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Recommendations for the process of classification of dams in Brazil

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Abstract
The Brazilian National Policy on Dam Safety (PNSB) was enacted in 2010 and there are still many actions to be carried out, especially the classification of dams as to associated hazard potential (PHA) and risk category (RC). The analysis conducted based on the Dam Safety Report 2020 informs that there are 21953 dams distributed throughout the Brazilian territory registered in National Dam Information System (SNISB). However, 14849 (67.64%) of the dams were not classified as RC and 13475 (61.38%) of the dams were not classified as PHA. There are 3724 dams classified as high PHA, 2407 (64.64%) of which are considered small in terms of reservoir capacity. Considering this scenario, bibliographic research was conducted on dam classification criteria used in Brazil, Portugal, International Commission on Large (ICOLD) and United States. In addition, bibliographic research was conducted on two studies that used artificial intelligence-based tools to forecast PHA classification. As a result, this study recommends future research with indicated classification criteria and with applications based on artificial intelligence to forecast PHA classification in Brazil.

Author Keywords. Dam Safety, Classification Criteria, Hazard Potential.

Type: Research Article

1. Introduction

The construction of dams provides countless benefits to society, since the reservoirs created may have several purposes such as providing water for human consumption, water supply for industry, irrigation, regularization and flood control, hydroelectric production, navigation, and recreational activities.

However, the existence of dams located near inhabited areas constitutes a potential risk for the populations, infrastructure and properties located in the downstream valley. Therefore, the dam safety subject possesses great relevance and should demand attention from dam owners, public authorities, and civil society.

The Brazilian National Policy on Dam Safety (PNSB)was enacted in 2010, this law brings the guidelines and obligations on dam safety in the Brazilian territory and brought enormous challenges for those involved in the area.

The Brazilian legislation established that dams must be classified in terms of risk category (RC), potential hazard associated (PHA) and reservoir capacity, based on general criteria established by the Brazilian National Water Resources Council of Brazil (CNRH). The classification is one of the criteria for framing the dam and defining the dam owner's obligations in the context of dam safety.

The criteria were defined in 2012 by CNRH resolution Nº143, July 2012(CNRH 2012). However, there are many actions to be carried out, such as the classification of dams. There are 21953 dams in Brazil registered in the National Dam Information System (SNISB) in the year 2020 and most of the dams are unclassified about RC and PHA (ANA 2021).Regarding PHA classification, most of the dams are classified with high PHA are small dams.

Considering this context, bibliographic research was conducted on dam classification PHA criteria used in International Commission on Large (ICOLD), Portugal and USA. These criteria were compared with the criteria used in Brazil, and from this comparison proposals emerged to improve the criteria used for the classification of PHA in Brazil.

Also, bibliographic research was carried out on tools based on artificial intelligence that facilitate PHA classification process. The objective is to propose future studies to evaluate new classification criteria, especially for PHA, and future studies to evaluate the applicability of machine learning based tools for the Brazilian reality

2. National Policy on Dam Safety - Brazil

PNSB aims to ensure compliance with dam safety standards in order to reduce the possibility of accidents and their consequences, and to foment the culture of dam safety and risk management (BRASIL 2010). This legislation is applied to dams that have at least one of the following characteristics:

- Dam height greater than or equal to 15 m (fifteen meters),
- Total capacity of the reservoirs greater than or equal to 3,000,000 m³ (three million cubic meters),
- Reservoirs containing hazardous waste, according to applicable technical standards,
- Potential hazard associated (PHA) category, medium or high, in economic, social, environmental terms or loss of human life,
- High risk category (RC), at supervising agency's discretion.

The supervision agencies are responsible for ensuring compliance with the dam safety legislation, for keeping a register of the dams under their supervision and for incorporating this information in the National System of Information on Dam Safety (SNISB).

The dams must be classified by the supervising agencies by Risk Category (RC) and by Potential hazard associated (PHA) and by the capacity of the reservoir, based on general criteria established by the National Water Resources Council (CNRH).

Dam classification has relevant importance in the conduct of PNSB, since PHA and RC classification constitutes a criterion for framing the dam and for defining the obligations of the dam owner in terms of compliance with the dam safety policy. For instance, EAP is mandatory for water storage dams that have been classified with High or Medium PHA (BRASIL 2010). The legislation also allows that the supervising agency may determine the elaboration of EAP for dams classified as high RC (BRASIL 2010) (ANA 2016a).

The EAP aims to protect lives and reduce material damage and this document contains measures related to dam safety, downstream valley near the dam, and identification of the agents to be notified (FEMA 2013) (ANA 2016a).

The ANA is responsible for the supervision of dams for water accumulation in federal rivers, except for hydroelectric dams, and for the articulation of the PNSB(BRASIL 2010). ANA faced with the challenge of classifying dams sought technical support from the World Bank to develop a simplified methodology for the classification of PHA(Petry et al. 2018).

The methodology should consider lack or low quality of available data and the methodology have the premise that could be replicable by other agencies. Therefore, the simplified inundation map generation methodology was developed with the assistance of the Portuguese National Civil Engineering Laboratory – LNEC (ANA 2014; Petry et al. 2018).

This methodology is based on empirical equations to represent flooding caused by dam failure and uses data on dam height, reservoir volume and location. The downstream terrain surface is represented by Shuttle Radar Topography Mission (SRTM).

The simplified methodology was important to begin the process of PHA classification in Brazil. However, this is a conservative methodology and has a screening character. Therefore, the methodology could overestimate the impacts of dam failure inundation

3. Overview of dams in Brazil

Brazil's dam information can be found in the SNISB. This system gathers information on dams with multiple uses of water, hydropower, industrial waste, and mining tailings. The information is provided by the inspection agencies and SNISB is managed by ANA.

The Dam Safety Report 2020 (RSB-2020) informs that there are 21953 dams distributed throughout the Brazilian territory registered in SNISB(ANA 2021).This includes dams for water reservation, dams for final or temporary disposal of mining tailings, and dams for industrial waste accumulation.

However, only 8478 dams that have been PHA classified. There are 3724 dams classified as high PHA, 1015 dams classified as medium PHA, and 3739 dams classified as low PHA (Figure 1). However, 13475 dams with no PHA classification. This represents 61.38% of the registered dams(ANA 2021).

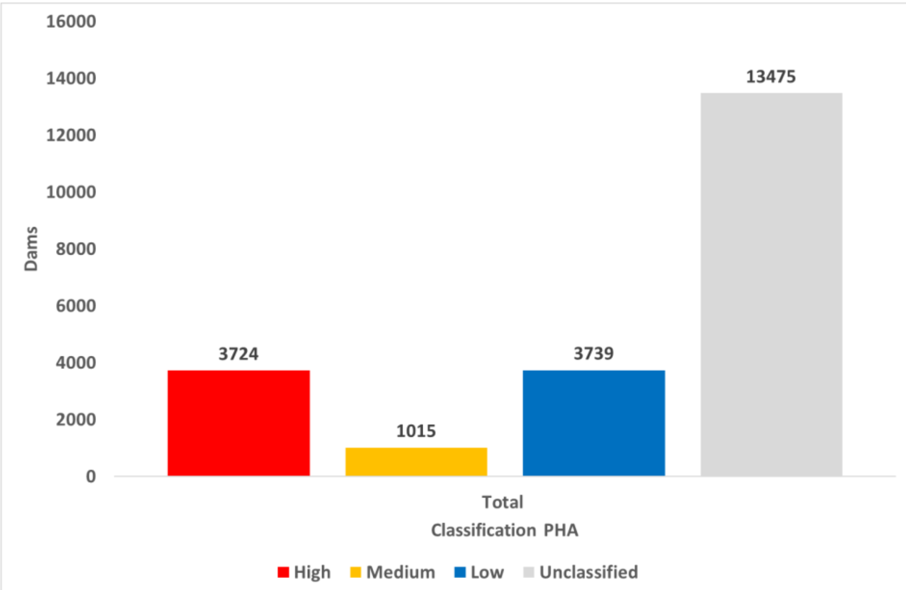

Figure 1: Brazil PHA classification in 2020. Adapted from (ANA 2021)

The number of dams classified as to RC is 6074, with 2074 dams classified as high RC, 1942 dams classified as medium RC and 2058 dams classified as low RC (Figure 2). Note that 14849 (67.64%)dams were not classified and another 1030 dams were not classified because they are not under dam safety legislation or because they are dams considered to be under construction (ANA 2021). Water storage dams, whose priority use is not hydropower, represent about 99.78% of the dams that were not classified as PHA or RC.

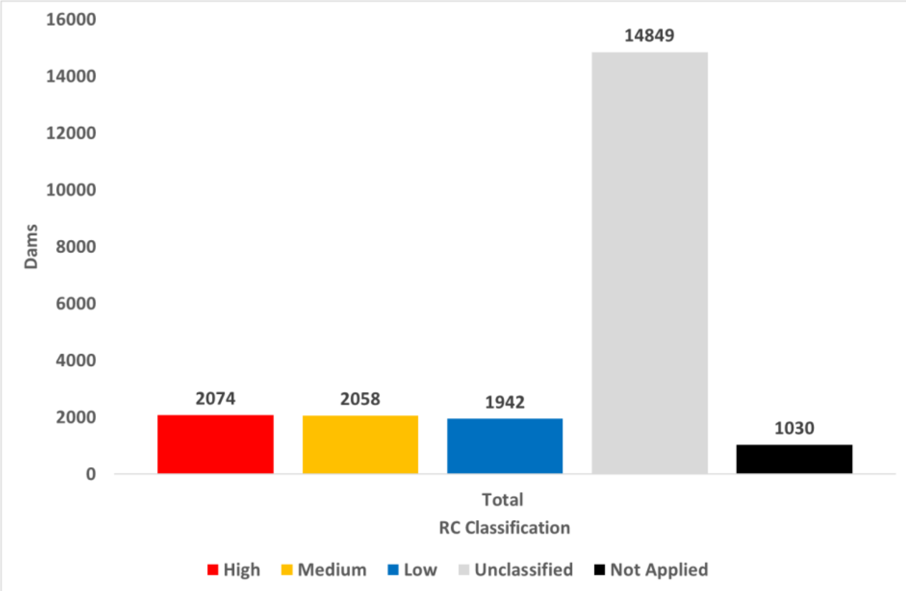

Figure 2: Brazil RC classification in 2020. Adapted from (ANA 2021)

There are 1161 dams classified concomitantly with RC and PHA high. Therefore, these dams contain relevant aspects that may result in the occurrence of an accident with high potential consequences in terms of loss of human lives and social, economic, and environmental impacts. Only 85 of these 1161 dams had EAPs in the year 2020.

Figure 3 presents the classification in terms of reservoir capacity. There are 585 dams classified as very large, 145 dams classified as large, 867 dams classified as medium, 15002 dams classified as small, and 4446 have no information on reservoir volume.

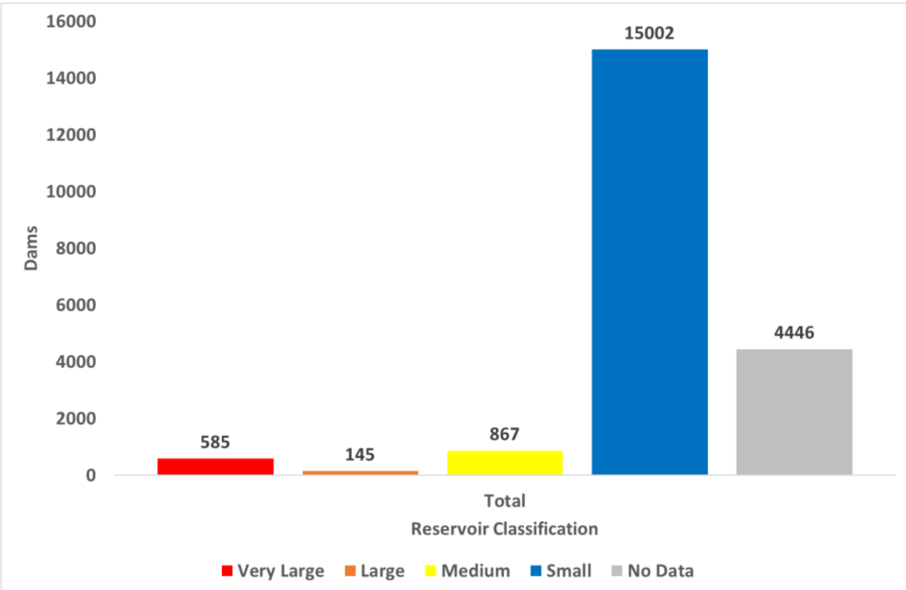

Figure 3: Brazil reservoir capacity classification in 2020. Adapted from (ANA 2021)

Figure 4: Presents the relation between the classification of reservoir capacity and dams with high potential damage. Thus, 3724 dams classified as PHA High, 2407 (64,64%) dams are considered small in terms of reservoir capacity, with 1620 dams having a reservoir capacity up to 1 hm^3.

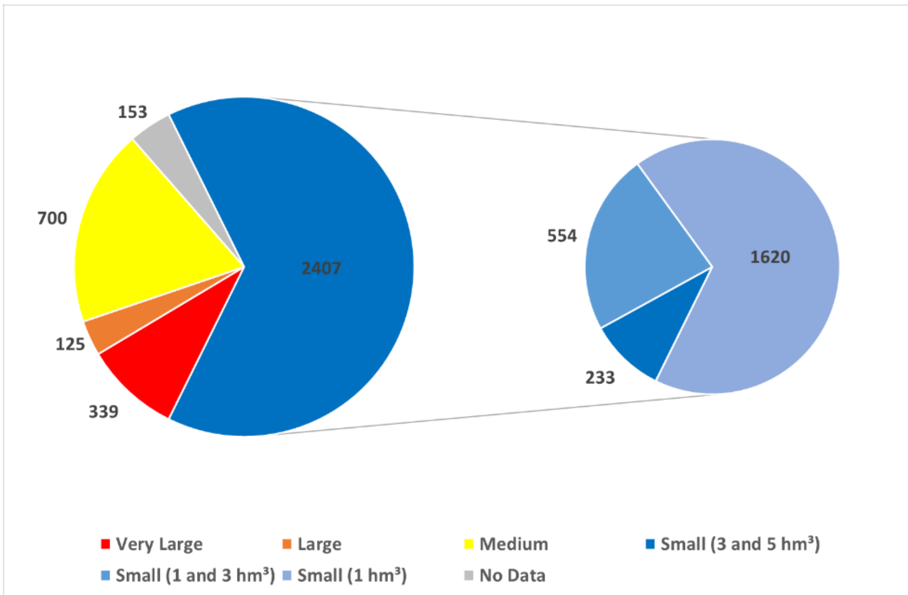

Figure 4: Relationship of reservoir capacity classification to PHA high

4. Dam Classification Criteria

Towards develop this study, a survey was conducted on the dam classification criteria used in Brazil and criteria that can be considered as reference and adopted by the International Commission on Large (ICOLD), Portugal and the United States.

4.1. Brazil

The Brazilian legislation is aimed at different types of dams. Therefore, the CNRH Resolution Nº143, July 2012, was published establishing specific classification criteria for dams for water accumulation and dams for mining tailings and industrial waste.

However, the classification criteria presented are for water accumulation dams. Dams are classified according to reservoir volume, Risk Category (RC) and Potential Hazard Associated (PHA)(CNRH 2012).

Dams are classified according to reservoir capacity according to the following criteria (CNRH 2012):

- Small: reservoirs with volume less than or equal to 5 hm^3.
- Medium: reservoirs with a volume of more than 5 hm^3 or equal to 75 hm^3.
- Large: reservoirs with a volume of more than 75 hm^3 and less or equal to 200 hm^3.
- Very large: reservoirs with a volume of more than 200 hm^3.

Dams are classified according to RC, which evaluates aspects of the dam that may influence the possibility of an accident occurring (CNRH 2012). The RC is determined based on 3 (three) matrices that evaluate and provide a score for aspects such as technical characteristics (TC), state of conservation (SC) and safety plan (SP). Table 1 summarizes the respective classification matrices that are used to define CR.

After calculating the score of each matrix, the sum of the values is performed to determine the RC of the dam under analysis according Equation (1).

$$RC = TC + SC + SP \quad (1)$$

The dam that obtains a score less than or equal to 35 points is considered RC low and the dam is considered RC medium if the score is between 35 and 60 points. The dam is classified as high RC if the score is greater than or equal to 60 points. The CR is also defined as high if any descriptor in the state of conservation matrix obtains a score greater than or equal to 8 points, Figure 5.

Technical Characteristics Matrix (TCM) Descriptors	**Score range**
Height (a)	0 to 3
Length (b)	2 to 3
Type of construction material (c)	1 to 3
Type of foundation (d)	1 to 5
Age (e)	1 to 4
Design flow conditions (f)	3 to 10
TC = ∑ (a to f)	8 to 28
Conservation Status Matrix (CSM) Descriptors	**Score range**
Confiability of spillway structures (g)	0 to 10
Confiability of outlet structures (h)	0 to 6
Seepage (i)	0 to 8
Strains and Settlement (j)	0 to 8
Slopes or faces deterioration (l)	0 to 7
Navigation Lock (m)	0 to 4
CS= ∑ (g to m)	0 to 43
Safety Plan Matrix (SPM) Descriptors	**Score range**
Existence of project documentation (n)	0 to 10
Organizational structure and technical qualification of dam's safety staff (o)	0 to 6
Procedures and routines of dam safety inspections and monitoring (p)	0 to 8
Operating rules for outlet hydraulic structures (q)	0 to 8
Dam safety reports with analysis and interpretation (r)	0 to 7
SP= ∑ (n to r):	0 to 39

Table 1: Summary of RC Matrices and their descriptors and score range(Viana et al. 2015)

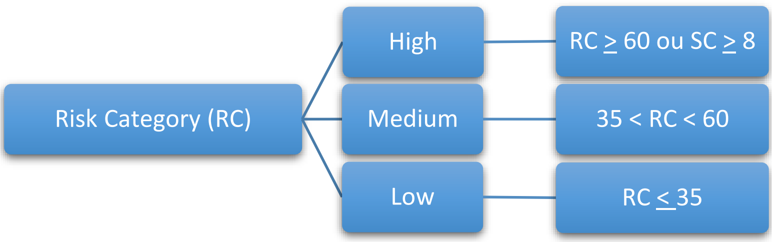

Figure 5: Risk Category classification of water accumulation dams

PHA evaluates the potential damage downstream of the dam, in which the impact due to dam failure, leakage, infiltration into the soil or malfunction of a dam is analyzed. In this case, impacts are verified according to loss of life, socioeconomic impacts, and environmental impacts (CNRH 2012)

The PHA classification criteria were made available in a matrix, Table 2. This matrix presents scores for reservoir volume, potential for loss of human life, environmental impact, and socioeconomic impact. Note that the PHA descriptors are subjective except for reservoir volume. Therefore, they depend on interpretations during evaluation.

The PHA classification is carried out with the definition of the score of each descriptor and the sum of these values. The dam with a score lower than 10 is considered low PHA and the dam is considered medium PHA if the score is between 10 and 16 points. Those dams that obtain a sum equal to or greater than 16 are classified as high PHA,Figure 6.

Reservoir Volume (a)	**Potential loss of human life (b)**	**Environmental Impact (c)**	**Socio-economic Impact (d)**
Small (< = 5hm³ (1)	NONE (There are no permanent/resident or temporary people/transiting in the area downstream of the dam) (0)	SIGNIFICANCE (the affected area of the dam does not represent an area of environmental interest, areas protected by specific legislation or is totally out of character for its natural conditions) (3)	NONE (there are no navigation facilities and services in the area affected by the dam accident) (0)
Medium 5 to 75hm³ (2)	INFREQUENT (There are no people permanently occupying the area downstream of the dam, but there is a neighboring road for local use. (4)	VERY SIGNIFICANT (dam affected area has relevant environmental interest or is protected by specific legislation) (5)	LOW (there is a small concentration of residential and commercial, agricultural, industrial or infrastructure facilities in the affected area of the dam or port facilities or navigation services) (4)
Large 75 to 200hm³ (3)	FREQUENT (There are no people permanently occupying the area downstream of the dam, but there is a municipal or state or federal highway or other place and/or enterprise where people may be affected. (8)		HIGH (there is a large concentration of residential and commercial, agricultural, industrial, infrastructure and leisure and tourism services facilities in the affected area of the dam or port facilities or navigation services) (8)
Very Large > 200hm³ (5)	EXISTING (There are people permanently occupying the area downstream of the dam, therefore, human lives could be affected. (12)	-	-
PHA = ∑ (a to d)	4 to 30		

Table 2: PHA Matrix and their descriptors and score range

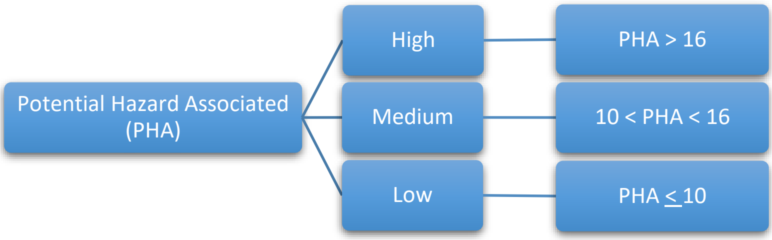

Figure 6 :Potential Hazard Associated classification of water accumulation dams

4.1.1. Complementary Criteria

The CNRH Resolution Nº143, July 2012, allows the supervisory agency to use technically justified complementary criteria for the classification of dams. In this case. The National Electric Energy Agency (ANEEL), which is responsible for supervising safety of hydropower dams, included the powerhouse evaluation in Technical Characteristics, the other matrixes were not changed(ANEEL 2015).

Table 3 summarizes the Technical Characteristics matrix used to define RC of ANEEL. This inclusion changed the score for RC definition as shown in Figure 7 The dam that obtains a score less than or equal to 35 points is considered RC low and the dam is considered RC medium if the score is between 35 and 62 points. The dam is classified as high RC if the score is greater than or equal to 62 points. The RC is also defined as high if any descriptor in the state of conservation matrix obtains a score greater than or equal to 8 points

Technical Characteristics Matrix (TCM) Descriptors	**Score range**
Height (a)	0 to 3
Length (b)	2 to 3
Type of construction material (c)	1 to 3
Type of foundation (d)	1 to 5
Age (e)	1 to 4
Design flow conditions (f)	3 to 10
Powerhouse(g)	0 to 5
TCM = ∑ (a to g)	8 to 33

Table 3: ANEEL Technical Characteristics Matrix descriptors and score range

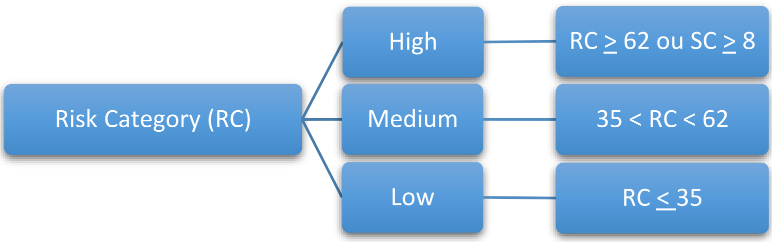

Figure 7 :Risk Category classification of Hydropower plants

Faced with this possibility, the National Water Agency (ANA) published Resolution Nº 132, February 2016, establishing complementary criteria for environmental impact and socio-economic impact (ANA 2016b).

The environmental impact analysis is based on the Brazilian National System of Nature Conservation Units of Brazil (SNUC), in which the degree of environmental impact is a function of the preservation status of the downstream area and the existence of a preservation unit protected by law. Quantitative criteria were adopted to define the impact socio-economic. This reduced the degree of subjectivity of the two descriptors (Table 4).

This proposal improves description of the criteria for the environmental and socioeconomic impact descriptors. In the case of the environmental impact descriptors, it also expands the scoring range.

Table 5 presents the descriptors and scores of the classification matrix used to define ANA's PHA. The criteria in the Resolution ANA Nº. 132/2016 do not change the total scoring range for dam classification, remaining the same as in Figure 6.

Environmental impact	Socio-economic impact
LOW SIGNIFICANT (the affected area of the dam does not represent an area of environmental interest, areas protected by specific legislation or is completely deprived of its natural conditions) (1)	NONE (there are no navigation facilities and services in the area affected by the dam accident) (0)
SIGNIFICANT (the affected area includes protected areas of sustainable use or when it is an area of environmental interest and is little deprived of its natural conditions) (2)	LOW (there are 1 to 5 installations residential and commercial, agricultural, industrial facilities or infrastructure in the affected area of the dam) (1)
VERY SIGNIFICANT (the affected area includes areas of strict protection. including Indigenous Lands – or when it is of great environmental interest in its natural state) (5)	MEDIUM (there are more than 5 to 30 residential and commercial, agricultural, industrial or infrastructure facilities in the affected area of the dam) (3)
-	HIGH (there is a large concentration of residential and commercial, agricultural, industrial, infrastructure and leisure and tourism services facilities in the affected area of the dam or port facilities or navigation services) (8)

Table 4: ANA PHA complementary criteria for environmental and socioeconomic impact descriptors

Potential Hazard Associated Matrix (PHAM) Descriptors	Score range
volume of the reservoir (a)	1 to 5
potential for loss of human life (b)	0 to 12
environmental impact (c)	1 to 5
socioeconomic impact (d)	0 to 8
PHAM = ∑ (a to d)	2 to 30

Table 5: ANA PHA Matrix and their descriptors and score

4.2. International Commission on Large Dams - ICOLD

The International Commission on Large Dams (ICOLD) is an international non-governmental organization which is a forum for the exchange of knowledge and experience in dam engineering. Therefore, ICOLD is international technical reference in dams and with representation in over 100 countries.

The ICOLD uses a classification of dams according to their associated potential hazard, which is determined based on the values of maximum dam height (H) and maximum accumulated volume (V). In this case, the height of the dam is considered from the deepest level of the foundation to the highest level of the crest of dam (ICOLD 2011).

The relationship of the parameters is carried out by Equation (2), which is a deterministic weighting factor applied in the evaluation of potential hazard and loss of life in an area subject to flooding in case of dam failure.

$$H^2\sqrt{V} \tag{2}$$

The combination of the parameters is used to obtain the dam's classification. The dams can be categorized into low, medium, and high classes, as shown in Table 6.

Component	**Potential Hazard Damage Associated**		
	Low	**Medium**	**High**
$H^2\sqrt{V}$	<20	$20 < H^2\sqrt{V} < 200$	>200
Life Safety Risk	~0	<10	>10
Economic Risk	Low	Moderate	High or Extreme
Environmental Risk	Low	High	Extreme
Social Risk	Low (rural area)	Regional	National

Table 6: ICOLD classification for Potential Hazard Associated

Dams are considered large when they have a height greater than 15 meters or dams with a height between 10 and 15 meters and a reservoir with a capacity to store more than 3 million cubic meters of water. (ICOLD, 2011) Figure 8 shows classification according to the size of the dams.

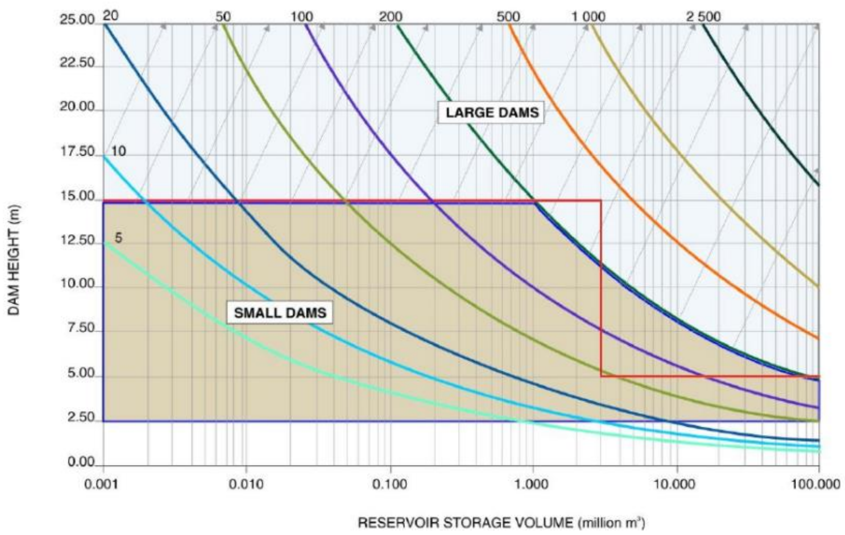

Figure 8 : ICOLD Classification according to the size of the dams (ICOLD, 2011)

4.3. Portugal

Portugal changed the dam safety regulation in 2018, with the publication of Decree-Law nº 21/2018. This decree also brought new criteria for classifying dams

The classification of dams in Portugal is conducted according to their danger and the potential dangerousness associated with flood wave corresponding to the most unfavorable accident scenario(Portugal 2018).

Equation (3) defines the dangerousness, where H is the height of the dam (meters), and V is the capacity of the reservoir(hm^3). Note that the equation is the same as used by ICOLD.

$$X = H^2\sqrt{V} \tag{3}$$

The potential damage is assessed in the valley region downstream of the dam, where flood wave may affect the population, property, and environment, should:

- The population is assessed according to the number of fixed buildings with a permanent residential character (Y).
- Potential damage is assessed considering the existence of important infrastructure, facilities, and environmental assets.

The legislation, Portuguese Decree-Law nº 21/2018, establishes delimitation of downstream valley region for the analysis of potential damage. Thus, the study should be carried out up to the location of the river where the flow resulting from the dam failure reaches the order of magnitude of the spillway flow(Portugal 2018). This reach of the river should be defined as follows:

- Based on results obtained by applying hydrodynamic models to the study of the flood wave, simplified models or empirical formulas may also be used, if duly justified.
- For a river section located 10 km downstream of the dam, in the case of dams with H equal or smaller than 15 m and X smaller than 100.

The classification is based on the grouping of the dams in classes in descending order of damage severity, considering the potential damage associated with the structures. Table 7 summarizes the classification used in Portugal.

Classes	Dam Hazard Classes and Potential Damage
I	$Y \geq 10$ *and* $X \geq 1000$
II	$Y \geq 10$ *and* $X < 1000$ or $0 < Y < 10$, regardless of the value of x or Existence of important infrastructure, facilities and environmental assets
II	$Y = 0$, regardless of the value of x

Table 7: Portugal classification for Potential Hazard Associated(Portugal 2018)

4.4. United States

USA is considered a technical reference in dam safety. There is a document considered reference for dam classification in the United States, the "Federal Guidelines for Dam Safety: Hazard Potential Classification System for Dams" (FEMA 333), prepared by the Interagency Committee on Dam Safety (ICODS) and published by the Federal Emergency Management Agency (FEMA) in 2004.

The dam classification used by Federal Emergency Management Agency (FEMA) performs the categorization of dams based on the information of the potential loss of life and the economic, environmental, and social impacts. The classification of the dam should be based on the probable worst case of the dam breaking or malfunctioning (ANA 2013).

Dam classifications are divided into 3 classes of associated potential damage: low, significant, and high. Presents the classification system proposed by (FEMA 2004). Table 8 presents the FEMA classification´

U.S. Army Corps of Engineers (USACE) is responsible for the operation and maintenance of approximately 740 dams and associated structures throughout the United States. Dams and their reservoirs provide benefits in the areas of flood control, navigation, water supply, hydropower, environmental management, fish and wildlife conservation, and recreation.

The USACE classification system assesses the loss of life, property, vital services, and the environment. The potential hazard is separated into categories: high, significant, and low (USACE 1997), Table 9.

Hazard Potential	Loss of Human Life	Economic, Environmental, Lifeline
low	None expected	Low and generally limited to owner
Significant	None expected	Yes
High	Probable. One or more expected	Yes

Table 8: FEMA Hazard Potential Classification System (FEMA, 2004)

Category	Low	Significant	High
Direct Loss of Life	None expected (due to rural location with no permanent structures for human habitation)	Uncertain (rural location with few residences and only transient or industrial development)	Certain (one or more extensive residential, commercial or industrial development)
Lifeline Losses	No disruption of services – repairs are cosmetic or rapidly repairable damage	Disruption of essential facilities and access	Disruption of critical facilities and access
Property Losses	Private agricultural lands, equipment and isolated buildings	Major public and private facilities.	Extensive public and private facilities.
Environmental Losses	Minimal incremental damage	Major mitigation required	Extensive mitigation cost or impossible to mitigate

Table 9: USACE Hazard Potential Classification System (USACE 1997)

USACE also has a classification system based on the size of the dam. This is a classification carried out with information on the height of the dam or the storage volume of the reservoir, Table 10.

Category	Altura	Volume
Small	25 a 40 ft 7,62 a 12,19 m	50 a 1000 ac-ft 0,06 a 1,23 hm^3
Medium	40 a 100 ft 12,19 a 30,48 m	1000 a 50000 ac-ft 1,23 a 61,67 hm^3
Large	> 100 ft > 30,48 m	> 50000 ac-ft >61,67 hm^3

Table 10: USACE Size Classification System (USACE 1997)

5. Classification criteria comparison

The classification criteria presented have similarities mainly regarding classification of the associated hazard. However, the USA and Brazil criteria are subjective as to loss of life, while the ICOLD and Portugal criteria present quantitative values. In the case of Portugal, loss of life is determined as a function of permanent residential buildings situated downstream of dam.

The ICOLD and Portugal criteria consider dam size in the hazard classification based on the ratio of H and V. This was not verified in the FEMA and USACE criteria. In the case of Brazil, reservoir volume is an item to be scored in the PHA matrix and height is an item to be scored in the EC matrix at RC classification. There is also a reservoir capacity classification, but it has no practical effect.

The environmental impact criteria are generally subjective except for the complementary criteria established by the ANA. The ANA established the criteria based on a specific law about environmental conservation areas in Brazil.

The hazard classification is performed by analyzing the downstream valley based on inundation maps. The legislation of Portugal presents conditions for the preparation of inundation maps and allows the use of simplified methodologies if they are justified. There is a document supporting the classification of small dams, in draft text, that defines the inundation map methodologies for small dams as a function of the value of X(APA 2018).

Brazil's dam classification includes a hazard assessment and risk category based on score. Viana et al. 2015 state that RC has the characteristics of a qualitative method for preliminary risk analysis.

Therefore, the PHA and RC classification has the potential to be used as a preliminary risk management tool, which can be an indicator for the implementation of dam safety policies. Dams with higher scores should receive more attention from public authorities.

6. Decision support tool

The number of unclassified dams is high, and this study envisions the possibility of using artificial intelligence-based methods to assist in the task of dam classification.

Such as the research conducted by (Assaad and El-adaway 2020), which developed a decision support tool based on artificial intelligence to assess the potential damage of dams in USA.

The authors used the data the National Inventory of Dams (NID)to classify the dams. The NID has information about the location, types, and sizes of dams, among others. This data is provided by state and federal dam regulators, and the NID is maintained and published by the USACE.

The authors used evaluated 25 variables non-spatial such as dam height, reservoir volume, dam material, height, purpose among others presented in the NID and identified 19 variables that influence the prediction of the potential hazard level of dams in the USA. The classification of the potential hazard of dams followed the FEMA criteria, Table 8.

This study used classification data from 79470 dams located in the US for model development. The data from 63573 dams (80%) was used for machine learning and the data from 15894 dams (20%) was used for model evaluation.

The model obtained the accuracy of 85.70%, the authors consider as acceptable Figure 9.This indicates that the tool developed can be used in decision support by the agencies responsible for dam management in the USA.

There are dams where the hazard was underestimated and dams where the damage was overestimated. The study does not present the reasons for the forecast error.

Values on the diagonals

		Predicted Hazard Potential				
		Low	Significant	High	Dam Count	Correct Predictions
True Hazard Potential	Low	9300	1391	200	10891	9300
	Significant	137	1788	225	2150	1788
	High	20	300	2533	2853	2533
				Total	15894	13621

Total Prediction Accuracy = (13621/15894)*100 = 85.70%

Figure 9: Matrix and prediction accuracy (Assaad and El-adaway 2020)

Kravits et al. 2021 state that the classification of the risk potential of the dam is carried out on a case-by-case basis, ultimately relying on human judgment. The authors understand that the process lacks objectivity and consistency across state boundaries and can be time-consuming.

Kravits et al. 2021 developed a study based on Assaad and El-adaway 2020. The authors developed a tool using non-spatial data and spatial data and with the aid of a machine learning algorithm for classification dam hazard.

Spatial data can be understood as downstream population, number of buildings, buildings footprint, exposure of buildings and others which can be found in FEMA's Hazard United States Multi-Hazard (HAZUS-MH) database. This type of data was used to predict dam risk (Aboelata and Bowles 2008).

The authors also made use of multi-objective model to adjust the parameters of the machine learning algorithm and additional parameters of the geospatial model. As a result, potential hazard screening model based on non-spatial and geospatial data was presented.

The research was performed on dams in Massachusetts, USA, and obtained an accuracy of 83%. The authors consider this a good result since it is close to the value of 85.7% (Assaad and El-adaway 2020).

Kravits et al. 2021 suggest future studies with the purpose of verifying the accuracy of this model in in dams classified. The authors understand as a potential improvement to the model, the utilization of inundation area produced by a hydraulic model and incorporating the probability of failure and the potential impacts of these failures. The adoption of quality inundation map and the adoption of failure probability can improve the model's accuracy.

Dam classification is an important issue and the use of tools for predicting damage classification should look for ways to increase accuracy, since a misclassified dam can lead to problems for dam safety management. An overestimated dam classification could lead to unnecessary legal obligations for the dam owner. While an underestimated dam could lead to risks for downstream population.

7. Directions for improving dam classification in Brazil

The classification of dams is an important point to be discussed. There are many unclassified dams, even though the classification criteria were established in 2012.

This study proposes recommendations improve the process of dam classification in Brazil. Part of the recommendations are based on the classification criteria presented previously, to be described as follows:

- Adoption of the relation of H and V, Equation (2) and Equation (3), according to (ICOLD 2011) and (Portugal, 2018). The criterion of the size of the dam allows directing specific actions for small dams. Currently, dams classified as high and medium PHA have the same requirements regardless of their size.
- Adopting quantification of residential buildings located downstream, (Portugal, 2018), as a criterion for potential for loss of life may decrease the subjectivity of scoring for potential for loss of human life (b) of the PHA matrix (Table 2).
- Adoption of criteria for the use of simplified methodology in function of dam size (Portugal, 2018). In Brazil, due to data availability the simplified methodology is used mainly for the classification of water storage dams, with no hydropower, regardless of their size. However, simplified methodologies are conservative and have a screening character, which can result in damage estimates that are higher than reality. Therefore, the classification process needs regulations that indicate and limit the use of simplified methods and establish the process for using hydraulic models to generate inundation maps.

Brazilian supervisory agencies can evaluate artificial intelligence techniques to reduce the number of unclassified dams, such as Assaad and El-adaway 2020 and Kravits et al. 2021. Therefore, artificial intelligence algorithms could be tested to predict PHA based on the data available in SNISB.

8. Conclusions

Dam safety is a topic of great importance because it involves the safety of the population, water safety, the environment, and allows for the development of economic activities.

In Brazil, this issue is addressed by Law Nº 12.334/ 2010, which established the National Dam Safety Policy (NDSP). However, there are many actions that require attention and the classification of dams as to PHA and RC one of these challenges.

There are many dams that have not been classified in Brazil and the solution to solve this issue is to change the classification criteria. There are best practices used in other countries that could be adapted to the PNSB. Emphasizes that current regulation allows the supervising agency to adopt technically justified complementary criteria for classifying dams(CNRH 2012)

The number of dams is high in Brazil, therefore artificial intelligence tools and multi-objective approach could support with challenge of classifying dams in Brazil. However, accuracy must be observed to avoid classification errors.

This study recommends pathways with the objective to improve the numbers of the classification of dams in Brazil. Thus, recommendations on the classification criteria and the use artificial intelligence tools should be the subject of future research.

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