Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio
©2023 ESREL2023 Organizers. *Published by* Research Publishing, Singapore.
doi: 10.3850/978-981-18-8071-1_P305-cd

A risk-based multicriteria approach for assessing and monitoring flood disasters under heavy precipitation

Lucas Borges Leal da Silva[1,3], Maria Clara Fava[2], Marcelo Hazin Alencar[3], Rodrigo José Pires Ferreira[3], Adiel Teixeira de Almeida[4], and Danielle Costa Morais[4]

[1]Management Engineering Department, Universidade Federal do Rio Grande do Norte – Natal, Rio Grande do Norte, Brazil.
[2]Institute of Exact and Technological Sciences (IEP), Universidade Federal de Viçosa – Rio Parnaíba, Minas Gerais, Brazil.
[3]Research Group on Risk Assessment and Modeling in Environment, Assets, Safety, Operations and Nature (REASON), Universidade Federal de Pernambuco – Recife, Pernambuco, Brazil.
[4]Center for Decision Systems and Information Development (CDSID), Universidade Federal de Pernambuco – Recife, Pernambuco, Brazil.
E-mails: borgesleal.lucas@gmail.com, maria.fava@ufv.br, marcelohazin@gmail.com, rodrigo@insid.org.br, almeida@cdsid.org.br, dcmorais@insid.org.br

Public administration, whether at the local or national level, faces new challenges in adapting human life to alarming trends such as an increase in the extent and frequency of natural disasters, threats to food and water supply, inadequate energy distribution, and migration crises. Given this context, the worsening of the climate crisis forces policymakers to adopt a new perspective to combat its damaging impacts on urban functioning, especially concerning the quality of life under the occurrence of hydrological events. This problem is multifaceted so usually conflicting objectives impose hard dilemmas to decision-makers (DMs) once heavy precipitations can potentially promote fatalities, displacements, contamination of water bodies, economic losses, and others. This paper aims to propose a novel multicriteria decision model for assessing and monitoring flood disasters, using the DM's subjective preferences to establish value judgements under risky situations. A numerical application in a Brazilian municipality is performed with the aid of a Decision Support System (DSS) with views to validate the new approach. By integrating statistical, graphical, and tabular information, this model is replicated in other urban areas in which the model assumptions are assumed. Moreover, the model results can be analyzed by DMs not only for taking preventive actions against floods but also for enhancing early warning systems to reduce disasters.
Keywords: Disaster Risk Management, Multi-Criteria Decision-Making, Urban Flood Risk, FITradeoff.

1. Introduction

The problems caused or aggravated as a result of climate change are complex and have been causing damage around the world. The effect of these changes increases the uncertainty in predicting extreme weather events due to the large spatial and temporal scales (Polasky et al. 2011), especially floods and landslides resulting from intense rainfall, making decision-making actions to reduce and mitigate disaster risks challenging. Another well-known problem related to floods is accelerated and unplanned urbanization, which aggravates flood problems, especially in large cities (Daksiya, Mandapaka, and Lo 2021). Idowu and Zhou (2023) found that all the twelve megacities worldwide investigated in their study have experienced devastating floods in the past two decades, therefore, evidencing the need to incorporate in flood risk management (FRM) the accounting of urban expansion patterns together with climate changes.

FRM involves several actions and decisions for disaster preparedness, warning, and response. There are many decision-making difficulties, such as selecting priority areas, action plans during extreme events, monitoring, and structural interventions to mitigate the impact of disasters. This is a highly complex and multidisciplinary field that involves numerous incommensurate factors. Therefore, it is imperative to devise disaster risk reduction plans that address the several factors and the challenges already at hand. Proper methods to aid the decision-makers are crucial for comparing, selecting, and ranking multiple options. When considering the whole level of decisions (from monitoring to estimation based on mathematical models), many attributes and parameters should be set up to construct a possible/candidate solution. Those setups can result in an incommensurate number of candidate solutions. Therefore, computationally efficient and effective multicriteria approaches must be developed to construct and evaluate promising solutions (Sanches et al. 2017; Emmerich and Deutz 2018).

Especially in the risk-based context, de Almeida et al. (2015) discussed a wide range of methods applicable to strategic decisions, including disaster risk management. In fact, FRM-related problems modeled as multicriteria decisions are an important trend to be addressed in future works (de Brito and Evers 2016; de Almeida 2020).

Despite many typical FRM problems being managed in the state-of-the-art, da Silva, Alencar, and de Almeida (2020) pointed out some limitations in this field, such as a lack of formal procedures that deal with the probabilistic aspects of flooding; few papers try to incorporate quantitative risk models in multicriteria approach; and a need for structuring replicable models in a different urban context. This way, these issues mean great opportunities for this paper in covering these gaps and proposing advances in flood risk modeling and monitoring.

Besides that, the authors commented that policymakers must consider the climate change effects in order to plan and execute adaptation measures to strengthen urban resilience against floods. For that reason, it might be useful for FRM-related professionals to consolidate a primary decision on urban adaptation policies, that is, how to map and track flood risks in urban areas.

In terms of flood risk assessment under an MCDM/A approach, this paper focused on the early findings of da Silva et al. (2020). The authors introduced a multidimensional risk evaluation for ranking critical area in an urban space, using the classical concepts of the Utility Theory and Decision Analysis. This way, this is the backdrop for improving their perspective, and adapting for the sorting problem, which is so important to real-life applications by control and monitoring agencies.

Considering what has been exposed, this paper aims to introduce a new approach to sorting and tracking flood risks with the Utility Theory, the ALARP principle and FITradeoff method for sorting problems, which employs a multicriteria decision model in the context of MAVT. This combined model incorporates the subjective preferences of decision-makers to make value judgments in risky circumstances.

The paper is structured as follows. Section 2 described the materials and methods used to propose the multicriteria model for sorting urban flood risks. Section 3 aims to validate the proposal with a numerical application in a Brazilian municipality. Finally, section 4 states some final remarks and draws up some guidelines for future research.

2. Materials and methods

The previous section discussed briefly the main aspects that justify the need for improving flood risk management (FRM) practices, from conception to implementation. Following a preventive perspective, multicriteria modeling has the potential to deal with multiple and even conflicting criteria in order to map flood risks and then structure adaptation measures to combat the cascading impacts in the urban context. This way, this section aims to present the risk-based approach for sorting urban flood risks thereby using the Utility Theory and FITradeoff method for sorting problems (da Silva et al. 2020; Kang, Frej, and de Almeida 2020). For didactical purposes, the proposed model is divided into two main steps, so that policymakers, with the aid of FRM-related professionals, can easily replicate in other urban areas in the world since the underlying assumptions described here are respected. This way, Fig. 1 outlines for readers the step-by-step procedure in order to sort flood risks under a multicriteria perspective. First of all, the intra-criterion evaluation means the starting point to investigate, in the light of the ALARP (As Low As Reasonably Possible) concept, which is the more appropriate risk category into which an alternative should be assigned. Afterward, the inter-criterion evaluation can be performed by considering the compensatory relationship between the relative preferences of the Decision-Maker (DM) over the criteria involved in the problem.

2.1 *Intra-criterion evaluation*

The intra-criterion evaluation is the first stage of the modeling proposal, in which the risk approach is integrated into the Utility Theory and the ALARP concept for assigning an urban area into a proper risk category.

As mentioned by de Almeida et al. (2015), a multicriteria problem is characterized by a set of alternatives to be evaluated in terms of DM's preferences over, at least, two criteria. Bearing this in mind, this modeling assumes that the DM is a policymaker who represents the public administration, so that he/she is able to tackle different risk dimensions in order to promote disaster risk reduction and urban adaptation against natural disasters.

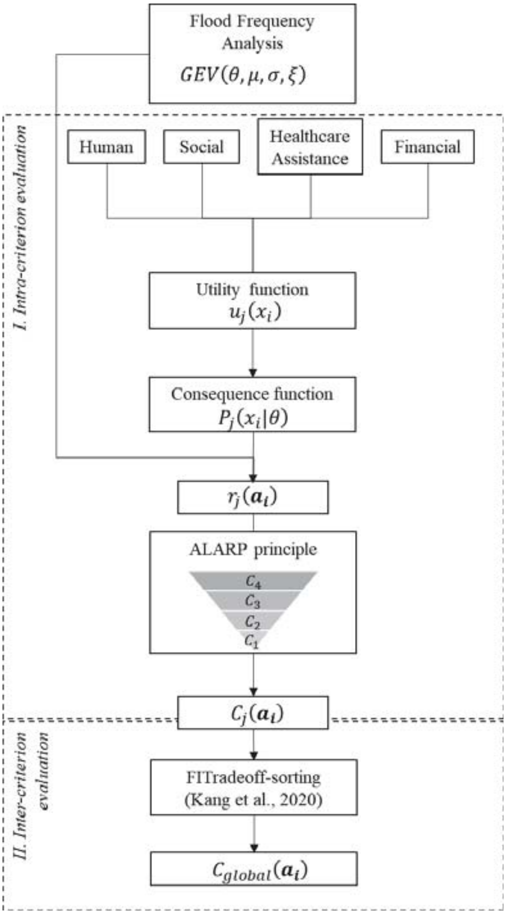


Fig. 1. Flowchart of the decision model that integrates Utility Theory and FITradeoff method for sorting flood risks in urban areas. Source: The Authors.

Despite many strategic decisions are taken by multiple DMs, this model assumes a single DM that takes responsibility for hard choices with regard to mitigating flood impacts. From a long-term horizon, the climate change impacts, as pointed out by the Intergovernmental Panel on Climate Change (IPCC 2018), have the potential to lead floods even more frequent and intense, so a summary for policymakers establish their duties and which professionals can be inserted into the decision problem as specialists. In practical terms, they play an important role giving factual information that supports the DM in establishing his/her relative preferences and risk behavior.

The set of alternatives (a_i, for i = 1..n) comprises a set of urban zones into a predefined site study. The DM, with the aid of specialists, can divide the site study according to geopolitical division of the area, or even homogenous characteristics thar might be useful to investigate the influence of flood risks in urban adaptation.

Given this context, the intra-criterion evaluation proposed by this work is based on the contributions of (da Silva et al. 2020) and its methodological insights (da Silva, Alencar, and de Almeida 2022; 2021), thereby considering the probabilistic behavior of flood phenomena when eliciting the DM's personal preferences in terms of utilities (Keeney and Raiffa 1976). It is the starting point for assessing flood risks assuming that it is compounded by three aspects: hazard assessment, exposure of vulnerable elements (people and assets, for example), and DM's value judgements. Next, this paper introduced how to mathematically evaluate the risk magnitude of floods in terms of financial, social and environmental criteria.

2.1.1 *Hazard assessment*

This risk component is obtained by hydrological modelling with views to estimate the flood frequency of precipitation indexes in the site study. This way, it is important to integrate historical series of pluviometry stations usually managed by local control and monitoring agencies in order to estimate from traditional techniques how intense and frequent the precipitation affect the urban functioning. Assuming then a strong correlation between rainfall and flood depths, which is aggravated with urban infrastructure problems (poor drainage system, for instance), extreme events caused by heavy precipitation can be modelled in terms of Probability Density Function (PDF); Esteves (2013) pointed out that extreme events such as floods are usually modelled (with statistical rigor) with the Generalized Extreme Value distribution (GEV).

Technically, da Silva, Alencar, and de Almeida (2022) uses GEV to sess probabilities of occurrence under three different hazard situations ($\boldsymbol{\theta} = \{\theta_1$ = *vigilance stage – low precipitation intensity,* θ_2 = *warning stage – medium precipitation indexes,* θ_3 = *crisis stage – high precipitation volumes*$\}$). Consequently, this risk component obtained π_θ, which represents the probability of occurrence for each θ.

2.1.2 Exposure of vulnerable people and assets

Urbanization growth and climate change turn it difficult to reduce the vulnerability of urban spaces so the exposure of people and assets in the urban area must be estimated with PDFs $P_j(x_i|\theta)$. This risk component aims to cover different criteria (j=1..m) of flood consequences (x_i), assuming that the velocity and depth of floodwaters can be the starting point to harm the urban functioning. In this stage, we purpose, four (m = 4) main criteria, as described briefly above:

- Financial (fin): monetary losses in public and private spheres (includes Industry, commerce and services, for example) – with a Lognormal distribution;
- Healthcare assistance (hca): number of people that got sick or injured by flood events – with a Poisson distribution;
- Human: amount of fatalities estimated in a flood severity level – with a Poisson distribution;
- Social: number of individuals who suffer displacements and then need social assistance from the public administration – with a Poisson distribution.

Specialists aid the decision-making process building $P_j(x_i|\theta)$ reasonably according to past experiences or historical data.

2.1.3 Eliciting Risk Attitudes with the Utility Theory and the ALARP principle

The subjective preferences over risky circumstances are extracted from the DM with the Utility Theory. This way, the strong protocol of Keeney and Raiffa (Keeney and Raiffa 1976) is implemented to elicit the utility function $u_j(x_i)$. In summary, it results from questions regarding hypothetical prospects, and represents the risk behavior under each criterion of evaluation.

Consequently Eq. 1 schemed the risk assessment formulation of and alternative i on considering the criterion j (da Silva et al. 2020):

$$r_j(a_i) = -\sum_{\theta} \pi_\theta \left[\int_{x_{min}}^{x_{max}} P_j(x_i|\theta) u_j(x_i) dx \right] \quad (1)$$

Afterward, the risk categorization can be properly obtained by using the ALARP concept, a classical principle used in many risk problems in Industrial management (Jones-Lee and Aven 2011; French, Bedford, and Atherton 2005).

This categorization is made as illustrated in Fig. 2. There, the main ALARP categories are standardized in risk problems.

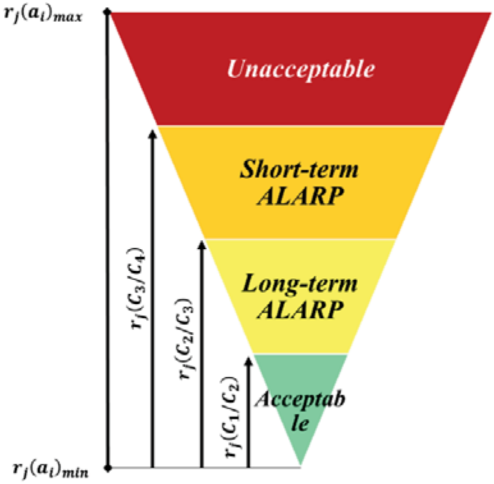


Fig. 2. ALARP principle applied to sorting flood risks of a criterion j into a pre-defined category. Source: The Authors.

Thus, the DM is able to define under the consequences establishes previously, the boundaries between the ALARP classes: C_1(low risk: broadly acceptable), C_2(medium risk: tolerable), C_3(high risk: manageable), and C_4(very high risk: intolerable). The definition of the boundaries C_1/C_2, C_2/C_3, C_3/C_4 is vital to check for each alternative i, with the aid of Eq. 1, which is the more appropriate category for it.

Consequently, we have a risk-consequence matrix for starting the final stage, as described next.

2.2 *Inter-criterion evaluation*

This model used the ALARP principle to simplify the risk categorization, so that FITradeoff for sorting problem is suitable, not only because it keeps the compensatory rationality from the DM in typical risk-based problems, but also facilitates the cognitive understanding of the inter-criterion evaluation. This way, FITradeoff is a flexible and interactive protocol that aims to evaluate, under the criteria involved, which is the best risk class to describe the set of alternatives, in a multicriteria perspective. (Kang, Frej, and de Almeida 2020).

In fact, this method established great advances for eliciting the scaling constants in order to aggregate the multiple risk perspectives (da Silva et al. 2022).

Each $C_j(a_i)$ represents the risk magnitude of a_i for the criterion j. It will be modelled in terms of linear value functions $v_j\left(C_j(a_i)\right)$ so, the inter-criterion evaluation aims to allocate a_i into a $C_{global}(a_i)$ on considering partial information concerning the scaling constants. That is why FITradeoff established a space of weights (φ) to model the overall performance , as observed in Eq. 2:

$$V(a_i) = \sum_{n} k_j\, v_j\left(C_j(a_i)\right)$$
$$s.t \qquad k_1 + k_2 + \cdots + k_j = 1; \qquad (2)$$
$$\varphi = \begin{cases} k_{1_{min}} < k_1 < k_{1_{max}}; \\ k_{2_{min}} < k_2 < k_{2_{max}}; \\ \cdots \\ k_{j_{min}} < k_j < k_{j_{max}}. \end{cases}$$

The space of weights (φ) is adjusted interactively after the DM answer some questions regarding the risk compensation between the criteria involved. Formally, a set of inequalities to be inserted into Linear Problem Programmings (LPPs) tries to allocate an alternative i to a proper global risk class.

To do so, C_1/C_2, C_2/C_3, and C_3/C_4 are fixed (25%, 50% and 75% of the 0-1 range, respectively). For more detail, see Kang, Frej, and de Almeida (2020).

3. Numerical application: results and discussion

For didactical purposes, the numerical application was performed with realistic data from public reports and open-access data of Recife, a Brazilian city consideres by the IPCC as the 16th city in the emergency climatic ranking and sea-level rise in catastrophic rates, so it must be strategic for different actors of the Society to enhance resource allocation, design and implementation of Nature-Based Solutions (NBS) and other decisions that might adapt this city for a changing climate.

This case study is composed by a pilot area, namely RPA-4, with 12 neighborhoods modelled as alternatives in the sorting model (da Silva, Alencar, and de Almeida 2022).

This way, the risk categorization of RPA-4 is the main objective to be addressed by the model. Apart from public and open-access data to support the modelling of consequence functions and hazard assessment, the database from APAC – Pernambuco Water and Climate Agency allows specialists in modelling the flood-frequency under the GEV distribution (APAC 2021).

On considering the preference elicitation from the DM, in terms of the utility functions for all criteria, the DM is encouraged to choose one of two hypothetical a lotteries, as mentioned Keeney and Raiffa (1976).

After that, from analyzing $u_j(x_i)$, the DM is prone-to-risk only in the financial criterion, while the others led them to be risk averse. After the DM defines the risk boundaries for each criterion, Eq. 1 implies the risk allocation into a risk category $C_j(a_i)$. Table 1 summarizes the intra-criterion evaluation, with Utility Theory and ALARP principle, which represents the risk consequence matrix for the inter-criterion evaluation with FITradeoff sorting.

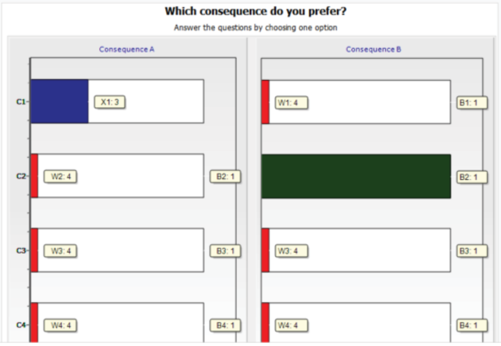
The inter-criterion phase was performed with a Decision Support System (DSS) (see www.fitradeoff.org.br). With this in mind, the DSS asks the Dm to order the scaling constants, as observed in Eq. 3.

$$k_{soc} > k_{hum} > k_{fin} > k_{hca} \qquad (3)$$

Apart from that, the FITradeoff for sorting problem introduced a heuristic that guides a series of questions regarding the choice of hypothetical risk levels, as outlined in Fig. 3.

Table 1. Summary of the ALARP-based intra-criterion evaluation. Source: The Authors.

Alternative/ Criterion	*fin*	*hca*	*hum*	*soc*
a_1	C_2	C_2	C_4	C_4
a_2	C_4	C_1	C_3	C_3
a_3	C_3	C_1	C_4	C_4
a_4	C_4	C_1	C_4	C_4
a_5	C_3	C_1	C_4	C_4
a_6	C_4	C_1	C_3	C_4
a_7	C_3	C_1	C_4	C_3
a_8	C_3	C_1	C_4	C_3
a_9	C_2	C_2	C_4	C_3
a_{10}	C_2	C_1	C_4	C_3
a_{11}	C_3	C_1	C_1	C_3
a_{12}	C_2	C_1	C_4	C_4



Which consequence do you prefer?

Answer the questions by choosing one option

Fig. 3. FITradeoff sorting DSS screen in the case study. Source: The Authors.

As seen in Fig. 3, FITradeoff introduces a more comfortable way to express preferences once it is based on partial information between the questions involved. Each answer by the DM reshapes the space of weights φ (see Eq. 2) and tries to assign all alternatives into a single risk class. For this numerical application, the DM need to answer 4 questions to obtain the final sorting, schemed in Table 2.

It must be remarked that, once FITradeoff is guided by partial information regarding the scaling constants, some alternatives can be allocated into more than one category if the space of weights does not guarantee only one risk class to be assumed by the DM. Consequently, it might support DM in understanding, for example, that a_1 is near to the boundary between C_3/C_4, paying attention to implement adaptation measures to reduce its global risk.

Table 2. Results of the risk sorting model for RPA-4. Source: The Authors.

Alternative	Risk Category
a_1	C_3/C_4
a_2	C_3
a_3	C_3/C_4
a_4	C_4
a_5	C_3/C_4
a_6	C_3
a_7	C_3
a_8	C_3
a_9	C_3
a_{10}	C_3
a_{11}	C_2
a_{12}	C_3

In practical terms, the method provides the DM with a broad range of information regarding the mapping of multidimensional risks in urban areas, thereby assigning priorities to urban areas according to their criticalities, which implies that urban adaptation policies enhanced with this information combat climate change and urbanization growth, exerting a great influence on saving lives, reducing economic damaged from Industry and Commerce, preventing illnesses and injuries on the people affected, and other public policies on a long-term horizon.

4. Conclusions

The need to investigate the interaction between climatic and socioeconomic issues with frequency/intensity of hydrological events and their harmful impacts means an opportunity for introducing the novel multicriteria decision model with the Utility Theory, ALARP principle and FITradeoff for sorting risks in urban areas. A broad range of information gathered by the model aid the DM in taking hard decisions with the methodological advances discussed in this paper. So, it aims to effectively impact the reduction of climate change impacts, such as fatalities, injuries, illnesses, economic losses, and so on. This way, control and monitoring agencies, local administrations, Civil Defense Institutions, and others can benefit from the information provided by the model, thereby supporting urban policies against floods in a long-term perspective.

Future research includes the extension of this model to the group decision context, as well as other criteria can be inserted to investigate and characterize flood risks hugely affected by climate change and urbanization growth.

Acknowledgement

This paper is part of a research study supported by the National Council for Scientific and Technological Development – CNPq, the Brazilian Council for Improving Higher Education (CAPES), the Fundação de Amparo a Ciência e Tecnologia do Estado de Pernambuco (grant number APQ-0952-3.08/22), the Municipal Secretariar of Civil Defense and Protection of Recife (SEDEC) and the Pernambuco Water and Climate Agency (APAC) for which the authors are grateful.

References

APAC - Agência Pernambucana de Águas e Climas. 2021. “Monitoramento Pluviométrico Do Estado de Pernambuco, Brasil.” 2021. http://old.apac.pe.gov.br/meteorologia/monitoramento-pluvio.php#.

Brito, Mariana Madruga de, and Mariele Evers. 2016. “Multi-Criteria Decision-Making for Flood Risk Management: A Survey of the Current State of the Art.” *Natural Hazards and Earth System Sciences* 16 (4): 1019–33. https://doi.org/10.5194/nhess-16-1019-2016.

Da Silva, L. B. L., Marcelo Hazin Alencar, and Adiel Teixeira de Almeida. 2020. “Multidimensional Flood Risk Management under Climate Changes: Bibliometric Analysis, Trends and Strategic Guidelines for Decision-Making in Urban Dynamics.” *International Journal of Disaster Risk Reduction* 50: 101865. https://doi.org/https://doi.org/10.1016/j.ijdrr.2020.101865.

Da Silva, L.B.L., J.S. Humberto, M.H. Alencar, R.J.P. Ferreira, and A.T. de Almeida. 2020. “GIS-Based Multidimensional Decision Model for Enhancing Flood Risk Prioritization in Urban Areas.” *International Journal of Disaster Risk Reduction* 48. https://doi.org/10.1016/j.ijdrr.2020.101582.

Da Silva, Lucas Borges Leal, Marcelo Hazin Alencar, and Adiel Teixeira de Almeida. 2021. “Exploring the Impact of Climate Change and Urbanization on Flood Risks with the NSMAUT Method.” In *Proceedings of the SRA 2021 Annual Meeting*. Washington, D.C.

———. 2022. “Exploring Global Sensitivity Analysis on a Risk-Based MCDM/A Model to Support Urban Adaptation Policies against Floods.” *International Journal of Disaster Risk Reduction*.

Da Silva, Lucas Borges Leal, Eduarda Asfora Frej, Adiel Teixeira De Almeida, Rodrigo José Pires Ferreira, and Danielle Costa Morais. 2022. “A Review of Partial Information in Additive Multicriteria Methods.” *IMA Journal of Management Mathematics*, February, 1–37. https://doi.org/10.1093/imaman/dpab046.

Daksiya, Velautham, Pradeep V. Mandapaka, and Edmond Y. M. Lo. 2021. “Effect of Climate Change and Urbanisation on Flood Protection Decision-making.” *Journal of Flood Risk Management* 14 (1). https://doi.org/10.1111/jfr3.12681.

De Almeida, Adiel T. de, Cristiano A. V. Cavalcante, Marcelo H. Alencar, Rodrigo J. P. Ferreira, Adiel T. De Almeida-Filho, and Thalles V. Garcez. 2015. *Multicriteria and Multiobjective Models for Risk , Reliability and Maintenance Decision Analysis*. New York: Springer. https://doi.org/10.1007/978-3-319-17969-8.

Emmerich, Michael T. M., and André H. Deutz. 2018. “A Tutorial on Multiobjective Optimization: Fundamentals and Evolutionary Methods.” *Natural Computing* 17 (3): 585–609. https://doi.org/10.1007/s11047-018-9685-y.

Esteves, Luciana S. 2013. “Consequences to Flood Management of Using Different Probability Distributions to Estimate Extreme Rainfall.” *Journal of Environmental Management* 115: 98–105. https://doi.org/10.1016/j.jenvman.2012.11.013.

French, Simon, Tim Bedford, and Elizabeth Atherton. 2005. “Supporting ALARP Decision Making by Cost Benefit Analysis and Multiattribute Utility Theory.” *Journal of Risk Research* 8 (3): 207–23. https://doi.org/10.1080/1366987042000192408.

Idowu, Dorcas, and Wendy Zhou. 2023. “Global Megacities and Frequent Floods: Correlation between Urban Expansion Patterns and Urban Flood Hazards.” *Sustainability* 15 (3): 2514. https://doi.org/10.3390/su15032514.

IPCC. 2018. “Summary for Policymakers.” In *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response* *to the Threat of Climate Change,* edited by V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, et al., 32. Geneva, Switzerland: World Meteorological Organization.

Jones-Lee, M, and T Aven. 2011. "ALARP—What Does It Really Mean?" *Reliability Engineering & System Safety* 96 (8): 877–82. https://doi.org/https://doi.org/10.1016/j.ress.2011.02.006.

Kang, Takanni Hannaka Abreu, Eduarda Asfora Frej, and Adiel Teixeira de Almeida. 2020. "Flexible and Interactive Tradeoff Elicitation for Multicriteria Sorting Problems." *Asia-Pacific Journal of Operational Research* 37 (5): 1–22. https://doi.org/10.1142/S0217595920500207.

Keeney, Ralph L, and Howard Raiffa. 1976. *Decisions with Multiple Objectives: Preferences and Value Trade-Offs*. New York: JohnWiley and Sons.

Polasky, Stephen, Stephen R. Carpenter, Carl Folke, and Bonnie Keeler. 2011. "Decision-Making under Great Uncertainty: Environmental Management in an Era of Global Change." *Trends in Ecology & Evolution* 26 (8): 398–404. https://doi.org/10.1016/j.tree.2011.04.007.

Sanches, Danilo Sipoli, Marcelo Favoretto Castoldi, João Bosco Augusto London, and Alexandre Cláudio Botazzo Delbem. 2017. "Analysis of Solution Quality of Multiobjective Evolutionary Algorithms for Service Restoration in Distribution Systems." *Journal of Control, Automation and Electrical Systems* 28 (6): 796–805. https://doi.org/10.1007/s40313-017-0344-9.