgs/indicators/database/? http://www.fao.org/faostat
22	Malnourishment	Population with insufficient calories required for active and health growth	Prevalence of malnutrition among children under five years; proportion of children moderately or severely wasted (%) SDG 2.2.2)	https://unstats.un.org/sdgs/indicators/database/? http://www.fao.org/faostat

S. No.	Impact	Description	Indicators	Source
23	Health impact from environmental consequences	Health impact from lack of safe drinking water	Mortality rate attributed to unsafe drinking water and poor sanitation and lack of hygiene (deaths per 100 000 people) (SDG 3.9.2)	https://unstats.un.org/sdgs/indicators/database/? http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

Source: Authors' own elaboration.

The achievement of the Sustainable Development Goals (SDGs) in relation to agricultural, land, soil and water systems require a comprehensive understanding of the linkages, interdependencies and role of the systems. The Driver-Pressure-State-Impact-Response (DPSIR) framework enables the identification of critical links between different elements of soil, land and water systems. This report presents the DPSIR framework, which was developed to describe the connections between the environment, socioeconomic and sustainable agricultural production systems. The report highlights the need for a comprehensive assessment of interventions and responses (technical, institutional and policy) for sustainably managing land and water resources and combating land degradation.

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