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A methodology for the quantification of direct and indirect tangible financial losses from natural disasters

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This Working Paper is aimed at presenting and disseminating a synthesis of the outcomes of World Bank Contract 7189620 “Feasibility study on methodology of quantification of indirect financial losses from natural disasters”.

1. Literature review of financial direct and indirect tangible costs of flood events[1]

1.1 Introduction

Floods are among the natural disasters causing the biggest threat to human lives and economic assets. Okuyama and Sahin (2009), based on a global sample of 184 disasters occurred over

[1] The VIU (Venice International University) team who contributed to the writing of this deliverable was composed by Marta Ellena, Carlo Giupponi, Roberta Padulano, Marco Valentini, with the support of Fabio Cian.

the previous 47 years, showed that 25 % of the total economic losses came from hydro-meteorological disasters, while 40 % were due to geophysical disasters such as earthquakes. Moreover, as the figure below shows, the damage caused by extreme flood events is evidently increasing over time, as a consequence of territorial developments (e.g. urbanism) and of changing climatic drivers. Therefore, governmental institutions and flood risk professionals and planners need to understand flood impacts to build flood resilient societies, with particular focus on cities (OECD, 2016). Assessments of costs and benefits are crucial for the design of such strategies and management practices.

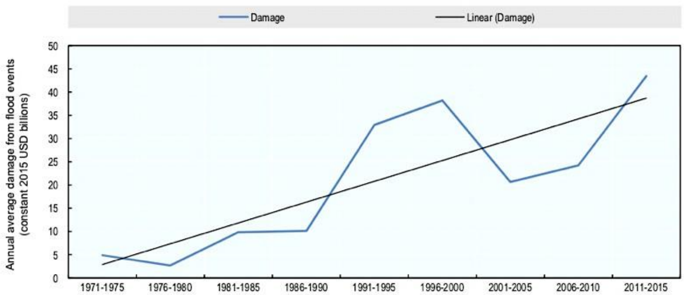

fig. 1
Annual average damage from flood events: 1971-2015 (average annual damage during each 5-year period) from OECD, 2016

Therefore, the need for defining methods for accurate assessment of costs deriving from flood damages is evident, but, notwithstanding the vast literature on the topic, the estimation of economic impacts remains a challenge. Both the methodological and the empirical bases show evident challenges, with the latter being particularly relevant, in particular for what concerns the accurate identification and quantification of the constituent elements, such as the allocation of costs to different categories and economic sectors.

The **general objectives of this consultancy** are:

• To design a methodology to estimate indirect tangible costs associated with high severity flood events;

• To produce estimates of the share of indirect economic costs as part of total economic costs, for a number of historical events and case studies covering various country risk profiles, exposure environments and severities.

The **specific objective of the present Deliverable A1** is to provide a review of the literature to describe the state of the art of methodologies employed for assessing direct and indirect tangible costs caused by natural disasters and, in particular, by floods.

1.2 Definitions

An initial effort has been dedicated to the exploration of the literature, to analyze terminologies adopted by various disciplines and different authors.

In general, the term **damage** refers to the **direct impact** of the hazardous event, during and immediately after the disaster and they can be measured in physical units, or in monetary ones.

Costs of flood damages are typically classified using two criteria (Giupponi et al., 2015; Merz et al., 2010; Messner, 2007; Olesen et al., 2017; Romali et al., 2018). The first criterion distinguishes between **tangible and intangible damages**. The second common distinction is between **direct and indirect damages**. **Tangible costs** are those deriving from the economic impacts. Their estimation has been mattering of a well-established body of research in the field of economics of natural disasters (NRC, 1999). **Intangible costs** are those values lost due to a disaster, which cannot, or are difficult and/or controversial to, be monetized, because they comprise non-market values (NRC, 1999). Intangibles mainly pertain to impacts on people and on the environment and are out of the scope of this work.

A **direct damage** is defined as any harmful effect that is caused by the immediate physical contact of flood water with humans, property and the environment and typically affects assets in terms of **stocks** of both physical and human capitals. In contrast, **indirect damages** are induced by the direct impacts and may occur – in space or time – beyond the immediate limits of the flood event and they are typically referred to changes in economic **flows** arising from the disaster.

The **Total Cost** of flood damage is given by the comprehensive assessment of the four categories of costs, but ***in this work we focus only on tangible direct and indirect costs.***

The damage cost of a natural hazard can be assessed in **financial or economic terms** (Olesen et al., 2017). Even if a clear distinction between the two is not always straightforward, **financial** analysis typically focuses on micro-scale and considers losses for local communities and individual households. Typical costs are those assessed by means of the prices of goods to be replaced as a consequence of the hazard. **Economic** loss assessment considers the macro impacts of hazards at broader national or even international scales. An example of the difference between the two is that financial analysis would consider the loss of business for individual firms, while economic analysis will assess nationwide effects, which could be positive or negative due to re-allocation of activities between competing businesses affected or not by the hazard (Penning-Rowsell et al., 2013). Financial losses consider taxes, while economic losses do not. ***In this work we focus on financial costs.***

1.3 Methodologies

In short, the assessment of flood damage costs can be done ex ante, or ex post. In the first case, the methodological context is that of risk assessment, in which the flood is considered as a hazard to which a probabilistic estimation of occurrence is hopefully attached. In the second case the assessment is carried out upon available information collected after a flood event, for example in the case of Post-Disaster Needs Assessment (PDNAs). Apart from the probabilistic vs. factual identification of the flood event, assessment methods can be referred to approaches for the calculation of **risk**, in particular those developed within the Disaster Risk Reduction (DRR) community, in which risk can be identified as the expected damages, computed as a function of hazard (H), physical and environmental vulnerability (V), and exposure (E) (Crichton, 1999):

$$R = f(H, V, E) \qquad [1]$$

Exposure here identifies the presence of people and assets and as much as possible the social, environmental, and economical value of them. **Vulnerability** is usually identified through maps result from the combination of environmental and social components. **Hazard** is characterized by probability distributions or specific return periods, and together with vulnerability, it is usually expressed as a dimensionless index, whereas exposure provides the unit of measurement of risk that can be expressed in physical or monetary terms. Therefore, in theory, the assessment of risk associated to a given hazard could be quantified in terms of damage costs by multiplying the monetary value of the exposed assets by two dimensionless indices, with values comprised between 0 and 1. In a **post disaster context**, as stated above, H is known and observed, and the consequent effects, i.e. the damages, should be considered as the specific combination of local states of V and E variable. According to this interpretation, a less vulnerable area is expected to show lower damages to a given flood magnitude, because of the combination of coping and adaptive capacities of the community, which reduced its vulnerability. These features could be considered as not relevant for immediate post-disaster assessment of damages, but they are instead quite relevant for the recovery and reconstruction phases, because they are at the basis of the resilience potential of the social-ecological system.

These methodological issues are developed in the second section, but what is already clear is that the damage cost assessment should primarily focus on the exposure component of the disaster risk assessment framework.

Concerning the distinction between direct and indirect damages, form the literature clear conceptual differences emerge between the approaches taken for their assessment, as reported in the table below.

Direct and indirect damages characteristics relevant for their assessment (adapted from Messner, 2007)

Direct damages	Indirect damages
Focus on the elements of the system (stocks)	Focus on system interactions (flows)
Static approach	Dynamic approach
Total costs as the sum of element costs	Total costs as a function of the main elements of the system and their interrelationships

A pre-requisite for cost estimation is the definition of the **spatial and temporal boundaries** of the assessment (Merz et al., 2010). Van der Veen (2004) distinguishes among micro-, meso- and macro- **spatial scales**, and also the scales of aggregation can be different: individuals, firms, communities, regions and nations (Scanlon 1988; Cochrane 2004).

In terms of **temporal scale**, floods can cause both immediate and long-term consequences, such as health effects, which are not captured if a short time horizon of the damage assessment is chosen (Merz et al., 2010).

Direct costing methodologies are quite well-established in the literature, but there still seems to be a mismatch between the relevance of the damage assessment and the quality of the available models (e.g., the stage-damage functions) and datasets. Indirect cost assessment methods are less consolidated, and many alternative approaches have been applied in the literature. Two methods are commonly used to quantify indirect tangible damages at micro scale:

- **unit cost method**, in which a sector specific loss unit is applied, since the indirect damages are mostly disruptions, and thus the damage cost is given as a cost per hour or day. The length of the disruptions can however be challenging to estimate and is the factor that causes the highest uncertainty in this damage class (Olesen et al., 2017);
- **percentage of direct tangible damage**, in which it is assumed that the indirect tangible damages are directly correlated to the direct tangible damages.

This work is aimed at exploring the feasibility of the adoption of the second method, at least as a first approximation for ex ante or (quasi) real time ex post assessments.

Assessment methods can be divided into four clusters of valuation techniques: (1) market-based (MB), (2) non-market-based (NMB), (3) traditional and integrated economic system modelling (T&IESM); and (4) benefit transfer methods.

Market price methods are mainly used to estimate the economic value of any product or service that is bought and sold in commercial markets. It can be used to value changes in the quantity or quality of a good or service. The estimation starts with assessing the supply and demand functions and proceeds with exploration of possible effects induced by flood shocks. The sum of surpluses represents the total net economic benefit of a good or service in a market (Logar and van den Bergh, 2012).

Non-market-based methods are of fundamental importance when intangible damages are concerned. Therefore, they are not of primary interest for the assessment of tangible damages as in our case. Nevertheless, they can be used in some circumstance also for the assessment of specific components of damage costs and they are then briefly presented below.

Traditional and integrated economic system modelling provide different types of modelling of the economic system that can be employed to explore in particular the indirect costs of a disaster. Three main sets of methods are considered here: (i) regional econometric models; (ii) Computable General Equilibrium (CGE) models; and (iii) Input-Output (I/O) models and Social Accounting Matrices (SAM); and (iv) integrated environmental-economic simulations.

Benefit transfer is a method that actually does not belong to any of the clusters presented and it is added here as it's often the simplest and most cost-effective way when other pertinent primary studies are available. Benefit transfer is the transfer of economic values estimated in an original study to a spatially and temporally different one. This practice is accepted when the characteristics and the context of the original study are similar to the new one. It is less time and resource consuming than the previous methods and therefore widely applied in meso and macro contexts where multiple single estimations would otherwise have been applied. The use of fixed ratios between previously assessed direct costs and indirect ones to be quantified is typically developed upon some sort of benefit transfer or meta-analysis surveys.

1.4 Case Studies

Studies of flood events have been selected from the scientific and grey literature with the aim to (i) have an overview of the attempts of tangible direct and indirect flood impacts assessment present in the literature, both scientific and grey, and (ii) understand the relation between direct and indirect impacts. In total, approximately 80 sources were analyzed. Given the scope of this research, we considered only the case studies that refer mainly to direct and indirect financial losses.

We ended up selecting 43 cases, categorized by i) country location and classification; ii) spatial scale; iii) flood type; iv) land use; v) direct damage sectors and assessment method; vi) indirect damage sectors and assessment method; vii) indirect/direct damage ratio; and viii) reference sources.

In general, 41% of the cases, refer to the macro-scale (country-scale assessment), followed by analyses at the meso-scale, 40 %. Only 19% of the cases (corresponding to 8 cases) refer to the micro scale, where most of them consider flood events in urban areas.

With reference to damage evaluation methodologies (see Section 3.3) cases were categorized in Market-Based (MB), Non-Market-Based (N-MB) and Traditional and Integrated Economic System Modelling (T/I-ESM). However, not all the methodologies fall directly into one of the mentioned groups, therefore we created an additional group named "Other methodologies/cost items", including also the cases of fixed percentages defined through benefit transfer approaches. The table below shows which methods were adopted in the studied cases for direct and indirect cost assessments.

Direct and indirect evaluation methodologies: frequency of use

DIRECT damage assessment methodologies

Macro-category	Method	Percentage of Use
MB	Replacement Costs	45%
	Market Price	9%
N-MB	Structured Survey	33%
	Stage damage function	6%
Other	"Book value"	5%
	Monetary value loss	2%

INDIRECT damage assessment methodologies

Macro-category	Method	Percentage of Use
MB	Market Price	2%
N-MB	Structured Survey	33%
	Travel costs	8%
T/I-ESM	Input/output analyses	4%
	Income Loss	37%
	Value added method	6%
Other	Fixed percentage method	4%
	Operating and provision cost method	6%

Concerning the ratio between direct and indirect damages, the following formula has been adopted in accordance with the literature:

$$R = \frac{Cumulative \;\; Indirect \;\; Damages}{Cumulative \;\; Direct \;\; Damages}$$

The R variable has a lower boundary at 0, when no indirect damages are found, but no upper boundary. The survey of cases shows that 79% of the case studies (34 out of 43) are characterized by R<100%, whereas the maximum observed value is about 200%, implying that for one case study ("BO 2008") indirect damages are twice bigger than direct damages.

To provide more detailed information on the relationships between direct and indirect damages, the latter were explored also with a sectoral analysis subdividing them into four main categories: (i) Private sector, Industry & Financial sector (**PIF**), (ii) Assets (**ASS**), (iii) Infrastructures (**INF**), and (iv) Agriculture (**AGR**). The table below presents the descriptive statistics for the ratio between indirect and direct cumulative damages.

Direct and indirect evaluation methodologies: frequency of use

SAMPLE	MEAN	MEDIAN	STANDARD DEVIATION	VARIANCE
R	56%	39%	36%	28%
R_{PIF}	23%	10%	31%	10%
R_{ASS}	10%	5%	13%	2%
R_{INFR}	14%	6%	20%	4%
R_{AGR}	23%	9%	34%	12%

With the ambition to explore the feasibility of identifying reference ratios between indirect and direct costs, statistical models have been applied to the data set of the ratios observed in case studies. The analysis of *R* data demonstrated that the distribution of observed values is far from a normal distribution. Much better fit can be found by adopting asymmetrical distributions, such as the lognormal, the gamma, or the exponential one, as demonstrated in the figure below.

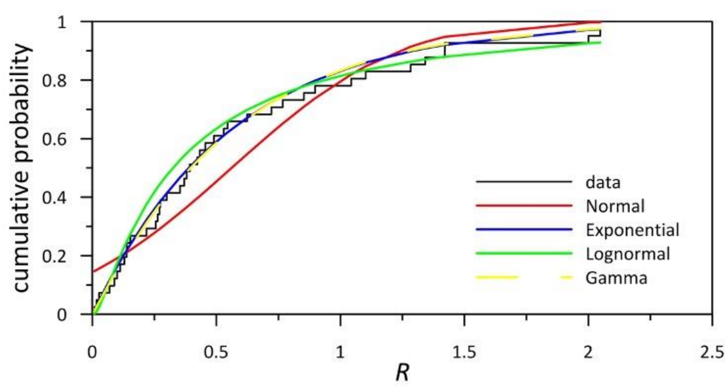

fig. 2
Cumulative probability distribution of the observed ratios between indirect and direct costs

The obtained probabilistic model enables extracting a series of **concise statements of potential interest**, which are listed below:

- The probability of R≤1 (namely cumulative indirect costs lower than direct costs) is 81%;
- The sample mean of *R* is 56% and the probability of *R*≤56% is

67%; the model mean is 72% and the probability of $R \leq 72\%$ is 73%.
• The median of the model is 32% (lower than the sample median, equal to 39%, whose associated lognormal probability level is 55%);
• There is 7% and 4% probability that indirect costs double or triple, respectively, the total tangible costs.

Concerning the potential use of the results obtained so far, the **high variability** of indirect damages with respect to direct damages, both in terms of cumulative costs and for the four investigated macro-sectors, as well as the intrinsic difficulties in quantifying such a variability should be remembered.

Such variability derives from well-known intrinsic case specific differences in the mechanisms determining the propagation of indirect costs from direct damages, as pointed out by several authors of the consulted literature. This evidence suggests treating with the greatest care the results obtained so far. Nevertheless, the probabilistic approach adopted can indeed be considered a possible solution for **real time *ex post***, or first approximation ex ante assessments, taking into account the effects of several sources of uncertainty (identification of cost categories, estimation methods, double counting problems, etc.) observed in the studied set of cases. From the results obtained, one could thus consider adopting a ratio around 0.35 when the median values are preferred. In other terms, a very first approximation of total tangible costs, in those cases in which only direct costs could be quantified would be to consider adding approximately 35% to their estimation. In those cases, in which more precautious estimations would be preferred, 150, or 200% increases of direct costs should be considered to include respectively the 90, or 95 percentiles of the observed values. Variations around those values could be defined with qualitative criteria deriving from the specific features of analysed cases. For example, precaution would suggest considering relatively higher values in those cases in which (i) floods extend beyond urban areas, (ii) when their relevance and extension suggest expanding the assessment to the meso- or macro-scale and (iii) when the affected areas are in less developed countries.

Indeed, a wider set of cases would allow for more robust use of the results, but the methodological approach and the management of data adopted herein easily allow for inclusion of more cases and model update, after the conclusion of this work, thus allowing the recalculation of the probabilistic model with wider data bases.

2. Methodological proposal for cost assessment of indirect financial losses from natural disasters[2]

2.1 Introduction

Risk is the crucial concept when dealing with natural disasters in an ***ex ante* context**. In this case, the methodological context is that of risk assessment, in which the flood is considered as a

[2] The VIU (Venice International University) team who contributed to the writing of this deliverable was composed by Carlo Giupponi and Marco Valentini.

hazard to which a probabilistic estimation of occurrence should be attached and risk is usually calculated as a function of hazard, exposure and vulnerability. Otherwise, in an ***ex post* context**, the assessment is carried out upon available information collected after a flood event and the focus is typically only the damages suffered by assets directly or indirectly exposed.

The review of the literature carried out in Deliverable A1 demonstrates that substantial discrepancies are evident in the literature, which is fragmented into many disciplinary streams and thus choices had to be made in terms of which pre-existing approaches had to be selected as main references.

In practice, we propose a damage cost assessment procedure that provides the monetary quantification of the **exposure** component of the broader disaster risk assessment framework, to be combined with **vulnerability** assessment for disaster relief applications and also with a probabilistic assessment of **hazard**, for ex ante risk assessment and planning.

We referred initially to the KULTURisk framework and its Socio-Economic Regional Risk Assessment method (i.e. SERRA; Giupponi et al., 2015), to answer the first of the two **general objectives** of this work:

- To design a methodology to estimate indirect tangible costs associated with high severity flood events:
- To produce estimates of the share of indirect economic costs as part of total economic costs, for a number of historical events and case studies covering various country risk profiles, exposure environments and severities.

Given the focus of this work to focus on tangible costs, the impacts on nature and cultural heritage are not considered, while those on people are included only for their contribution to indirect damages (evacuation costs, for example) The proposed approach thus considers **flood damage costs of the following components of economic activities**:

- private sector, industry and financial sector (tangible direct and indirect);
- assets (e.g. buildings and vehicles) (tangible direct and indirect to people);
- infrastructures (tangible direct and indirect);
- agriculture (tangible direct and indirect).

Moreover, given the relevance of the **DaLA approach** for the practice of damage assessment (GFDRR, 2013), and the role played by that approach in the cases examined in the literature review, its sector based approach has been interfaced with the receptor based approach adopted by SERRA.

By developing upon the integration of the SERRA and the DaLA approaches, we identified the variables to be quantified and we proposed a series of formulas for the calculation of the various components of direct tangible damaged and indirect ones. In order to facilitate the interface between the proposed approach and DaLA, in the mathematical notations we identified indirect damages as “losses”.

In total **12 formulas** are proposed, developed upon a common structure, which foresees the identification of the hazard with a given probability P, to be multiplied by the sum of the assessed costs for the receptor in question, which are typically derived from surveys and/or stage-damage functions. In the case of direct damages, the result of probabilistic damages are in turn multiplied by a site specific vulnerability index, which may vary between 1 (maximum vulnerability giving rise to the maximum expected damages) and a theoretical value of zero, in those – unrealistic – cases in which the social system is so strong and resistant to shocks that no consequences should be expected in terms of damages for the flood considered[3].

It is foreseen that P will not be considered for obvious reasons in case of post-disaster assessment, while the V index could still be considered in order to account for the effects of the indicators used to calculate the index on the resilience of the system during the phase of recovery. In other words, areas with high social vulnerabilities are expected to have lower resilience and thus the index can be useful as a first approximation estimation of the local capacities to recover after the disaster.

Given the current state of the art, the KULTURisk Project[4], an EU funded research aimed at developing a culture of risk prevention by evaluating the benefits of different risk prevention initiatives, has approached the development of a novel methodology for integrated assessment of water-related catastrophes. As proposed in the original proposal and in Deliverable A1, we will then refer to that framework (Giupponi et al., 2015), to answer the first of the two **general objectives** of this work:

- To design a methodology to estimate indirect tangible costs associated with high severity flood events;
- To produce estimates of the share of indirect economic costs as part of total economic costs, for a number of historical events and case studies covering various country risk profiles, exposure environments and severities.

The KULTURisk methodological framework and its operational approach **SERRA (Socio-Economic Regional Risk Assessment)**, were developed upon the well-established Regional Risk

[3] Details about the calculation of the vulnerability index can be found the KULTURisk Project deliverables, cited in the text below.
[4] KULTURisk: Knowledge-based approach to develop a cULTUre of Risk prevention. FP7-ENV-2010 Project 265280 (http://www.kulturisk.eu/)

Assessment literature (Landis, 2004), with specific focus on: (i) the integration of physical/environmental dimensions and the socio-economic ones; (ii) the consideration of social capacities of reducing risk, (iii) the economic valuation of risk that goes beyond the direct tangible costs for decision support on risk mitigation measures, and (iv) the integration of CCA in DRR[5]. As stated above, **disaster risk** is considered as the product of the interaction of the hazardous natural event and the vulnerability conditions of the combined natural and human elements exposed to the event itself (Gain et al., 2015). Overall formula [1] holds in the various processes proposed in SERRA (e.g. risk being necessarily null, when hazard is zero), even if not necessarily the algorithm is forced to produce two independent and dimensionless indexes (H and V) to be used in a multiplicative combination with one monetary index of exposure.

Figure 3 depicts how the variables of formula [1] are assessed in SERRA to produce a quantification of risk. In the case of a flood event, the outcomes of *hazard* assessment are typically one or more maps of intensity (expressed in terms of depth, persistence, and/or velocity) of the flood, usually provided by a combination of hydrological modelling and remote sensing. SERRA considers multiple **receptors** which, in accordance the European Flood Directive (EC, 2007), may be categorize into four categories: people, economic activities, cultural goods, and the environment. In this work the focus is limited to economic activities, i.e. one subset of the theoretical range of exposure components to be assessed.

According to SERRA, the spatial characterization of hazard, should be combined (map overlaying) with exposure maps and also with vulnerability maps, which in turn result from the combination of the assessment of receptors' Susceptibility (the likelihood that receptors located in the flooded area could potentially be harmed), Adaptive Capacity (the ex-ante preparedness of society given their risk perception and awareness to combat hazard and reduce its adverse impact) and Coping Capacity (the ex-post skills to cope with and overcome the impacts of the hazard considered). A list of indicators that can proxy the three dimensions of vulnerability is proposed in SERRA (Mojtahed et al., 2013) and will not be reported here for brevity.

5 For details about the KULTURisk approach to RRA, see Project deliverables 1.2 and 1.7 at http://www.kulturisk.eu/results/wp1.

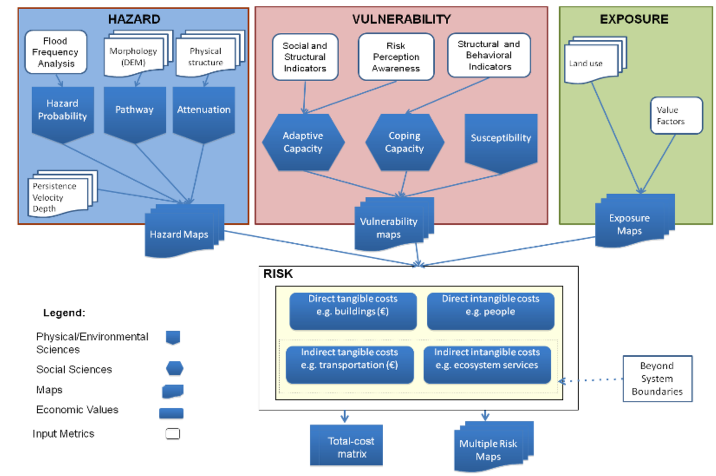

fig. 3
The KULTURisk Framework with the identification of the main sources of data for the quantification of nodes

The application of SERRA allows calculating ex-ante the expected damages related to the risks associated to different hazardous scenarios, quantified as the damages to be expected as a consequence of hazards with different probability levels, and to be compared with the costs of possible prevention measures. The effects expected from the measures are thus expressed either in terms of monetary benefits (avoided costs), or by means of effectiveness indicators and they are compared together with their expected costs, by means of Cost-Benefit (CBA) or Cost-Effectiveness Analysis (CEA), respectively. The same approach can also support the quantification of risks for the development of insurance instruments and the quantification of premiums.

Given the objective of this work to focus on tangible costs, the impacts on nature and cultural heritage are not considered, while those on people are included only for their contribution to indirect damages (evacuation costs, for example) The proposed approach thus considers **flood damage costs of the following components of economic activities**:

- private sector, industry and financial sector (tangible direct and indirect);
- assets (e.g. buildings and vehicles) (tangible direct);
- infrastructures (tangible direct and indirect);
- agriculture (tangible direct and indirect).

From the above, it is evident that the focus of this work should be on the top right block of Figure 2 (Exposure) and on the left hand part of risk, i.e. direct and indirect tangible costs. Nevertheless, the proposed methodological framework is designed to consider more broadly risk assessment and planning and thus other receptors and intangible damage costs could be easily included in future developments and applications.

2.2 Assessment of Tangible Damage Costs on Economic Activities

Hazard, vulnerability, and exposure are usually reported as maps. Therefore, they are spatially explicit, and typically managed in a GIS context (Geographical Information System), such as raster based maps of inundated areas produced by hydrologic models, or census based maps representing the distribution of people, or remotely sensed maps of assets and flooded area.

There is not a single procedure for the quantification of the SERRA components included in Figure 2, because the approach should be adapted to the specific objectives and the conditions (e.g. scale, data availability, study boundary, etc.) of each implementation. For instance, simpler solutions can consider aggregate costs and/or indicators of social capacities, instead of spatial ones. Examples can be found in a series of previous publications (Gain et al., 2015; Giupponi et al., 2013; Giupponi et al., 2015; Mojtahed et al., 2013).

Given the relevance of the **DaLA approach** for the practice of damage assessment (GFDRR, 2013), and the role played by that approach in the cases examined in the literature review of Deliverable A1, its sector based approach has been cross-tabulated with the receptor based approach adopted by SERRA, in order to clarify how they could be interfaced and integrated (see table below).

Tangible Direct and Indirect Damages in DaLA and SERRA

		DaLA Sectors									
		Infrastructure			Social Sectors			Productive Sectors			
	SERRA Receptors	Water&Sanit	Electricity	Transp&Comm	Housing	Education	Health	Agriculture	Industry	Commerce	Tourism
	People				x	x	x				
EconAct	Buildings				x	x	x	x	x	x	x
EconAct	Comm&Ind.Build.								x	x	x
EconAct	Infrastructures	x	x	x							
EconAct	Agriculture							x			
	Nature										
	Culture										

2.2.1 Assessment of direct damage costs on economic activities

2.2.1.1 Buildings

It is a common practice in the literature (e.g., Kiefer and Willett, 1996; Smith, 1994) to determine percentage of damage, susceptibility, to a certain type of receptor depending on the hazard metrics such as depth and debris factor. However, buildings' structures differ in their level of susceptibility that is based on used materials and age. In practice, since the detail of each building is often not available or it is costly to acquire, different buildings are not considered individually, but they are clustered into blocks (Scawthorn et al., 2006) and averaged flood depth damage functions are adopted. The same is applied for the damages to buildings' contents, which are estimated on the basis of buildings' features such as the value of buildings, the type of businesses, city zones, and others. The SERRA procedure starts from the identification of the cost per square meter of a new construction (given the foundation, material, etc.) that enables us to calculate the value of structure by multiplying it by the total square metres of building. The proposed algorithm builds on prior studies (e.g., Dutta et al., 2003), and includes the yearly probability P of return of a flood, computed according to the historical frequency and then uniformly distributed over the years: for a flood of 100-yr return period, the probability of occurring in each year is then 0.016. The cost analysis should be applied on each cell (i,j) of a GIS raster layer, in which buildings have been identified, resulting in the calculation of Db (**Damage to buildings**), as indicated below:

$$Db = P \cdot \sum_{g} \sum_{k=1}^{2} \sum_{ij} \left[\left(N_{ij,k,g} \cdot ASM_{ij,k,g} \cdot UC_{ij,k,g} \right) \cdot V_{ij} \right] \quad (1)$$

where (i,j) is the cell in row i and column j in the GIS grid; g is the type of the buildings: residential, commercial and industrial, hot spot, agricultural; and k represents the class of the buildings: single storied building have (k=1) and multi-storied (k=2). $N_{ij,kg}$ is the number of buildings of class k and type g in the grid cell (i,j), with average square meter equal to $ASM_{i,j,kg}$[7]; $UC_{i,j,kg}$, the repairing and construction costs as defined by a specific damage function in the area (i,j) for building class k and type g, and $V_{i,j}$ the vulnerability in the cell (i,j).

For commercial and industrial buildings structural damages are very similar to the residential buildings and they are defined by sectors (industrial and commercial) and size of companies.

For estimating damages to "hot spot" buildings such as hospitals, fire stations, and other which produce an infrastructural or emergency service for the community, a customized vulnerability index is applied to take into account the lower susceptibility of these buildings against natural hazards.

[6] The same meaning should be applied to all the other formula in which P is included.

[7] In case data on building is extracted from GIS layers N and ASM can be jointly detected as the total built area of the cell (i,j).

The content **damage to residential buildings**, Dbc_R, of the ground floor and basements of households in each cell (*i,j*) is

$$Dbc_R = P \cdot \sum_{l=1}^{3} \sum_{ij} \left[(NH_{ij,l} \cdot ASM_{ij,l} \cdot \gamma UC_{ij,l} \quad) \cdot V_{ij} \right], \qquad (2)$$

where, *l* is the type of the household that may be made to vary as a function of the income level, or of the location of the buildings (e.g. rural vs. urban); $NH_{i,j,l}$ is the number of households on the ground floor and basements of each class *l* in a grid cell *(i,j)*; γ is the proportion of the repairing and construction costs as defined by a specific damage function in the area *(i,j)* for residential buildings class *l*. Similarly, the **business content damage**, Dbc_B, is formalized by:

$$Dbc_B = P \cdot \sum_{g} \sum_{ij} \left[\left(PA_{ij,g} - DEPR_{ij,g} \right) \quad \cdot V_{ij} \right] \qquad (3)$$

Where *PA(i,j,g)* is the value of the physical assets, which should be available from the financial position (or balance sheet) for the firm that is held in the non-residential building on ground floor and basements in the cell *(i,j)*. The values of *g* represent the type of the buildings: commercial-industrial, hot spot, agricultural ones[8]. And *DEPR(i,j,k,g)* is the value of depreciation of the physical assets, available in the financial position as well. The value of the content, in brackets, must be multiplied by the vulnerability V_{ij}. When there is the impossibility to obtain the balance sheet, the value of the content (the one within parentheses in Equation 4) must be computed on its liquidation value.

To estimate **clean-up costs** (Dcu), it is important to account for demolition and rubble removal operations. Dcu is formalized by:

$$Dcu = P \cdot \sum_{g} \sum_{ij} \left[(N_{ij,k,g} \cdot ASM_{ij,k,g} \cdot \delta UC_{ij,k,g}) \quad \cdot V_{ij} \right] \qquad (4)$$

Where δ is the proportion of *UC*, the repairing and construction costs as defined by a specific damage function in the area *(i,j)* for building type *g* on ground floor and basements, used to calculate clean-up costs per building typology, including agricultural ones.

[8] Here dead animals should be considered as part of the content of agricultural buildings as well as tractors and other equipment used in agriculture.

2.2.1.2 Infrastructures

The value of infrastructure is shown when the service they provide is not fully functional. Floods may also hit various elements of the infrastructure – also called "lifeline system" (O'Rourke, 2007): roads and railways (transportation), electricity pylons, lines and substations (electric power), telephone exchanges and lines (telecommunications and internet), sewerage system (waste disposal), gas and other fuels conducts (fuel lines) and water conducts (water supply). In an interconnected system, such as that of infrastructures, connections between nodes may on the one hand provoke cascade effects of propagation of a failure in one point throughout adjacent nodes of the system, while on the other hand a slightly higher capacity of the edges may increase the resilience of the network to failures, thus avoiding total breakdowns. For instance, in a power grid the failure of a transmission substation may create a cascading effect in the electrical network, rapidly degrading the efficiency of the transmission along alternative paths, if the nodes do not have enough margin to handle an increased load (Kinney et al., 2005).

The essential feature of a system of infrastructure is that it connects nodes (i.e., pylons, substations in an electrical network, crossroads or train-stations in a transportation network) or set of points through edges (railways, roads, telephone or internet cables and others) that would otherwise be separated. For instance, a road could be of critical importance to connect a local economy to the larger outside economy. Thereby, mitigating damages to the system that infrastructures empower is increasingly pivotal with the integration of systems.

In the estimation of damages, the cost of components, the impacts to the systems' functionality, and the overall amount of time to re-establish it must be taken into account. Impact to systems' functionality can be analysed by considering the connectivity of the network, i.e., the presence of substitute paths and their efficiency in carrying the load of a non-functional path. For instance, roads can be alternative paths to a highway to reach a destination starting from the same origin, thus they can reduce the negative impact to the system produced by damages to the highways.
Tables of replacement and clean up unit cost ($ per square meter, meter, or kilometre) for any type k of infrastructure are necessary to estimate the damages.

To compute the **costs of repairing the infrastructure**, we assume that the objective is to re-establish the functionality of the system as it was prior to the occurrence of the disaster. Thus, the total damages of the system must be fully covered. Therefore, to assess them, we must start by computing the damages to infrastructure type k caused by a flood.

The total damages sustained by the type k of infrastructure are caused by the combination of the hazard severeness and the exposure of infrastructure and can be estimated by means of damage functions based on its characteristics, and inundated line length of edge ($L_{ij,k}$).

$$Di = P \cdot \sum_{k} \sum_{i,j} \left[(UC_{ij,k} \cdot L_{ij,k}) \cdot V_{ij} \right] \quad (5)$$

The damage to the system *k* is the sum of the unit cost per length unit (*UC*), given by cleaning and repairing, to the infrastructure *k* (Transport, Power grid, Water supply and treatment, Gas and fuel networks, Telephone and internet) for each specific flood severeness, as defined by a *k* specific damage function, and $V_{i,j}$ the vulnerability in the cell *(i,j)*.

Damage to **vehicle stocks** — including automobiles, buses, trucks and other smaller vehicles — must be estimated in the transport sector assessment. Care should be taken to avoid double counting of vehicles belonging to business actors, that could be accounted also under their specific sector.

2.2.2 Assessment of indirect damage costs on economic activities

2.2.2.1 Tangible damages on people

Indirect tangible damages on people (*Lpe*) refer to possible higher temporary costs and lower revenues incurred during the recovery and reconstruction period after the flood and they can be calculated as follows:

$$Lpe = P \cdot \sum_{k} \sum_{ij} \left[(NP_{ij} \cdot UCP_{k} \cdot Day_{ij}) \cdot V_{ij} \right] \quad (6)$$

Where *Lpe* identifies the total tangible losses (i.e. indirect damages)[9] on people. NP_{ij} is the person number in the cell *(i,j)*, V_{ij} the vulnerability, Day_{ij} is the number of emergency days and UCP_{ijk}, is unit cost and type *k* identifies:

1. Evacuation: Cost of labour, capital, and transportation for evacuation;
2. Subsistence: Cost of housing peoples in emergency shelters and providing food and water, including housing during evacuation;
3. Reoccupation: Costs associated with travel time and transportation modes to preoccupied destinations;
4. Education: Cost to continue schooling in new locations to enable the routine mission of education;
5. Public Agencies: Cost to continue routine services to maintain social functions;
6. Indoor Recreation Facilities: Cost of loss to serving the public's general information and recreational needs;
7. Medical: Cost to continue providing routine services to people who would have been injured regardless of flood, at non-flooded

[9] We use here the term losses in analogy with the DaLA approach, as a synonym of indirect damage cost.

facilities. Cost of hospital evacuation, disaster medical assistance team and elder care.

2.2.2.2 Infrastructures

As stated above, infrastructures are physical assets that play a *nodal* role for the functionality of the service they provide. If they are damaged in a way not to be able to provide the usual service, they must be treated analogously to the case of node removal in a network, but to do so, the network of infrastructure must be mapped.

The extent of indirect losses depends on factors such as availability of alternative sources of supply and markets for products, the length of production disturbance, and deferability of production. Yet, the costs of the distress caused by the lack of efficiency of the system must be computed and added to provide an accurate estimate.

For **transport infrastructures**, we estimate the damage due to loss of efficiency as the sum of marginal costs (extra costs for accomplishing the same goal with an alternative path, e.g., reaching the same destination through a longer or bumpier road), or, when efficiency of the path is zero – the infrastructure is broken and does not allow the performance of the activity – as the opportunity costs. The additional cost is computed as the difference of the cost of of getting from s to t through two different paths: the best – but longer – path available after the event, and the optimal path prior to the hazard.

The total additional cost is computed by multiplying the additional time to get from s to t, for the number of days in which such discomfort exists and for the average salary per unit of time.

$$Lti = P \cdot \sum_{k} \sum_{st} \left[AS \cdot (AT_{k,st} \cdot Day_{k,st} \cdot FL_{k,st}) \right] \tag{7}$$

Where Lti sums discomfort cost for transport infrastructure k to reach t from s, AS is average salary per unit of time, AT is additional time, Day is number of day of inefficiency, FL is volume flows of traffic. **Communication infrastructures** can be treated similarly to transportation, by adapting Equation 8.
Indirect costs on infrastructure different from transportation, typically **utility infrastructures**, refer to the changes in operational performance of the sector enterprise(s), and usually include both a decline in revenues (for providing services), and increased operational costs[10]:

$$Lui = P \cdot \sum_{k} [NI_k \cdot (HC_k + DR_k) \cdot Day_k] \tag{8}$$

Where k represents electricity, gas and fuel, water and sanitation sectors, NI_k is the enterprises number, V_k the vulnerability,

[10] These costs can be considered also in some circumstances for transport infrastructures, e.g. in the case of highways subject to tolls.

Day_k is the number of emergency days and HC_k and DR_k, are respectively: higher operational costs incurred by the enterprises due to use alternative that have higher unit cost of operation; lower operational revenues from sales due to the temporary, total interruption of service and the temporary decline in demand from user sectors.

2.2.2.3 Business Sector

Furthermore, we need to compute the impacts of floods on **business activities**, and we call it loss on business *Lb*. We provide a rough estimate of losses for business activities not related to tourism, agriculture, utility and transport and communication sectors, by multiplying the number of days in which the firm *m* is not efficient and its average value added (*VA*), as in Equation (10).

$$Lb = P \cdot \sum_{m=1}^{N} (Day_m \cdot VA_m) \qquad (9)$$

The estimate in Equation (10) is computed on the business activity of the affected firms, whereas the impact may cause a cascade effect on the entire supply chain of the business. The harmful effects can propagate through an interconnected network of firms linked to the one directly affected by the hazard. The network can be forwardly or backwardly shaped. Forwardly linked are those businesses that rely on regional customers to purchase their output. Backwardly linked are those that rely on regional suppliers to provide their inputs. Thus the business of firms in the supply chain is susceptible to be negatively affected or interrupted even if they are remote from the flooded area.
To assess such indirect damages, we have two alternative approaches that should be considered, depending on the scale of the event. A **"micro" approach**, suitable in particular for events of limited magnitude and limited propagation effects, should investigate the set of affected firms and calculate Lb as proposed in Equation 10. Otherwise, when the magnitude of the event is such to propagate substantial effects on the economic system of a broad area (up to the national level and beyond), a **"macro" approach** should be preferred, taking into account the input-output interdependencies between the products of firms directly affected by the flood and those of their partners along the supply chain. This can be done when information about input-output (I-O) matrix for the economic system affected is available (i.e. national or regional).

Economic losses of **tourism activity** can be calculated from data about the loss of visitors to the flood-stricken region and can be treated as a demand shock that piles up with potential damages to hotels and facilities addressed to accommodating tourists that might reduce the supply capacity. The value factors needed for this assessment are the number of visitor-days (*VS*) lost, their average daily expenditures (AE), and the period after which businesses return to normal activity.

$$Lt = P \cdot (Day \cdot AE \cdot VS) \quad (10)$$

Damages on **agricultural activities** depend on duration, depth of flooding, and on timing, i.e., the season of the year in which the flood occurs. They depend also on the agricultural activity affected by the flood. Here we make a distinction between damages on annual crops and damages on perennial crops, livestock and fisheries.

Concerning crops, losses depend on the cultivation stage ranging from land preparation, as the first phase, to harvesting and packing, as the last phases. A comprehensive list of agricultural phases and related costs is provided in Table below.

Damages to agricultural activities (http://coststudies.ucdavis.edu/current.php).

Costs	Description
Group 1 – Cultivation costs	
1. Irrigation	The cost varies according to method of irrigation, crop type, and the month of the year.
2. Fertilization	The cost varies according to the type of crop.
3. Weed/Insects Control	The cost varies according to the month of the year.
4. Pest Control	
Group 2 – Harvest or Post harvest cost	
1. Cutting	
2. Hauling	
3. Packing	
Group 3 – Establishment cost	
1. Preparation	Costs of chiselling the ground to a certain depth.
2. Planting	Based on the season changes.
3. Production	
4. Cash overhead	Property tax, insurance, crop insurance, office expenses, management and supervisor costs, annual maintenance.

Loss of gross income should be added to the cost of agricultural damages. Gross income can be estimated based on the market prices of each crop and the average yield of that crop per hectare. The following formula adapted from Dutta et al. (2003) and Ganji et al. (2012), allow us to calculate the **losses for annual crops deriving from limited production due to floods**:

$$La = P \cdot \sum_{k} \sum_{ij} \left[(PR_k \cdot Y_k \cdot D_k) \cdot A_{ij,k} \right] \quad (11)$$

where *La* is the total agricultural loss; *k* is annual crop variety *k*; $A_{(i,j,k)}$ is the total cultivated area of crop *k*; PR_k is the estimated price per unit weight of crop *k*; Y_k is the annual yield per unit area for crop *k*; *D* Percentage decline in average crop *k* yield. In case of total loss of production due to a flood occurring before all the production costs have been sustained, the expenses not yet occurred should be deducted from *La*.
Three other **agricultural sub-sectors with multi-annual production cycles** should be considered besides annual crops, as mentioned above: perennial crops, livestock and fisheries.
Loss is equal to the sum of the value of the full standing production loss[11] (*PL*) at the time of the disaster plus the value of future production losses (*FPL*) over time. Moreover, higher production costs (*HC*) have to be accounted for.

$$Lp = P \cdot \sum_{k} [PL_k + FPL_k + HC_k] \tag{12}$$

where *Lp* is the total loss; *k* is perennial crops, livestock and fisheries. Death of animals used for meat and broilers should be included in the direct damage part of the livestock sub-sector, while in loss calculation the male animals used for draft purposes, cows and buffaloes used for milk, poultry for eggs and honey bees for honey are to be considered.

2.2.2.4 Taxes

A tax revenue loss is another important component of the indirect loss, which affects regional authorities or the governmental sector. SERRA methodology appraises the aggregated tax revenue impact by multiplying the change in sector's outputs by indirect business tax (IBT) coefficient. We can develop IBT coefficients covering property taxes, sales taxes, licenses and fees.
The loss of tax revenue due to flood can affect the local or governmental income in the next fiscal year. It is also possible to enhance decision makers' view on winners and losers of the disaster by incorporating the Input-Output (I-O) matrices. This matrix contains the percentage of income that flows to each of other income brackets from each of the categories of I-O tables. Alternatively, loss of tax can be estimated multiplying the change in sector's outputs by indirect business tax (IBT) coefficient. We can develop IBT coefficients covering property taxes, sales taxes, licenses and fees.

[11] Examples are: value of production loss from the perennial crops; loss of milk production; loss of meat production; loss of egg production; loss of honey production; loss of wool production; loss of draft power due to stress; decline in fish yield for aquaculture; and decline in fish catch. The estimated value can be obtained by multiplying the affected area with average unit yield in a normal year and the average farm gate price and the quota of production loss in the case of partial damage.

3. Test of the proposed approach in two case studies[12]

The purpose of this activity was to test the methodology proposed in Deliverable A2 in two cases selected in countries of primary interest for the World Bank: Bangladesh and Morocco. Important is to point out that a comprehensive assessment and damage estimation of the two flood events was instead out of scope, for evident limitations in time and financial resources.

[12] The VIU (Venice International University) team who contributed to the writing of this deliverable was composed by Carlo Giupponi and Marco Valentini.

Those limitations did not allow to organise an adequate program of dedicated missions in the two countries. Therefore, the solution for the identification of specific flood cases and the acquisition of available information was found in the activation of pre-existing contacts with scholars of the two countries who supported the team of consultants in remote. In parallel to their activities and with their guidance and suggestion, an extensive and in-depth search of internet sources carried out in remote allowed for the collection of both spatial information stored in GIS format and qualitative and quantitative information used as input for the assessment variables and as sort of ground control points for the validation of the damage estimation.

A preliminary exploration with local contacts brought to the identification of two cases with extremely different features, which appeared as good opportunities for the validation of the proposed method: one case affecting a very large rural area, which lasted for weeks, in a country subject to annual monsoon floods, and another one which affected the capital of a relatively dry country, with an exceptional event of heavy rain and flash floods, which lasted for no more than few hours, or days depending of the neighbourhoods.

The two cases are briefly introduced below.

1) The first is the pre-monsoon flood of spring 2017, which affected the Haor region in the north-eastern part of Bangladesh, as consequence of heavy rains which started in late March and continued until late April. Floods affected approximately 850,000 households causing severe damage in the agricultural sector, with impacts also on infrastructures, including bridges and roads, with severe damages affecting mostly the ready-to-be harvested "boro" paddy crop in low-lying areas. According to the Global Information and Early Warning System on Food and Agriculture (GIEWS) of the FAO, the most affected districts were Sylhet, Moulvibazar, Sunamganj, Habiganj, Netrokona and Kishoreganj[13], and the last one was selected for in depth analysis in this report.

This case was selected in collaboration with local contacts, because it was an unusual event (in a season that is usually safe from floods), affecting a country prone to floods and thus prepared to deal with them (e.g. infrastructures designed to resist to submersion, houses built on relatively elevated places, etc.). For this reason the event appeared as a case of interest which could be analysed for its financial effects going beyond the usual monsoon floods affecting the country every year.

[13] www.fao.org/3/a-i7876e.pdf

2) The second is the flash flood of 23 February 2017, which affected Morocco in various parts of the country and including the cities of Rabat and Salé, with particular strength on the second. Reports of the event mention mainly flooded streets, commercial activities and ground floors of houses, and interruptions of services of national railways and of the trams connecting the two cities located on the sides of the river Bouregreg[14]. The rainfall recorded at the Rabat-Salé station reached a record high of 119 mm in during the afternoon; three times the previous daily rainfall record (45.5 mm) for the month of February since 1981, or twice the average of the monthly rainfall of the same month (64.5 mm) during the last 36 years.

This case was selected in collaboration with the local contact, because it was of exceptional magnitude, hitting an urban area which was not prepared to deal with such flash flood events, thus suffering from damages on properties and infrastructures, not being designed to be resilient to flood.

The distinct features of the two cases allowed also for testing the potential of previously developed approaches for flood mapping with remotely sensed information, thanks to the collaboration with Dr. Fabio Cian. As expected, the combination of large scale and long duration of the event in Bangladesh in open (rural) areas, allowed to confirm the potential of previously developed algorithms based upon a combination of active and passive remote sensing. Instead, the case of Morocco, showed how events of very short duration (in the order of hours or few days) and in urban areas cannot be effectively detected and mapped with those techniques.

In order to collect standardized information for the application of the proposed methodology, a questionnaire was designed and sent to local contacts. From the questionnaire (see section 3.3), it is quite evident that Kishoreganj is a rural area, which is regularly flooded during the monsoon season and thus people are adapted to floods and the society is relatively resilient. This explains why indirect damages are much higher than direct ones, which appear instead to be quite limited. According to the analyses carried out in this work, direct damages amount to 450 million BDT, while instead losses jump at almost 9 billion BDT. Hence, the ratio between indirect and direct costs is almost 20, which can be considered as an outlier in comparison to the results obtained in the literature review carried out for Deliverable A1. Besides the reasons mentioned above, such a high value was determined by the timing of the flood which hit the country a few days before the harvest of main crops, as it can be seen from the figure aside[15]. If the flood

[14] http://floodlist.com/africa/morocco-rabat-sale-floods-february-2017
[15] http://www.fao.org/giews/countrybrief/country.jsp?code=BGD

occurred only two or three weeks ahead, most of the indirect damages would have disappeared because of the harvesting of the crops. For the reasons explained above, the results obtained were considered as justified by the peculiar features of the case.

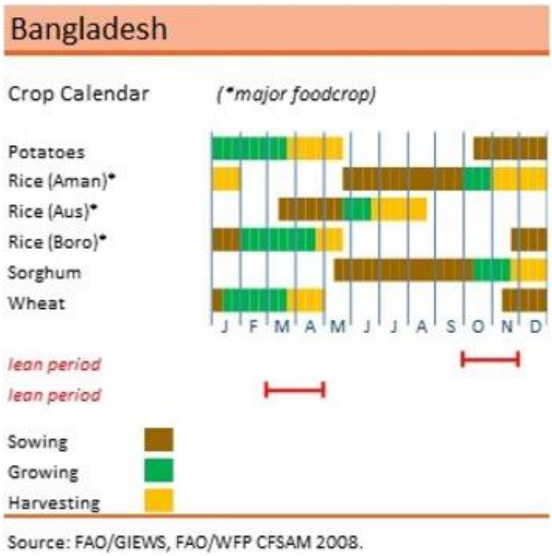

fig. 4
Bangladesh crop calendar and lean periods.

The table below reports the results of the application of the proposed approach in the Kishoreganj Districts, with values reported in local currency (Bengalese Taka, BDT).

Type	Receptor	Issue	Unit	Quantity	Unit value	Value	Total
Direct	Buildings	Repairing Clean-up	ha	42	12,690	533,000	
	Infrastructure	Repairing &Clean-up	km	66	6,818,182	450,000,000	
		Vehicle				--	
					Total direct damages		**450,533,000**
Indirect	People		Households (3 months)	65,000	1,700	331,500,000	
	Infrastructure		Days	5	692,679	3,463,396	
	Business					--	
	Tourism					--	
	Agriculture	Annual	ha	150,571	57,398	8,642,428,400	
		Perennial				--	
		Fish	ha	42	140,357	5,894,999	
	Taxes					--	

Total indirect damages (losses)	**8,983,286,795**

After the experimental application of the proposed methodology to the two cases, notwithstanding the limitations in the available information, it appears that the methodology proposed in Deliverable A2 can be considered practically applicable, comprehensive, allowing to take into account the most relevant components of both direct and indirect damages, selective, avoiding double counting, and flexible to be adapted to cases with extremely different characteristics.

Indeed, a more extensive application to other cases with adequate resources could provide more extensive opportunities for comprehensive testing the algorithms proposed, but we expect that the overall framework would confirm its strengths.

The positive perspectives in terms of application potentials of what proposed in this work is supported also by the efforts made to make the proposed approach coherent and complementary with the most popular current approaches (DaLA in particular) and ready to exploit spatial environmental and economic information available worldwide.

4. Final remarks about the observed relationships between direct and indirect damages

In conclusion to the work carried out for this contract, we provide some reflections about the overall question concerning the possibility of identifying reference values for the ratio between indirect and direct damage costs.

In particular, we would like to answer the following questions:

what is the current capability for ex ante estimation of the ratio between indirect and direct costs, given the updated results of the review conducted for Deliverable A.1? How do the two case studies carried out in Deliverable A.3 fit within the observed variability?

In order to answer these questions we ran a regression between indirect and direct damage ratio (dependent) and the values of some variables associated to literature cases, used as predictors. In this way we don't aim at developing a general statistical causal model, but only to identify whether it is possible to identify covariates to the costs, which show significant effects on the damage ratio.

In this exercise we use as independent variables the following factors extracted from the selected literature: OECD membership; land use of flooded area (urban or rural-urban); if flooding was flash, pluvial, fluvial and their combination; the scale of the estimation (micro, meso and macro); a dummy variable which is true (=1) if the share of private and public building damages (ASS) of total direct damages is at least 50%, expressed as a proxy of vulnerability (expecting that the higher is this share the lower would be the ratio, because the flood should affect productive activities to a lesser extent, hence the changes in economic flows caused by the disaster should be "low").

As reported in Deliverable A.1, we considered 43 cases, but only in 37 of them were considered here, because ASS damages were not quantified in some of them and in one case data were only reliable for agricultural sector.

In order to allow for the parameter interpretation, we first estimated a linear multiple regression using standard Ordinary Least Squares (OLS). Standard assumption about normality is not satisfied (in deliverable A1 we showed damage ratio's distribution can be approximated by log-normal or gamma), but linear models are very easy to interpret so they can be considered as a good starting point. Moreover, given the great variability of our 37 cases in terms of geo-localisation, year, calculation method of damages and so on, we estimated robust standard error to heteroskedasticity.

Running OLS regression on the abovementioned variables, OECD membership, type and scale of flooding resulted as not significant. Instead, the following variables resulted as statistically different from zero: land use, ASS share and their combination.

For the baseline (that is cases not purely urban, where ASS damages accounted less than 50% of direct damages) the damage ratio is on average 0.83 (see constant value of the model presented in the table below), but, if the flooded region is only urban, then the damage ratio decreases to an average value of 0.18 (i.e. the coefficient of -0.65 reported in the table below, subtracted to the baseline of 0.83). If the area suffered public and private properties and structural damages (ASS) higher than 50% of direct damages, then the damage ratio should decrease by 0.41 point: this means that the average damage ratio would be 0.42. Both coefficients match the hypothesis that for urban and vulnerable regions the damage ratio should tend to decrease, as observed in the Salé case.

Finally, for urban area where ASS share is higher than 50% we found a positive coefficient (0.539), which means that the average damage ratio becomes 0.31 (=0.83-0.65-0.41+0.54), which is very closed to our estimates in Morocco[16].

Indeed, the percentage of the total explained variance is low (R2 = 0.197, i.e. less than 20%) and thus the statistical model should not be used for predictive purposes on the basis of two variables only, but still is showed its value for explorative and explanatory purposes.

OLS regression: damage ratio on Urban and ASS share

Variable	β Coeff.	Robust Std. Err.	P-value
Urban	-0.649	0.173	0.001
ASS share >=50%	-0.406	0.188	0.038
Urban & ASS share >=50%	0.539	0.252	0.040
Constant	0.830	0.159	0.000
R^2=0.197			

From first deliverable we know damage ratio follow log-normal distribution, hence the natural logarithm of damage ratio follows normal distribution. For this reason, we estimated also a generalized linear model with natural logarithm as link function and a Gaussian distribution for the dependent variable. In the log-normal model the interpretation of the estimated coefficient β is more complicated than in the linear model presented above: one-unit increase in the value of a regressor X (here the variables Urban and ASS-share) will produce an expected increase in log Y (dependent variable) of β units. In terms of Y values, this means that each 1-unit increase in X multiplies the expected value of Y by e^{β}.

The table below confirms previous results. Urban area has a damage ratio of 0.183, which is 22% (0.218) of the baseline (i.e.: Constant 0.830 x 22% = 0.183). The regions where ASS share was at least 50% showed a damage ratio of 0.42 (i.e.: Constant 0.830 x 51% = 0.42), and for Urban area with ASS share at least 50%, the damage ratio is 0.313 (i.e.: Constant 0.830 x 22% x 51% x 340%=0.313). Once more, 0.313 is very close to our Morocco estimate.

[16] We could not consider the Bangladesh case study here, because it concerns agricultural sector only.

Log-normal regression: damage ratio on Urban and ASS share

Variable	β Coeff.	Exp (β Coeff.)	Robust Std. Err.	P-value
Urban	-1.523	0.218	0.089	0.000
ASS share >=50%	-0.671	0.511	0.149	0.021
Urban& ASS share >=50%	1.223	3.396	2.239	0.064
Constant	-0.186	0.830	0.152	0.309

Of course, these exploratory estimates (we are using 37 cases, two observables and R2 is about 0.2) could be substantially improved in view of possible predictive uses, if:

- the number of cases could be increased. For example, focusing on an heterogeneous country and applying our method (Deliverable A2) in numerous (e.g. 100) pilot sub-regions, could allow to reduce the current noise due to heterogeneity of methods for the estimation of damage costs and, obviously, would increase the number of observations in the regression model;
- other covariates at regional (i.e. sub-national) level could be collected and associated to the damage estimations: regional GDP per capita, density of route and railways infrastructures, agriculture share of GDP, number of companies per unit area, direct damages in relation to regional GDP, depth and length of flooding…

Expanding the number of cases and taking into account the abovementioned covariates could contribute dramatically to explain the variability of damage ratios and thus the model fitting.

A final consideration should be devoted to vulnerability. From a conceptual viewpoint, it is evident that the vulnerability of the place [potentially] affected by the flood should be considered as one of the most important explanatory variables for the magnitude of the damages and losses and their typologies. The question thus emerges about whether quantitative variables such as the one examined in this work, plus the ones proposed above for future studies can allow for inference on vulnerability, or instead an ad hoc vulnerability index should be defined and associated to the other variables in the quantification/explanation of damages and losses.

Our opinion is that a quantitative vulnerability index should be considered in these analyses to improve the quality of models and estimations, as proposed in Deliverable A.2.

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