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Non-Structural Flood Management in European Rural Mountain Areas—Are Scientists Supporting Implementation?

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Abstract: Mountain areas are highly exposed to flood risks. The latter are increasing in the context of climate change, urbanization, and land use changes. Non-structural approaches such as nature-based solutions can provide opportunities to reduce the risks of such natural hazards and provide further ecological, social, and economic benefits. However, few non-structural flood mitigation measures are implemented in rural mountain areas so far. The objective of this paper is to investigate if the scientific boundaries limit the implementation of non-structural flood management in rural mountain areas. In the study, we statistically analyzed the knowledge about flood management through a systematic literature review and expert surveys, with a focus on European rural mountain areas. Both methods showed that scientific knowledge is available for decision makers and that nature-based solutions are efficient, cost-effective, multifunctional, and have potential for large-scale implementation.

1. Introduction

Floods are natural processes in the global hydrological cycle in many terrestrial and transitional zones. They provide many regulating, provisioning, supporting, and cultural services and are crucial for the functioning and health of riverine ecosystems [1–10]. However, flooding can be a major threat to people and goods [11–13] and has become one of the most common natural hazards since 1990, especially in the Asia-Pacific region and Europe [9,13–17]. In Europe, flood risks have mainly been caused by flash floods and river floods [18,19]. Flood risk is characterized by the hazard (e.g., the flood amplitude), exposure (e.g., if houses are within the floodplain) and vulnerability (e.g., if houses are sensitive to flood). Flood events are characterized by factors such as the intensity of precipitation, land use, stream network and size, and catchment area size and properties, in particular slope and soil conditions [6,20–23].

Mountain areas are an important component in the hydrological system as they are water-harvesting areas [24]. Riverine floods and flash floods are by far the most common types of floods in mountain regions [6,25,26]. Both are mainly driven by snowmelt or ongoing precipitation. Flash floods originate from quick, heavy, and often localized rainfalls resulting in concentrated overland runoff, and riverine floods are characterized by a rising stream water level with possible bank overtopping and inundation of adjacent areas caused from excessive discharge [19]. The risk of flash floods is the highest in mountainous areas because the slopes and narrow valleys lead to high and quick runoff with high flow velocity, and the water level can rise to extreme values within a few minutes [27,28].

Changing weather patterns, hydro-morphological modifications of the rivers, and land use change such as urbanization increase both flood exposure and hazard in the entire catchment area [6,27,29–35]. First, climate scenarios predict that climate change

in Europe will modify both spatial and seasonal rain events increasing the risks related to extreme weather events [2,6,26,30,36–38]. By 2050 and by 2080, the flood damages could be 5-fold and 17-fold, respectively, compared to 2020 [2,39]. The same studies also revealed that in mountainous regions, a greater increase in flood risks will be observed compared to lowlands. In the mountains, increased rainfall will substitute snow and ice formation [38] and consequently reduced snow and ice buffers that are particularly critical for delaying flood generation in higher mountain elevations [2]. Second, considering hydro-morphological changes, in Europe, most of the hydrological systems are altered by structural interventions to safeguard human settlements against small to medium floods, e.g., by dams [10], thus increasing risk during extreme events due to unexpected hazards in areas with high exposure and vulnerability. While rivers are natural drainage systems, hydro-morphological changes have led to dysfunctions. For example, in Germany, around 80% of the rivers Elbe and Rhine are highly modified, and 63% to 95% of wetland ecosystems are partially to completely altered [9,40,41], mostly in favor of anthropogenic space such as housing and cropland [40].

Flood management (FM) can broadly be understood as the enhancement of society to cope with flood hazards, where development efforts should not increase flood vulnerability [42]. In Europe and North America, in the context of hazard reduction, risk management composed of phases such as preparedness, response, and recovery [43] is applied to decrease the disastrous impacts of flood events [42] (Figure 1). Various FM approaches exist: structural (or technical or engineered) and non-structural, including instrumental (or governance, planning, land use change, and land management) and natural measures (or nature-based solutions, NBS) [7,31]. Structural measures are, for example, flood reservoirs, instrumental measures are regulation or communication, and natural measures are, for example, reforestation and river restoration [7]. While human interventions in natural systems, especially structural measures, have often shown to be effective in flood mitigation, they often produce negative economic, social, and ecological responses [1,6,32,41,44–46]. Considering risk management, structural measures are increasingly considered controversial inducing, for example, the so-called levee effect [47]. This is characterized by a translocation and exacerbation of the risk downstream [48]. Furthermore, structural measures have often exacerbated floods [21] by increasing river's transport capacity and its flow velocity leading to bank erosion and burial in the riverbed, unstable morphology and sedimentation, poorer water quality and clarity (turbidity), and reduced hydrological and biological diversity (up to −60%) [49]. Moreover, installation, maintenance, and repairs of structural measures can cost much more than NBS [50]. Consequently, structural measures are increasingly considered as both inadequate and insufficient [35] as well as being of economically or ecologically questionable impact [44,51,52]. Non-structural measures such as NBS are promising solutions that tackle the disadvantages of structural measures and ensure resilient FM as they are cost-efficient, multifunctional, and provide many co-benefits.

FM strategies depend on administrative, cultural, social, technical, and scientific factors. In Europe, the Flood Directive is one of the drivers of change from structural to an integrative FM approach. Integrative FM is based on non-structural measures and is increasingly implemented worldwide to tackle increasing flood risks. Despite the great need to implement non-structural FM, little has been done to design flood management based on non-structural measures as NBS [36,53–57]. Experiences in FM design have been largely made in lowlands, but upscaling measures in mountainous areas are limited because of different spatial conditions [23,58–60], having more available room to handle floodwater with features such as bigger stream channels and wider floodplains. Furthermore, little knowledge exists about FM in rural mountain areas. FM literature mainly focuses on cities and coastal areas [19,34,61–63]. FM in rural mountain areas is faced with specific challenges. The warning time for upcoming flooding is relatively short, only about a few hours [27,61,64,65], reducing the effectiveness of warning systems. The narrowness, or steepness, and shallow soils limit the water storage capacity in mountains, requiring more

and decentralized FM such as numerous small water retention basins [23,59]. Rural areas are considered to have great potential for water retention [66] but also higher vulnerability to natural hazards, fewer resources, and more need for assistance in their management [67].
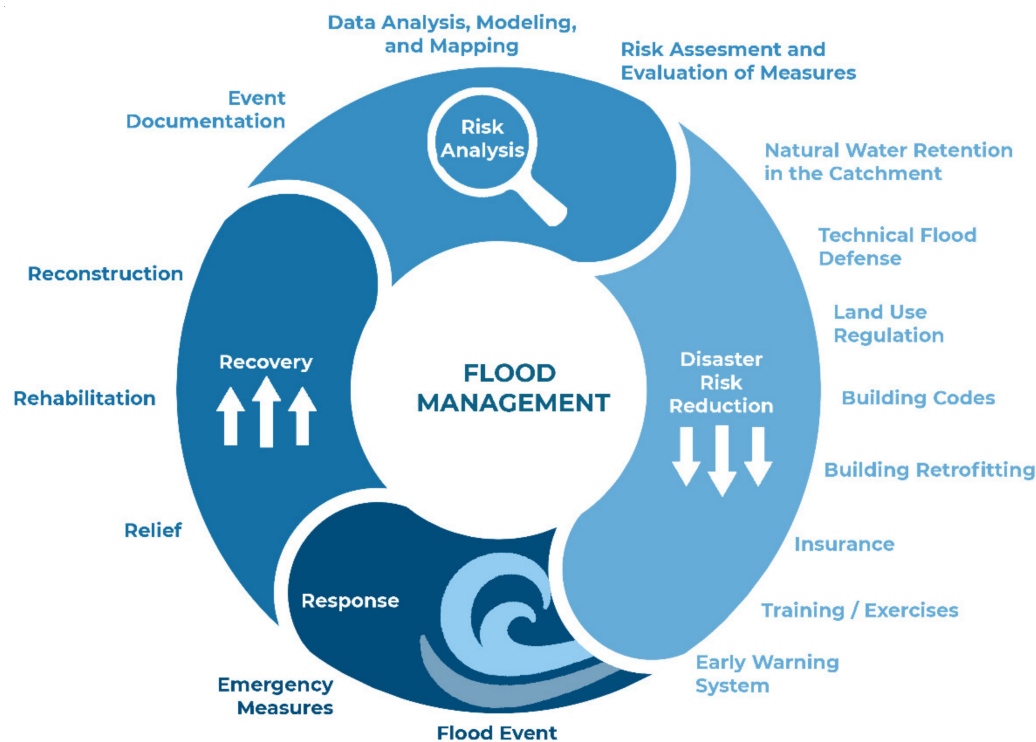

Figure 1. Management cycle in flood management (FM) inspired by [43]. Reproduced with permission from Annegret Thieken.

Implementation of FM highly depend on administrative, cultural, social, technical, and scientific boundaries. While EU legislation induces positive administrative context for non-structural FM and technical solutions exist to reduce flood risk, few non-structural projects have been implemented. Furthermore, while many studies report on FM, they focus only on single flood measures and limited locations in European rural mountainous areas (ERMA). Therefore, knowledge about the scientific boundaries remains lacking. To our knowledge, no review about the characteristics and impacts of flood measures across ERMAs has been released. However, knowing about the needs, limitations, and advantages of certain flood measures is necessary to improve current situations and adapt to future tasks. In this context, we want to answer the hypothesis of whether scientific boundaries hinder the implementation of non-structural FM in ERMA. Our study contributes to the understanding of flood measures and managements in rural mountain areas. In this context, the study's overall aim is to point out available and missing knowledge on FM in ERMAs within the scientific community by joining information from literature and expert surveys. The main objective of the study is to evaluate the accordance among literature and experts upon (1) the applicability, spatial range, and co-benefits of FM; (2) the prioritization of FM properties; and (3) preferred FM phases in ERMA. The study presents a brief overview of the state of the scientific knowledge about FM in mountainous areas, which was found to be actually encouraging rather than hindering implementations of flood measures.

2. Materials and Methods

The knowledge boundaries of FM in ERMAs were assessed by a systematic literature review and an expert survey followed by a comparison of both approaches, after statistical analyses (Figure 2).
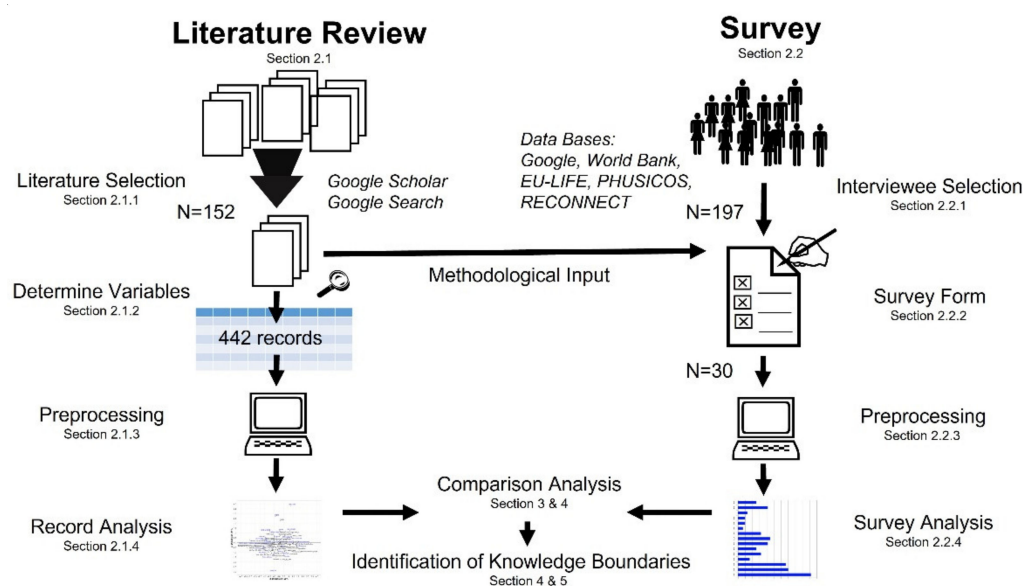
Figure 2. Methodological proceeding.

2.1. Literature Review

2.1.1. Literature Selection

A literature review on FM in mountain regions following the PRISMA method [68] was conducted using the search engines Google Scholar and Google Search with the terms "flood", "rural", "mountain", and "Europe" on 16 November, 20 November, and 2 December 2020. In total, 152 sources were selected from the first 30 pages of the search engines (600 results) through expert-based selection using systematic analyses of content of the titles and of the abstracts (Table A1).

2.1.2. Variables

Data were extracted from the text during reading and entered in factsheets for further analysis (Table 1, Supplementary Material S3). If a data source dealt with several measures, these were evaluated individually and only once per source, considering similar expressions for measures. All or same modalities were noted for all individual evidence if global statements or no differentiation were done, respectively. Evidence about indirect flood control, e.g., with a negative effect on flood occurrence (e.g., soil sealing) [69–72], the reverse was annotated [49,73], e.g., soil protection.

Table 1. List of flood management (FM) solutions used in the expert survey and literature description, with abbreviations and examples in brackets.

List of Variables	Modalities
Continents [Subregions] [1]	Global *, [East, South, West, and North] Asia, Australia, [East] Africa, [North, South, and Central] America, [Central, East, South, West, and North] Europe, Missing
Period of Year	1981_1999, 2000_2009, 2010_2015, 2016_2021, Missing
Measure Block [2]	Non-structural, Nature-based, or Natural (NAT); Structural, Technical, or Engineered (ENG); Instrumental (Governance (GOV), Land use & land management (LULM), Urban and rural planning (URP))

Table 1. *Cont.*

List of Variables	Modalities
Measures [2] [wording in literature analysis]	NAT: Environmental and ecological preservation or [Nature conservation], Water catchment area restoration (rewetting, rewilding, temporal flooding of areas) or [Watershed restoration], Terrestrial ecosystem and habitat restoration (drylands, wetlands) or [Ecosystem restoration], River restoration (Living River Strategy, Room for the River), Sponge vegetation restoration (replanting woods, bushes, reed zones); ENG: Water catchment area modifications (terracing, relocation of embankments) or [Watershed modifications], River modifications (grand ox, dredging, channeling, BioGrout, walls, dams, levee, sleeper, protection from log jam), Soft flood water retention (polder, swale), Constructed water retention (water retention basin, reservoir, or pond), Water retention slowdowns and drainage systems (weirs, sluice, bypasses, throttle, sewer tunnel, siphon, pumping systems) or [Water drainage Systems], Mobile embankments ** (sandbags, TubeBarrier, Water-Gate); URP: Flood-adapted infrastructure (bridges, railway dams, pedestrian dams, vehicles, boats), Flood-adapted architecture & dry or wet building (stilt house, architrave block house, water shutter, adobe walls, fences); LULM: Diverse and heterogenous land management (land use planning, zoning, subdivision ordinance, land acquisition), Managed retreat (e.g., translocation of settlement), [Flood-adapted] Lifestyle and livelihood (up-and-downhill migration, agriculture, aquaculture, fishery, water retention), Flood-based farming (paludiculture, (rain) water resource management, inundation canals, depression agriculture) or [Flood-based Agriculture], Extensification (land use or land cover transformation, ecological practice, or conversions), Water and soil protection (rotating, intercropping, catch crop, mulch, green manure); GOV: Official frameworks (building code, guidelines, directives, laws, legislative instruments, plans, projects, programs), Cooperative society (participation, communication, organisation, goninggumi, family & friends, microfincancing, rituals) or [Societal Cooperation], Emergency preparation (rescue, flood emergency reservoir), Evacuation system (location of evacuation areas and evacuation routes), Compensation system (state or index-based insurance, flood-prone ID), Analysis of management practices ** (failures and successes), Inclusion of knowledge (also indigenous, local, ecological) & provision of education (i.e., marks) or [Knowledge Transfer Systems], Media and telecommunication (TV, radio, internet, phones) or [Tele-Media-Communications], Warning system (yells, movements, instruments, EFAS, GloFAS, GFDS, WeSenseIT), Hydro-geo-information (mapping, forecasting, database, remote sensing, modelling, future risk analysis)
General Flood Mitigation Effect	Positive, Potentially positive, Negative
Spatial Setting	Urban, Rural, Lowland, Mountain, RuralLowland, RuralLowlandMountain, RuralMountain, UrbanLowland, UrbanRural, UrbanMountain, UrbanRuralLowland, UrbanRuralMountain, UrbanRuralLowlandMountain, Missing
Spatial Effect Range [Distances] [3]	Local [<100 km], Regional [100 km to 250 km], and Supraregional [>250 km], LocalRegional, RegionalSupraregional, LocalRegionalSupraregional, Missing
Effect on Flooding	Increasing, Directly Reducing, Indirectly Reducing, Increasing to Directly Reducing [4], Missing
Technical Feasibility	Easy, Complex, EasyComplex [5], Missing
Environmental Effect	Friendly, Damaging, FriendlyDamaging [6], Missing
Economic Effect	Cost-effective, Costly, CheapCostly [7], Missing

Table 1. *Cont.*

List of Variables	Modalities
Societal Effect	Enhancing, Weakening, Missing
Flood Severity [8]	HQ10, HQ50, HQ100, overHQ100, HQ100overHQ100, HQ10HQ50, HQ10HQ50HQ100, HQ10HQ50HQ100overHQ100, HQ50HQ100, Missing
Effect on Peak Discharge	Delaying, Reducing, DelayingReducing, Missing
Delay of Peak Discharge	13 min, 15 min, 30 min, 180 min, 2400 min, 4800 min, Missing
Reduction of Peak Discharge	0%_24%, 25%_49%, 50%_74%, 75%_100%, over100%, Missing

[1] following [74,75]. [2] following [7,76]. [3] following [26,77]. [4] e.g., [20]. [5] e.g., [78]. [6] e.g., [45,69]. [7] e.g., [52]. [8] recurrence probability HQ in years following [21,64,79]. * Meaning global analyses such as reviews. ** Only found as mentioned in literature for FM in non-European rural mountainous areas.

2.1.3. Pre-Proceeding

We extracted a total of 442 records about measures published in 152 references and analyzed them using Multiple Correspondence Analysis (MCA) in RStudio (RStudio Team 2020, v 1.3.1073) with R (v4.0.3, 2020-10-10). MCA is an extension of Correspondence Analysis, which analyzes more than two categorical variables [80]. The analysis is generally used to reveal so-called typologies [81] or patterns in a data set for modalities with the same and a significant orientation in the considered dimensions [80]. Variables of the data set defined as "active" are used to perform the mathematical calculation, which can then be interpreted by records (individuals) and modalities (categories of active variables), as well as described by supporting variables ("supplementary") and their categories [80]. We combined variables which were separate in the initial characterization of sources ("rural" and "mountain") to new ones ("spatial setting") (Table 1) to gain a more meaningful MCA [80]. To further increase the efficiency of the calculation and the graphical interpretation of the MCA, an equal number of modalities per variable across the data set was aimed for [82], e.g., through grouping (e.g., "period of year", "continents [subregions]", "reduction of peak discharge" in Table 1). The statistics-based literature analysis was performed on three sub-data sets (SDS): (SDS-1) measures in ERMA (92 records from 25 references), (SDS-2) measures in non-European rural mountainous area (NERMA) (74 records from 17 references), and (SDS-3) measures in other mountainous areas (OMA) (276 records from 64 reference). SDS-3 included, e.g., measures implemented in more urbanized and lowland mountainous areas and excluded records already used in SDS-1 and SDS-2.

2.1.4. Analysis of the Measures and Flood Management Extracted from the Literature

Previous research underlined the use of MCA on data extracted from literature by text mining approach [83–87], as well as the stratification of the created data set [88–90]. In contrast, subset MCA would be proposed in case of analyzing only a set of categories or variables [91,92].

MCA was performed on the SDS using R package *soc.ca* (v0.7.3) [93]. The percentages of missing data points varied within variables and SDS, which led to deviating combinations of active and supplementary variables for the built models. Variables such as "authors", "country" and "region", "measures", and "measure keywords" were defined as supplementary variables and excluded from calculations due to their disproportional number of modalities. All other variables were initially assumed to be active variables and included in calculations. The model most efficiently explaining every SDS was built by successively declaring variables with higher and more unbalanced number of categories as well as higher percentage of data gaps as "supplementary" in descending order. We aimed for the smallest possible number of dimensions with the highest possible homogeneity in the explanatory contributions of the active variables explaining at least 80% of data set variability. Missing data points could be handled in soc.ca-package by excluding them from calculation through a label ("Missing") turning the analysis into a specific MCA. This gives the advantage of preserving and including the available information of lacky

records to the MCA. In that way, we increased the information gain and power of the analysis [91]. Even though imputation of data gaps exists [94], it requires at best only 10% or less of the data to be missing [95,96], which was not the case, otherwise the quality of imputation decreases [97]. We mainly used the Euclidean positional distance ED (next to contribution, and correlation coefficient) to assess the MCA output. A modality with an ED vector amount above 0.5 [80] and between 0.40 and 0.49 was considered significant.

The prioritization of FM phases was assessed by 63 sources and the FM characteristics by 89 sources (Table A1) following the same process of data collection described in Section 2.1.1. Information was extracted by reading when mentioned in the text following the terminology displayed in Table 2, counting an FM phase or FM characteristic only once per source, considering similar keywords and terms. Finally, 15 phases and 34 characteristics were assessed in the literature analysis (Table 2). A simple comparison of counts for FM phases and for FM characteristics was conducted in a ranking scheme to assess their value in FM, defining more counts as more important.

Table 2. Modalities used for the assessment on prioritized FM phases inspired by [43] (# plus a number indicating its position in FM cycle) and assessed FM characteristics in the expert survey and analyzed literature. "Phases" were the same in both analyses while the literature analysis assessed "characteristics" and "additional characteristics" and, in the survey only, "characteristics".

	Phases	**Characteristics**	**Additional Characteristics**
Modalities	Natural water retention (e.g., Sponge vegetation) (#1); Technical flood defense (e.g., Levee) (#2); Land use regulation (e.g., Zoning) (#3); Building codes (e.g., Flood-prone ID) (#4); Building retrofitting (e.g., Water shutter) (5); Insurance (e.g., Refunding) (#6); Training or exercises (e.g., Workshop) (#7); Early warning systems (e.g., EFAS) (#8); Emergency measures (e.g., Evacuation, sandbag wall) (#9); Relief (e.g., First aid, food, clothes) (#10); Rehabilitation (e.g., Clean up, viable infrastructure) (#11); Reconstruction (e.g., Damaged levees) (#12); Event documentation (e.g., Marks, resource demand) (#13); Data analysis, modeling and mapping (e.g., Flood risk maps) (#14); Risk assessment and evaluation of measures (e.g., Failures and successes) (#15);	Ecosystematic integral or Ecologically integrated (socio-ecological); Cost-effective; Social, accepted, communicative, participative, collective; (eco) Sustainable, long-term; Complementary/not enough/combination/mixture; Holistic/monitoring; Multifunctional; Strategic, smart, systematic, organized; Resilient; Decentralized/autonomous; Adaptive; Flexible, agile; Heterogenic/diverse; Transformable; Modular; Robust; Redundant; Climate fair; Feasible	Proactive; Innovative; Traditional/technical; Natural; Non-Structural; Structural; Preventive; Resistance; Protective; Prepared; Central; Maintenance/modernization; Private; Mobile; Coevolutionary;

2.2. Survey

2.2.1. Interviewee Selection

An expert-based survey was conducted according to type 3 delphi process [98]. To recruit potential interviewees, two approaches were chosen to create a pool of experts (Table 3). In total, 197 experts were invited to participate in the survey.

Table 3. List of pools used to identify interviewees for the expert survey. * Projects before 1999 lacked contact information and seemed outdated.

Sources for Interviewee Pool	Number of Interviewees	Link to Project Data Bases	Filters	Notes
Google Search	121	Google.com	"flood" "research" "university"	16 November 2020
World Bank	20	projects.worldbank.org/en/ projects-operations/	"flood" Europe after 1999 *	24 projects, some shared the same leader
EU-LIFE	27	ec.europa.eu/environment/ life/project/Projects/	flood	
RECONNECT	7	-	-	
PHUSICOS	22	-	-	

2.2.2. Survey Form

The online platform SosciSurvey (soscisurvey.de, SoSci Survey GmbH, Munich, DE) was used to create and conduct the survey (Supplementary Material S1). The survey ran between 21 December 2020 and 25 February 2021. After a brief description of the project and the survey procedure, as well as conditional consent to participation (anonymous), socio-professional information of the participant was first requested. The answer options or even complete questions of the survey could be omitted and skipped in the later sections of the survey. The questions regarding FM consisted of the following: (1) Which aspect(s) (flood reduction, technology, environment, economy, society) can be covered by a flood management measure?; (2) Which of the following measures in flood management could be applied in rural mountain areas across Europe (1 = rarely applicable to 5 = totally applicable)?; (3) What is the spatial impact or effect of a measure (local: <100 km, regional: 100 km to 250 km, supraregional: >250 km)?; (4) How important are certain flood management aspects like prevention, protection, reaction, and lessons learnt to you (1 = important to 15 = unimportant)?; and (5) What should (future) flood management look like (e.g., decentralized or holistic) (1 = important to 19 = unimportant)? Alternatively, optional answers could be given, checking lack of experience ("limited experience"), insufficient information ("more information"), or none of the options provided ("none"). Questions 1 and 3 were asked with multiple response options. Questions 2, 4, and 5 were designed as simple analysis of variance by ranks and blocks with repeated measures. The prioritization of FM phases and characteristics was assessed by the terminology and from the sources in Tables 2 and A1, while only 19 of 34 characteristics used in the literature analysis were given to keep the task simple (Table 2). Sources and terminology were generated as described in the Section 2.1.1.

2.2.3. Survey Data Pre-Proceeding Process

Survey data were downloaded from SosciSurvey at the end of the survey period and analyzed in RStudio. Only questionnaires with at least one of five questions answered were considered in the analysis. Answers completely missing for a question were removed for the respective analysis. Individual missing data points were replaced with the median of the corresponding category answer. Average response rate accounted for 18.8% records available from analysis (37 experts), however, sample sizes varied for each question due to incomplete parts by some interviewees.

2.2.4. Analysis of Survey Data

Descriptive and exploratory factorial statistical methods were applied to the socio-professional information and Question 1 and 3. Questions 2, 4, and 5 were subjected to a two-sided Friedman test (R-package *PMCMRplus* v1.7.1), followed by a Friedman Conover test (post-hoc test) (R-package *PMCMR* v4.3). The respective test functions friedmanTest()

and posthoc.friedman.conover.test() were used and set to y = ratings, groups = measure categories, blocks = people rating, p.adjust.method = "BY". The reliability or agreement of and among expert ratings was assessed by Kendall's coefficient of concordance (Kendall Wt in R package *DescTools* v0.99.39 with <data, correct = TRUE, test = T>), the likert() function (R-package *likert* v1.3.5) and the consensus() function (R-package *agrmt* v1.42.4) [99,100]. The results of the post-hoc tests were visualized by a compact letter display for calculated medians with confidence interval by group [101].

3. Results

The results of the systematic literature review are ordered according to the SDS and contain in the first part a general description of SDS and MCA and, in a second part, a detailed comparison of similarities and dissimilarities among SDS results. The second half of this section covers the expert survey and finishes with a comparison of literature and survey.

3.1. Analysis of Literature

The MCA part considers the first three dimensions since they explained more than 80% of the data variability (Table 4) based on the final configurations (Table A2, Figures A1–A3). In all SDS, little reporting was available on the variables "spatial effect range", effects in economy, technology, ecology, and society and influences on peak discharge (<10% to 30% of the cases), which were then configured as supplementary in MCA calculations. Despite the unexpectedly rich knowledge in the literature about FM in mountainous areas, only 21% of the publications found related to FM in ERMAs (Table 4).

Table 4. Overview of sub-data set (SDS) information (N = 442) used in MCA.

Variables	SDS-1	SDS-2	SDS-3
Proportion of publication	21%	17%	62%
First publication found	2005	2007	1981
Publication hotspot	2006–2008, 2011/12, 2016/17	2007, 2016, 2018/19	1995, 2007/09, 2015–2017, 2019/20
Geographical focus	Central Europe	Asia	Global (Europe, America, Asia)
Proportion of studied natural measures	39%	20%	25%
Proportion of studied engineered measures	23%	15%	25%
Proportion of studied instrumental measures	38%	65%	50%
Explained data variability by the first three dimensions	85.5%	93.2%	90.9%

In SDS-1, natural solutions are the most studied (39%), while in SDS-2 and SDS-3, more instrumental solutions were reported on (65% and 50%, respectively) (Table 4). Interestingly, in ERMAs, NBS were found to be associated with addressing multiple flood severities and a higher peak reducing function than engineered solutions (Table 5). However, generally, only few details on the multifunctionality of measures were found for ERMAs (Table 5). In addition, no publications on ERMAs were found to deal with warning systems, emergency preparation, nature conservation, flood-based agriculture, managed retreat, mobile embankment, tele-media-communication, and watershed restoration (Figure 3).

Table 5. Synthesis of the assessment of the solutions (* European rural mountainous areas, # non-European rural mountainous areas, + other mountainous areas). Instrumental solutions gathered: governance, urban and rural planning, and land use and land management solutions.

Variables	Engineered Solutions	Natural Solutions	Instrumental Solutions
General Effect	Negative *	Potentially positive +	Potentially positive #
Spatial Effect Range	Local + Regional +	Local * + Regional * +	Local # + Regional # Supraregional # +
Effect on Flooding	Directly reducing # + Directly Increasing +	Directly reducing +	Indirectly reducing # +
Technical Feasibility	Easy # Complex *	Easy * Complex *	not significant
Environmental Effect	Damaging * + Friendly # +	Friendly * # + Damaging # +	not significant
Economic Effect	Costly + Cheap #	Costly + Cheap *	Costly *
Societal Effect	Enhancing * #		Enhancing +
Flood Severity	HQ50 +	HQ10 * + HQ50 * + HQ100 * +	HQ10 * HQ50 * HQ100 * +
Effect on Peak Discharge	Delaying # + Reducing * +	Delaying * # + Reducing * # +	not significant
Delay of peak discharge	15 min + 30 min + 180 min + 4800 min +	15 min * + 30 min + 180 min + 4800 min +	not significant
Reduction of Peak Discharge	−0% to −49% * + −50% to −74% * + >100% +	−0% to −74% + −25% to −49% # −75% to −100% * + >100% +	not significant

The MCA of SDS-2 showed that not only NBS but also engineered solutions could exhibit positive functional effects and a broad spectrum of effects compared to the information for engineered solutions within SDS-1 (Table 5). Interestingly, while NBS were assessed as effective on flood protection, they were assessed as conducive to damaging the environment (Table 5), either through increased water-soil-infiltration and surface roughness by vegetation cover [102] or worsened drought through changing it from deciduous to coppice stands [69], respectively. No publications in NERMAs were found to report on managed retreat, mobile embankment, river restoration, soft floodwater retention, tele-media-communication, and watershed restoration (Figure 3). Interestingly, instrumental solutions were a research focus mostly in urbanized areas. In OMA, the functions of engineered and natural solutions remain rather unclear because of a broad range of effects (Table 5).
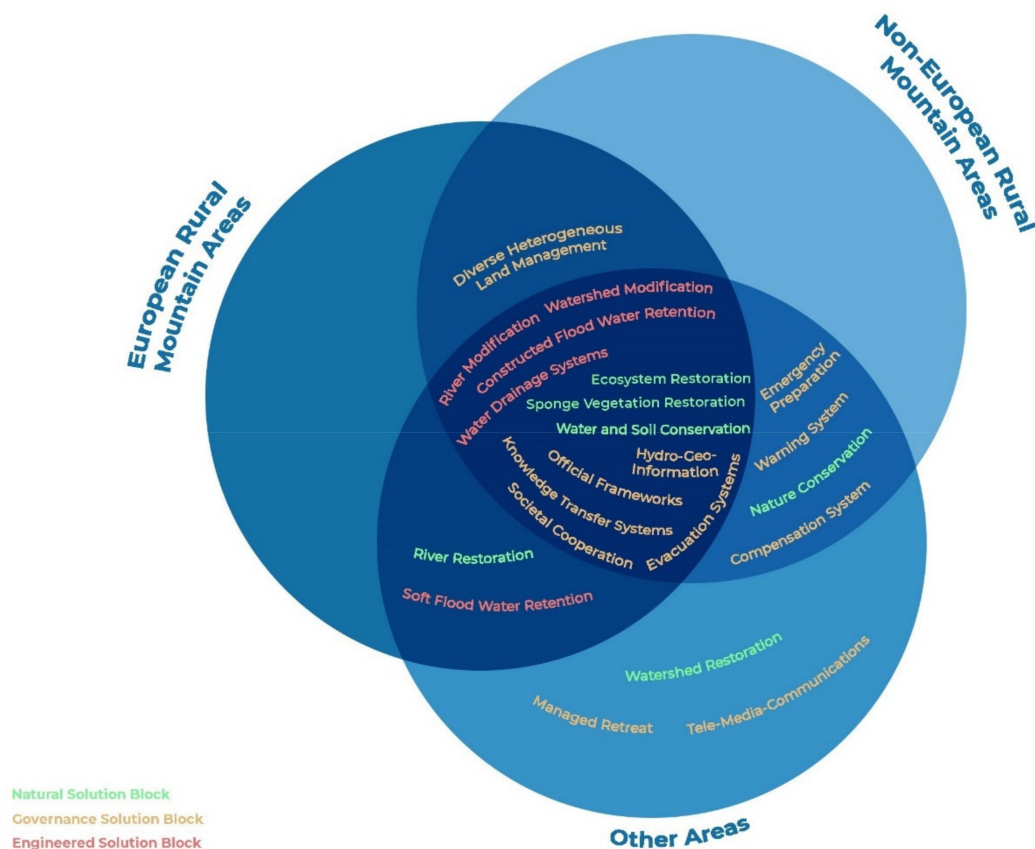
Figure 3. Distribution of the FM measures (FMM) presented in each sub-data set.

3.1.1. Combination and Comparison of Dissimilarities and Similarities between the Distinguished Geographical Areas (Sub-Data Sets)

Combining all the found knowledge in literature, it was possible to obtain a broad assessment of the solutions, however, disparities existed (Table 5). First, the overall picture resulting from the combination of the data showed that engineered solutions had an overall negative effect. They were efficient for delaying and reducing the peak discharge of medium floods but inefficient with large floods such as HQ100 and greater, causing more direct increases in the flood risk. The spatial effect of the measures was mostly local and regional. Second, considering the natural solutions, data showed an overall positive assessment of the measures. They showed a great efficiency for small to large floods, acting directly to reduce the hazards (reduction and delay of the peak discharge). No significant association to risk increase and large-scale effect by NBS was found. The spatial effect of measures was significant on a local to regional scale. The feasibility and costs varied. Instrumental solutions showed indirect flood risk reduction and a local to supraregional scale of effect. They were efficient for all types of flood severity but costly.

Comparing the knowledge between the sub-data sets showed disparities. First, natural solutions in ERMAs were assessed as environmentally friendly and cheap, while NERMA studies and OMA studies were more skeptical when considering the effect on the environment. Furthermore, while NBS were assessed as cost-efficient in ERMAs and NERMAs, they were assessed as costly in OMAs. The efficiency of the measures, namely delay and reduction of peak discharge, were identified in all distinguished geographical areas. However, peak discharge reduction was the most variable in OMAs (0% to over 100%), followed by ERMAs (74% to 100%), and then NERMAs (25% to 49%). Delays in peak discharge were short in ERMAs (15 min) and from short up to very long in OMAs (15 to 4800 min). Second, engineered solutions were negatively assessed in ERMAs and positively assessed in NERMAs. In OMAs, the assessment was heterogeneous, especially

when considering environmental friendliness and effects on the hazard. In all areas studied, engineered solutions were assessed as effectively reducing medium flood events with some negative consequences, such as being cost-intensive, environmentally damaging, or even increase in hazard. In NERMAs, engineered solutions showing characteristics such as NBS had positive connotations. Third, instrumental solutions showed the fewest significant associations of modalities in all geographical areas but assigned a local to supraregional scale of flood mitigation and indirect flood risk reduction for NERMAs and OMAs. Studies in ERMAs gave considerable associations between non-structural solutions and flood severities between HQ10 to HQ100.

3.1.2. Phase Prioritization of (Flood) Disaster Management

Few differences were seen in the relevance of FM phases comparing the mention in the reviewed literature to the reading order (clockwise) of the established flood risk management circle. Changes occurred in the back and front midfield (Figure 1 vs. Figure 4). Immediate post-event phases were less studied (3–8%), and early pre-event phases were studied extensively (33–50%), "natural water retention" being most often mentioned in the reviewed literature (Figure 4). It is worth noting that intermediate pre-event phases (e.g., training or exercises) and late post-event phases (e.g., risk assessment and evaluation of measures) received 12.7% to 22.2% of the attention in the literature studied. It was found that intermediate pre-event and late post-event phases appeared far more often in the reviewed literature than their place in the flood risk management cycle would suggest. However, other intermediate pre-event phases, e.g., building codes, were mentioned less often than it would be expected from the flood risk management cycle.
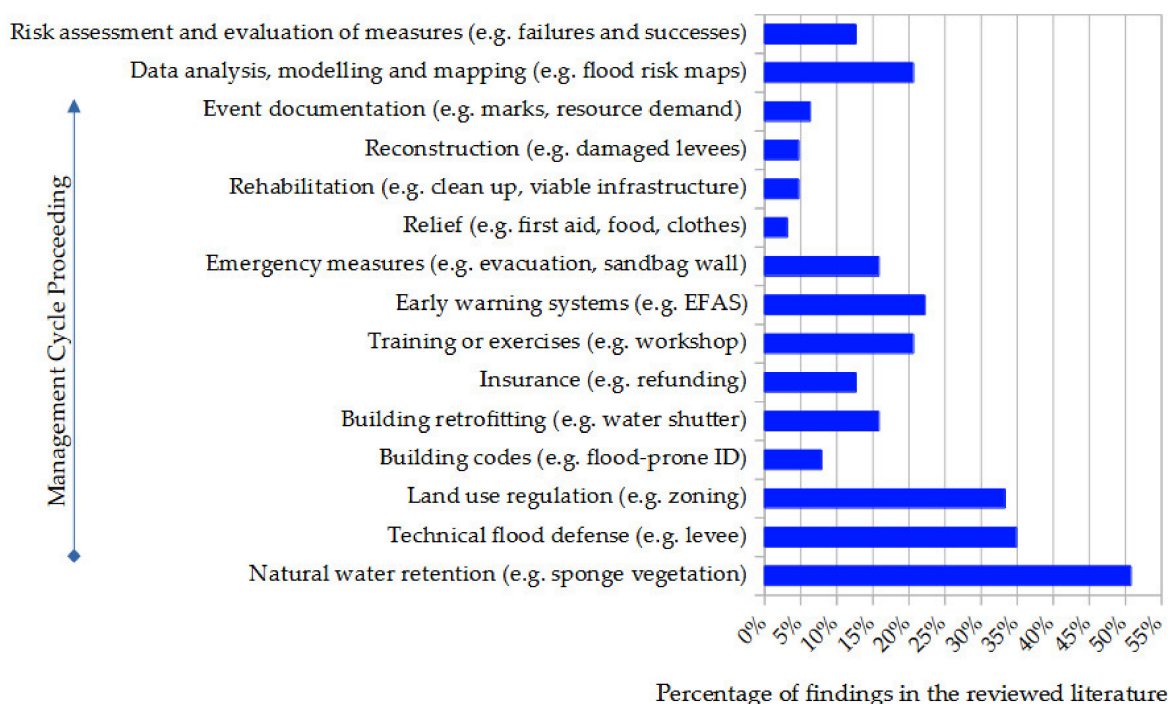

Figure 4. Percentage of literature referring to phases in the FM cycle (N = 63).

3.1.3. Important Characteristics for Flood Management

The characteristics described for FM in the reviewed literature included primarily ecological and socially acceptable aspects, as well as a combination of FM, maintenance, and decentralization (Figure 5). Other similar characteristics, such as "modular", "climate-fair", or "robust", were found less frequently.
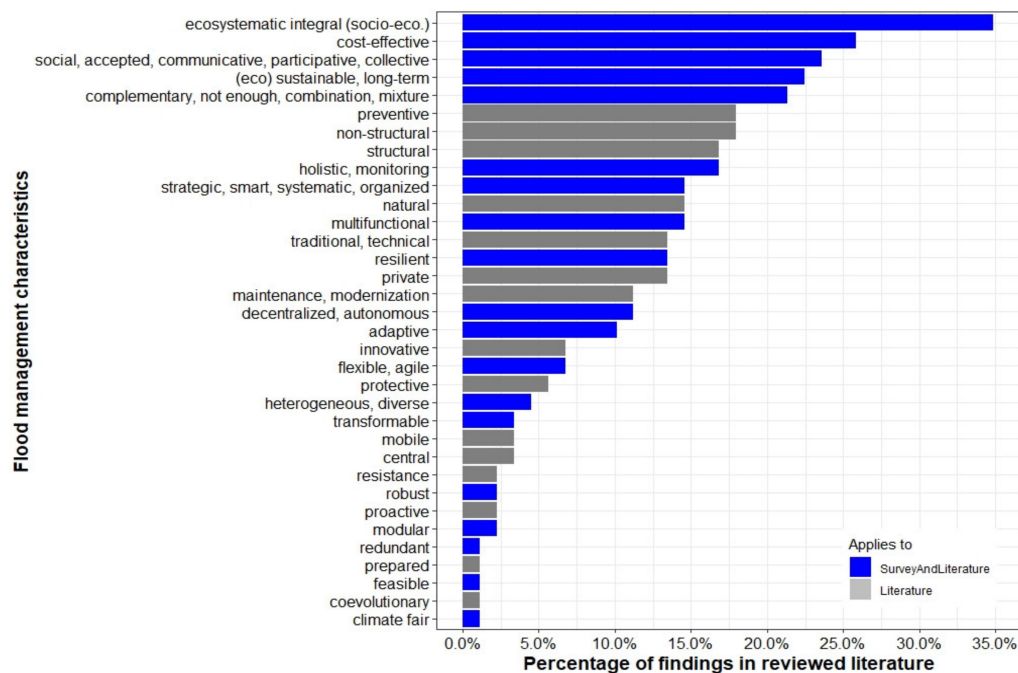
Figure 5. Percentages of characteristics important for FM (N = 89). Characteristics considered in the survey are with blue bars, and both blue and grey were considered in the literature analysis.

3.2. Analysis of Expert Survey

After a detailed examination of the socio-professional information, it was found that the experts showed 1 to 55 years of experience in the field (12 ± 11.86 years, median ± MAD) and worked in the European region and especially in the ERMA. For these reasons, their statements made in the survey were considered as legitimate for the purpose of the study. Details and information about the distribution of Likert scores (Figures A4–A6) and consensus values (Figures A7–A9) among experts can be found in Appendices C and D, respectively.

3.2.1. Multifunctionality of Flood Mitigation Measures

The evaluation of functions of the measures highly varied between the experts (Figure 6). Seventeen people were not able to assess the functions of measures. At least one function was assigned to all measures (Figure 6), with "not available", "limited experience", or "flood reduction" being under the top 20 mentions in applying functionalities assigned by experts. "Emergency preparation" was the most cited measure for economic and societal benefits (ten mentions), closely followed by "river restoration" (without easy technical implementation) and "constructed flood water retention", with nine mentions on economic and societal benefits, and by "water retention slowdowns and drainage systems" with nine mentions for flood reduction function, the latter being the single functionality mentioned most often (37 times). The combination of the flood-reducing, environmentally friendly, and economically beneficial, as well as the socially beneficial functionalities of a measure was mentioned 21 times, as well as the combination of flood-reducing and economically and socially beneficial.
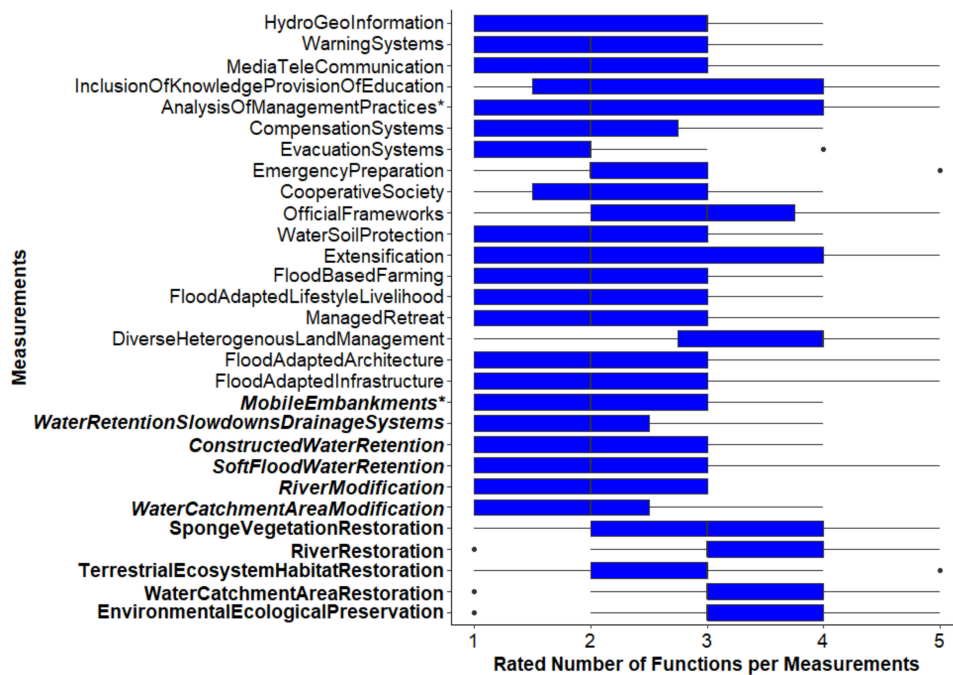
Figure 6. Rated multifunctionality of measures by experts (N = 33). Multiple choice was possible. * Only represented in sub-data set 2 (SDS-2) about FM in non-European rural mountain areas. Instrumental (plain), structural (***bolditalic***), and natural solutions (**bold**).

3.2.2. Applicability of the Measures for European Rural Mountainous Regions

Around two-thirds of the measures (20 of 29) were assessed as moderately to highly applicable to ERMA, especially high for NBS (Figure 7).
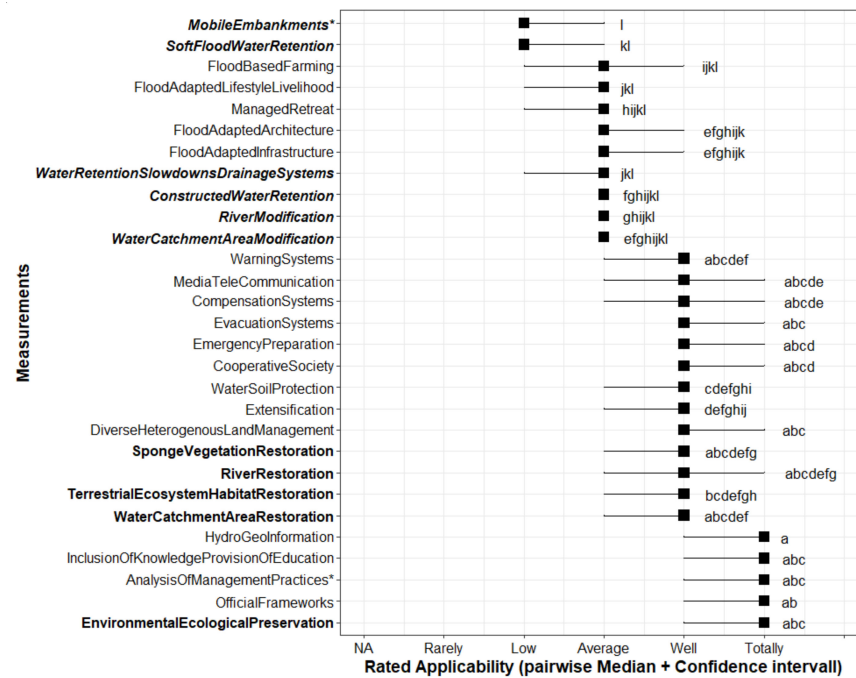

Figure 7. Statistical differentiation by the Friedman Conover test of measures regarding their applicability in European rural mountain areas (Friedman χ_{fm} and Kendall Wt test-statistics: $p < 2.2 \times 10^{-16}$, df = 28, χ_{fm} = 231.37, Wt = 0.285). Ratings of measures sharing a letter (e.g., "a" in OfficialFrameworks and RiverRestoration) could not be statistically differentiated. * Only represented in SDS-2. Instrumental (plain), structural (***bolditalic***), and natural solutions (**bold**).

The remaining third rated with low to moderate applicability is composed of many instrumental and engineered solutions (Figure 7). Only a few measures were given low or very good applicability for ERMAs, e.g., "mobile embankments" or "hydro-geo information", respectively (Figure 7). It is worth noting that measures missing in SDS-1 but available in SDS-2 (NERMA) and described as effective there (i.e., nature conservation, compensation systems, and warning systems) were assessed as highly to very highly applicable in ERMAs (Figure 7). Furthermore, for about half of the measures, it could be said that those with higher applicability in ERMAs provided also more than one functionality (Figures 6 and 7).

3.2.3. Spatial Impact of the Flood Mitigation Measures

The assessment revealed that the spatial range was heterogeneous, so that either no clear spatial effect or only one spatial extreme (local or supraregional) was indicated by the experts (Figure 8). Deviations were shown by "flood-adapted architecture", "hydro-geo information", and "river modifications", which showed local and supraregional ranges (Figure 8). A few measures were found to have almost exclusively 50% local effects, while the vast majority were found to have 50% regional effects and occasionally supraregional effects. All measures received at least one or more mentions of limited experience from the experts.
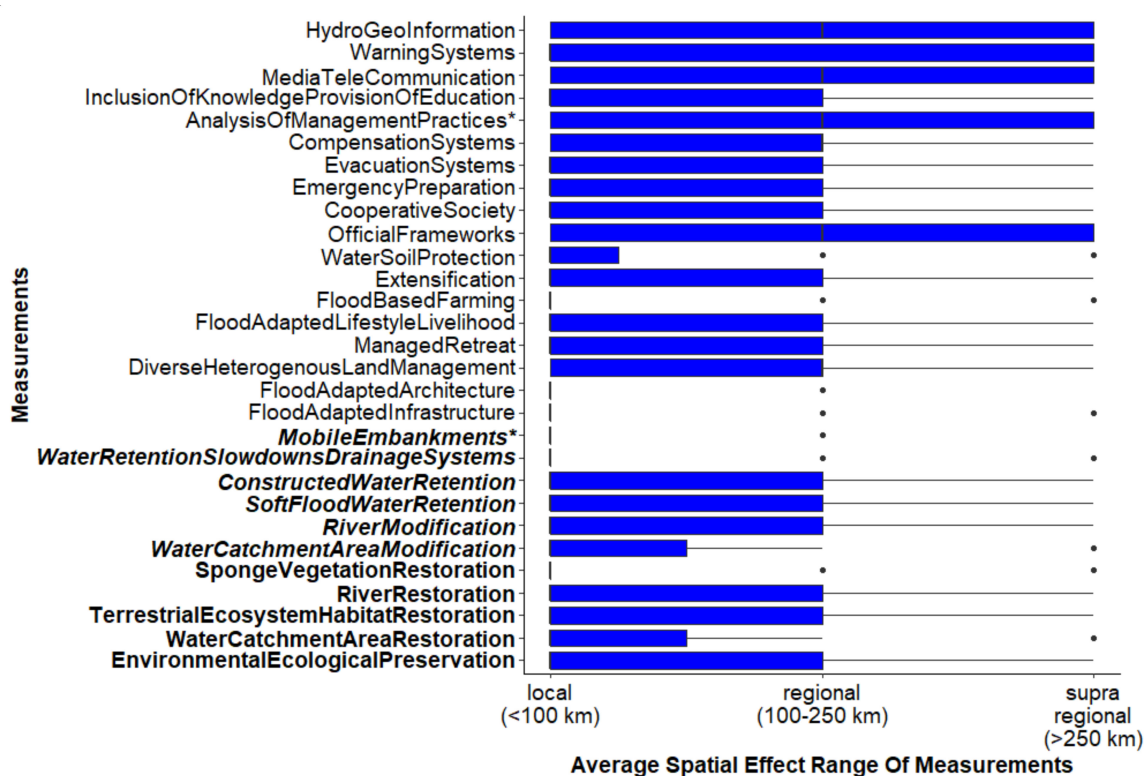

Figure 8. Average effective spatial range of FMM (N = 29). Multiple choice was possible. * Only represented in SDS-2. Instrumental measures (plain), structural measures (***bolditalic***), and natural measures (**bold**).

3.2.4. Prioritization of Flood Management Phases by the Experts

The most common medians ranked around 10 or 11 (less important), such as for insurance or rehabilitation, and 5 (more important), as for natural water retention (Figure 9). The experts showed less consensus in ranking the priority of FM phases compared to rating the applicability of measures (Figure A7 vs. Figure A8). Phases of prevention and precaution (including natural water retention, technical flood defense, land use regulation, and building regulations) were rated most important for FM (Figure 9). The applicability in ERMA of measures belonging to these phases was rated as feasible (Figures 7 and 9).
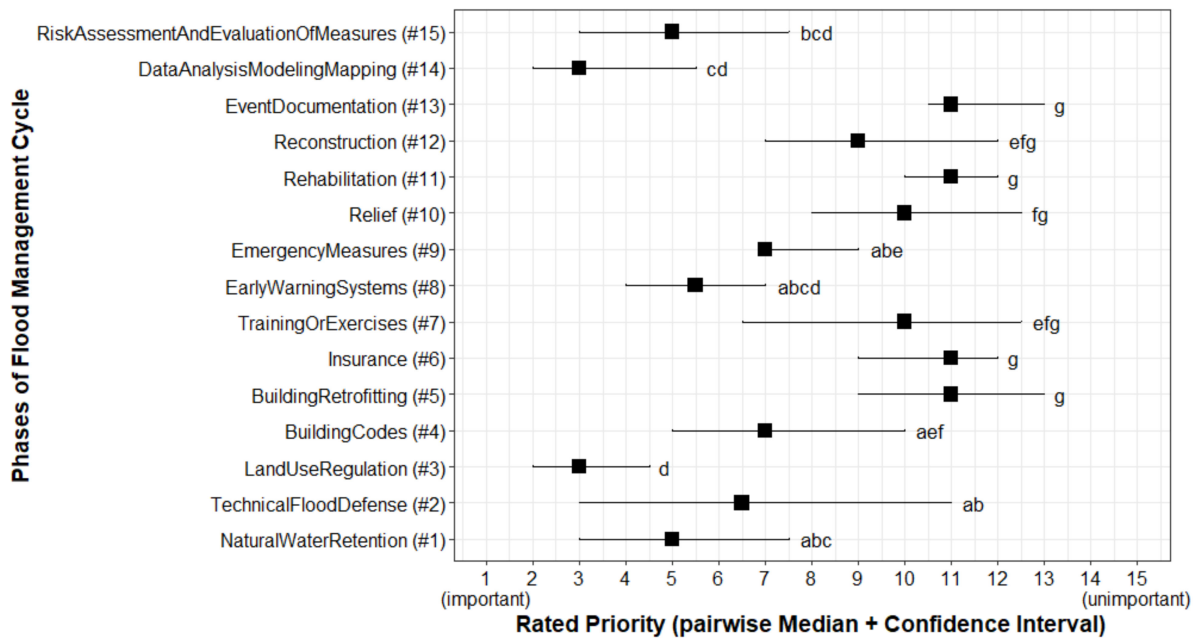
Figure 9. Statistical differentiation by the Friedman–Conover Post hoc test of phases in FM cycle regarding their importance (Friedman χ_{fm} and Kendall Wt test-statistics: $p < 2.2 \times 10^{-16}$, df = 14, $\chi_{fm} = 108.22$, Wt = 0.276). Ratings of phases sharing a letter (e.g., "a" in EmergencyMeasures and NaturalWaterRetention) could not be statistically differentiated. The # followed by a number refers to their position in the FM cycle (see Sections 1 and 3.1.2).

3.2.5. Important Characteristic for Flood Management

The agreement within the group of experts showed a relatively strong polarity for the presented characteristics with only few assigned to middle ranks (Figure 10 and Appendices C and D). A plateau occurred at ranks 6 until 11, between "climate-fair" and "strategic/smart" (Figure 10). The most unimportant rated characteristic was "redundant" and the most important "sustainable, long-term" (Figure 10).

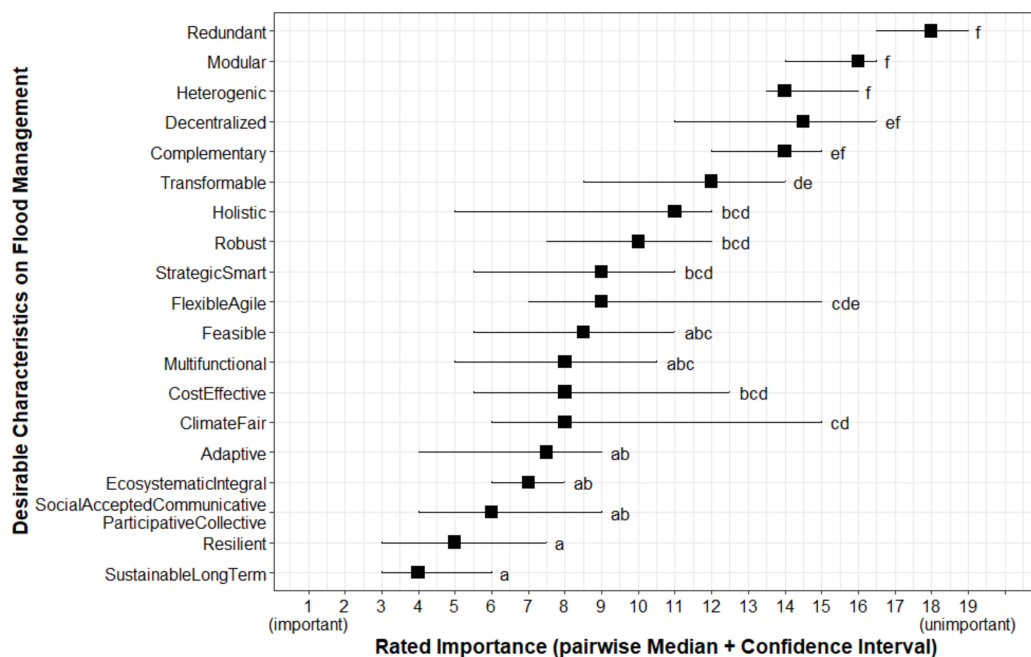**Figure 10.** Statistical differentiation by the Friedman–Conover test of characteristics attributed to FM regarding their importance (Friedman χ_{fm} and Kendall Wt test-statistics: $p < 2.2 \times 10^{-16}$, df = 18, $\chi_{fm} = 156.74$, Wt = 0.311). Ratings of characteristics sharing a letter (e.g., "a" in Resilient and Feasible) could not be statistically differentiated.

3.3. Comparing the Findings between the Literature Review and Expert Survey

Discrepancies became visible when comparing the survey ratings on the applicability and prioritization of FM measures and phases with the literature (Table 6). First, considering the prioritization, experts rated phases of the risk analysis and those of prevention, as well as early warning systems and emergency measures, as having a high priority. In the literature, major references on phases in the FM cycle were made with regards to preventive and precautionary measures, along with emergency measures and data analysis, modeling, and mapping (="hydro-geo information").

Table 6. Synthetic comparison between written and expert-based knowledge about flood management in rural mountainous areas.

	Literature Review	Expert Survey
Scale	Local to (supra-)regional	Local > regional >> Supraregional
Technical feasibility	Easy to Complex	Not available
Functionality	Low and negative (Structural) High and positive (Non-Structural)	Low and Flood reduction (Structural) > High and Multiple Benefits (Non-Structural)
Efficiency/Applicability	High >> Low	Average, Well, and Totally Applicable
Phase with knowledge available/High Priority	Disaster Risk Reduction and Risk Analysis	Disaster Risk Reduction and Risk Analysis
Knowledge missing/Low Priority	Building Codes and Event Documentation, Recovery (Phases)	Building Retrofitting, Training or Excises and Insurance, Recovery (Phases)
Recommendation	Socio-/ecological, Cost-Effective, Sustainable/Long-term, Complementary	Ecologically integrated, Social, Adaptive, Sustainable/Long-term, Resilient

Considering the applicability, "compensation systems" or "emergency preparation" were rated with good applicability for ERMAs, while the phase of insurance or emergency measures were rated as less important. Event documentation was rated as unimportant, but the corresponding measure "inclusion of knowledge and provision of education" was rated as very suitable for ERMAs. Additionally, natural water retention received a very high rating as a phase in the FM cycle, but its applicability in ERMAs (="soft flood water retention") was considered to be low. Nevertheless, it should be noted that NBS such as "sponge vegetation restoration" or "terrestrial ecosystem and habitat restoration" were judged to be well applicable. Likewise, warning systems and engineered solutions received low-rated applicability compared to a high rating of the phases early warning systems and technical flood defense. Emergency measures received medium importance, whereas corresponding "mobile embankments" were evaluated as rather unsuitable for ERMAs. The phases of data analysis, modeling and mapping, land use regulations, risk assessment and evaluation of measures, and natural water retention were found to be both important and very applicable or suitable for ERMAs.

When comparing measures for the different areas (SDS-1 to SDS-3), it is worth noting that experts showed greater knowledge than the publications. All three SDS missed many measures, such as information about instrumental solutions, and especially "mobile embankments" and "analysis of management practices". However, knowledge about functionalities was especially scarce in relation to the technical feasibility of measures, both in the literature review and in the expert surveys.

Regarding important characteristics of FM, the literature findings and the results of the experts survey largely coincided. For example, "ecologically integrated", "social", and "sustainable, long-term" were mentioned most often or as very important in the literature and by experts. "Redundant", "robust", "modular", "transformable", and "heterogenous" were indicated as unimportant in both the literature and the survey. "Climate-fair", "resilient", and "feasible" were considered important characteristics in the surveys but

showed few mentions in the assessed literature. It is also notable that characteristics such as "complementary", "holistic", and "decentralized", were classified as less important in the survey but were mentioned far more frequently in the assessed literature. In the midfield of both analyses were characteristics such as "strategic/smart", "multifunctional", and "flexible/agile".

4. Discussion

The study presented an overview of the scientific knowledge available from publications and experts (incl. EU-funded projects) to advise the implementation of suitable FM measures in ERMAs. The hypothesis about scientific boundaries hindering the implementation of flood measures and management in ERMAs could be partly rejected. The study showed that both sources of knowledge are available and encouraging the implementation of non-structural solutions. These sources define such solutions as being sufficiently applicable, cost-effective, multifunctional with efficient flood risk reduction, and having a great potential for large-scale implementation. Considering the environmental effect of engineered solutions, the assessment of European and non-European publications (SDS-1 vs. SDS-2) was conflicting. In OMA (SDS-3), engineered solutions were assessed as being potentially either beneficial or damaging to the environment. The associated feasibility and implementation costs varied. Interestingly, NBS were classified as environmentally friendly in Europe and mostly damaging the environment outside Europe for the observed cases.

4.1. Addressing the Causes Instead of the Symptoms

The study showed that more knowledge is available for the phase "disaster risk reduction" than for "recovery". The focus on pre-flood event phases corresponds to the particular environmental conditions and flood characteristics in mountain regions. These make the use of warning systems as short-term actions difficult due to the very sudden and sometimes very severe onset of flash floods and riverine floods [27,28,103], while in Japan, 90% of flood damage could be reduced despite increasing rainfall [104]. Furthermore, studies demonstrated that preventive and precautionary phases should be given greater focus over reactive and recovery phases in disaster management [105–107]. A reason for this statement is the higher costs incurred by recovery measures after a catastrophic flood event which potentially could be avoided if precautionary measures were taken [106,108]. In the context of climate change, namely, the unpredictable change of weather patterns with an expected increase of flood severity and frequency, a focus of FM design on precautionary measures is highly recommended [7]. The approach of addressing the causes instead of the effects of a natural hazard can be achieved through passive, permanent, as well as temporary structural as well as non-structural implementations of measures [61]. Furthermore, the results from the experts survey and literature analysis indicate a trend towards preventive FM in the scientific community [58].

While the documentation of historical events is of little help to predict floods, especially due to land use and climate change, modeling can highly improve the estimation of risks. Increased use of electro-technical systems (e.g., remote sensing and geospatial information systems [24,109], WeSenselt [110]) can be supported by continued technological innovation, increased capacity, and computational performance [24,32]. In addition, societal awareness of the risk and willingness to live in a more nature-friendly way may facilitate the transition and understanding of, e.g., building and land use regulations (private houses cannot be built everywhere). Despite great investments and more precautions, complete flood protection will not be possible [64,111], which is why reactive and post-flood measures should not be neglected, especially during strong and rare flood events [112]. This is due to, first, the predictability of flood events, which is fraught with uncertainty [58], second, the capacity limits of non-structural measures [34], and third, the catastrophic failure possibilities of structural measures, e.g., dam breakage [27,44,47,103]. The lack of FM analyses found in the literature review on FM in mountain areas may be explained by the fact that FM can also be handled without risk analysis [113]. The overview on FM in

North American rural mountain regions attributes the challenges in FM and difficulties of flood resilience to, among other things, the complex conditions in these regions, including future conditions, insufficient data and infrastructure, and lack of long-term governance structures [24]. Information-based systems, measure failures, and maintenance in particular are also seen to be hampered by the difficult accessibility of rural mountain regions as challenges, while technological advances, e.g., in monitoring measures, data dissemination, communication networks, and forecasting, might provide relief [24]. Shortcomings in North American FM of rural mountain areas were found also for FM in other geographical areas [24,31,32,111].

Emergency measures such as mobile protection systems have very limited potential in rural mountainous areas. For example, dams made of sandbags require a lot of personnel, time, and materials during a disaster [103] and can only be implemented by physically fit people [114]. These are possible reasons for the poor suitability of these protection systems in rural mountain regions, especially since the construction would have to happen very quickly during the sudden flood events. Therefore, more consideration of socio-demographic information in FM strategy development is recommended [115,116]. Instrumental FM measures, such as financial aid, are also necessary because some population groups are privately unable to make a sufficient contribution to FM by protecting themselves and recovering after perturbations [116].

4.2. Natural Solutions as Cost-Efficient Measures

The results of the study showed that natural solutions in ERMAs are cost-effective. In comparison to measures implemented in OMAs, they are eventually characterized as "cheap". This may be explained by the reduced number of owners in rural mountainous area. However, even in lowlands, floodplain restoration is considered as having a higher monetary value than engineered or structural measures [117]. Furthermore, FM requires minimal resource expenditure by using nature's regional capacities [32]. For example, forest management is 5 to 10 times cheaper than implementing structural solutions [12]. Regular maintenance is needed to ensure the effectiveness and functionality of engineered measures, which makes natural measures cost-effective only in the long term [31,111]. In this context, maintenance also includes adapting and modernizing the measures to the development trends of flood severity [32]. Under natural circumstances, it would be possible to predict the future behavior of a landscape feature, such as a river, from its flood history [1]. In Europe, this is likely to be complicated and only possible to a limited extent for a short period of time [10,19].

4.3. Natural Solutions as Multifunctional Measures

As shown in this study, both natural and structural solutions are considered operational for rural mountain regions, with more favorable suitability on the side of NBS. NBS can also address other gravity-related natural phenomena [19,118]. Looking at the literature, decentralized natural measures are described as easy to implement, with positive ecological, economic, and aesthetic effects, and they are effective in flood reduction when used in a mosaic-like network [44]. Surprisingly, non-European publications suggested that natural measures may also damage the environment (e.g., increasing the risk of drought through pine stand establishment [69] or loss of biodiversity through the reforestation of grassy biomes [119]). Further research should investigate the unexpected damages to the environment and address them. It is expected that damages are short term and caused by massive perturbations of the ecosystem during restoration works [120], which may result in negative long-term effects such as on biodiversity. On the other hand, studies highlight that structural solutions are not just damaging the environment but also increasing the hazard (e.g., [45,49,72,121]). However, structural solutions are evolving to become more environmentally friendly. For example, structural measures can be designed as low-impact riparian structures [23], ecologically sensitive dams [66], planted/navigable dikes [122–124], or with living weirs [125]. This allows for more functions to be combined

in one measure and compensate for the restricted applicability of natural measures in urban areas. Furthermore, the studied literature revealed that the outscaling of solutions applied in urbanized settings should be applied with caution.

The special conditions in mountain regions make it indispensable to use a variety of different FM measures, especially recommended for European mountain ranges [31,62] and in view of climate change and increasing flood frequency and severity [47,49,66], as well as efficient and socio-economically justified design [29,112]. This can be attributed in part to the fact that restoring natural conditions is difficult in ERMA and engineered measures are neither socio-ecologically nor easily transferable to other regions [44]. For example, dike relocation turns out to be feasible but spatially limited, and river restoration turns out to be rapidly effective [37]. To some extent, a combination of engineered and natural solutions is possible [6,19,118]. Such heterogeneous landscapes can be very effective in reducing rapid runoff and an alternative to complete landscape afforestation [23,126], especially when considering wetlands, grasslands, etc. [119]. Looking elsewhere in the world, it is also possible to make heterogeneous landscapes multifunctional [127].

Public participation in FM is also limited by spatial constraints and land use requirements [47,115,128]. Therefore, a general call for more instrumental measures is made [7,32]. For example, a standardized compensation system is suggested by the literature [79]. Such an approach would be worthwhile for all parties involved and affected. Studies demonstrated that flood-adapted building construction reduces damage from 10% to 100% on valuable property [47,61,112,129]. The absence or low number of insurance or compensation schemes is also criticized [7] and has been reflected in the literature review and results from the expert survey. However, public–private FM should be pursued with the participation of all relevant individuals and entities, as governments alone cannot provide complete flood protection [7,24,32,122,130]. Examples of such whole-of-society disaster management approaches include the Sendai Framework for Disaster Risk Management, the Partnership for Environmental and Disaster Risk Reduction (PEDRR), the World Water Forum, and the IUCN Water and Nature Initiative (WANI) [131]. The State Disaster Event Insurance System NFIP or the Napa River Flood Protection Project may be used for guidance in this regard [24,44], as well as the EU Commission's 2004 action thread [113] and the Flood Framework Directive 2007/60/EC [132]. State-led flood mitigation measures should be linked to end land degradation and the promotion of regenerating natural landscapes, such as floodplains and green infrastructure, as well as other nature-based and basin-wide solutions with multiple ecosystem services and disaster applications [6,34].

4.4. Natural Measures with Great Large-Scale Implementation Potential

Floods can affect a large area, and this is the reason for FM to be planned on a large-scale (watershed scale) [128]. In smaller watersheds, special attention must be paid to freeing up the small water storage capacities for subsequent water intakes [22,132]. Small-scale NBS are considered insufficient, especially under the different aspects of climate change but also in relation to reducing runoff and pollutant control. However, small near-natural retention basins can be easily integrated into national road networks [73]. Nevertheless, it must be kept in mind that due to land use pressures in some regions, such as in Europe, instrumental measures are needed to enable large scale implementations [133]. Tools developed in Sweden [134] and Germany [135], or pedo-geological maps [136] and stream management concepts [58,133] can facilitate the FM planning in this regard. Additionally, more emphasis should be given to large-scale, interconnected, and combined measures (NBS chain) [22] both in research and in practice due to capacity limits in small retention basins and the complex implementation of larger NBS chains [12,34]. Nevertheless, when measures or functions are combined, vulnerabilities may occur at interfaces between the measures and structures or settlements that need to be addressed [16]. Effectively implemented FM, however, could prevent up to 60% of flood damage [47]. In the rural mountain regions, NBS such as afforestation, reforestation, and slope stabilization, and for rivers, dike relocation and protective dams, can be particularly helpful in FM [34].

At best, this should be in place along the entire length of the stream [41]. Also, restricting residential development in floodplains, adapting existing structures, and strengthening building structures must be considered [137]. The implementation of measures should be designed around the impact areas of flood events (transboundary coordinated watershed management) rather than national, regional, or community boundaries, e.g., in the Netherlands through "water boards" [7,24,58]. The decentralization of FM at all levels, i.e., from types of measures to responsibilities and participation, can ensure resilient FM under the dynamic, complex, and peculiar conditions of rural mountain regions. Large-scale implementation also allows for the reduction of the flood hazard before it arrives in vulnerable areas [73,79,122,136,138], e.g., extend the concept of sponge city to landscape scale [17,139,140]. Therefore, on-land floodwater retention in areas upstream is recommended [58] and can be provided by decentralized FM [29] also in a quick manner [40] and effectively in cases of spatial and land use conflicts [23]. However, centralization has lowered the controllability and predictability of floods [9], and e.g., provoked the burial of the Isar River [121]. Future developments of rural mountain areas should prompt the rethinking of FM for these reasons [141].

4.5. Social Boundaries as a Barrier to the Implementation of Natural Solutions

While, historically, society was accustomed to living with flood risk and even taking advantage of floods (e.g., at the Nile River) [142], FM strategies developed between the 18th and 20th centuries and focused on fighting the flood instead of adapting to it. Shifting to a novel FM strategy based on NBS could pose difficulties in social acceptance, as societies are culturally shaped by engineered approaches. They are perceived as "looking efficient". NBS should be easily accepted by the public because of the societal co-benefits but are still perceived by laypeople as having limited flood mitigation effects [143]. Widespread awareness of the attributes of FM should therefore be pursued [143,144]. Integrative FM will require public education and involvement for a successful implementation [47,62,144]. Nonetheless, the restoration of a socio-ecological system requires a willingness to compromise in society [46]. In addition, a "flood dementia" and shifting of responsibility quickly undermines societal "co-working" because persons not directly affected by flood damages underestimate the impact of a flood event, or external factors such as influence of climate change or mismanagement are blamed as the cause of floods [62,145]. Therefore, a culture of remembrance should be established before adapting to flood events [48]. Because values in a society change very slowly, there is a need for accompanying research and work, such as socio-hydrology, that addresses societal and hydrological developments equally [48].

In addition, knowledge about FM, e.g., by civil society, should be promoted more strongly and no longer be designed only for economic damage limitation, i.e., risk reduction and loss sharing [7,58]. The European Alpine Strategy captures such cross-regional cooperation [133]. Otherwise, the divergent FM of other regions in a water catchment area creates counterproductive effects [146]. Solutions at larger scales should therefore incorporate adaptive land use [127]. Resettlement, often as a last resort solution, is also considered feasible, moderately costly, and compatible [7,47], as in the case of the French coastal towns of Vendée and Charente-Maritime [147]. Avoiding risky and vulnerable areas for certain uses would be a first step to flood protection [47,49]. Especially when economic aspects come into play, only the legal minimum is usually required [7]. With greater involvement and encouragement of the private sector, "dormant" social potential in FM can come to fruition. Flood mitigation measures can be maintained by the community, as exemplarily applied in Japan [122]. Only such integration into community understanding and continuous monitoring of measures generates effective, socio-ecologically resilient FM [7]. In addition, FM should be about intervening in the socio-spatial spread of humans rather than nature and establishing strategic and autonomous FM with individual and societal behaviors [7]. Floods must be viewed as a holistic societal-ecological phenomenon in order to implement comprehensive FM.

4.6. Limitations of the Study

This study provides an overview on the available published and personal knowledge about FM and in particular in the case of ERMA. The analysis of published knowledge was based on the mathematical closeness or association found for variables in the different MCA models. However, it should not be forgotten that by means of the MCA neither a statement about the nature nor the strength of the relations can be made. Nevertheless, it was shown that relations exist between certain profiles. In general, caution should be exercised in its interpretations. Individual cases can distort the correspondences, and missing data points can lead to strong discrepancies in the frequency and heterogeneity of profiles [148–150]. For example, one such outlier was observed in the SDS-2 (see [69]). Across all SDSs, and in 70% to 99% of the cases, FM had no information on their multifunctionalities, the effects on the runoff peak, or the range of effects or flood severity. In the case of only a single literature evidence, e.g., on the society-enhancing effects or runoff peak delays of 4800 min, caution should be taken when interpreting the MCA output, too. In addition, most evidence for Europe is situated in Central Europe and is missing other European mountain regions such as the Scottish Highlands, Caucasus, or Pyrenees. In the case of the heterogeneous distribution of variables, it would need to be clarified whether homogenization, equal number, and mass of modalities would consolidate or improve MCA results. Thus, more balanced data would be beneficial for such an analysis. An imbalance can also be a consequence of publication bias, with more positive than negative or non-significant results being published [151]. Despite the dimensional reduction in the SDS through MCA, more than 80% data variability were explained in the first three dimensions with strong associations among modalities in the data on FM in different mountainous areas.

The contradictions of the coherence between consulted literature and experts described in Section 3.3 were attributed to the search procedure on relevant literature, but it also reflects the previous focus in research and practice on urban and lowland regions, as evident in, e.g., [61]. Furthermore, the discrepancies observed for important characteristics in FM assigned in the literature and from experts, some being more important or found less frequent, may be due to different focuses in research, study, or publication. In addition, there were notable differences between the characteristics of FM for Europe and those outside Europe, i.e., geographic effects. Climatic conditions and much more natural land cover in tropical mountain regions, as well as a focus on traditional and indigenous ecological knowledge in FM, might explain the observed differences between Europe and other regions of the world. More favorable environmental conditions outside of Europe enable the use of FM practices in mountain regions that cannot be adopted one-to-one in ERMAs.

Finally, the response rate for the survey was within the usual range of expectation, with approximately 30 usable survey questionnaires from approximately 200 people contacted, mostly from both universities and research institutions. This might explain the largely matching results for the literature analysis and surveys, but it also suggests extending future research to the administrative, cultural, social, and technical boundaries and include knowledge from, e.g., technical relief agencies, planning departments, or disaster crisis teams, who are missing from the assessment, may also explain the lack of information on short-term pre- and post-flood phases in the prioritization rating. The survey yielded first definable results, namely, drawing the scientific boundaries of FM in ERMAs, as measured by the indicators of agreement, but it would be preferable to undergo a second round of surveys to consolidate answers, as is usual for a Delphi process.

5. Conclusions

Structural solutions are facing major difficulties in protecting goods and people in a changing environment, namely under land use and climate change, population development, regional conditions, and hydro-meteorological evolutions. Particularly mountains are experiencing a great increase in flood risk. Changes in FM are needed. Non-structural

measures such as natural solutions have been recognized as potential FM measures to adapt to a fast-changing environment. However, their implementations remain limited in non-urban mountainous areas. Strategies in FM depend on administrative, cultural, social, technical, and scientific boundaries. While pilot measures showed that technical knowledge exists and the European political agenda supports natural measures, what are the scientific boundaries supporting implementation? This study showed that scientific knowledge can support decision makers and is encouraging the implementation of non-structural solutions because they are efficient, cost-effective, multifunctional, and have great potential for large-scale implementation. However, scientific boundaries exist for the implementation of FM in rural mountain areas. Scientific knowledge gaps remain for building- and training-related phases, as well as ecological and environmental issues. Furthermore, a lack of FM assessment and of knowledge about technical feasibility exist. Moreover, scientific boundaries should benefit from further studies on the general effect of measure on flooding, on the spatial effect range and on the reduction in peak discharge, and further research should focus on the recovery phase of FM in ERMAs. A major lack of knowledge concerns the development of high-potential electro-technical systems such as early warning or modeling and of assessment procedure of the co-benefits or multiple functionalities of non-structural solutions. Finally, an investigation on the effects of instrumental solutions is urgent.

Appendix A. List of Publications Used in the Systematic Literature Review

Table A1. List of references used in the systematic literature review, for the MCA, phases of flood risk management cycle, and important characteristics for flood management.

Sources Used in the Multiple Correspondence Analysis of Sub-Data Sets	Sources Used in the Assessment of Prioritized Phases in Flood Management Cycle	Sources Used in the Assessment of Important Characteristics for Flood Management
[6,9,12,20–24,27,29,31,33,34,36,37,40,45–47,52,61–63,65,67,69,70,73,78,102,104,108,110,113–115,118,119,121,122,126,128,129,132,133,136,138,140,141,145,152,153,153–198]	[7,9,11–13,17,20,23,24,28,29,31,32,34,36,40,43,44,46,47,49,58,61,70,73,78,79,104,108,112–114,116,118,129,131,135,136,138–140,143–145,152,155,156,163,164,173,175,177,192,198–207]	[1,7,9,11–13,16,17,19,20,22–24,29,31,32,34–37,39,40,43,44,46,47,49,52,58,61,62,66,73,78,102,104,108–114,116,118,119,122,127–136,138,139,143,144,146,152,176,179,185,186,188–190,192,197,199,203,204,206–219]

Appendix B. MCA Model Configurations

Table A2. Final configuration of models used in the analysis of the literature data, in other words, sub-data sets (SDS) for flood management in (1) European rural mountain areas (ERMA), (2) non-European rural mountain areas (NERMA), and (3) other mountain areas (OMA).

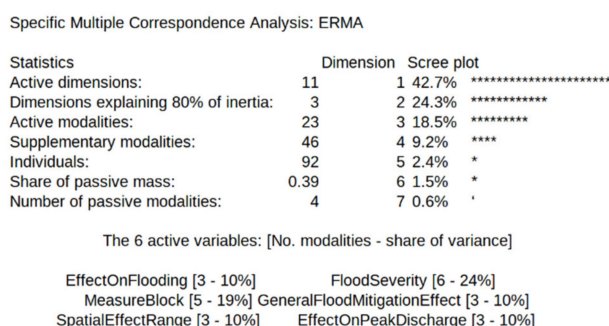|	SDS-1 (REMA)	SDS-2 (RNEMA)	SDS-3 (OMA)
Active Modalities	Flood Severity, General Flood Mitigation Effect, Effect on Flooding, Measure Block, Spatial Effect Range, Effect on Peak Discharge	Measure Block, General Flood Mitigation Effect, Effect on Peak Discharge, Spatial Effect Range, Effect on Flooding, Environmental Effect	Spatial Setting, General Flood Mitigation Effect, Effect on Flooding, Measure Block, Spatial Effect Range, Effect on Peak Discharge
Supplementary Modalities	Year Period, Subregions, Measures, Technical Ease, Environmental Effect, Economic Effect, Societal Effect, Peak Discharge Dilatation Minutes, Peak Discharge Reduction	Year Period, Subregions, Measures, Technical Ease, Flood Severity, Economic Effect, Societal Effect, Peak Discharge Dilatation Minutes, Peak Discharge Reduction	Year Period, Subregions, Measures, Technical Ease, Environmental Effect, Economic Effect, Societal Effect, Peak Discharge Dilatation Minutes, Peak Discharge Reduction, Flood Severity

Figure A1. MCA model of rural European mountainous areas (sub-data set 1).

Specific Multiple Correspondence Analysis: NERMA

Statistics		Dimension	Scree plot
Active dimensions:	9	1 51.0%	***************************
Dimensions explaining 80% of inertia:	2	2 33.3%	***************
Active modalities:	20	3 8.9%	****
Supplementary modalities:	48	4 3.4%	**
Individuals:	74	5 2.0%	*
Share of passive mass:	0.42	6 0.6%	'
Number of passive modalities:	4	7 0.5%	'

The 6 active variables: [No. modalities - share of variance]

MeasureBlock [5 - 22%] GeneralFloodMitigationEffect [3 - 11%]
SpatialEffectRange [4 - 17%] EffectOnFlooding [3 - 11%]
EnvironmentalEffect [2 - 6%] EffectOnPeakDischarge [3 - 11%]

Figure A2. MCA model of rural non-European mountainous area (sub-data set 2).

Specific Multiple Correspondence Analysis: OMA

Statistics		Dimension	Scree plot
Active dimensions:	11	1 48.0%	************************
Dimensions explaining 80% of inertia:	2	2 35.4%	******************
Active modalities:	24	3 7.5%	****
Supplementary modalities:	70	4 4.2%	**
Individuals:	276	5 2.2%	*
Share of passive mass:	0.25	6 1.6%	*
Number of passive modalities:	3	7 0.4%	'

The 6 active variables: [No. modalities - share of variance]

MeasureBlock [5 - 19%] EffectOnFlooding [4 - 14%]
SpatialSetting [4 - 14%] GeneralFloodMitigationEffect [3 - 10%]
SpatialEffectRange [5 - 19%] EffectOnPeakDischarge [3 - 10%]

Figure A3. MCA model of Other Mountain Areas (sub-data set 3).

Appendix C. Figures of Likert Percentages
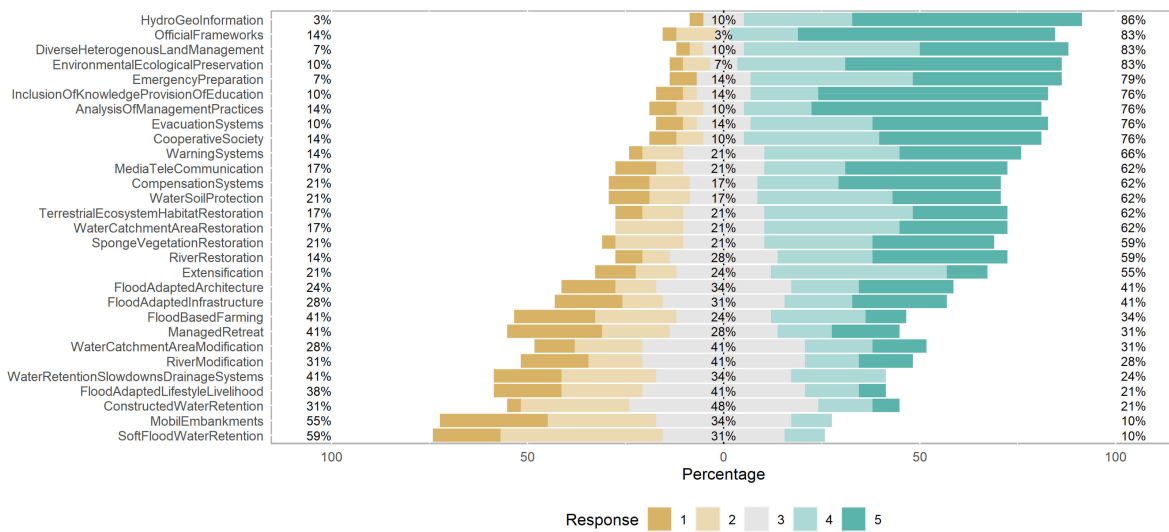
Figure A4. Percentages of Likert Scores for the applicability of flood measures from 1 being rarely applicable to 5 being totally applicable to rural mountain areas.

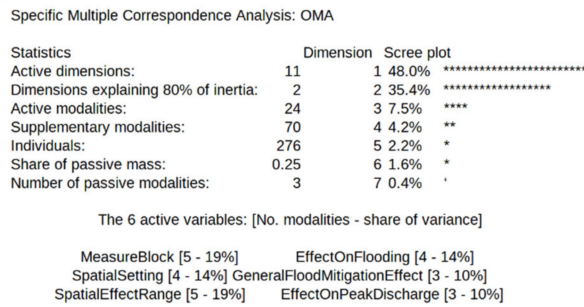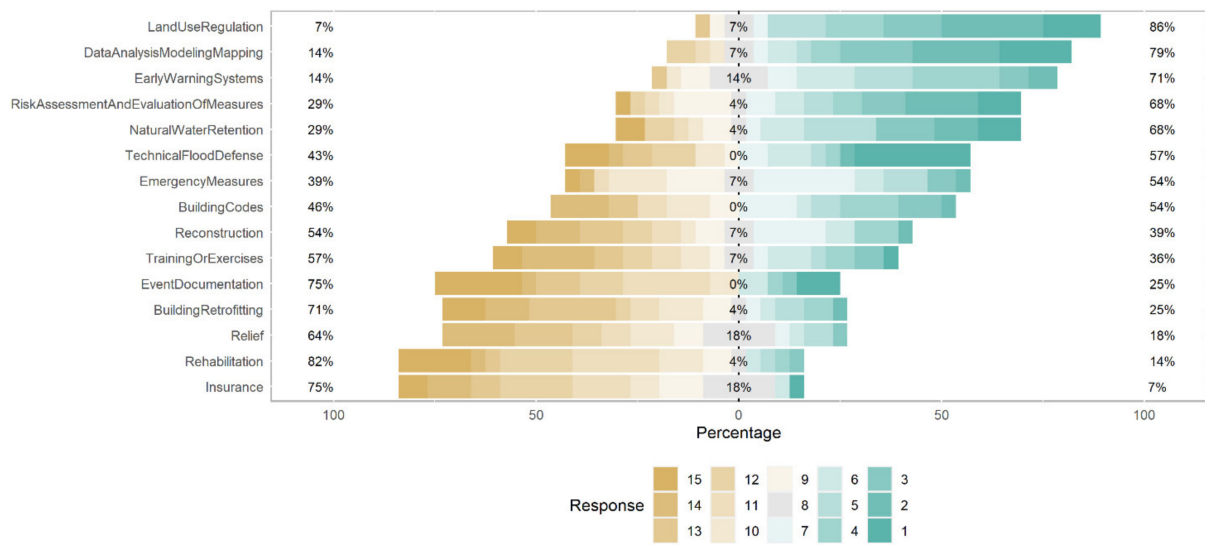**Figure A5.** Percentages of Likert Scores for the prioritization of flood measure from early (1) to latest (15) in rural mountain areas.
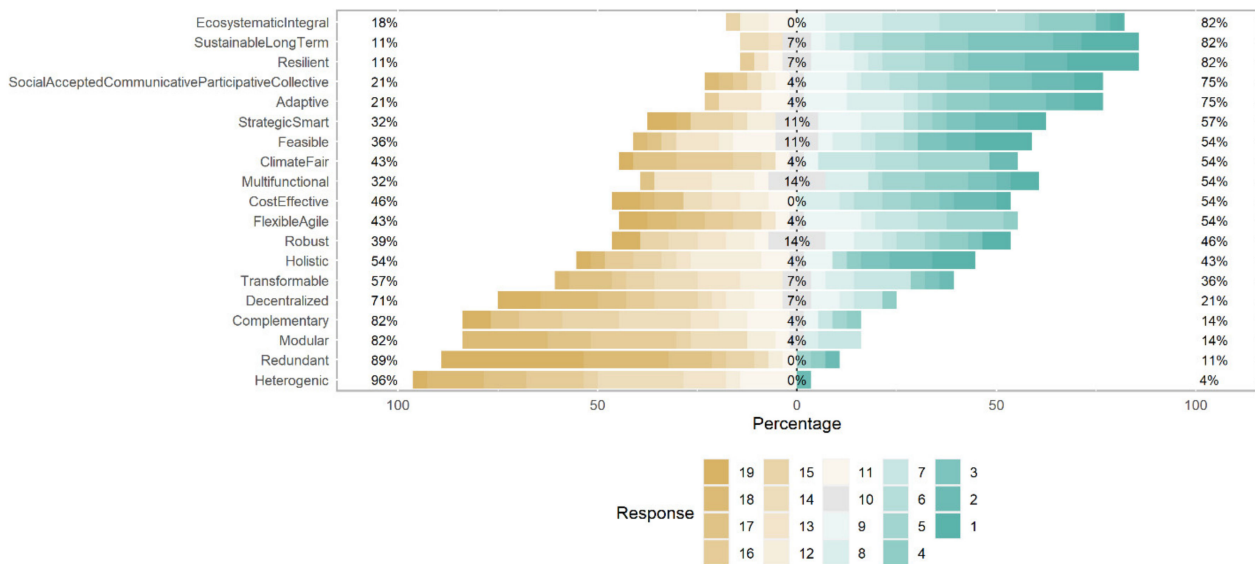
Figure A6. Percentages of Likert Scores for the important characteristics of flood management from important (1) to unimportant (19) in rural mountain areas.

Appendix D. Figures of Consensus
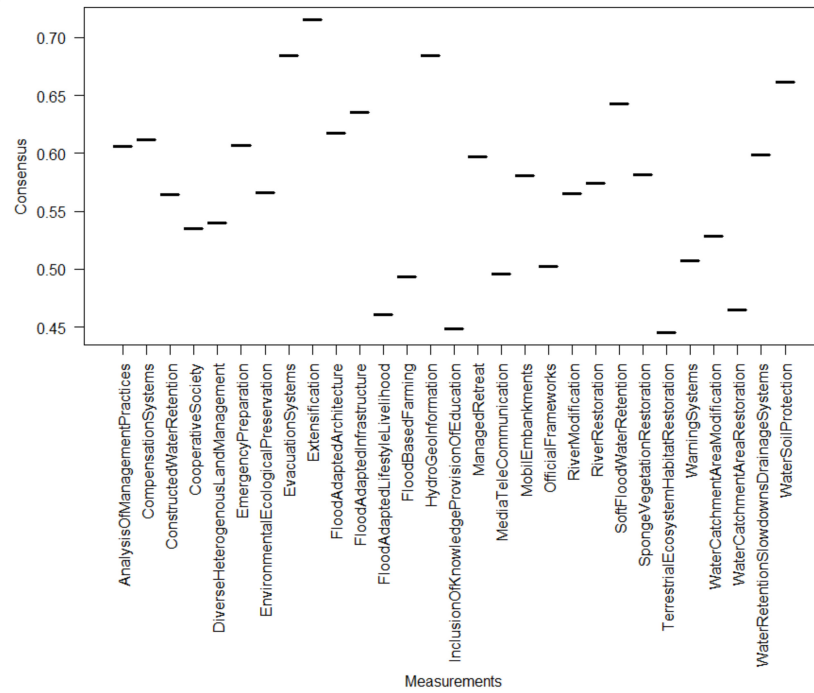
Figure A7. Agreement (consensus) among survey participants of the applicability of flood measures to rural mountain areas (the higher value, the more homogeneous the given responses; scale from 0 to 1).

Figure A8. Agreement (consensus) among survey participants of the prioritization of flood management phases (components) to rural mountain areas (the higher value, the more homogeneous the given responses; scale from 0 to 1).

Figure A9. Agreement (consensus) among survey participants of the desirability of characteristics for flood management to rural mountain areas (the higher value, the more homogeneous the given responses; scale from 0 to 1).

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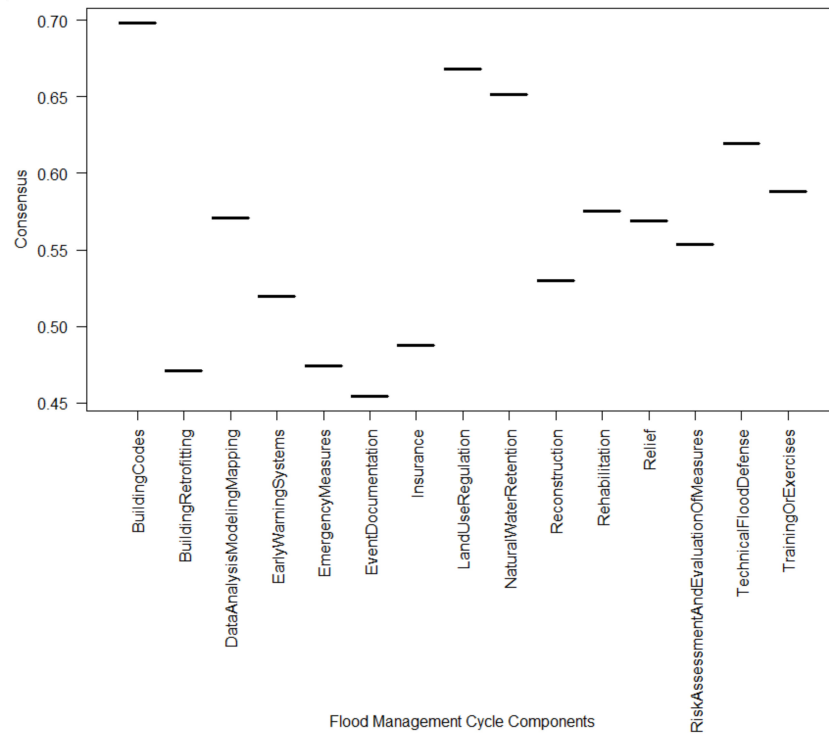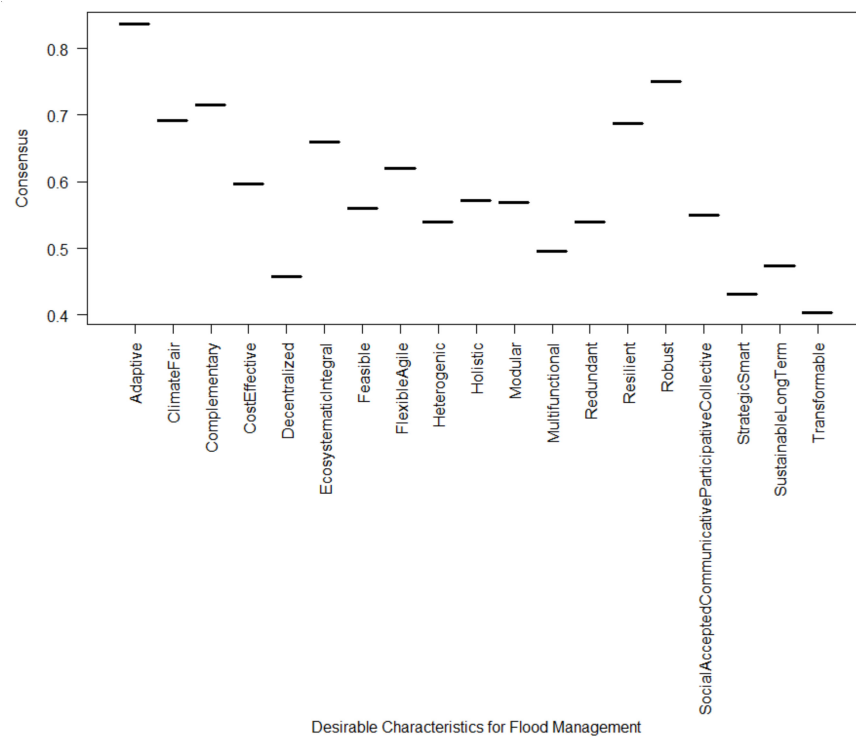2. Nagl, G.; Schönauer, S. *Ökologischer Hochwasserschutz—Raum Für Naturnahe Gewässer, Auen Und Feuchtgebiete—Schutz Für Die Menschen*; Bund für Umwelt und Naturschutz Deutschland e.V. "BUND", Ed.; BUNDhintergrund; Natur & Umwelt Verlag: Berlin, Germany; Köln, Germany, 2002.
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