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Chapter 2

Index of Proportional Risk (IRP) Flood-Risk Assessment Model and Comparison to Collected Data

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Additional information is available at the end of the chapter

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Abstract

After the publication of the flood directive hazard and risk maps, risk assessment and risk evaluation became useful tools to set priorities for flood management and for countermeasure financing. Regione Piemonte, in collaboration with Politecnico di Torino and University of Turin, proposed a procedure for risk assessment (named IRP model, Index of Proportional Risk), already applied in different case studies. The comparison among the obtained results and the collected data on damages recorded during the recent 2016 flood in Piemonte region showed the effectiveness of the IRP procedure for the quantitative assessment of direct damages. The IRP model can also be usefully applied to the revision and the updating of flood directive risk maps and to assess the cost/benefit ratio of the designed countermeasures (National Repository for Soil defense (Re.N.Di.S.) procedure).

Keywords: European flood directive, flood risk, vulnerability, flood mapping, flood-risk maps, flood damage

1. Introduction

In 2007, with the European Flood Directive (EFD) [1], legislation came into force, with the aim "*to reduce the risk of adverse consequences from flooding, especially for human health and life; the environment; cultural heritage; economic activity; and infrastructure.*"

The EFD has been implemented in the Italian Legislation with the Legislative Decree 49/2010, taking into account the applicable national legislation.

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The concept of flood risk in the EFD, that is,

> *"'flood risk' means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event".*

is similar to that already adopted in the PAI (Hydrogeological Asset Plan), a plan adopted by the Po Basin District Authority (PBDA [2]) in 2001, which aims at assessing and managing natural hazards and risks in the Po watershed basin (Italy). Risk was defined as ([2], p. 190).

> *"expected value of the damage that the receptors can undergo on average in a predetermined period of time".*

therefore implying the concept of damage and of probability of occurrence.

According to PAI, risk can be considered the superposition of the three elements, corresponding to a conceptual formula of this kind:

$$R = ExVxH \tag{1}$$

where E is the exposure, V is the Vulnerability, and H is the hazard.

The aim of PAI was to express *relative* comparison of risks on the Po watershed basin, highlighting, in relative terms, the distribution of natural risks on the territory. The flood risk was not quantified in economic terms, but only qualitatively assessed with the use of indicators. The risk was determined through the use and superposition of indicators and aggregated into four classes with increasing value (1 = moderate, 4 = very high); a risk level was associated to each municipality.

Therefore, the risk maps in PAI showed the different classification of municipalities in terms of relative risks.

The presence of PAI on the Italian territory has provided an adequate base, suitably updated, homogenized, and valued, to fulfill the obligations referred to the Article 6 of EFD. Therefore, the hazard and flood-risk maps have been obtained starting from those contained in PAI and in accordance with the "Operational guidelines" issued by the Ministry for the Environment, Land and Sea (MATTM) [3], with the contribution of ISPRA (*Superior Institute for Protection and Environmental Research)*, of the National Basin Authorities and State Regions technical board.

The EFD requirements about risk mapping forced public administration to find different methodologies to assess and map risk on the territory. Actually, the EFD, Article 5, forces Member state to *"identify those areas for which … potential significant flood risks exist or might be considered likely to occur,"* and risk maps have to be referred to the scale of areas at risk. Therefore, the municipality scale of PAI had to be changed according to the EFD requirements.

Italian Ministry fulfilled the requirements of the flood directive, as far as the following steps are concerned: (i) preliminary assessment, (ii) hazard and flood-risk maps, and (ii) management plans of flood risk (PGRA).

In Po river basin, flood maps and risk management plan came into force with the acts of the General Secretary decree (n.122/2014) and of the decree of the President of the Ministry Council (DPCM 26.10.2016), respectively.

As far as flood hazard assessment is concerned, the item has been widely described in other papers and is here summarized.

2. Risk assessment in land-use planning (Po basin)

The "Operational guidelines" issued by MATTM explain the contents of EFD and highlight the difficulties in risk mapping, that is ([3], p. 20),

> *"By considering the difficulties in quantifying parameters and the unavailability of reliable data of sufficient detail (…) it is reasonable to adopt, at least in this first phase, simplified methodological criteria for an assessment and representation of risk".*

and, as far as vulnerability is concerned ([3], p. 20),

> *"Therefore, in this first phase of drawing up the risk maps, we refer to an estimate of the vulnerability … assuming an equal value (vulnerability equal to 1) in the flood prone areas; consequently exposure and potential damage (…) have been considered to be equivalent."*

Consequently, damage has been deduced in a simplified way, that is, by associating the categories of exposed receptors to the *potential damage*. In practice, three potential damage classes have been identified: (i) D4—very high potential damage, (ii) D3—high potential damage, (iii) D2—medium potential damage, and (iv) D1—moderate (or null) damage, which are described in **Table 1**.

As a consequence of the damage ranking in four classes, the risk has been assessed by means of a matrix method. Risk categories have been deduced by those proposed by the former decree of the Prime Minister (D.P.C.M. 29.09.98, which contains the guidelines for the adoption of urgent countermeasures against natural hydro-geological risks, regarding hazard assessments).

Damage class	Description of the damage class
D1	(Moderate or null potential damage). It includes areas with no urban or productive settlements; free flow of floods on floodplain is possible.
D2	(Medium potential damage). It includes (i) areas where floods have limited effects on people, on productive activities (agriculture), (ii) secondary infrastructures, and (iii) public green areas.
D3	(Very high potential damage). It includes (i) areas with relevant damages for people and economic system, (ii) areas with relevant communication lines, and (iii) important productive activities.
D4	(Very high potential damage). It includes areas which can be affected by floods with serious risks for human life, relevant damages to economic activities, and/or environmental disasters.

Table 1. List of the classes of damage, according to the act of MATTM ([3], p. 24).

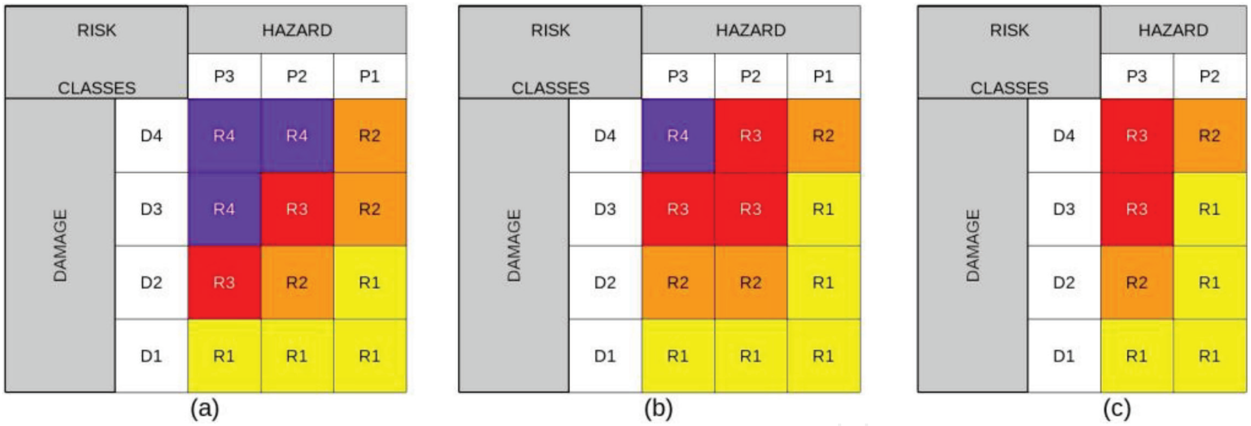

Figure 1. The matrices adopted in PGRA, by Po basin District Authority. Hazard classes P1, P2, and P3 refer to the return period indicated in EFD (P1 for T = 20–50; P2 for T = 100–200; P3 for T = 500).

As far as the Po basin District Authority ([4], p. 17) is concerned, the risk is assessed by the combination of the damage and hazard classes, through a matrix approach. The rows show the damage classes and the columns the hazard levels, that is, the probability of flood occurrence. The implementation of this matrix allowed associating a risk class to each exposed element (receptor).

To distinguish the different impacts in terms of human life and anthropic activities risk, three different matrices were used, each for a different flooding process: (i) first matrix (a) in **Figure 1** refers to flooding in main rivers, (ii) second matrix (b) to lake flooding and Apennines rivers, and (iii) third matrix (c) refers to plane secondary rivers.

On the basis of hazard and flood-risk maps, the District Authorities prearrange the flood-risk management plans (PGRA), coordinated at the level of river basin district.

3. Limitations in the approach to risk and vulnerability assessment

Risk matrices approaches are widely used by public administration as a basis for risk management decisions, with applications [5] from terrorism risk analysis, to highway construction project management, to dam and levee safety and climate change risk management. Risk matrices are widely used for risk reporting, risk prioritization, and risk monitoring [6].

On one hand, they are easy to use and intuitive, and they are often defended as a practical way to flood-risk management, especially when quantitative information is scarce or nonexistent [7]. On the other hand, their theoretical basis is superficial and their employ in decision making is hard, especially when different technical solutions for flood-risk management have to be compared to each other.

At present state, it is sustained that "*the flood directive asks for vulnerability parameters only. The risk as such is not explicitly requested, but implicitly the notion of risk is an integrated part*" (*Handbook on good practices for flood mapping in Europe* [8]). In other terms, the EFD does not require a quantitative estimation of risk. The cited handbook addresses the map of assets at risk (i.e., the distribution of population, vulnerable groups, and buildings at risk) more than to "*risk maps.*"

The same *Floods Directive Reporting Schemas* [9], which should be followed by countries in reporting to European Commission, allow different methods for reporting, and quantitative estimation is optional. Actually, according to the reporting schema, damage can be indicated (i) as a range, (ii) as a percentage of the total GDP for the flood event, (iii) by classes (Insignificant, Low, Medium, High, Very high), or (iv) by means of other numerical measure indicative of the degree of (potentially) adverse consequences, leaving a wide choice for implementation.

Therefore, the report of quantitative damage is not compulsory, qualitative estimations are widespread, even if the risk formula, which implies the quantification of risk, is often reported in official documents (see [9], p.23).

There are several practical problems with matrix approach, either with respect to the guidelines of the EFD or theoretical.

First, the scales shown in the matrix are ordinal (i.e., rank-ordered); consequently, mathematical operations with ordinal scales are meaningless.

Second, the risk matrix generally shows only probability and consequence, and rank risks by that pair of measures; vulnerability is implicitly considered in the matrix or set equal to a constant value.

Third, communication to people may reveal to be captious; for example, the damage in D4 class in **Table 1** is not necessarily twice the damage of D2 class, in spite of the damage class indication.

Fourth, it is questionable if risk matrices actually improve decision making. Cox has been particularly critical of risk matrix and hazard ranking systems, concluding that "*Applying portfolio optimization methods instead of risk prioritization ranking, rating, or scoring methods can achieve greater risk-reduction value for resources spent*" [10].

The present limitations of risk mapping approach adopted in the implementation of EFD can be reviewed and in the next step of "*…reconsideration and updating…*" in the flood directive.

Actually, the *management plans for flood risk (PGRA)* should be periodically reviewed, and if necessary updated, taking into account "*…the likely impacts of climate change on the occurrence of floods*" (EFD, art.14). Italian legislation provides the time limits to review the preliminary flood-risk assessment (before 09/22/2018 and at a later stage, every 6 years), the hazard maps and flood risk (before 22.9.2019 and thereafter every 6 years) as well as the Management Plans (before 22.09.2021 and thereafter every 6 years).

To this aim, ISPRA edited "*Methodological proposal for updating hazard and risk maps for risk mapping*" [11]. The document aims at proposing some approaches, taken from scientific literature, to be implemented in the revision and updating of the flood-risk maps.

On the basis of the proposal of the ISPRA document, a model (named IRP model) has been proposed by public administration in Piemonte region to quantify and evaluate risks, in view of the revision of the flood-risk maps. The model can also be a usable instrument to fulfill the requirements of the Re.N.Di.S. (National Repository for Soil defense) platform, described in the following paragraph.

4. The Re.N.Di.S. platform for planning

Flood damage quantification and assessment is not only a (optional) requirement for the implementation of EFD, but it has recently become a requirement for the evaluation of the projects of countermeasures and for the eligibility of public financing.

Actually, with the recent 2015 decree of the President of the Ministry Council (2015DPCM in the following), a new discipline to evaluate the priority of public financing for flood protection projects came into force in Italy. To set priorities is fundamental when financial resources are scarcer than necessities. Actually, at the moment, the total needs for protection (by considering all the kinds of natural hazards, which are floods, landslides, flash floods, debris flows) amount to about 30G€, by far higher than the resources available at the moment (**Table 2**).

The model for prioritization proposed by the 2015DPCM is based on a score approach.

According to the 2015DPCM, flood defense projects have to be collected into the so-called Re.N.Di.S. procedure, which is a national repository of projects for soil defense. For a given project, either the assessments by public administration, or the level reached by design, or the effectiveness of the designed countermeasures are scored. The Re.N.Di.S. procedure allows to associate a total score to each proposed project, included in the Re.N.Di.S. procedure. The criteria are listed in **Table 3**.

For the sake of simplicity, it can be said that, for a given project of flood protection measures included in the Re.N.Di.S procedure, the priority to financing is based on its total score: the higher is its score, the higher is its ranking and therefore the probability for public financing. As shown in **Table 3**, flood damage evaluation score is relevant with respect to other criteria: if the damage evaluation is given, there is a 10-point score.

	Total number of interventions eligible for financing	**Total financing requirements**	**Public financing requirements**
Floods in Italy	3284	15,046.00 M€	13,809.40 M€
Floods in Piemonte	417	1179.20 M€	(not available)
Total*	9397	29,110.00 M€	26,407.90 M€

*The total includes avalanches, soil-slips, coastal erosion, and other natural hazards.

Table 2. Total amount of proposed interventions for risk reduction and financing necessities (taken from [12]).

Criteria contained in the DPCM	Description of the criteria	Min-max score
Priority by public administration	The priority level is expressed by public administration and expressed in three levels. The cost/effectiveness rate should be considered	0–20
Design level (low/medium/high)	Italian laws consider three levels of design. The higher the level, the higher the score	3.3–10
Completion	Higher score for projects that are complementary to other projects	0–10
Directly endangered people	Higher score for a higher number of protected population	0–60
Goods at risk (properties, communication lines, etc.)	Higher score for projects that allow the protection of goods at risk	0–30
Frequency	Higher score if the project allows the protection to more frequent floods	4.2–30
Effectiveness of the project in terms of damage reduction	*The criteria allow a higher score for projects which quantify the effectiveness in terms of damage reduction*	*0—no quantification* *10—damage quantification*
Effectiveness of the project in terms of the reduction of the total number of involved people	*The criteria allow a higher score for projects which allow the reduction of the total number of people involved*	0–30
Compensation and mitigation measures	Presence of compensation and mitigation measures, which can mitigate the effects on environment	0–5
The higher is the total score, the higher is the ranking of the project for public financing.		

Table 3. List of the evaluation criteria of the projects, with the respective scores (table taken from the 2015DPCM).

Without a uniform methodology for damage assessment and quantification, the damage assessment and the cost/benefit analysis (upon which also the prioritization of the public administration is based) is meaningless, either for the aims of EFD or for the Re.N.Di.S. procedure. Heterogeneity would undermine the usability of the analysis.

Therefore, a uniform methodology for risk evaluation is required. It should be homogeneous at the national scale and based on databases available and preferably free to public and updated.

5. The IRP model

In order to overcome the constraints of the present methodologies for risk mapping, Regione Piemonte public administration in collaboration with the Politecnico of Turin and the University developed a methodology for risk assessment and quantification, which is based on the quantification of the *Index of Proportional Risk* (IRP).

The model has been developed by referring to specific types of risk, according to **Table 4**.

The IRP is quantified by applying the following expression:

$$IRP = \frac{1}{T}\sum_{i=1}^{N} e_i A_i v(h) \quad (2)$$

where *N*: total number of receptors in the flooding area; *T*: return period (years); *h*: flow depth (m); *A*: area of the receptor (m^2); *e*: OMI value (€/m^2); *v*(*h*): vulnerability (adim.); *IRP* dimension is €/year. The multiplication of the IRP and the return period is called *index of proportional damage* (IDP).

The model implicitly assumes the definition of risk contained in the EFD, as it refers either to the probability (the return period) or to the consequences of flood in terms of the flood damage.

According to Eq. (2), the model assumes that the total risk is proportional to the area of the receptor. A short description of the terms in Eq. (2) is given in **Table 5**.

The vulnerability V(h) is estimated by means of the JRC "European" curve in [13].

Flood depths maps can be easily obtained by following the procedure contained in [14, 15] and widely applied in the project of "Orco river flooding assessment," developed in collaboration with the former Po basin Authority [16].

The choice of the JRC curve has been guided by the necessity to adopt a "robust" formulation, which is based on a "*…globally consistent database…*" of depth-damage curve.

The proposal of a vulnerability curve usable for Po river floodplain is not simple, in particular due to the lack of detailed damage data, so that a vulnerability curve cannot be easily obtained for the receptors in Piemonte region and Padana plain.

As it is well known, many flood damage models using depth-damage curves have been proposed in scientific literature in different countries. They are generally based on analysis of past flood events and on regression of available data. However, such damage curves are not available for all regions, and their use can be questionable in some areas. Moreover, "*due to*

	Applicability	**Possible extension**
Type of risk	Direct and tangible risks; the model has been developed by referring to structural (and content) damage	The model allows to obtain a quantitative estimation of damages (and risks), to which other damages (and risks) can be correlated (e.g., indirect damages)
Type of processes	Major river flood processes in plains. By taking into account sediment transport, the model can also be applicable to stream floods	The model can be extended to processes like debris flows/soil-slips, as far as E is concerned. The approach to H and V should be revised
Main field of application/ objective	Spatial and land planning	Possible extension to real-time risk (civil protection)

Table 4. Natural hazards and types of processes to which the IRP model refers to.

different methodologies employed for various damage models in different countries…damage assessments cannot be directly compared with each other, obstructing also supra-national flood damage assessments" [13].

The discussion about the depth-damage curve to be adopted for risk mapping is in course among regions in Po watershed basin, the Po District authority, the Turin University, the Politecnico of Turin, and of Milan.

In the proposed model [14, 15], exposure is evaluated by referring to the OMI (*estate market observatory*, free available online, [17]) database. The exposure *E* of each receptor has been computed by the product of the area A of the receptor for its economic value "e"; this parameter is reported in the *OMI* dataset and, as applied in [14, 15], varies depending on the prevalent use of receptors (commercial, residential) and their location in the urbanized areas (*OMI* zones), which are considered homogeneous from the economic market point of view.

Item	Description
h	Water depth, computed at the centroid of the receptor. For receptors outside the flooding area, it is h = 0. The depth h is calculated at the barycenter of the i-th receptor, that is, by using a GIS terminology, at its *centroid*
e	The value of the receptor expressed in €/m^2, as indicated in the OMI database; OMI database is periodically updated and available to public
A	Receptors are contained in the Regione Piemonte BDTRE database, available to public (in *shape* format). The area of the receptors can be easily and automatically quantified by means of GIS software (e.g., QGIS©)
V(h)	The equation for vulnerability is contained in the JRC publication for "Europe" [13]

Table 5. Constitutive elements in the proposed model (H, E, V) and discussion (see [14, 15] for details).

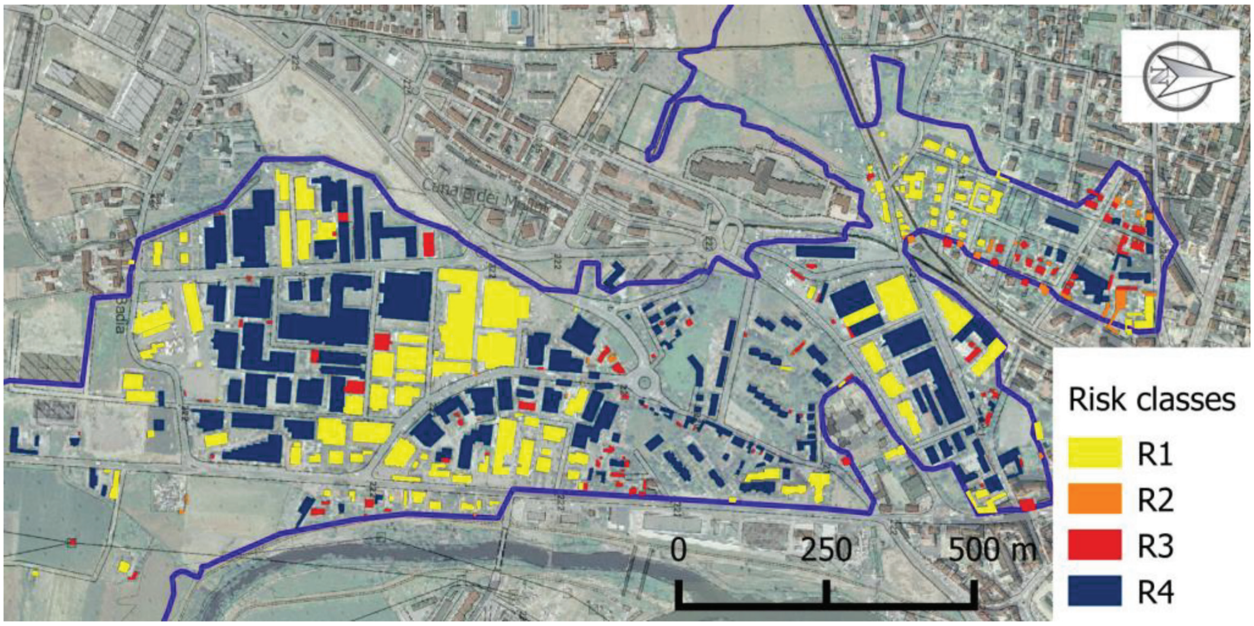

Figure 2. An example of the application of the procedure to the Chisola river. The map has been obtained by referring to the 2016 flood. Risk classes are on a log-scale (R1 class: 0–1000.00€; R2 class: 1000.00–10,000.00€; R3 class: 10000.00–100,000.00€; R4 class: >100,000.00€; the blue line indicates the borders of the flooding areas).

The IRP model can be easily used to rank flood risk, according to quantitative criteria. At present, it can be used to calculate the risk (and the damage) on receptors (buildings), as well as for risk mapping (**Figure 2**).

6. Model validation

The model has been extensively applied to different case studies, in Piemonte region, for the risk assessment and the cost/benefit analyses [14, 15].

In this work, a sort of validation of the model has been tried by comparing the IDP computed by the model and the damages recorded in the recent 2016 flood.

The term "validation" is not appropriate, as the comparison is not simple. Actually, it should be highlighted (see Section 8) that the real damages suffered by residential or commercial receptors may not be equal to the indemnifications by public administration [18]. This point will be discussed in the next paragraphs.

However, a comparison between the computed index damages and the requested indemnification for residential or commercial activities has been tried, in order to estimate the gap between the computer IDP and the available data.

In the following paragraphs, three applications will be shown and discussed, referring to 2016 flooding in Chisola river, Bormida river, and Tanaro river. A comparison between the computed IDP and the requested indemnifications is also shown.

7. Application

In the last 10 days of November 2016, Piemonte region was affected by a flood event with meteorological characteristics similar to other events of the past. According to ARPA Piemonte (*Regional Environment protection Agency of Piemonte*), the flood severity was similar to the most severe historic event occurred in the past in the Tanaro river watershed.

The flood event on November 24–25, 2016, has also significantly affected the basins of the Bormida di Millesimo and Bormida di Spigno rivers. In particular, the Bormida di Millesimo flood involved important production companies in the Bormida valley, as well as residential buildings and farms, causing considerable damage to the agricultural cultivation [19, 20].

According to the flood report ([20], p. 2), the event caused extensive damages to flood control structures, sediment deposits, bank erosions, and meander changes and extensive flooding with serious involvement of inhabited settlements and productive activities.

According to the report ([20], p. 3), important economic activities, generally insured against flood damage, risked not to benefit from reimbursements by insurance companies; these in fact generally cover the damage only in the presence of a *declaration* of an emergency *status*,

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by the Council of Ministry. Consequently, some companies, which were affected by the flood and suffered extensive property damages, asked for the *declaration* of the emergency *status* and also claimed the restoration of damages and the reinstallation of adequate defenses in order to continue to stipulate insurance with adequate contractual conditions. The Council of Minister declared the emergency *status* on December 16, 2016, only for Turin and Cuneo Provinces. Afterwards, Regione Piemonte public administration asked to extend the *declaration* to Asti and Alessandria. On February 23, the Council of Ministers approved the resolution, extending the emergency *status* to the provinces of Asti and Alessandria, providing the allocation of financial resources.

After the flood event, the Regional Departments started some activities, aiming to map and assess the flood effects, upon which the hazard evaluations of the IRP model have been based. These activities are the following:

- systematic mapping of requested interventions by means of the EMETER (*Emergency and Territory Management Information System*) application; the EMETER is a web-GIS system useful for regional officials of the Public works Directorate, which operates both in ordinary situations and in case of extraordinary events;
- field surveys along the main rivers, including Bormida river and Tanaro river; the technicians carried out systematic surveys in order to integrate and evaluate the information deriving from remote sensing; analysis of satellite data from the Cosmo platforms and from the platforms belonging to the European Copernicus system was performed;
- acquisition and processing of aerial photographs; a flight was made in the week following the event; aerial photo interpretation allowed to integrate the satellite and ground surveys.

Flood maps were the basis upon which the hazard estimation procedure of IRP started from. The procedure to obtain the flood depth maps has been described elsewhere [14, 15].

In this application, the exposure of receptors in the flooded area refers to the 2018 OMI database. The variability in time of the asset value (i.e., from the date when the flood occurred to present days) is negligible. The total number of flooded receptors and municipalities is summarized in **Table 6**.

After the 2016 flood, data of damages have been collected by public administration according to the civil protection procedures [18]*"Procedure for the recognition of the needs for the restoration of damaged public and private structures and infrastructures, as well as for the damages to economic and productive activities, to cultural heritage, and to the housing assets."* The procedures are followed by Regione Piemonte administration [19, 20] and are available to public. According to them, the requests for residential and productive damage indemnification have to be collected in the so-called *B-sheet* (*Recognition of the needs for the restoration of private buildings* sheet, which contains all the requests regarding residential damages) and *C-sheet* (*Recognition of damages suffered by economic and productive activities* sheet, which contains all the requests regarding damages to economic/productive activities), respectively. These have to be filled by privates and confirmed by technical assessments.

Case study	Total number of involved receptors	Municipalities included in the analysis
Tanaro reach	104 (85 residential)	Govone, San Martino Alfieri, Costigliole d'Asti, Antignano, Isola d'Asti, Revigliasco d'Asti, Asti, Azzano d'Asti
Bormida di Millesimo reach	170 (159 residential)	Vesime, Cessole, Loazzolo, Bubbio, Monastero Bormida, Sessame e Bistagno
Chisola reach	1858 (1243 residential)	Candiolo, Cumiana, La_Loggia, Moncalieri, None, Piobesi_Torinese, Piossasco, Vinovo, Volvera

The total number of receptors is referred to the flooding mapped area as described before. The analyses were focused only on the river reaches where damage data were available.

Table 6. Applications of the model to the case studies.

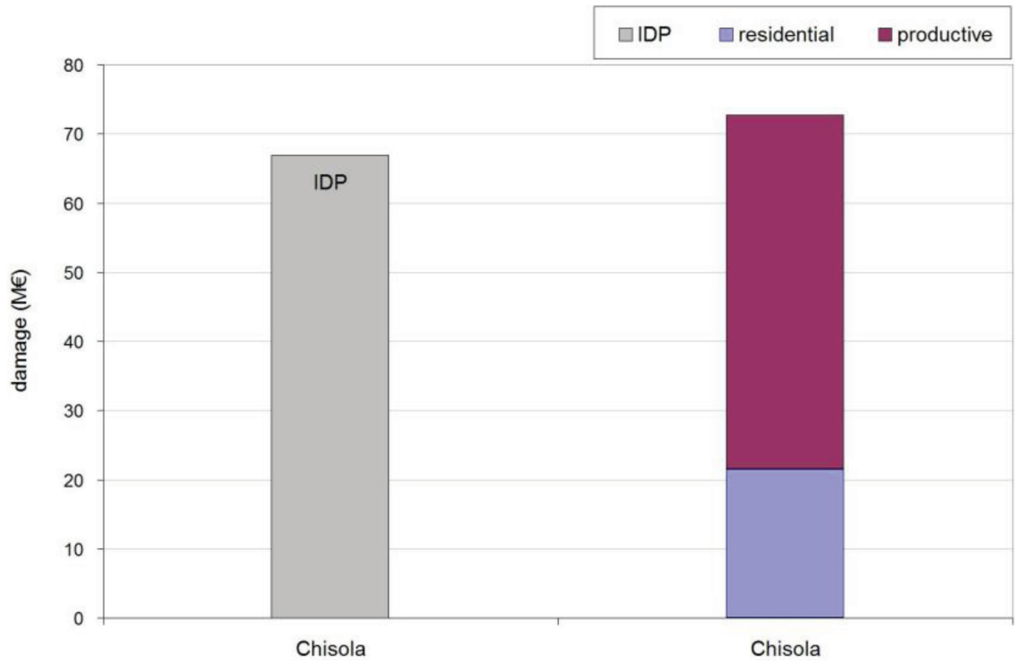

Figure 3. Comparison among the IDP and collected data in Chisola case study.

Comparison of IDP index has been made by referring to the total requests in B-sheet and C-sheet. The results of the comparison are shown in **Figures 3** and **4**.

It should be highlighted that the categories of damages refundable by Public administration are specified by the Council of Ministry. Actually, the recent deliberation of the Minister council (July 28, 2016; *Directional criteria for the determination and granting of contributions to private individuals for damage to buildings and housing assets*.) contains the list of the damages that can be eligible for indemnification. They may not match with the real damages.

Moreover, as it can be seen from the figures, the rate of residential and productive damages to the total damage varies in a wide range.

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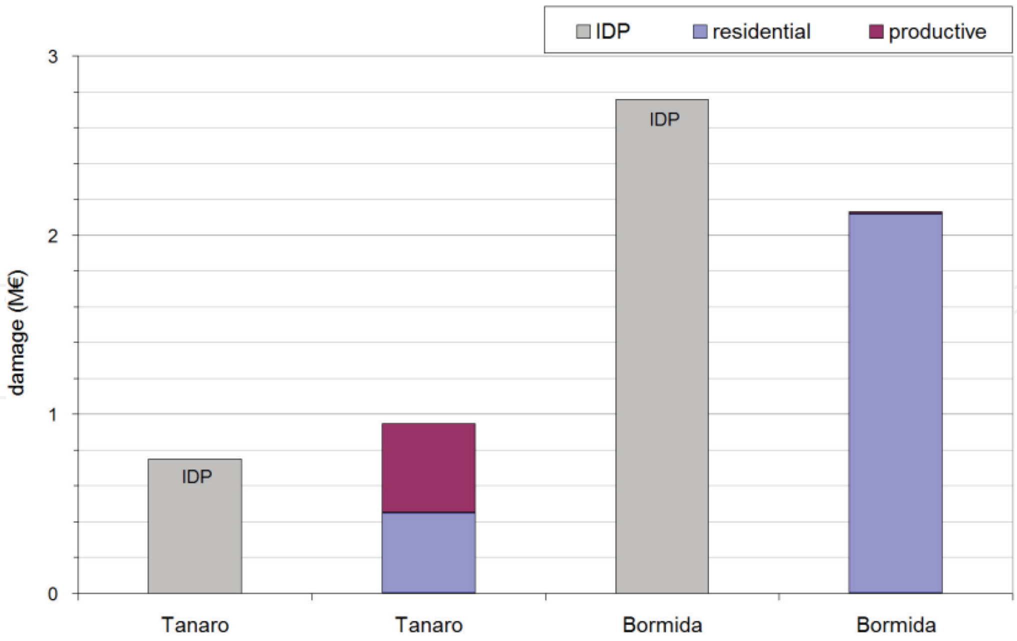

Figure 4. Comparison among the IDP and collected data in Bormida and Tanaro case studies.

River	IDP (total)	Damage to private properties	Damage to productive activities
Chisola	€ 6,933,305.00	€ 21,520,781.16	€ 51,191,427.49
Tanaro	€ 751,473.12	€ 451,153.28	€ 496,860.00
Bormida	€ 2,757,522.90	€ 2,116,426.00	€ 13,885.00

Table 7. Comparison among the IDP and the collected data.

The interpretation of the comparison, shown in **Figures 3** and **4** and summarized in **Table 7**, is not immediate, and a discussion is provided in the following paragraph.

8. Discussion

The IRP model, extensively applied to different case studies in Piemonte region, demonstrated to be a suitable tool to risk and damage estimation, either for the aims of the implementation of flood directive or for the design of the countermeasures. The model aims at expressing an "index," where estimation is based on a scientific approach (i.e., on the definition of damage and of risk) and on the basis of databases available at regional and national scale. The usability of the model has been proven elsewhere, and it is confirmed by the application to the 2016 case study, to Tanaro, Bormida and Chisola rivers (**Figures 3** and **4**).

The comparison shows that IDP can lead to an under/overestimation of the collected data. The use of the term "collected" is preferable to others, as it substantially refers to the kinds of damages reported by privates for indemnification. These categories of damages may, or may not, match with the categories of "refundable" damages by Ministry. Moreover, the quantification of damage made by "not expert" privates after the flood can overestimate/underestimate real damages assessed by professionals.

The gap between the collected damages (contained in the B-sheet and C-sheet) and the refundable damages can lead to an over (or under)estimation of the former with respect to the latter. **Table 8** shows a list of the main factors for this gap.

Consequently, the quantification of real damages, and the calibration of the model, is a very difficult task. The computed IDP cannot be easily compared to collected damage "data," as the latter refer to conditions which are highly influenced by regulations, personal attitudes, and so on.

For this reason, the proposed model aims at the computation of an *index* (the Index of Proportional Risk, or the index of proportional damage) more than to the precise computation of physical damages.

Moreover, it should be considered that the total flood damages can be by far higher than the residential and/or productive ones. Actually, in the recent *flood report* of Regione Piemonte administration ([19], p.84), "flood costs" have been divided into different groups:

Factors	Description	Effects
Bureaucracy	The procedures are felt to be "complex." Regulations [19, 20] indicate that different modules to be filled, with different obligations for the owners	The total number of collected B-sheet and C-sheet can be by far lower than the affected receptors
Necessity to produce a technical assessment	The technical assessment has to be made by professionals, to quantify the damages of residential houses. Professionals are paid by privates	The quantification by professionals can be different from assessment by privates (B-sheet, C-sheet)
Maximum amount of public contribution (e.g., max 1500.00€ for chattels)	Damages to chattels can be of the same order of the total maximum contribution or less. Bureaucracy costs can be too high with respect to the possible indemnification	Citizens avoid to produce B-sheet and C-sheet if the technical costs for bureaucracy are of the same order of refunds
Kinds of refundable damages	According to regulations, only some damage categories can be refunded. For example, • damaged or destroyed chattels in secondary houses are not refunded; • damages to secondary buildings are not refundable; • damages to cars and to mobile registered goods are not refundable	The requests in B-sheet and C-sheet can overestimate the total refundable damage
Insurance to natural disasters	Damages covered by private insurances are not contained in the available data	The available data can underestimate the real damage

Table 8. Main factors that cause a gap between the total amounts of real damages suffered by residential/commercial receptors and damages that can be eligible for public indemnification.

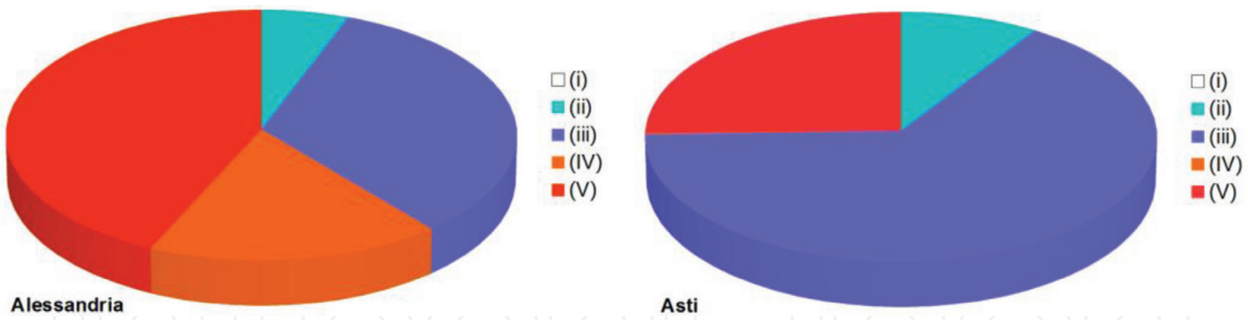

Figure 5. Total flood costs referred to 2016 flood event, recorded by public administration [19, 20] in Alessandria and Asti provinces.

(i) costs for people rescue; (ii) costs for highly urgent interventions: restoration of public services and infrastructures of strategic networks; (iii) interventions to reduce the residual risk (strictly connected to the event); (iv) costs contained in the *Recognition of the needs for the restoration of private buildings (B-sheet);* and (v) costs contained in *Recognition of damages suffered by economic and productive activities (C-sheet)*.

As shown in **Figure 5**, the total flood costs are by far higher than the "collected" damages from private (residential and productive). The IDP can allow an estimation of the (iv) and (v) components.

In spite of the fact that model calibration is a very difficult task, the computation of IDP can prove to be a useful means for the estimation of the total damages after a flood.

Actually, the estimation of the (iv) and (v) components by means of the IDP can indirectly allow the estimation of total costs. For example, by referring to the damages to Alessandria and Asti provinces in 2016 flood, the total cost is 1.6 or 3.9 times (respectively) the private damage (i.e., given by the addition of the (iv) and (v) components).

The variability of the total damage with respect to the private one depends on variables that are highly dependent on the kind of processes and the affected area of flooding.

At present, it is preferable, for public administration, to focus on simple and robust models that can predict the order of magnitude of damages (preferably based on free- and open-source software [21]), more than to complex models hard to be applied in practical conditions.

9. Conclusions

The IRP model, extensively applied to different case studies in Piemonte region, demonstrated to be a suitable model to risk and damage estimation, either for the aims of the implementation of flood directive or for the design of countermeasures. The model aims at expressing an "index," where estimation is based on a scientific approach (i.e., on the definition of damage and of risk) and on the basis of available databases at the regional scale (Piemonte region) and national scale (Italy).

The usability of the model to compute an "index" has been proven elsewhere, and it is confirmed on the present application to the 2016 case study, to Bormida, Tanaro, and Chisola rivers.

The comparison between the computed "index" and the *collected* residential and productive damages proves that if the former should be used to estimate the real damages, an *over-* or *under*estimation of the latter could be done. Moreover, collected damages can be very different with respect to real damages. This is due to the many factors, including the attitude of privates, or legislation. Application to Bormida river also showed a strong variability in the total amount of indemnification requested by economic activities.

For this reason, it should be considered that, at the present state, a real calibration of the model is not possible and the use of the term *index* should be maintained. However, the IDP can be a useful index to estimate the order of magnitude of the total indemnification requests by privates or to estimate the total flood costs. Available data on 2016 flood show that, for Alessandria and Asti provinces, the total costs are between 1.6 and 3.9 times the private requests.

The adoption of the IRP allows the risk quantification and its ranking; in spite of the fact that, at present, risk quantification in EFD is not compulsory, in this frame, IRP can be a useful instrument to (i) improve risk ranking and mapping and to (ii) estimate damages for the application of Re.N.Di.S. procedures.

Obviously, over/underestimations by the model should be taken into account by decision makers and public administration, especially in Re.N.Di.S. procedures.

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Conflict of interest

The authors declare that there are no existing or possible conflicts of interest, including financial, personal, or any other relationship which could influence their scientific work, at the time of manuscript submission.

List of acronyms

DPCM	Decree of the President of the Ministry council
EFD	European Flood Directive

IDP	index of damage risk
IRP	Index of Proportional Risk
ISPRA	Superior Institute for Protection and Environmental Research
MATTM	Ministry for the Environment, Land and Sea
OMI	Estate Market Observatory
PAI	Hydrogeological Asset Plan
PGRA	Management Plan for Flood Risk
Re.N.Di.S.	National Repository for Soil defense

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