UCL RISKMASTERS

Team members:

Djanga Gildas
El Hadi Oussama
Majdoubi Hiba
Yousra Rwawi

Advisor :

Mr. Karim Barigou

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Executive Summary

In the report , we propose a national insurance program for earthen dams in Tarrodan , an imaginary country that addresses the risks of dam failure and promotes preventative maintenance. And we will develop an equitable pricing structure and test different reinsurance strategies to ensure the program's financial sustainability. Our approach involves constructing models to compute the pure premium price using predictions of the probability of dam failure and severity models to estimate potential losses. Premiums are calculated respecting the reinsurance risk mitigations for extreme losses. The report details the methodology and presents recommendations for an efficient , preventative national dam insurance program, along with a progressive timeline for its implementation.

1 Objectives

A national insurance program is essential for safeguarding Tarrodan's economic stability and public safety. The urgency of such a program is underscored by historical data, revealing significant risks that could result in severe economic, environmental, and societal consequences.

Currently, 34% of Tarrodan's dams are classified as High or Significant hazard levels, posing threats to downstream communities and critical infrastructure. Additionally, 88% of the country's dams were built in the previous century, and 91% have never been renovated, making them highly susceptible to structural failure. With 818 dams rated as being in Poor or Unsatisfactory condition, the need for intervention is urgent.

Beyond the immediate safety concerns, dams play a crucial role in flood mitigation, water supply, irrigation, and recreation, particularly in regions like Flumevale. In Flumevale alone, agriculture accounts for 5.9% of the local economy, making a reliable irrigation infrastructure critical to sustained growth and resilience.

Given these risks and the critical role dams play in Tarrodan's economy and public safety, a national insurance program would provide a structured mechanism to manage financial risks associated with dam failures, ensuring both long-term sustainability and disaster resilience.

The proposed national insurance program is designed to address the specific risks associated with **earthen dams**, which make up **93.1%** of Tarrodan's total dams. Its primary objectives are threefold:

1. **Compensate affected communities** in the event of a dam failure, ensuring swift financial relief for victims.
2. **Reconstruct failed dams**, restoring critical infrastructure to maintain water supply, flood control, and agricultural sustainability.
3. **Enhance dam resilience** through structural improvements, increased inspections, and reinforced safety measures, reducing the likelihood of future failures.

To monitor the program's success, we will track key performance metrics, including:

- **Risk Reduction**: Decrease in the probability of failure among insured earthen dams.
- **Reconstruction Impact**: Number of earthen dams rebuilt or reinforced under the program.
- **Inspection Efficiency**: Reduction in inspection frequency from the current **2.1 years** to **1 year**, ensuring more frequent monitoring and early detection of structural weaknesses.
- **Financial Stability**: Reduction in uninsured losses and claims processing time.

2 Program Design

2.1 Insurance and Non-Insurance Features

2.1.1 Insurance Features:

- **Risk Transfer Mechanism:** The present insurance feature is to transfer the financial risk of dam failure from individual dam owners to a national risk pool. This pool will be managed and financially backed by the national insurance program. In return, dam owners must pay a premium to mitigate the risk.
- **Premium-Based Funding:**Premiums are collected from dam owners to fund the insurance program and will be based on risk, reflecting the probability of failure and the potential severity of loss, as determined by models such as *proba_model*, *sev_prop*, *sev_liab*, *sev_bi*. Dam owners will pay higher premiums depending on the frequency and severity of potential losses.
- **Claims Payouts:** In the event of a dam failure covered under the policy (defined by specific criteria and exclusions), the program will provide financial compensation to cover the defined losses (property damage, liability, business interruption). Payout amounts will be determined based on pre-agreed policy terms and loss assessment processes.
- **Mandatory Participation (Requirement):** To ensure a broad and diverse risk pool and mitigate adverse selection (see third point), participation in the insurance program should be a necessary for all earthen dams meeting certain size or hazard classification criteria (especially areas that are exposed to high risk).It is a requirement for the insurance features to function effectively at a national level.

2.1.2 Non-Insurance Features (Risk Management & Prevention Focus):

- Implementation of safety standards and structural improvements.
- Periodic inspections and condition assessments.
- Incentives for infrastructure enhancements and risk mitigation efforts.

2.2 Timeline for Implementing the Program

- **Year 0-1: Program Design and Regulatory Approval**
  - Finalize program structure and legal framework.
  - Engage stakeholders and secure capital from state and private partners.
  - Develop actuarial models for pricing and risk assessment.
- **Year 1-2: Pilot Implementation**
  - Launch pilot in high-risk region(s) (e.g., Flumevale).
  - Conduct inspections and test operational processes.
- **Year 3-5: National Rollout**
  - Expand to all regions (Lyndrassia, Navaldia).
  - Implement risk-based premiums and finalize reinsurance agreements.
- **Year 5+: Continuous Evaluation and Optimization**
  - Adjust premiums, inspection schedules, and incentives based on performance.

2.3 How to Prevent Adverse Selection

- **Mandatory Participation** for all high or significant hazard dams.
- **Risk-Based Premiums** aligned with model outputs (proba_model, sev_prop, sev_liab, sev_bi).
- **Subsidies** for low-risk dam owners to encourage full participation.
- **Standardized Inspections** to validate risk classification and premium levels.

2.4 The Potential for the Program to Drive Improvements in the Infrastructure

- **Premium Incentives** for structural upgrades and mitigation measures.
- **Shortened Inspection Cycles** to identify and address deficiencies earlier.
- **Direct Co-Financing** for critical rehabilitation projects on aging or high-risk dams.
- **Public-Private Partnerships** for modernization and resilience projects.
- **Compliance Audits** linked to premium discounts and safety outcomes.

2.5 Any Other Key Program Features or Requirements

- **Reinsurance Framework** to manage catastrophic risks.
- **Climate Resilience Measures** incorporated into mitigation strategies.
- **Emergency Response Fund** to address immediate post-failure needs.
- **Centralized Digital Platform** for inspection records and risk profiles.
- **Stakeholder Forums** for continuous feedback and program refinement.

2.6 Quantitative and Qualitative Justification for the Features or Requirements of Your Proposed Program

- **Quantitative Justification:**
  - Risk-Based Premiums (using models): Our proba_model and severity models (e.g., sev_prop, sev_liab, sev_bi) provide the quantitative foundation for risk-based premiums. The models allow for objective and data-driven differentiation of premiums based on dam characteristics and predicted risk, as demonstrated by the code.
  - Cost-Benefit Analysis (of infrastructure improvements): By linking premiums to risk and providing incentives for risk reduction, the program implicitly conducts a cost-benefit analysis. Dam owners are incentivized to invest in upgrades where the cost of the upgrade is less than the long-term reduction in premiums and risk exposure.
  - Potential Reduction in Losses: While difficult to quantify precisely ex ante, the program aims to reduce overall economic and social losses from dam failures by:
    * Driving infrastructure improvements that reduce failure probabilities.
    * Providing financial compensation to mitigate the impact of failures when they do occur.
    * Creating a more resilient dam infrastructure system over time.
  - Financial Sustainability Modeling: Actuarial modeling and financial projections can be used to quantitatively assess the financial sustainability of the program, considering premium income, expected claims payouts, reserve fund requirements, and reinsurance costs.
- **Qualitative Justification:**

2.7 Short and Long-Term Time Periods Over Which the Program Will Be Evaluated

- **Short-Term Evaluation (Years 1-5):**
- **Long-Term Evaluation (Years 5-10):**

3 Financial Results

3.1 Inflows and Outflows and Their Description

The main inflows of our program consist of premiums intended to cover losses related to earthen dams, the portion of claims paid by the reinsurer, and an initial capital to ensure the viability of the insurance program and guarantee its solvency at its launch. This capital will be funded 50% by the State and 50% by dam-operating companies (see appendix for more details).

On the other hand, the outflows include compensation for claims (property, liability, and infrastructure damages), premiums paid to the reinsurer, and the costs of maintaining and improving the dams to keep them in good condition.

In the following sections, we provide a quantification of these cash flows in their present values.

3.2 Assessment of Short and Long-Term Fiscal Sustainability

The annual pure premiums in the three regions of Tarrondan are summarized in the table below. It is important to note that these premiums do not account for the uncertainties of claims (which will be covered by the capital) in order to keep the premiums as affordable as possible for the citizens of Tarrondan, ensuring that everyone can purchase coverage.

Type	**Flumevale (Qm)**	**Lyndrassia (Qm)**	**Navaldia (Qm)**
Prop	5409.76	4111.72	8618.90
Liab	10241.33	20866.81	15303.26
BI	690.13	994.28	1316.32
Total	**16341.22**	**25972.81**	**25238.48**

Table 1: Pure premium by Region and Type of Loss (Measured in millions of Qalkoons)

This capital is calculated as the sum of the differences between the estimated losses in the worst-case scenario and the collected premiums.

Using a Monte Carlo simulation, we calculate the worst-case scenario as the Value at Risk (VaR) at the 99% confidence level for the simulated total losses. For 10,000 simulations, this results in the values 39,384.46 (QM), 39,820.18 (QM), and 29,654.51 (QM), respectively, for Navaldia, Lyndrassia, and Flumevale.

Thus, the capital ensures the solvency of the program with a 99% probability (which corresponds, on average, to one failure every 100 years).

The net present values (in Qm) for each region, using a 10% Quota-share reinsurance and considering renovation costs of 10% in addition to the capital, are given over the short- and long-term periods as follows:

- **Long-term:** Navaldia: 136,588.6, Lyndrassia: 125,208.4 , Flumevale: 123,307.5
- **Short-term:** Navaldia: 59,876.94, Lyndrassia: 62,473.74, Flumevale: 59,408.13

4 Assumptions

To perform the calculations and project the cash flows related to our program, we have made the following assumptions:

- **Deriving Annual Failure Probabilities:** To estimate the annual failure probabilities of the dams from the 10-year failure probability, we assume **independence of failures across years** and a **constant annual failure probability**.
- **Tax Treatment of Program Funds:** We assume that the funds of the national insurance program are exempt from taxation, as it is a non-commercial initiative established for the common good of Tarrodan.

5 Risk and Risk Mitigation Considerations

5.1 Risk Analysis

Our proposed national insurance program for Tarrodan's earthen dams is exposed to several key risks, both quantitative and qualitative, which could materially impact its performance (Dickson, Hardy, & Waters, 2019) .

5.1.1 Quantifiable Key Risks

- **Dam Failure Risk:** Based on the dam dataset, each dam has an independent probability of failure within a 10-year period (mean probability = 0.47). The risk of failure varies significantly across dams, influenced by factors such as dam age, condition, inspection frequency, and hazard potential.
- **Financial Loss Risk:** The expected losses associated with dam failures are substantial, including:
  - Average repair costs of **Q132 million** per dam.
  - Average third-party and environmental liability of **Q185 million** per dam.
  - Business interruption losses averaging **Q4.5 million** annually per affected dam.
- **Macroeconomic Risk:** Changes in Tarrodan's macroeconomic environment, such as inflation or GDP fluctuations, may affect premium adequacy, reserve sufficiency, and government funding requirements.

5.1.2 Qualitative Key Risks

- **Regulatory Risk:** New policies or changes to existing dam safety regulations and environmental requirements could increase program costs.
- **Stakeholder Risk:** Misalignment of interests between regions (Flumevale, Lyndrassia, Navaldia), insurance contributors, and the federal government could challenge program implementation.
- **Public Perception Risk:** Negative media coverage following dam failures or disputes over equitable pricing could erode public trust and participation.

5.1.3 Ranking of Key Risks

Risk	Likelihood	Severity
Dam Failure	High	Very High
Financial Loss	High	High
Macroeconomic Instability	Medium	Medium
Regulatory Changes	Medium	Medium
Stakeholder Misalignment	Medium	High
Public Perception Issues	Medium	Medium

Table 2: Key Risks Ranked by Likelihood and Severity

5.2 Risk Mitigation Techniques

(Sweeting, 2017)

- **Preventative Maintenance Incentives:** Implement funding subsidies for regions to improve inspection frequencies (currently averaging 2.1 years) and address poor assessments proactively.
- **Reinsurance Agreements:** Engage global reinsurers to provide financial support in catastrophic scenarios, reducing solvency pressure on the national pool.
- **Reserve Buffer:** Establish conservative reserves accounting for higher-than-expected failure probabilities or repair costs.
- **Dynamic Pricing Model:** Introduce region-specific premium adjustments based on updated dam condition assessments and macroeconomic indicators.
- **Public Awareness Campaigns:** Enhance communication strategies to build trust and understanding among stakeholders and citizens.

5.3 Sensitivity Analysis

We performed sensitivity analyses to understand how deviations from key assumptions would affect the program (*Quantitative Risk Management | Princeton University Press*, 2015):

- A **10% increase** in dam failure probabilities would result in approximately **Q4 billion** additional liability over a 10-year horizon.
- A **15% escalation** in repair costs (e.g., from inflation or supply chain disruptions) would reduce solvency margins by **8%**.
- A **5% GDP contraction** in Flumevale (Tarrodan's largest region) could reduce premium contributions by **Q210 million** per annum, pressuring overall funding adequacy.

5.4 Climate Change Considerations

Climate change introduces systemic risk factors (Gurenko, 2015), such as:

- **Increased Flooding in Flumevale:** Heavier precipitation and river flooding may elevate dam stress and failure rates.
- **Tropical Storms in Navaldia:** Rising sea temperatures may intensify storms, exacerbating coastal dam vulnerabilities.
- **Avalanches and Seismic Activity in Lyndrassia:** Thawing patterns and tectonic shifts may increase structural risks to dams in mountainous regions.

To address these risks, we recommend incorporating climate scenario modeling into risk assessments and introducing green infrastructure incentives (e.g., afforestation in Flumevale and coastal buffer zones in Navaldia) as part of long-term mitigation strategies.

6 Data and Data Limitations

The dataset includes numerical and categorical variables describing the structural, geographical, and risk-related characteristics of dams in Tarrodan. However, high proportions of missing values in "Years Modified" (91.3%), "Spillway Type" (61.5%), and "Loss given failure – BI" (51.6%) affect risk assessments and financial modeling. k-Nearest Neighbors (kNN) imputation was used for categorical variables, ensuring logical consistency by replacing missing values with the most frequent category among similar observations. Date fields like "Assessment Date" and "Last Inspection Date" were numerically processed before restoration.

Despite these refinements, some limitations persist. The lack of historical modification records makes it difficult to assess structural upgrades, while incomplete inspection data (e.g., 47% missing in "Assessment Date") forces reliance on outdated evaluations. Additionally, missing geographical information (e.g., 49.2% missing in "Distance to Nearest City") may introduce biases in location-based risk modeling. Regular updates and real-time hazard assessments are essential to improve accuracy.

* A detailed visualization of missing data distribution is provided in Appendix .

A Appendix

A.1 Funding of initial capital

- **50% covered by the State**, which has a vested interest in supporting this program to **protect critical infrastructure**, reduce the financial burden of disasters on public finances, and reassure investors. These funds can be raised through **subsidies** or the issuance of **sovereign bonds**.
- **50% financed by dam-operating companies** (hydroelectric companies, agri-food corporations...), which have a direct interest in securing their operations against major losses and avoiding higher financial requirements in case of a disaster.

A.2 The probability of dam failure and severity modeling

Probability model

The following relationship allows us to derive the annual probability P_i from the 10-year failure probability P^{failure}:

$$P^{\text{failure}} = 1 - (1 - P_i)^{10}$$

which gives:

$$P_i = 1 - (1 - P^{\text{failure}})^{1/10}$$

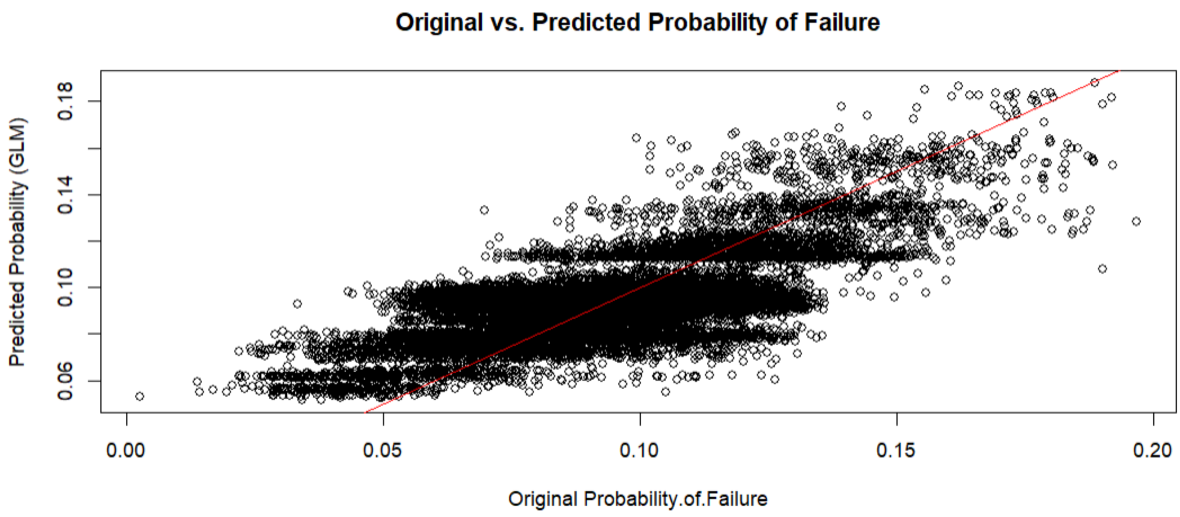
Logistic regression is useful when the dependent variable is categorical (e.g., presence or absence) and the explanatory (independent) variables are categorical, numerical, or both (Menard, 2002). An odds ratio Prob_fail, representing the probability of a dam failure over 10 years, is defined as :

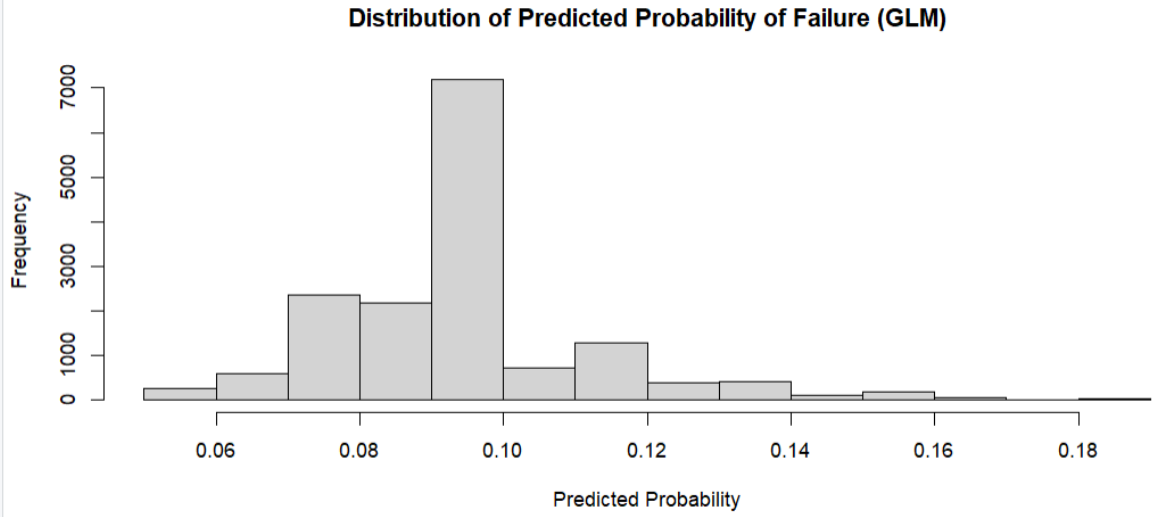
$$logit(Prob\_fail) = \beta_0 + \sum_{j=1}^{p} \beta_j \cdot x_{i,j}$$

with :

$$Logit(P) = \ln \frac{P}{1 - P}$$

(Dong, Tung, Chen, Liao, & Pan, 2011)





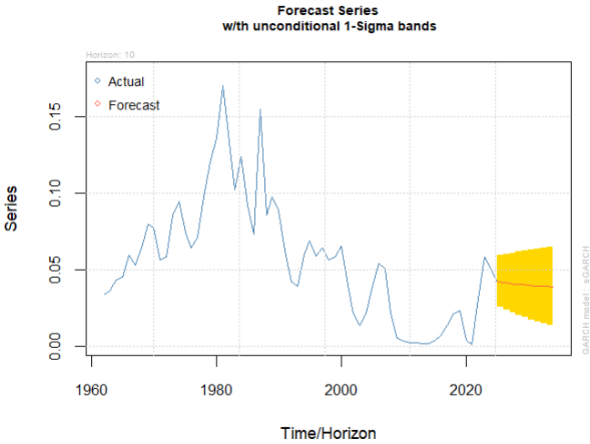
Severity:

The three GLM models used for severity (Denuit, Hainaut, & Trufin, 2019) modeling are written as follows:

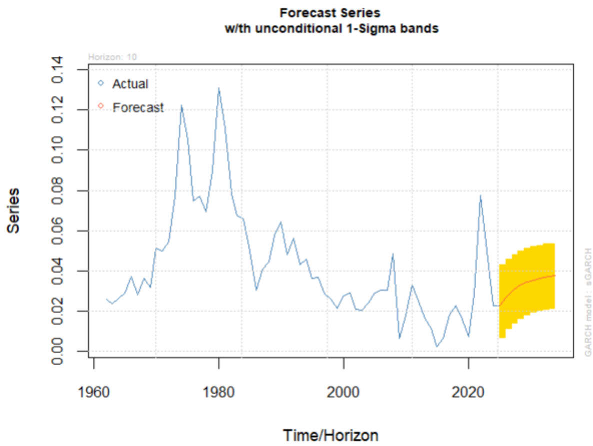
$$\ln(\mathbb{E}(X_i^{\text{prop}} \mid \mathbf{X} = x_i)) = \beta_0^{\text{prop}} + \sum_{j=1}^{p} \beta_j^{\text{prop}} \cdot x_{i,j}$$

$$\ln(\mathbb{E}(X_i^{\text{liab}} \mid \mathbf{X} = x_i)) = \beta_0^{\text{liab}} + \sum_{j=1}^{p} \beta_j^{\text{liab}} \cdot x_{i,j}$$

$$\ln(\mathbb{E}(X_i^{\text{bi}} \mid \mathbf{X} = x_i)) = \beta_0^{\text{bi}} + \sum_{j=1}^{p} \beta_j^{\text{bi}} \cdot x_{i,j}$$



(a) GARCH model for risk-free spot rate



(b) GARCH model for inflation

Figure 1: GARCH models for risk-free spot rate and inflation

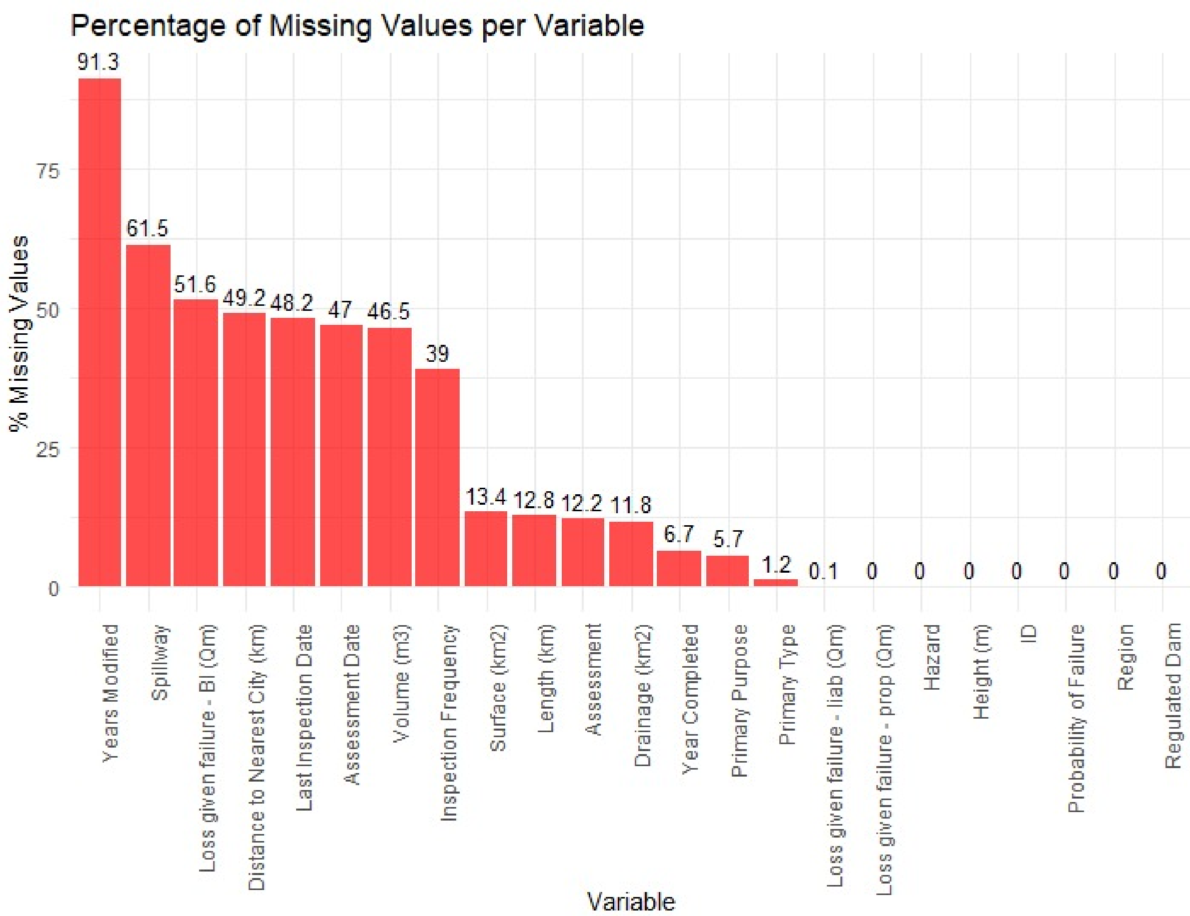
With X_i representing the loss of the i-th dam, and $x_{i,j}$ the value of the characteristic of this dam for the j-th explanatory variable.

The present value of future cash flows is calculated using the following formula:

$$PV = \sum_{n=1}^{10} CF_n \cdot \left(\frac{1+i}{1+r}\right)^n$$

where i and r are, respectively, the forecasted inflation rate and the risk-free rate.

A.3 Representation of th frequencies of missing values



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