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PARALLELIZATION OF MULTI-RISK INSURANCE MODEL FOR HYDROLOGICAL EXTREMES: A CONCEPTUAL APPROXIMATION

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RESUMO

O marco do fundo de seguros foi desenvolvido para mitigar os impactos econômicos que a sociedade sofre com os extremos hidrológicos, tornando-se uma ferramenta necessária em um ambiente em constante mudança relacionado ao contexto de secas e inundações. A aplicabilidade desses marcos é limitada considerando a distribuição espacial. Como modelos concentrados, faltam informações que orientem as partes interessadas a investir em fundos de seguro de acordo com sua situação espacial. Este último aumenta a complexidade multivariável de otimização para valores de prêmios, além disso, requer um longo tempo para execução do algoritmo quando considera a heterogeneidade espacial como imagens de uso e cobertura do solo, o que representa uma restrição devido ao processo iterativo para cada pixel na imagem para grandes áreas de estudo. Hoje em dia este é um problema comum devido ao alto processamento computacional que é abordado com métodos típicos de programação. Para este problema, é proposta uma metodologia conceitual de otimização multivariável para aprimorar a análise tradicional do arcabouço do seguro hidrológico, impulsionada pela programação paralela, que poderia reduzir o tempo de processamento e fornecer informações mais detalhadas para a tomada de decisões relacionadas aos prêmios a pagar em um fundo de seguros, para aumentar a resiliência econômica contra impactos hidrológicos devido a eventos extremos.

Palavras chave: Optimização, Descenso do gradiente, Modelo distribuído.

ABSTRACT

The insurance fund framework has been developed to mitigate economic impacts in which society suffers from hydrological extremes, becoming a necessary tool in a constantly changing environment related to droughts and floods context. The applicability of these frameworks is limited by considering spatial distribution. As lumped models, there is a lack of information to guide the stakeholders to invest in insurance funds according to their spatial situation. The latter increases the multivariable complexity optimization for premiums values, besides that, it requires a long time for algorithm execution when it considers spatial heterogeneity as land use and cover images, this represents a constraint due to the iterative process for each pixel in the image for big study areas. Nowadays this is a common problem due to the high computational processing which is addressed with typical programming methods. For this problem, it´s proposed a conceptual methodology of

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multivariable optimization to improve the traditional analysis of hydrological insurance framework, boosted by paralleling programming, which could reduce time processing and provide more detailed information for decision making related to premiums to pay in an insurance fund to increase economic resilience against hydrological impacts due to extreme events.

keywords: Optimization, Gradient descent, Distributed model.

1. INTRODUCTION

The knowledge concerning water availability within watersheds it's of vital importance for primary and secondary sectors development, and for urban supply, however, climate change has impacts in the hydrological regime, provoking frequency and severity increase of hydrological extremes such as floods and droughts (Aerts and Botzen, 2011), resulting in a worldwide scenario of higher economical vulnerability and risk.

The Brazilian context, as a country with high agricultural activity dependency and continual urban development, is under constant risk due to these hydrological extremes. To cope with this issue, insurance funds such as the Hydrological Risk Transfer Model (MRTH-SHS) have been created (Righetto *et al*., 2007; Graciosa, 2010). Risk transfer tools promote economic resilience (Hudson *et al*., 2016), and indicate pathways for adequate management for future scenarios of water availability (Guzman *et al*., 2020). However, this framework is limited by lumped answers related to optimal premium values (Mohor and Mendiondo, 2017; Laurentis, 2012).

The lumped framework generates structural uncertainty that has to be addressed to provide better information for stakeholders, however, spatial analysis is necessary to cope with this issue, i.e., providing insurance premium values for different land use and cover or flood depths. The latter brings the problem of high computational processing cost due to iterative instructions, even though the improvements of the last 50 years facilitated mathematical analysis of large quantities of data in various areas (Nocedal and Wright, 2006).

Both exposed constraints are present in the MRTH-SHS, first, lumped insurance premiums, and second, high computational processing cost when the first problem is addressed. Methods such as gradient descent for multivariable optimization (Ruder, 2017) and parallel programming are applied in order to achieve faster computations (Amoretti, 2020).

On one hand, the gradient descent algorithm allows optimizing multivariable functions at the same time, which is the main structure to optimize neural networks in the machine learning field (Ruder, 2017). On the other hand, parallel processing is getting high relevance in the hydrology context due to its advantages (Hofierka *et al*., 2017; Zhang *et al*., 2017), and it is becoming more accessible to the public, i.e., google colaboratory which is a free cloud service (Carneiro *et al*., 2018).

With this, we hypothesize that multivariable optimization by the gradient descent method allows obtaining a more accurate premium value in the insurance model, and thought of parallel programming the process could be repeated to obtain spatialized results in a shorter time of processing.

The main objective of this paper is to propose a conceptual methodology to improve the MRTH-SHS optimizing and providing spatialized values of insurance premiums to advance stakeholders' decision-making process, and then, to increase economic resilience against extreme events.

2. PROBLEM CONCEPTUALIZATION

The MRTH-SHS framework has been modified to coping with different hazards. Graciosa (2010) addressed damages due to floods in urban areas, and for the dry season Laurentis (2012), Mohor and Mendiondo (2017), Guzman *et al*. (2020), studied water supply. The model structure is composed of three main modules; the hazard module where hydrological data is processed and provides synthetic data to the next module; the vulnerability module where the synthetic data is associated with a damage cost function related to a hydrological extreme; and finally, the financial module where premium insurance optimization is made.

Our study focus is on the last module where premium insurance optimization is commonly determined by an average of optimal premiums, which were obtained separately by each synthetic streamflow series associated with a cost function (Laurentis, 2012; Guzman *et al.*, 2020; Mohor and Mendiondo, 2017). The latter is a source of uncertainty for considering individual constraints and not as a group for all synthetics series; in other words, multivariable optimization could better address this uncertainty. Related to the high computational processing cost to cope with the MRTH-SHS as a distributed model on large-scale study areas, parallel programming will allow an iterative process of the financial module in a shorter period.

2.1. Multivariable optimization

For the multivariable optimization, the gradient descent method will be employed. This method starts with a random point in the function, then makes differential moves in the direction of every component of the multivariable function until an optimal point is reached according to a loss function. The method provides a simple process for optimization functions with multiple dimensions or variables (KUBAT, 2017). The partial derivative of the function for each variable is defined as a vector (Equation 1). It's worth mentioning that each variable or vector component represents a function that relates the synthetic series associated with a cost function.

Besides that, the movement magnitudes in each component are defined by the difference between the initial point and the gradient assessed value (Equation 2), this procedure is iterative according to the number of components that the vector has until an optimum value is reached according to a loss function.

$$\begin{pmatrix} \nabla_{\emptyset 0} J(\emptyset_n) \\ \vdots \\ \nabla_{\emptyset n} J(\emptyset_n) \end{pmatrix} = \nabla F(\emptyset_n) \qquad (1)$$

$$\emptyset = \emptyset - \alpha * \nabla_{\emptyset} F(\emptyset) \qquad (2)$$

where ø is the function component; $\nabla F(\emptyset_n)$ is the partial derivative of the function; α is the learning rate; n is the number of the components in the function. It stands out that the learning rate "α" has a high influence on the magnitudes movements and is a key point on the optimization algorithm efficiency, then, it could be possible the necessity of a parameter adjustment, therefore, methods such as Momentum, Adam, Nadam, among others will be compared (RUDER, 2017).

2.2. Parallel programming

For images of land use and cover such as the Mapbiomas product (Mapbiomas, 2019) or output data of flood depths generated by and hydrologic-hydraulic model such as the model for Large Basin MGB-IPH (Pontes et al., 2017), a boost processing through parallel programming will be necessary. To cope with this, google colaboratory is a free cloud service that allows users to use graphic process units (GPUs). With this advantage, the iterative process of the financial module of the MRTH for each pixel can be executed in a short period of time, sending processes into an available core in a GPU (Figure 1). One constraint of this alternative is that the GPUs available on the google colab cloud service are limited by core numbers (Carneiro *et al*., 2018).

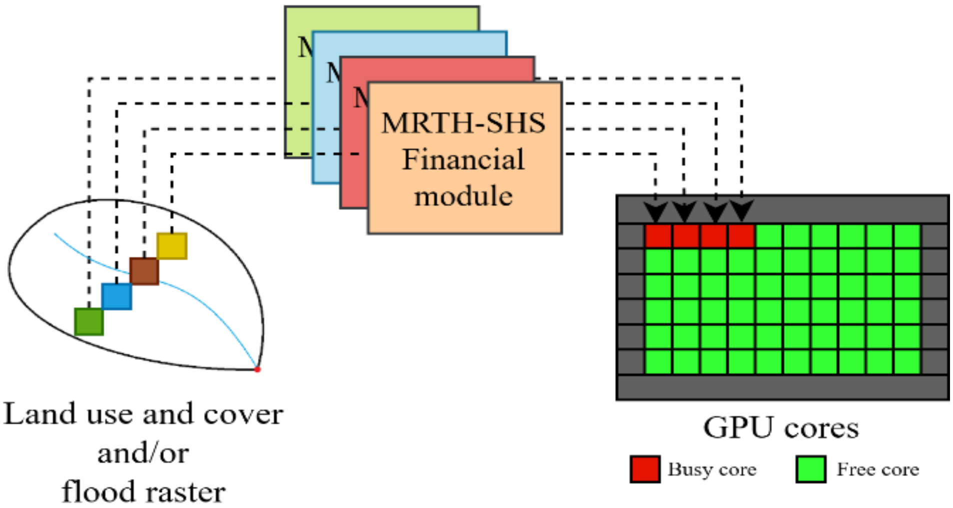

Figure 1 – Parallel programming for the MRTH financial module.

3. PROPOSED METHODOLOGY

The conceptual framework is proposed to be tested in a pilot study area (Figure 2), therefore hydrological and hydraulic modeling is required, which the MGB-IPH model already demonstrates these capabilities with these tasks (Pereira *et al*., 2013; Pontes *et al*., 2017; Schmitt and Fan., 2020). Then, synthetic streamflow series will be generated by the Thomas and Fiering (2014) method, and later associated with a cost function according to the hazard assessed. Finally, the iterative process of multivariable optimization is executed.

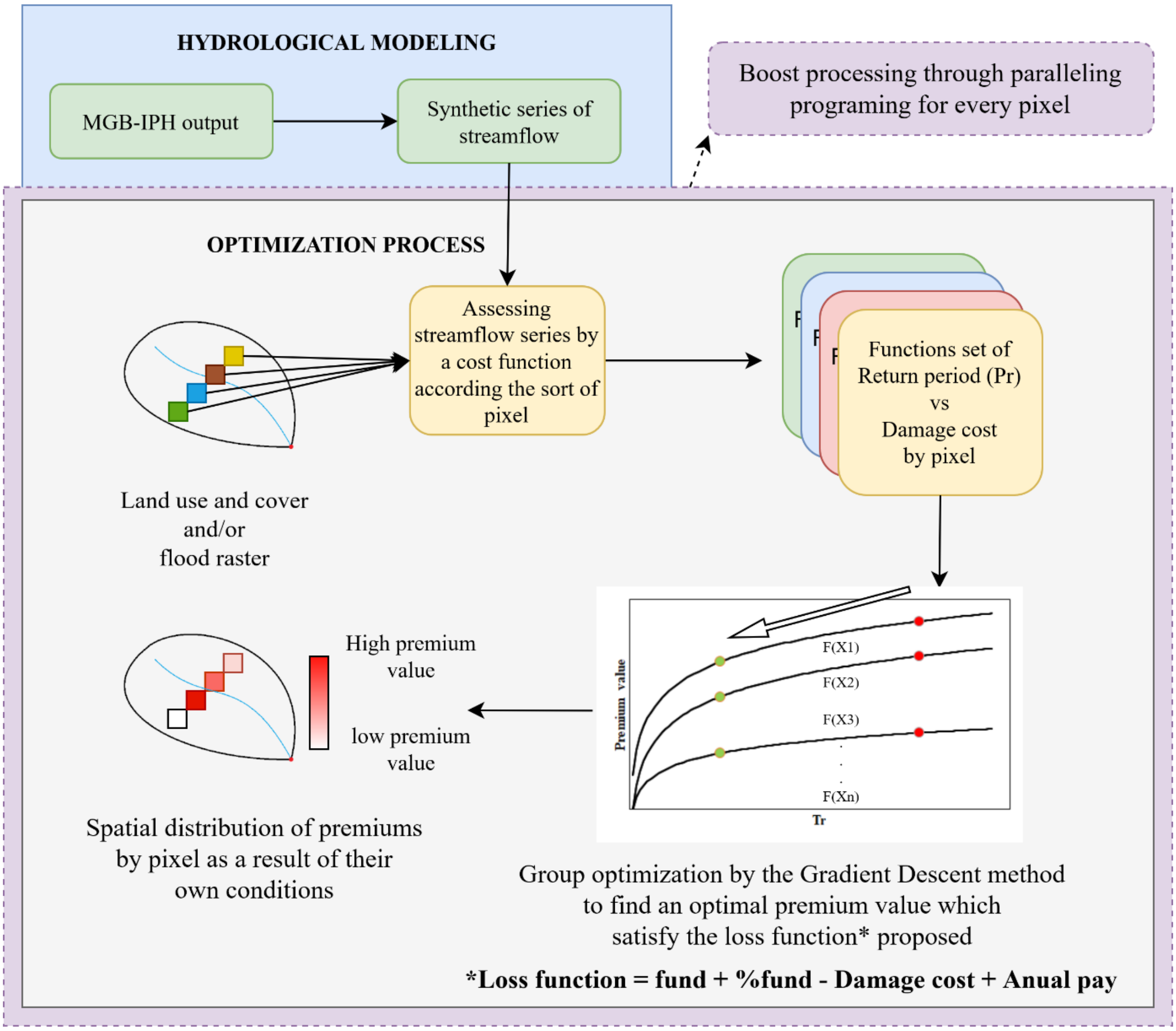

Figure 2 – Proposed methodology of multivariable optimization.

Notice that the loss function in Figure 2 is a simple equation of initial fund, annual fund contribution, damage cost and periodicals income. It's worth mentioning that the loss function can change according to other criteria to optimize the insurance premium.

3.1. Pilot study area

The Cerrado (Brazilian savannah) is a very important biome production and environmental conservation in Brazil. We selected as a study area the Mortes River Basin (MRB) in the Mato Grosso State (Brazil). This basin has some Cerrado characteristics from the region, i.e., still have native vegetation conformed by riparian forest, also, has areas used by agriculture and livestock purposes, which led to consider it as a pilot basin for research (Zeilhofer and Klemp, 2011; Liniger *et al.*, 2017). Besides that, according to Valente and Latrubesse (2012), this basin has periodically flooded savannah (Araguaia floodplain or Bananal Island). It's worth mentioning that this study area is subject to two types of threats, which let us analyze it in a multi-hazard context.

4. FUTURE RECOMMENDATIONS

According to the conceptual proposed methodology, it could reach some benefits related to better information for stakeholders at the decision-making time, moreover, it allows to obtain more accurate insurance premium values in less processing time. Nonetheless, it is not absinthe of limitations and uncertainties, also, it could be improved in some ways.

The methodology could be improved including the benefit from the biodiversity which is used for human well-being (Ecosystem services) (Paul *et al*., 2020) as such as Ebas, PES, NbS, among others. For this, spatial information about biodiversity could be included as a positive value in order to optimize the insurance premium.

Future scenarios of hypothetical land use and cover can be included in the analysis to optimize the insurance premium; however, socio/political patterns of land-use change could be constraints related to scenarios reality.

According to the uncertainty conceptual propose, streamflow generated for specific gauging stations and linked to each pixel of land use and cover, represent a lack of information for the optimization of the insurance premium value analysis due to comparing streamflows between different points with incompatible drainage areas.

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