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Abstract

One of the key aspects of reducing economic loss from disasters consists in a comprehensive analysis of the impacts generated and their associated cost. Detailed assessments of overall loss and damage are regularly carried out by governments and multilateral organizations following large-scale disasters using different methodologies. However, when applied to agriculture, these assessments often fail to capture the specificities of the sector and result in an imprecise or under-estimated evaluation of disaster impact. This hampers adequate agricultural disaster risk reduction (DRR) policy and planning, and leads to under-investment in resilient agriculture. The Food and Agriculture Organization of the United Nations (FAO) has developed an agriculture-specific methodology, which provides a framework for identifying, analyzing and evaluating the impact (damage and loss) of disasters on the sector. Seeking to standardize disaster impact assessment in agriculture, FAO's Damage and Loss methodology corresponds to universal norms, commitments and collective action at the global level, while remaining flexible enough to be applied in various country/regional contexts. The tool serves both national policy and planning needs as well as the post-2015 international resilience agendas, including the Sendai Framework for Disaster Risk Reduction (SFDRR) and Sustainable Development Goals (SDG).

Keywords

Disasters, agriculture, damage and loss assessment, FAO methodology, SFDRR, SDG, Sectoral DRR/DRM

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1. Introduction

Over the past decades, disasters have struck developing and developed countries alike, with growing frequency and intensity. The number of recorded disasters, along with their associated economic and social impacts has been increasing significantly at global as well as national and local level. For the decade between 2005 and 2015, economic loss from disasters in developing countries is valued at USD 580[1] billion, over 70 percent of which is associated with climate-related disasters. (CRED, 2018).

While the more immediate impacts of disasters – in terms of fatalities and destruction of critical infrastructure – are given the highest prominence within the Disaster Risk Management (DRM) discourse, the impacts on agriculture remain poorly analyzed and seldom quantified. Yet agriculture tends to be one of the main economic activities in developing countries, contributing on average between 10 and 20 percent of national Gross Domestic Product (GDP) in lower-middle-income countries and over 30 percent in low-income countries. In some cases in Africa, the agriculture sector is the backbone of the economy, contributing up to 39 percent (the Niger) or 41 percent (Ethiopia, Mali) to national GDP (World Bank, 2017). Recurrent and prolonged natural hazards and disasters, such as drought, floods, storms, spread of pests and diseases and saltwater intrusion, can have a devastating impact not only on agricultural livelihoods, but can lead an entire economy into recession. At the microeconomic level, disasters often lead to declines in agricultural employment and/or wages among farmers and farm laborers and income redistribution due to loss of arable land and eroding livelihoods. Disturbance of the economic system often brings social insecurity, especially in circumstances when food systems are being disrupted. On the other hand, risk-resilient agriculture plays a key role in balancing the social, economic and environmental aspects of development while providing durable employment, sufficient income as well as decent living and working conditions for smallholder farmers and rural populations (FAO, 2018).

Given its crucial reliance on weather, climate and natural resources for production, the agriculture sector is particularly vulnerable to natural hazards, disasters and extreme events. According to recent Food and Agriculture Organization (FAO) findings, between 2005 and 2015 natural disasters cost the agricultural sectors of developing country economies a staggering USD 96 billion in crop and livestock production loss. About 23 percent of the overall impact of disasters in developing countries is felt the agriculture sector. Until recently, the impact of disasters on agriculture remained largely

[1] FAO own analysis based on launched the Emergency Events Database of the Centre for Research on the Epidemiology of Disasters (EM-DAT CRED) data; figures include economic impact reported for all low-, lower middle- and upper middle-income countries in the period between 2005 and 2015, reported in USD.

undocumented and poorly understood, with only limited statistics and information available. Data on agricultural losses is not collected in a structured and systematic way and methodological discrepancies often result in inconsistent and incomplete information.

Since 2015, the FAO has been working towards building a comprehensive knowledge base on the impact of disasters on the sector. As part of this effort, FAO is producing regular bi-annual reports, which examine the latest trends in disaster impact, analyze the specific vulnerabilities of the agri-subsectors (crops, livestock, aquaculture, fisheries, and forestry) and provide key policy recommendations. Furthermore, the FAO has developed a standard methodology to assess disaster damage and loss in agriculture, which is currently presented to countries for their adoption and implementation. This methodology is both holistic enough to be applied in different country/regional contexts, and precise enough to consider all agricultural subsectors (crops, livestock, apiculture, forestry, aquaculture and fisheries) and their specificities. Furthermore, it is geared towards measuring the effects of a broad range of disasters of different type, duration or severity – from large-scale shocks to small and medium-scale events, from sudden-onset to slow-onset disasters with a cumulative impact.

In partnership with United Nations Office for Disaster Risk Reduction (UNDRR), FAO's methodology has been adopted into the two main 2015 international agendas, which recognize resilience as fundamental to their achievement, namely the Sustainable development goals (SDG) and the Sendai Framework for Disaster Risk Reduction (SFDRR). As such, it contributes to monitoring the achievement of specific targets on reducing direct economic loss from disasters. Specifically, the FAO methodology is used to track progress of Sendai Indicator C-2 on reducing direct agricultural loss attributed to disasters, and the corresponding SDG indicator 1.5.1.

This paper presents the FAO Damage and Loss Assessment methodology as a framework for identifying, analyzing and evaluating the impact of disasters on agriculture, including crops, livestock, aquaculture, fisheries and forestry. Its potential is explored as a strategic tool for assembling and interpreting new or existing information to inform risk-related policy decision-making and planning. Furthermore, the FAO methodology is presented in the larger context of the current global resilience agendas, such as the SFDRR, while its linkages and complementarities with similar approaches are explored. In addition, the flexibility of the methodology in terms of estimation and data needs, as well as its ease of use and wide range of applicability are emphasised.

While, several case study-based publications have been produced so far (on drought in Ethiopia and Typhoon Haiyan in the Philippines, FAO, 2018), this paper presents the first structured and systematic documentation of the methodological rationale, forged by a detailed elaboration of the methodological framework.

2. Methodological background – assessment of disaster impact in agriculture

While the importance of their impacts is undisputed, disasters continue to pose various methodological conundrums, such as the debate on how to define a disaster and classify it accordingly as well as what impact assessment techniques should be employed.

Estimations of the impacts of disasters in agriculture are often limited in scope and are not among the list of priorities in typical post-disaster impact assessment contexts. The scope is even more restricted when applied to small-scale disasters, which tend to have a negligible impact on human lives or the economy, but bring significant cumulative consequences for agriculture. Most disaster impact assessments focus on the direct and visible impacts of large- and medium-scale natural disasters, in order to provide governments with an estimate of the cost of relief efforts to address immediate needs. Such assessments typically only focus on strategic impacts, such as deaths and injuries, damage to buildings, subsistence and commercial crops, and economic and social infrastructure (AusAID, 2005).

In order to formulate a functional system for damage and loss assessment for the agricultural sector, a categorization of the term *disaster* is first established, in order to identify what constitutes a disaster in general and for the sector. Then, the context of current methodological practices is explored in view of identifying prevailing gaps and establishing a foundation for agriculture-sector assessment.

Identifying a disaster

Basic definitions of disaster and disaster impact assessment help promote a common understanding on the subject among disaster risk reduction (DRR) practitioners, decisions makers and researchers. Accordingly, one of the major current challenges in this field is to overcome the limitations induced by the lack of clear classifications and definitions, which lead to inconsistencies and poor inter-operability of different disaster data compilation initiatives.

Among the most universally adopted set of definitions is the one developed by UNDRR. Developed to support international DRR frameworks such as the Hyogo Framework for Action (HFA) 2005-2015, the UNDRR Terminology contributes to a common understanding and usage of DRR concepts among the DRR efforts of authorities, practitioners and the public. The most recent version of 2016[2], developed through a highly consultative process, stipulates the basic terms and definitions along with additional context, qualification and explanation.

[2] See website at https://www.unisdr.org/we/inform/publications/51748

For the purpose of the FAO Damage and Loss Assessment methodology, the DRR concepts used in this paper are framed from an agricultural perspective, while relying on the universal definitions. Retaining the established official UNDRR terminology, some adjustments have been made for use in an agricultural context. First, an analysis of key indicators (e.g. climatic, environmental, geophysical, hydro-meteorological, biological indicators) is used to identify key characteristics of agriculture-relevant hazards, such as their location, intensity, area affected, speed of onset, duration and frequency. A disaster that may disrupt agricultural operations and jeopardize livelihoods can be one of three general types: natural (e.g. hydrometeorological, geophysical or biological), technological or complex (disasters that go well beyond natural hazards and involve conflicts, famine, climate change induced disasters, etc.).

Considering the above, the official definitions the FAO methodology relies on are as follows:

- **Hazard**: a process or phenomenon that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. While hazards may be natural, anthropogenic or socio-natural in origin, this report refers to hazards of natural origin only.
- **Disaster**: a serious disruption of the functioning of a community or a society due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental loss and impacts.
- **DRR:** the policy objective aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contributes to strengthening resilience.
- **Damage:** the total or partial destruction of physical assets and infrastructure in disaster-affected areas, expressed as replacement and/or repair costs. In the agriculture sector, damage is considered in relation to standing crops, farm machinery, irrigation systems, livestock shelters, fishing vessels, pens and ponds.
- **Loss:** refers to the changes in economic flows occurring as a result of a disaster. In agriculture, loss may include decline in crop production, decline in income from livestock products, increased input prices, reduced overall agricultural revenues, higher operational costs and increased unexpected expenditures to meet immediate needs in the aftermath of a disaster.

One key aspect of the disaster definition is the non-rigidity of its parameters. This implies that the relevant national and local authorities have the freedom and flexibility to outline their own specific criteria of what constitutes a disaster in a given area or country, while using the United Nations (UN) definitions as a guideline. This is particularly important, since the magnitude of an event that is capable of bringing "a serious disruption of the functioning of a community" varies widely across countries and is strongly dependent on the particular socio-economic, demographic, vulnerability and resilience profile of the disaster-impacted area. While one disaster may constitute a crisis of humanitarian proportions in one area, that same disaster may be felt as a mere disturbance elsewhere. This is even more evident when it comes to the agriculture sector, where certain climatic events, such as drought, cause little disruption of urban economic activities and do not claim any human lives, yet may cause profound disruptions in agricultural production and erode rural livelihoods. Moreover, most advanced economies have developed coping strategies for risk resilient agriculture, while the vast majority of the developing world remains extremely vulnerable to disaster impact.

Existing methodologies

The most widely recognized impact assessment methodology is the Damage and Loss Assessment (DaLA) methodology of the UN Economic Commission for Latin America and the Caribbean (ECLAC), which is widely used in the context of Post-Disaster Needs Assessment (PDNA) processes, as well as the more targeted HAZUS tool. The **ECLAC-DaLA Methodology** was initially developed by ECLAC in 1972. Improvements over recent years, in the context of PDNAs, have focused on capturing closer approximation of damage and loss due to disaster events. This remains a flexible tool for economy-wide assessment, which can be adapted to specific disaster types and government ownership requirements. It uses national accounts and statistics as baseline data to assess damage and loss. It also factors in the impact of disasters on individual livelihoods and incomes to identify the needs for recovery and reconstruction. A DaLA assessment typically evaluates the damage of physical assets and the loss in economic flows associated with the absence of damaged assets; ultimately, it aims to provide an estimation of the overall impact on post-disaster macroeconomic performance, with respect to economic growth/GDP, the balance of payments and fiscal situation of the Government.

The **PDNA** framework incorporates an updated version of the DaLA methodology combined with a human recovery needs assessment approach. It typically provides the recovery and reconstruction framework that guides the post-disaster recovery strategy. The PDNA is an inclusive, government-led and government-owned process, which draws upon the capacity and expertise of both national and international actors. Typically, the country would be assisted by a multi-agency team comprising the World Bank, United Nations Development Group (UNDP), the European Commission, and other relevant stakeholders. The methodology employed leverages on the DaLA and is revised jointly by the UNDP, the European Commission and the World Bank to include particular assessments of damage, loss and macro-economic impacts on the affected economy as well as impacts on livelihoods, incomes, and human development. Ultimately, the objective is to establish the short, medium, and long-term recovery and reconstruction needs and to mainstreaming particular DRR measures in post-disaster recovery and reconstruction plans. Over the recent years, the PDNA framework has become the universal template of assessing economy-wide net impact following large-scale disaster events.

Finally, **HAZUS** is a geographic information system-based natural hazard analysis tool developed and distributed by the US Federal Emergency Management Agency (FEMA). It is a standardized methodology, which contains models for estimating potential losses from earthquakes, floods and hurricanes, using Geographic Information Systems (GIS) technology. It provides estimates of the physical, economic and social impacts of the three disaster types.

Among these methodologies and frameworks, two different classification types are used for disaster impact assessment. The first classifies impact according to its nature into tangible / intangible and direct / indirect. Tangible impacts can be measured in monetary terms, such as destruction of vehicles, buildings or infrastructure, reduction in income or increase of costs. Conducting cost estimations for tangible impacts is much easier. On the other hand, intangible impacts – such as deaths, injuries, cultural artefacts, environmental impacts and psychological effects – are difficult to estimate, as there is no systematic or universal method to measure them (ECLAC, 2003; Hallegatte and Przyluski, 2010; Middelmann, 2007). Direct impacts represent the partial or complete physical destruction caused by disasters to people, buildings, infrastructure, vehicles and assets, while *indirect impacts* are a consequence of the direct impacts caused by the hazard. Indirect impacts, are more difficult to identify and harder to estimate (ECLAC, 2003; National Research Council 1999). Examples of indirect impacts are changes in income or flows of goods and services that will not be produced and that may extend throughout the rehabilitation and reconstruction periods and increase of the unemployment rate (Calderón Patier *et al.*, 2003; ECLAC, 2003; FEMA, 2002; National Research Council 1999).

The second classification distinguishes impacts based on the affected sector. For instance, the ECLAC methodology divides impacts into social, infrastructure, economic and overall effects in addition to categorizing direct and indirect impacts.

Gaps in current assessment frameworks and the need for a holistic agriculture-centered methodology

Across the existing disaster impact calculation methodologies and needs assessment frameworks, a targeted damage and loss component for the agricultural sector is either lacking or is not consistently implemented. In addition, assessments conducted for agriculture using a non-agriculture specific methodology often fail to provide reliable results in a transparent fashion. This poses considerable limitation for impact assessments in agriculture. The lack of consistency among methodologies concerning the definition of various concepts is another barrier when analyzing disaster impact in agriculture. Each assessment exercise may use similar terms to group different kind of impacts, resulting in divergent estimation results.

A further challenge in impact assessment in agriculture is to know what should be included and how. For example, if a drought results in animal deaths, there is no doubt that the cost of the animals should be estimated, however, the foregone future production of animal production should also be added to the overall cost in a standardized way.

Furthermore, efforts need to be made in order for different methodologies to align and to apply universal standards for data collection, recording and disaster loss database management and data dissemination. Current data loss recording practices suffer from lack of synchronization of minimal data requirements for disaster impact recording, lack of universal legal frameworks, and lack of blueprints for databases and methodology. While common guidelines and principles across countries are desirable, it is also imperative to leave a degree of flexibility when it comes to country-specific processes. The challenge is to define a streamlined systematic approach in recording disaster losses for agriculture, which would rely on country- and context-specific institutional arrangements, technical processes and codes of quality assurance and data management.

The list of persisting gaps, limitations and challenges highlights the need for a targeted methodology and an inclusive framework for assessing disaster impact on agriculture, which retains compatibility with existing economy-wide processes, such as the PDNA, yet integrates a dynamic perspective of the agricultural sector and sub-sectors, their production cycles and data specificities. Moreover, complementarity with assessment frameworks should be sought, which would allow for a stronger focus and more detailed evaluation of sector impacts.

In response to this need, the FAO Damage and Loss methodology represents a standardized approach to evaluating disaster impact in agriculture, applicable to a wide range of disasters in different geographical context. It provides a useful tool for assembling and interpreting existing information about both past and future events. It provides an agriculture-specific structure to record various impacts under precise categories, which resolves any ambiguity as to what should be included into assessments. The clearly delineated definitions of main concepts and categories, as consistent as possible with existing global frameworks, ensure that the results of assessments conducted with this methodology will provide consistent results across countries and contexts.

Furthermore, its application supports countries in the institutionalization of national damage and loss information systems, thus directly addressing the prevailing knowledge gaps in the sector. The adoption of a standardised damage and loss information system at country-level is meant to ensure an integrated approach to the entire process – from data collection, management, assessment, reporting and dissemination of key information on disaster impact in agriculture. This will facilitate the generation of reliable, transparent and timely results, thus improving the evidence base for key programmatic decisions. A D&L information system will also ensure the same minimal data requirements for disaster impact recording and provide a blueprint for databases and methodology at country-level.

Box 1. Key concepts of the methodology

Damage vs. Loss

Damage is defined as the replacement/repair cost of totally or partially destroyed physical assets and stocks in the disaster-affected area.

Loss refers to changes in economic flows arising from the disaster (i.e. declines in output in crops, livestock, fisheries, aquaculture and forestry).

Production vs. Assets

Each subsector is presented in terms of its production and its assets. The production component consists of both inputs and outputs; the assets component consists of facilities, machinery, tools, and key infrastructure related to agricultural production.

Furthermore, FAO's methodology is grounded in and builds upon existing frameworks, tools and methods for disaster impact assessment, mainly the PDNA and ECLAC's DaLA. Its focus is on creation of structures for regular data collection on damage and loss in agriculture as well as capturing smaller-scale and localized disaster impacts. This means that the FAO methodology is compatible with the PDNA process, while also complementing it.

The logical structure behind this methodology is based on the following steps: (1) the identification of the natural hazard and its magnitude, (2) the identification of the causal linkage between the hazard and damage and loss in agriculture, (3) the assessment of damage and losses caused by the hazard on agriculture, which constitute a measure of the disaster, i.e. the natural hazard impact on the primary sector. Further information on the logical framework of the methodology can be found in FAO's 2016 publication **Notes on an Information System on Damage and Losses from Disasters in Agriculture**, which investigates the linkages between disaster impact and indicators on natural hazards, providing a sound logical structure. The next section outlines the main components and structure of the methodology and presents the main computation steps and formulas.

3. Overview of the FAO Damage and Loss Assessment methodology

Aiming for a consistent approach to assessing disaster damage and loss in agriculture, the FAO D&L methodology provides a set of procedural and computational steps for consistent damage and loss assessment across disasters, countries and time. It can be applied in a variety of country/regional contexts and to a wide range of disaster events (including natural-hazard induced disasters, climate-related events, crises and conflicts, food chain crises, etc.) of different proportions – from large-scale shocks to small- and medium-scale events with a cumulative impact.

Structure

The D&L methodology uses a standardized computation method to assess the direct damage and loss that occurs in the agricultural sector as a result of disasters, which takes into consideration the specificities of each subsector, i.e. crops, livestock, forestry, aquaculture and fisheries.

The methodology consists of five components:

- DL (C): Direct damage and loss to crops
- DL (L): Direct damage and loss to livestock
- DL (FO): Direct damage and loss to forestry
- DL (AQ): Direct damage and loss to aquaculture
- DL (FI): Direct damage and loss to fisheries.

In combination, these indicators aim to capture the total effect of disasters on agriculture:

Impact to Agriculture = DL (C) + DL (L) + DL (FO) + DL (AQ) + DL (FI)

In order to capture the full impact of disasters on each sub-sector, FAO's methodology for damage and loss assessment distinguishes between **damage**, i.e. total or partial destruction of physical assets, and **loss**, i.e. changes in economic flows arising from a disaster. Furthermore, each subsector is divided into two main components: **production** and **assets**. This allows for an estimation of the extent and value of damage and loss for all components in each subsector and for the formulation of a globally standardized assessment of the impact. In order to capture the direct impact of disasters on agriculture, it is important to take into account both the damage and the loss accrued in agricultural production and assets.

The production component measures disaster impact on agricultural inputs and outputs. Damage includes the value of stored inputs (e.g. seeds) and outputs (e.g. crops) that were fully or partially destroyed by the disaster. On the other hand, production loss refers to declines in the value of agricultural production resulting from the disaster. The assets component measures disaster impact on facilities, machinery, tools, and key infrastructure related to agricultural production. The monetary value of (fully or partially) damaged assets is calculated using the replacement or repair/rehabilitation cost, and is accounted for under damage.

Table 1 below provides a visual representation of the FAO Damage and Loss Methodology, including an indication of the items and economic flows that should be considered in the assessments. In line with the main methodological concepts (Box 1), each sub-sector is divided into three main sub-components, namely production damage, production loss and assets damage.

Table 1. Damage and Loss Assessment methodology

		DAMAGE	LOSS
Crops Livestock Fisheries Aquaculture Forestry	**PRODUCTION**	**Pre-disaster value of destroyed stored production and inputs** * Items: seeds, fertilizer, pesticides, fodder, fish feed, stored crops, stored meat, dead animals, etc.	**Difference between expected and actual value of production and Short-run disaster expense** * Items: crop yield reduction, animal production reduction, destroyed timber, lost fish capture, cost of re-planting, etc.
	ASSETS	**Replacement or repair value of destroyed machinery, equipment, tools** * Items: tractors, harvesters, silos, barns, milking machines, boats, fishing gear, pumps, aerators, etc.	

The **production damage sub-component** measures damage on production inputs (e.g. seeds, fertilizer, fish lings, perennial trees, tree lings etc.) and outputs (e.g. stored crops, animal products, fish catch, tree logs etc.) whose are partially or completely destroyed. The value of recuperated animals whose product can be merchandised should be subtracted from the total damages.

Production loss captures the decline in production of each sub-component that is irreversibly lost due to disaster. In the case of crops, production loss includes fully destroyed standing crops, decline in production in partially affected areas, as compared to pre-disaster expected yields, and, the discounted value of lost production in fully damaged areas, until perennial crops become fully productive again. In the case of livestock loss includes difference between expected and actual value of primary and secondary livestock products from the productive animal in the year that disaster struck, and, discounted expected value of livestock products (primary and secondary) from dead animals until full recovery of livestock. Production loss in aquaculture and fisheries follows the same pattern as in previous sub-sectors as it includes: difference between expected and actual value of fisheries/aquaculture capture in disaster year, and in the case of aquaculture the pre-disaster value of production lost in fully damaged aquaculture areas. Forestry production loss includes difference between expected and actual value of production in non-fully damaged harvested area and pre-disaster value of fully destroyed standing forest products. For each of the sub-sectors a short-run maintenance costs expenses used to temporarily sustain production activities (immediately post-disaster) should be included as production loss.

The **asset damage** sub-component measures disaster impact on facilities, machinery, tools, and key infrastructure related to agricultural production. Crop-related assets include, among others, irrigation systems, machinery, equipment; livestock-related assets include sheds, storage buildings; fisheries assets include ponds, hatcheries, freezers and storage buildings, engines and boats, fisheries equipment; forestry assets include, among others, standing timber, firebreaks and watch towers, forestry equipment and machinery, fire management equipment. The monetary value of (fully or partially) damaged assets is calculated using the replacement or repair/rehabilitation cost, and accounted under damage.

Underlying assumptions

The FAO Damage and Loss Assessment methodology is based on number of assumptions, which are listed below.

- Single disaster assessment. It is assumed that shocks to the agricultural sector are independent and their effects are not cumulative.
- Prices used in the damage and losses assessment are farm gate prices.
- Annual crops are not affected in the years that follow the disaster.
- Changes in yields and changes in the size of the area harvested are assumed to be independent.
- For perennial crops, yields are assumed to show a constant linear behavior through time in the years before the disaster (e.g. 5 years' time series).
- For perennial crop losses, fully damaged hectares are replanted the same year of the disaster and no production is available until full recovery.
- Replanting of the annual crops is feasible in the same season only if the natural hazard strikes before or during the sowing season. If replanting is still possible, the productivity is considered a linear function of the time available for replanting (e.g. if the planting is possible 5 months per year and the natural hazard strikes at the 4th of the 5 months, then 20 percent of the of total expected production for the

same year can be retrieved. A more flexible functional form would allow to relax the linearity assumption and to have room for more accurate calibration.

- It is assumed there is no mixed use of assets (infrastructure, machinery, tools) in order to avoid double counting. A relaxed version of this hypothesis is also proposed in the methodology.
- The repair and rehabilitation cost of assets is linearly correlated with the level of damage.
- Changes of area harvested are calculated as the difference of the first data available for hectares before the disaster and the first available after the disaster, in order to avoid accounting for changes in area harvested not strictly related to the shock(s) of the same year. Multiple shocks in the same year are still a source of bias in the methodology.
- The area harvested after the disaster is assumed to remain constant at pre-disaster levels in the counterfactual scenario of no disaster.
- It is assumed that no additional investments in assets are done except for investments needed to restore pre-disaster production,
- The physical weight of each type of livestock is assumed to be constant across time but livestock-specific.
- It is assumed that restoring the size of the livestock happens in bulk after a livestock-specific amount of time, if immediate intervention is not possible.
- Following existing disaster assessment approaches, this methodology focuses on damage and losses. Potential benefits from natural disasters are not considered.
- All projections are based on pre-disaster information.

The Computation in detail

Table 2. Notation used in the methodological formulas

i	Output
j	Geographical units affected by disaster
k	asset (equipment, machinery, tools, facilities) used to produce an agricultural output
x	input used for agricultural production
h	perennial crop trees
t	the first time unit when post-disaster data are available
t-1	the first time unit when pre-disaster data are available
$y_{i,j,t}$	yield of item i in zone j at time t
$p_{x(\text{or } i \text{ or } h),j,t-1}$	price of input x (or product i or tree h) in zone j at time t-1
$p_{k,j,t}$	price (or repair cost) of one unit of asset k in zone j at time t

$q_{i,j}$	quantity of item i in zone j
$q_{i(or\ x)(stored),j,t}$	stored quantity of item i (or input x) in zone j at time t
$q_{k,j,t}$	number of assets used for item i in zone j at time t
$ha_{i,j,t}$	number of hectares devoted to item i in zone j at time t
$\Delta ha_{i,j,t}$	unexpected change in the number of hectares where i is produced
w_i	average weight (in tons) of item i
$P_{(short\ run)}$	lump sum of expenses used to temporarily sustain production activities after a disaster
α	share of the value of dead animals that can be sold
$area_{j,t}$	size of aquaculture area (cages, tanks, pens, etc.) in zone j at time t
T	number of days devoted to fishing activities
r	real interest rate
$R_{non-timber}$	revenue from non-timber forest activities

Damage and loss in crops

DL (C) = Annual crop production damage + Perennial crop production damage + Annual crop production loss + Perennial crop production loss + Crop assets damage (complete and partial)

Production Damage for Annual Crops PD (AC) is composed of the:

1) Pre-disaster value of destroyed stored inputs: $\Delta q_{x,(stored)j,t} \times p_{x(stored),j,t-1}$
2) Pre-disaster value of destroyed stored annual crops: $\Delta q_{i,(stored),j,t} \times p_{i(stored),j,t-1}$

- The term **($\Delta q_{x,(stored)j,t} \times p_{x(stored),j,t-1}$)** represents the quantity of inputs q for annual crop production by input type (such as seeds, fertilizer, pest control, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are done by input type for all affected inputs.

- The term **($\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}$)** represents the quantity of stored crops by commodity (rice, maize, potatoes, cassava, beans, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are done for every affected stored crop commodity.

- The overall Production Damage for Annual Crops is the summary of both terms.

$$PD\ (AC)_{i,j} = (\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}) + (\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1})$$

Production Damage for Perennial Crops PD (PC) is composed of the:

1) Pre-disaster value of destroyed stored inputs:	$\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}$
2) Pre-disaster value of destroyed stored perennial crops:	$\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}$
3) Replacement value of fully damaged trees:	$\Delta ha_{i,j,t} \times h_{i,j} \times p_{h,j,t-1}$

- The term ($\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}$) represents the quantity of inputs q for perennial crop production by input type (such as fertilizer, pest control, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are done by input type for all affected inputs.

- The term ($\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}$) represents the quantity of stored crops by commodity (avocado, bananas, coconuts, coffee beans, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are done for every affected stored crop commodity.

- The term ($\Delta ha_{i,j,t} \times h_{i,j} \times p_{h,j,t-1}$) represents the replacement value of destroyed tress expressed as the number of tress h per hectare in disaster affected area Δha (number of hectares of affected perennial crops), valued at pre-disaster-level re-forestation/plantation price p at level (t-1).

- The overall Production Damage for Perennial Crops is the summary of all three terms.

$$PD\ (PC)_{i,j} = (\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}) + (\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}) + (\Delta ha_{i,j,t} \times h_{i,j} \times p_{h,j,t-1})$$

Annual Crop Production Loss PL (AC) is composed of the:

1) Difference between expected and actual value of crop production in non-fully damaged harvested areas:	$p_{i,j,t-1} \times \Delta y_{i,j,t} \times ha_{i,j,t}$
2) Pre-disaster value of destroyed standing crops in fully-damaged areas:	$p_{i,j,t-1} \times y_{i,j,t-1} \times \Delta ha_{i,j,t}$
3) Short-run post-disaster maintenance costs: (expenses used to temporarily sustain production activities immediately post-disaster):	$P_{short\text{-}run\ (lump\text{-}sum)}$

- The term ($p_{i,j,t-1} \times \Delta y_{i,j,t} \times ha_{i,j,t}$) represents the crop production that has been reduced as a consequence from the disasters – this formula is applied in the case where a disaster impacted the crop land only partially and harvest took place after the event, however the crop yield was reduced due to the impact of the event. The calculation consists of multiplying the reduced yield per hectare Δy by the number of hectares of the fully-affected area ha. The overall reduction in harvest is then valued at pre-disaster price p at level (t-1). This calculation done by crop for each crop affected.

- The $(p_{i,j,t-1} \times y_{i,j,t-1} \times \Delta ha_{i,j,t})$ represents the crop production that has been fully lost as a consequence from the disasters – this formula is applied in the case where a disaster completely devastated the crop land and no harvest took place as a result. The calculation consists of multiplying the number of fully destroyed hectares Δha by an estimate of the average expected yield of the destroyed crop in normal conditions y and value the overall amount of lost harvest at pre-disaster price p at level (t-1). The average (expected) yield estimates could be based on five- (or more) year trend of the reported crop yield data.

- The term $P_{short\text{-}run}$ captures any short-run disaster-related expenses that have been incurred by farmers in the short aftermath of a disaster in order to maintain production activities or to restore activities to pre-disaster level. This could entail hiring generators, expenses for clearing up after earthquakes or landslides, short-run hire of machinery, hire of irrigation services, etc.

- The overall Production Loss for Annual Crops is the summary of the three terms

Perennial Crop Production Loss PL (PC) is composed of the:

$$PL\ (AC)_{i,j} = (p_{i,j,t-1} \times \Delta y_{i,j,t} \times ha_{i,j,t}) + (p_{i,j,t-1} \times y_{i,j,t-1} \times \Delta ha_{i,j,t}) + P_{short\text{-}run}$$

1) Difference between expected and actual value of crop production in non-fully damaged harvested areas:	$p_{i,j,t-1} \times \Delta y_{i,j,t} \times ha_{i,j,t}$
2) Pre-disaster value of destroyed standing crops in fully-damaged areas:	$p_{i,j,t-1} \times y_{i,j,t-1} \times \Delta ha_{i,j,t}$
3) Short-run post-disaster maintenance costs (expenses used to temporarily sustain production activities immediately post-disaster):	$P_{short\text{-}run(lump\text{-}sum)}$

- The term $(p_{i,j,t-1} \times \Delta y_{i,j,t} \times ha_{i,j,t})$ represents the crop production that has been reduced as a consequence from the disasters – this formula is applied in the case where a disaster impacted the crop land only partially and harvest took place after the event, however the crop yield was reduced due to the impact of the event. The calculation consists of multiplying the reduced yield per hectare Δy by the number of hectares of the fully-affected area ha. The overall reduction in harvest is then valued at pre-disaster price p at level (t-1). This calculation done by crop for each crop affected.

- The **($p_{i,j,t-1} \times y_{i,j,t-1} \times \Delta ha_{i,j,t}$)** represents the crop production that has been fully lost as a consequence from the disasters – this formula is applied in the case where a disaster completely devastated the crop land and no harvest took place as a result. The calculation consists of multiplying the number of fully destroyed hectares Δha by an estimate of the average expected yield of the destroyed crop in normal conditions y and value the overall amount of lost harvest at pre-disaster price p at level (t-1). The average (expected) yield estimates could be based on five- (or more) year trend of the reported crop yield data.

- The term **$P_{short\text{-}run}$** captures any short-run disaster-related expenses that have been incurred by farmers in the short aftermath of a disaster in order to maintain production activities or to restore activities to pre-disaster level. This could entail hiring generators, expenses for clearing up after earthquakes or landslides, short-run hire of machinery, hire of irrigation services, etc.

$$PL\ (PC)_{i,j} = (p_{i,j,t-1} \times \Delta y_{i,j,t} \times ha_{i,j,t}) + (p_{i,j,t-1} \times y_{i,j,t-1} \times \Delta ha_{i,j,t}) + P_{short\text{-}run}$$

- The overall Production Loss for Perennial Crops is the summary of the three terms.

Assets Damage in Crops AD (C) is composed of the:
1) Repair / replacement cost of partially / fully destroyed assets at pre-disaster price: **$p_{k,j,t-1} \times \Delta q_{k,j,t}$**

- The term *($p_{k,j,t-1} \times \Delta q_{k,j,t}$)* represents the total asset damage, where the quantity of damaged or destroyed items Δq is valued by their respective repair or replacement cost p at pre-disaster level (t-1). This Assets category includes crops-specific infrastructure, machinery and equipment, for example: tractors, balers, harvesters, storage facilities, etc.

$$AD\ (C)_{i,j} = p_{k,j,t-1} \times \Delta q_{k,j,t}$$

Damage and loss in livestock

DL (L) (Livestock damage and loss) = Livestock production damage + Livestock production loss + Livestock assets damage (complete and partial)

Livestock Production Damage PD (L) is composed of the:

1) Pre-disaster value of stored inputs (fodder and forage): $\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}$
2) Pre-disaster value of destroyed stored animal products: $\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}$
3) Pre-disaster net value of dead animals: $(\Delta q_{i,j,t} \times w_i) \times (p_{i,j,t-1} - \alpha \times p_{i,j,t})$

- The term $(\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1})$ represents the quantity of inputs q for livestock production by input type (such as animal feed, vaccines, medicine, pest control, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are done by input type for all affected inputs.

- The term $(\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1})$ represents the quantity of stored primary livestock products by commodity (frozen meat from previous slaughters, milk, eggs, skins and hides, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are done for every affected stored livestock commodity.

- The term $[(\Delta q_{i,j,t} \times w_i) \times (p_{i,j,t-1} - \alpha \times p_{i,j,t})]$ represents the value of dead animals expressed as the number of dead animals by type Δq , multiplied by carcass weight[3] w and valued at pre-disaster-level (t-1) meat prices p and subtracting the share of sold meat from dead animals α at post-disaster price p of time t.

- The overall Production Damage for the Livestock Sector is the summary of all three terms.

$$PD\,(L)_{i,j} = (\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}) + (\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}) + [(\Delta q_{i,j,t} \times w_i) \times (p_{i,j,t-1} - \alpha \times p_{i,j,t})]$$

Livestock Production Loss PL (L) is composed of the:

1) Difference between expected and actual value of production (of livestock products): $q_{i,j,t} \times p_{i,j,t-1} \times \Delta y_{i,j,t}$

[3] Carcass weight data should be given in terms of dressed carcass weight, excluding offal and slaughter fats. Production of beef and buffalo meat includes veal; mutton and goat meat includes meat from lambs and kids; pig meat includes bacon and ham in fresh equivalent. Poultry meat includes meat from all domestic birds and refers, wherever possible, to ready-to-cook weight. Data on poultry-meat production reported by national statistical offices could be expressed in terms of either live weight, eviscerated weight, ready-to-cook weight or dressed weight. Data for countries reporting in other than ready-to-cook weight have been converted into the ready-to-cook equivalent.

2) Short-run post-disaster maintenance costs: **$P_{short\text{-}run}$**

- The term **($q_{i,j,t}$ × $p_{i,j,t-1}$ × $\Delta y_{i,j,t}$)** represents the livestock production directly lost as a consequence from the disasters – this refers to either reduced production or completely ceased production of milk, eggs, etc. due to injured or killed animals. This term does not include the meat production form dead animals if this has already been fully counted towards estimating the value of dead animals as part of the Livestock Production Damage. The calculation consists of multiplying the number of animals dead/injured q by the reduced output per animal Δy and times the price per output at pre-disaster price p at level (t-1).

- The term **$P_{short\text{-}run}$** captures any short-run disaster-related expenses that have been incurred by farmers in the short aftermath of a disaster in order to maintain production activities or to restore activities to pre-disaster level. This could entail hiring generators, expenses for clearing up after earthquakes or landslides, short-run hire of machinery, veterinary expenses, etc.

- The overall Production Loss for the Livestock Sector is the summary of both terms

$$PL\,(L)_{i,j} = (q_{i,j,t} \times p_{i,j,t-1} \times \Delta y_{i,j,t}) + P_{short\text{-}run}$$

Livestock Assets Damage AD (L) is composed of the:
1) Repair/replacement cost of partially/fully destroyed
assets at pre-disaster price: **$p_{k,j,t-1} \times \Delta q_{k,j,t}$**

- The term **($p_{k,j,t-1}$ × $\Delta q_{k,j,t}$)** represents the total asset damage, where the quantity of damaged or destroyed items Δq is valued by their respective repair or replacement cost p at pre-disaster level (t-1). This Assets category includes livestock-specific infrastructure, machinery and equipment, for example: milking machines, dairy machines, feeding machines, barns and stables, etc.

$$AD\,(L)_{i,j} = p_{k,j,t-1} \times \Delta q_{k,j,t}$$

Damage and loss in forestry

DL (FO) (Forestry damage and loss) = Forestry production damage + Forestry production loss + Forestry assets damage (complete and partial)

A forest typically consists of two productive asset classes: the forest and the land the forest grows on. The former is a capital asset whose value can be increased through investment, silvicultural activities and biological timber growth over time; alternatively, its value can be decreased by timber harvesting or natural disturbances. Land, on the other hand, tends to be fixed in supply and its value may be changed through alternative uses and management intensity. Forestry-specific disasters, such as fires or pest outbreaks only damage the forest and not the land, while only soil erosion can seriously damage the productivity of the land. This methodology focuses on damage to the forest (timber) only, and not forest land.

Furthermore, a forest often consists of many timber stands, each having different characteristics (Pearse 1990; Helms 1998). A timber stand is a contiguous group of trees sufficiently uniform in age-class distribution, composition, and structure, and growing on a site of sufficiently uniform quality, as to be a distinguishable unit (Helms 1998). Merchantable timber stands consist of trees that have the size, quality, and condition to be salable under a given economic condition by a given time (Helms 1998). Pre-merchantable timber stands are stands composed of trees that are too immature to be profitably harvested and sold for manufacturing forest products at a specific time, which in this case is time of disaster occurrence (Zhang and Pearse 2011). The time when a disaster occurs (t) is therefore the reference point of time for determining stand maturity.

Forestry production damage PD (FO) is composed of the:

1) Pre-disaster value of stored inputs: $\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}$

2) Pre-disaster value of destroyed stored products: $\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}$

- The term $(\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1})$ represents the quantity of inputs q for forestry production by input type (such as fertilizer, pest control, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are specified by input type for all affected inputs.

- The term $(\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1})$ represents the quantity of stored timber by which has been destroyed by a disaster, valued at pre-disaster price p at level (t-1).

- The overall Production Damage for Forestry is the summary of both terms.

$$PD\ (FO)_{i,j} = (\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}) + (\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1})$$

Forestry Production Loss PL (FO) is composed of the:

1) (Discounted) present value of timber production from both merchantable and pre-merchantable stands: $\mathbf{(P_{t-1}/m^3 \times y\ m^3/ha \times ha) / (1+r)^{60-age}}$

2) (Discounted) present value of non-timber forest products: $\mathbf{R_{non\text{-}timber} / (1+r)^n}$

3) Minus the value of timber salvaged and marketed post-disaster: $\mathbf{- P_{t-1}/m^3 \times y\ (m^3)_{(salvaged)}}$

- The production loss value for a forest is the summation of the production loss values for all stands. The **production loss for a merchantable timber stand** equals the market-determined (unit) timber price times the standing timber volume in a stand. For example, if the unit price for a pine stand is USD 25/m^3 and the pine timber stand has 120 cubic meters per hectare, the value of the merchantable pine timber stand is (120 m^3/ha) × (USD 25/m^3) × (10 hectares) = USD 30 000. Therefore, the term $\mathbf{[P_{t-1}/m^3 \times Y\ m^3/ha \times ha]}$ represents the production loss value of the forest stand affected expressed as the volume of timber by stand, valued by the current price of timber P_{t-1} and multiplied by size of the stand in hectares.

- The **production loss for a pre-merchantable timber stand** is calculated as an estimate of the value of the stand's projected future income at the time of the disaster (Zhang and Pearse, 2011). Under this approach, the value of a pre-merchantable timber stand is equal to the timber stand's projected (potential) revenues discounted to the stand's age at the time of damage. This is achieved by adding the discount factor $\mathbf{(1+r)^{60-age}}$. For example, if a natural hardwood stand can be expected to produce 120 cubic meters of saw timber per hectare in 60 years, assuming that the current price of USD 25/ m^3 is going to stay in the future (which means that this is a real price net of inflation), the real (net of inflation) interest rate is 4 percent, then the production loss for a 15-year old pine stand is: [USD 25/m^3 × 120 m^3/ha × 10 ha] / $(1 + 0.04)^{60-15}$ = USD 5 135.

- Other than timber value, a forest (of many merchantable and pre-merchantable timber stands) often generates income from non-timber forest products such as fuelwood, fruit, mushroom, flowers, and recreational activities. Unlike timber production loss, income from non-forest products are not associated with a specific stand, but are attributed to the whole forest. Thus, the present value of all income from non-timber products is usually calculated for the whole forest (however, it can also be adjusted to the size of damaged portion of the forest). The term $\mathbf{R_{non\text{-}timber} / (1+r)^n}$ represents the income obtained from non-timber forest activities R, which will be lost due to the effect of the disaster, divided by the discount factor in order to obtain the net present value of future income lost until full recovery of normal forest (non-timber) incomegenerating activities **$(1+r)^n$**, where r is the interest rate and n is the number of years until full recovery of activities.

- The value of the timber which was salvaged and marketed following a disaster should be taken into consideration. The term **$- P_{t-1}/m^3 \times Y\ m^3_{(salvaged)}$** represents the overall volume of re-sold timber Y m^3, valued at the pre-disaster level price of P_{t-1} per cubic meter.

- The overall Production Loss for Forestry is the summary of the three terms.

$$PL\ (FO)_{i,j} = [(P_{t-1}/m^3 \times Y\ m^3/ha \times ha) / (1+r)^{60-age}] + (R_{non\text{-}timber} / (1+r)^n) + (- P_{t-1}/m^3 \times Y$$

Forestry Assets Damage AD (FO) is composed of the:
1) Repair / replacement cost of partially / fully destroyed assets at pre-disaster price: **$p_{k,j,t-1} \times \Delta q_{k,j,t}$**

- The term **$(p_{k,j,t-1} \times \Delta q_{k,j,t})$** represents the total asset damage, where the quantity of damaged or destroyed items Δq is valued by their respective repair or replacement cost p at pre-disaster level (t-1). This category includes forestry-specific infrastructure, machinery and equipment, for example: skidders, forwarders, tractors, feller bunchers, etc.

$$AD\ (FO)_{i,j} = p_{k,j,t-1} \times \Delta q_{k,j,t}$$

Damage and loss in aquaculture

DL (AQ) (Aquaculture damage and loss) = Aquaculture production damage + Aquaculture production loss + Aquaculture assets damage (complete and partial)

Aquaculture Production Damage PD (AQ) is composed of the:
1) Pre-disaster value of stored inputs: **$\Delta q_{x(stored),j,t} \times p_{x(stored)j,t-1}$**
2) Pre-disaster value of destroyed stored aquaculture products: **$\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}$**
3) Pre-disaster net value of broodstock[4] loss: **$(\Delta q_{broodstock,i,j,t} \times p_{t-1})$**

- The term **$(\Delta q_{x(stored),j,t} \times p_{x(stored)j,t-1})$** represents the quantity of inputs q for aquaculture production by input type (such as fingerlings, fish feed, fertilizer, medicine, etc.) which

[4] Broodstock, or broodfish, are a group of mature individuals used in aquaculture for breeding purposes. Broodstock can be a population of animals maintained in captivity as a source of replacement for, or enhancement of, seed and fry numbers.

have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are done by input type for all affected inputs.

- The term **($\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}$)** represents the quantity of stored primary aquaculture products by commodity (frozen fish, caviar, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are specified for every affected stored aquaculture commodity.

- The term **($\Delta q_{broodstock,i,j,t} \times p_{t-1}$)** represents the value of broodstock fish expressed as the number of broodstock fish Δq lost, multiplied by their pre-disaster-level (t-1) prices p.

- The overall Production Damage for the Aquaculture sector is the summary of all three terms.

$$\mathbf{PD\ (AQ)_{i,j} = (\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}) + (\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}) + (\Delta q_{broodstock,i,j,t} \times p_{t-1})}$$

Aquaculture Production Loss PL (AQ) is composed of the:

1) Difference between expected and actual value of aquaculture production in non-fully damaged aquaculture areas:	$\mathbf{area_{j,t} \times p_{i,j,t-1} \times \Delta y_{i,j,t-1}}$
2) Pre-disaster value of aquaculture production lost in fully damaged aquaculture areas:	$\mathbf{\Delta area_{i,j,t} \times p_{i,j,t-1} \times y_{i,j,t-1}}$
3) Short-run post-disaster maintenance costs:	$\mathbf{P_{short\text{-}run\ (lump\text{-}sum)}}$

- The term **($area_{i,j,t} \times p_{i,j,t-1} \times \Delta y_{i,j,t-1}$)** represents the aquaculture production, which has been reduced as a consequence from the disasters – this formula is applied in the case where a disaster impacted the area of aquaculture cages and pens only partially and harvest took place after the event, however the fish yield was reduced due to the impact of the event. The calculation consists of multiplying the amount of reduced yield per hectare (or square meter) of aquaculture facilities Δy by the number of hectares (square meters) of the fully-affected area $area_{i,j,t}$. The overall reduction in harvest is then valued at pre-disaster price p at level (t-1). This calculation done by area affected.

- The term **($\Delta area_{i,j,t} \times p_{i,j,t-1} \times y_{i,j,t-1}$)** represents the aquaculture production, which has been fully lost as a consequence from the disasters – this formula is applied in the case where a disaster completely devastated the area of aquaculture cages and pens and no fish harvest took place as a result. The calculation consists of multiplying the number of fully destroyed hectares (or square meters) Δarea by an estimate of the average expected fish yield in normal conditions y and value the overall amount of lost harvest at pre-disaster price p at level (t-1). The average (expected) yield estimates could be based on five- (or more) year trend.

- The term $\mathbf{P_{short\text{-}run}}$ captures any short-run disaster-related expenses, which have been incurred by farmers in the short aftermath of a disaster in order to maintain production activities or to restore activities to pre-disaster level. This could entail hiring generators, expenses for clearing up, short-run hire of machinery, hire of irrigation services, etc.

- The overall Production Loss for Aquaculture is the summary of the three terms.

$$\mathbf{PL\ (AQ)_{i,j} = (area_{i,j,t} \times p_{i,j,t-1} \times \Delta y_{i,j,t-1}) + (\Delta area_{i,j,t} \times p_{i,j,t-1} \times y_{i,j,t}) + P_{short\text{-}run}}$$

Aquaculture Assets Damage AD (AQ) is composed of the:
1) Repair / replacement cost of partially / fully destroyed assets at pre-disaster price: $\mathbf{p_{k,j,t-1} \times \Delta q_{k,j,t}}$

- The term $\mathbf{(p_{k,j,t-1} \times \Delta q_{k,j,t})}$ represents the total asset damage, where the quantity of damaged or destroyed items Δq is valued by their respective repair or replacement cost p at pre-disaster level (t-1). This Assets category includes aquaculture-specific infrastructure, machinery and equipment, for example: aquaculture feeders, pumps and aerators, feeding machines, cold storage, aquaculture support vessels, etc.

$$\mathbf{AD\ (AQ)_{i,j} = p_{k,j,t-1} \times \Delta q_{k,j,t}}$$

Damage and loss in fisheries

DL (FI) (Fisheries damage and doss) = Fisheries production damage + Fisheries production loss

Fisheries Production Damage PD (FI) is composed of the:
1) Pre-disaster value of stored inputs: $\mathbf{\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1}}$
2) Pre-disaster value of destroyed stored capture: $\mathbf{\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}}$

- The term $\mathbf{(\Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1})}$ represents the quantity of fishing inputs q for by input type (bait, etc.) which have been destroyed by a disaster, valued at their respective price p at pre-disaster level (t-1). Calculations are done by input type for all affected inputs.

- The term **($\Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}$)** represents the quantity of stored fisheries capture which has been destroyed by a disaster, valued at pre-disaster price p at level (t-1).

$$\mathbf{PD\ (FI)_{i,j} = \Delta q_{x(stored),j,t} \times p_{x(stored),j,t-1} + \Delta q_{i(stored),j,t} \times p_{i(stored),j,t-1}}$$

Fisheries Production Loss PL (FI) is composed of the:

1) Difference between expected and actual value of fisheries capture in disaster year: $\Delta T_{j,t} \times y_{i,j,t} \times p_{i,j,t-1}$

- The term **($\Delta T_{j,t} \times y_{i,j,t} \times p_{i,j,t-1}$)** represents the fisheries capture which has been lost due to disasters, expressed as the time where fishermen will be prevented from conducting normal fishing activities T (in number of days) multiplied by the average capture per day in normal conditions y and valued at pre-disaster level prices p at level (t-1).

$$\mathbf{PL\ (FI)_{i,j} = \Delta T_{j,t} \times y_{i,j,t} \times p_{i,j,t-1}}$$

Fisheries Assets Damage AD (FI) is composed of the:

1) Repair / replacement cost of partially / fully destroyed assets at pre-disaster price: $p_{k,j,t-1} \times \Delta q_{k,j,t}$

- The term **($p_{k,j,t-1} \times \Delta q_{k,j,t}$)** represents the total asset damage, where the quantity of damaged or destroyed items Δq is valued by their respective repair or replacement cost

$$\mathbf{AD\ (FI)_{i,j} = p_{k,j,t-1} \times \Delta q_{k,j,t}}$$

p at pre-disaster level (t-1). This Assets category includes fisheries-specific infrastructure and equipment, for example: boats, fishing vessels, engines, fishing gear, cold storage, etc.

Optimal and minimal data requirements

The outlined computation method for the FAO Damage and Loss Assessment methodology provides a large degree of flexibility regarding data requirements, as it can function with variable degrees of data availability. Below are the optimal and minimal data requirements necessary for a functional damage and loss assessment in each sub-sector. Indications of the necessary baseline data is also provided.

1. Data requirements for damage and loss assessment in crops:

- number of hectares of crops damaged and/or destroyed, by disasters, disaggregated by type of crop (minimal requirement);
- expected yield reduction in partially affected plot areas (t/ha) by crop (minimal requirement);
- number of damaged/destroyed machinery, equipment and facilities by type (optimal requirement);
- volume of destroyed stored crops by crop type (optimal requirement);
- volume of destroyed stored inputs by input type (optimal requirement);
- average yield (t/ha) by crop (minimal requirement);
- types of cultivated crops per area (minimal requirement);
- hectares of planted crops by crop type (minimal requirement).

2. Data requirements for damage and loss assessment in livestock:

- number of livestock deaths, by animal type (minimal requirement);
- number of livestock injured, sick or affected by disasters, by animal type (minimal requirement);
- expected reduction in milk, egg, etc. production per affected animal by product type (minimal requirement);
- volume of destroyed stored animal products from previous slaughters by type (optimal requirement);
- volume of destroyed stored inputs by input type (optimal requirement);
- number of damaged/destroyed machinery, equipment and facilities by type (optimal requirement);
- average volume of meat production per animal by animal type (minimal requirement);
- number of livestock herd size by animal type (minimal requirement).

3. Data requirements for damage and loss assessment in forestry:

- size in hectares of destroyed merchantable forest stands by stand type (minimal requirement);
- size in hectares of destroyed pre-merchantable forest stands by stand type (minimal requirement);
- standing timber volume per hectare in merchantable stands by stand (minimal requirement);
- average timber volume per hectare in pre- merchantable stands by stand (minimal requirement);
- age of destroyed pre-merchantable stands (minimal requirement);
- stored timber volume destroyed by disaster (minimal requirement);

- salvaged and re-sold timber volume (minimal requirement);
- real interest rate (minimal requirement);
- number of stands per forest (minimal requirement);
- number of damaged/destroyed machinery, equipment and facilities by type (optimal requirement);
- average annual value of non-timber forest activities (optimal requirement).

4. Data requirements for damage and loss assessment in aquaculture:

- types of aquaculture activity in affected areas (land-based pens, water-based tanks, etc.);
- size in hectares of fully-affected aquaculture areas by type (minimal requirement);
- size in hectares of partially-affected aquaculture areas by type (minimal requirement);
- average production per hectare by aquaculture activity type (minimal requirement and baseline);
- expected yield reduction per hectare in partially-affected aquaculture areas (optimal requirement);
- volume of destroyed stored production by aquaculture type (optimal requirement);
- volume of destroyed inputs by input type (optimal requirement);
- number of damaged/destroyed machinery, equipment and facilities by type (optimal requirement).

5. Data requirements for damage and loss assessment in fisheries:

- types of fishing activities in the affected areas (small-scale, industrial, etc.) (minimal requirement);
- average volume of daily/weekly/monthly capture by fishing activity (minimal requirement);
- number of days fishing activities are suspended due to disaster by fishing activity (minimal requirement);
- number of fully and/or partially damaged infrastructure, vessels, equipment and other assets by asset type (minimal requirement);
- volume of inputs and stored capture destroyed by disaster (optimal requirement).

Strengths and weaknesses of the methodology

While the proposed computation method is based on a set of assumptions and exogenous knowledge-based parameters (listed above), disaster impact valuation results may be biased for a variety of reasons. First, the lack of data (both pre- and post-disaster) and the impossibility of relaxing the assumptions implies the utilization of expert judgement.

Second, errors may occur due to distortions and simultaneous causes of changes in agricultural outputs, other than the hazardous event (e.g. policy changes). Third, lack of sensitivity in the measurement may be a significant source of bias.

The methodology and computation methods focus uniquely on the impact of disasters on agricultural assets and production flows. Nevertheless, it is acknowledged that disasters have negative effects beyond agricultural production and along the entire food and non-food value chain. In medium- and large-scale disasters, high production losses can lead to increases in imports of food and agricultural commodities to compensate for lost production and meet domestic demand. They can also reduce exports and revenues, with negative consequences for the balance of payment. When post-disaster production losses are significant and in countries where the sector makes an important contribution to economic growth, agriculture value-added or sector growth falls, as does national GDP. At the community level, disasters may undermine rural livelihoods and threaten food security.

It is important to note that this methodology could easily incorporate a resilience parameter, accounting for the specific context in which it is used. Resilience parameters would indicate a higher reconstruction cost in areas where resilience is lower. This would be of particular relevance in the estimation of damage to assets employed in all sub-sectors. Resilience parameters can be obtained, for instance, by incorporating reconstruction time and costs through indices such as the Vulnerability and Lack of coping capacity dimensions of the Index for Risk Management (INFORM), or other indices such as the Resilience Index Measurement and Analysis (RIMA), which are open-source methodologies for quantitatively assessing crises and disasters risk. The higher the risk, as defined by such indices, the higher would be coeteris paribus, the cost attached to the disaster in a specific area, given similar hazard intensity. It should also be noted that certain aspects of resilience are already endogenously incorporated into the methodology through the variability in yields.

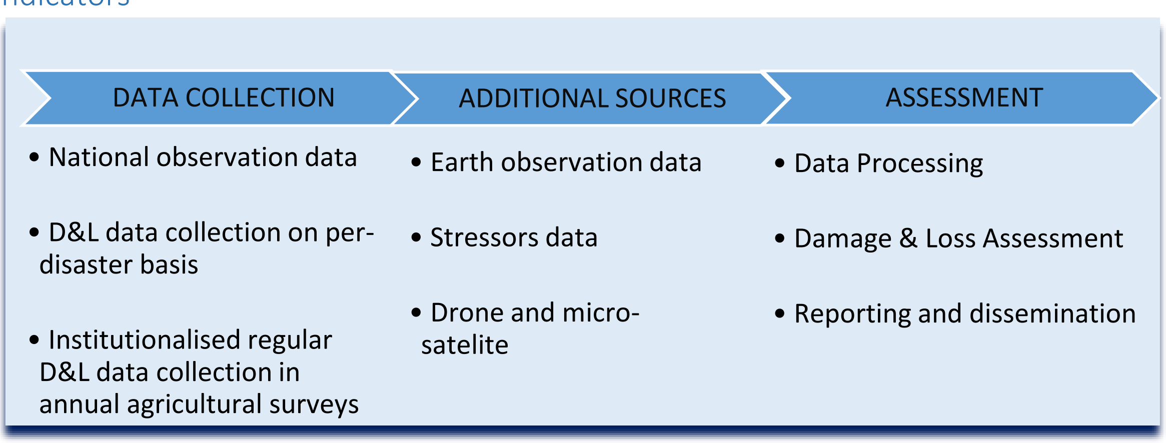
4. Towards an information system for damage and loss assessment

The definition of a standardized methodological framework is meant to support the establishment of institutionalized Damage and Loss Information Systems at country-level, which would cover the entire process – from data collection at national and sub-national level and database management to the calculation of disaster damage and loss in agriculture and dissemination of results to policy makers, investors and practitioners. The collection of relevant data is a first stepping-stone and can be organized in a variety of ways. A damage and loss component can be included in the country's existing suite of agricultural surveys. This is the optimal approach since collecting data on a regular (annual or semi-annual) basis allows to best capture the effect of disasters on agricultural production. As far as crop production is concerned, the impact of disasters should be surveyed at the end of the harvesting period, which is when most agricultural surveys are conducted. Furthermore, the methodology relies on a variety of "baseline" information, which is normally part of agricultural production questionnaires, i.e. plot area, crops by plot, production by crop, etc. Alternatively, data can also be collected on a per-disaster basis, upon early warning indications or in the immediate aftermath of the event. In this case, separate data collection forms should be developed and a parallel survey deployment mechanism should be established.

In order to complement the assessment process, information from alternative data sources can be incorporated, such as (micro) satellite and drone imagery, other earth observation data, and stressors data (e.g. climatic and environmental indicators). The use of airborne sensors on-board drones as well as micro-satellite imagery has been the subject of increasing interest due to their high resolution and timely and flexible acquisition capabilities. Additional damage and loss data can be therefore obtained through high quality drone or micro-satellite reference information, which can support the precise delineation of key elements of interest (e.g. crop fields).

Finally, the primary data is processed, stored and organized in order to develop a database of relevant post-disaster information and a reliable baseline for robust counterfactual analysis. Ultimately, the assessment stage implies implementing the FAO methodology and assigning the relevant values to the damage and loss categories in each sub-sector. The results of the sector assessment should then be disseminated to the relevant data users, namely policy and decision makers, development practitioners, international organizations, sub-national bodies and organizations and national reporting bodies responsible for Sendai and SDG monitoring. Figure 1 below outlines the overall process.

Figure 1. Damage and loss information system for agriculture: from data to indicators



In order to establish an efficient Information System and achieve reliable assessment results, it is crucial to conduct a thorough data collection process. Since this is often the biggest challenge in the entire process, sufficient emphasis and effort should be placed on improving access to data and standardizing data collection procedures. Moreover, integrating a D&L component in existing data collection is a useful strategy in order to avoid effort duplication and reap synergies.

In the case where regular agricultural data collection activities are not conducted, the FAO has developed a practical toolkit to assist country governments with the institutionalization of tailored National-level Damage and Loss Information Systems for agriculture. This tool kit consist of sample survey forms, data collection tools and database templates and guidance documents, which can serve to augment capacity for damage and loss assessment in national governments and help lay down standard operating procedures for regular disaster damage and loss data collection in agriculture.

As far standardizing assessment methods in the Assessment phase is concerned, the FAO Methodology allows to: (1) define how damage and loss measurements for all components (i.e. production and assets) in each agricultural sub-sector can be globally standardized; (2) develop estimation and imputation procedures to provide reliable figures for disaster impact assessments in the agricultural sector, even when relevant data are only partially available. The ultimate goal is to fully rely on primary data and use estimation procedures only when data are irretrievable.

5. FAO's methodology and the Global Resilience Agenda: Sendai Framework and SDG Reporting

Recently integrated into global resilience initiatives such as the SFDRR and the SDG agenda, the FAO methodology will further serve to measure progress towards reducing the monetary impact of disasters on agriculture. The SFDRR offers the opportunity to scale up DRR efforts in agriculture, which can be measured against tailored development outcomes and calls for a more proactive approach to DRR. Through the dedicated indicator on direct agricultural loss attributed to disasters (SFDRR Indicator C-2), FAO's methodology has the opportunity to contribute to the first global system for recording disaster loss.

The SFDRR 2015-2030 was adopted at the Third UN World Conference in Sendai, Japan, on 18 March 2015. It is the outcome of stakeholder consultations initiated in March 2012 and inter-governmental negotiations from July 2014 to March 2015, supported by the UNDRR at the request of the UN General Assembly. The SFDRR is the successor instrument to the HFA 2005-2015 and aims to achieve the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries over the following 15 years. The implementation of the SFDRR is under the custodianship of UNDRR.

A set of 38 indicators, recommended by an Open-ended Intergovernmental Expert Working Group, will track progress in implementing the seven targets of the SFDRR as well as its related dimensions reflected in the SDG 1, 11 and 13. The Sendai Framework Monitor will also function as a management tool to help countries DRR strategies, make risk-informed policy decisions and allocate resources to prevent new disaster risks.

In partnership with UNDRR, FAO's methodology will directly contribute to implementing and monitoring the SFDRR and – by the common reporting standards – the SDG Agenda. Specifically, it will be used to track the achievement of the SFDRR indicator C-2 on assessing direct agricultural loss attributed to disasters, and SDG target 1.5, which aims to build resilience and reduce exposure and vulnerability to climate-related extreme events and other shocks and disasters. The FAO Methodology therefore puts forward agricultural resilience monitoring within the UN-wide system by providing a standardized set of procedural and methodological steps that can be used at global, national and subnational levels. This will enable a thorough damage and loss assessment in the sector, ensuring consistency across countries and disasters.

Since both the Sendai and the SDG instruments support the Paris Agreement indicators and advance the goals of the Warsaw International Mechanism for Loss and Damage Associated with Climate Change Impacts, FAO's methodology will play a key part in further informing and enriching the climate change adaptation agenda.

Concluding remarks

FAO's methodology corresponds to universal norms, commitments, collective action and shared rules at the global level. Seeking to standardize disaster impact assessment in agriculture, it is both holistic enough to be applied in different disaster events and in different country/regional contexts, and precise enough to consider all agricultural subsectors and their specificities. In addition, it provides a framework for identifying, analyzing and evaluating the impact of disasters on the agriculture sector, and constitutes a useful tool for assembling and interpreting existing information to inform risk-related policy decision-making and planning. FAO's methodology can provide the backbone for damage and loss analysis in agriculture. Nevertheless, challenges lie ahead. While the foundation is laid, improved data and information structures are necessary to both inform and successfully apply the methodology according to its universal potential.

Once widely adopted, FAO's methodology will be instrumental in reinforcing planning, benchmarking and accountability at the national and subnational levels. It could help catalyze further integration of existing work on damage and loss assessment at the national level, while identifying and addressing persisting gaps and challenges in data collection.

Its framework requires an active multi-stakeholder participation and can further widen that perspective by incorporating aspects of climate change-induced impacts. Therefore, the FAO methodology offers a basis for strengthening national institutions and their statistical capacities for effective monitoring and disaster data collection in agriculture. It also emphasizes the need to foster cooperation and partnerships in support of strengthening agricultural resilience. In turn, this could help to direct policy and investment into the sector in a way that is commensurate with agriculture's crucial role in eradicating hunger, achieving food security and poverty alleviation and promoting sustainable development and economic growth.

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