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Decomposition of Disaster Region using Earthquake Parameter and STDM Distance: Catastrophe Bond Pricing Single Period

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ABSTRACT

Investor interest in single-regional earthquake catastrophe bonds has the potential to decline in the future. To pique investor interest, disaster bond prices can be determined by decomposed disaster zones using seismic parameters and Space Time Depth Magnitude (STDM) distance. Therefore, this study aims to develop a Decomposition of Disaster Region Using Earthquake Parameters and STDM Distance on the Earthquake Catastrophe Bond Pricing (DECBP) model for a single period. The basic idea of developing the model is to observe earthquake characteristics in an area by clustering the area based on the Earthquake Disaster Risk Index (EDRI), earthquake parameters (earthquake magnitude and depth), and STDM distance. The research and development (R&D) methodology used in this work is pursued through the creation of a mathematical model for calculating the price of earthquake catastrophe bonds over a single period. The development stages carried out are regional decomposition modelling, payment functions modelling, distribution of extreme earthquake magnitude values modelling, prediction of interest rates and coupons, numerical simulations, and analysis of the effect of interest rates, coupons, and the amount of regional decomposition on earthquake bond prices. Interest rates, coupons, and the number of regional decompositions that affect bond prices for earthquake events are the results of the analysis of the model that's been developed. The resulting model in this study is expected to assist the Super Purpose Vehicle (SPV) in determining the price of earthquake bonds and serve as a reference for future researchers developing models for the price of earthquake catastrophe bonds.

Keywords:

Regional decomposition; Earthquake disaster; Disaster bond pricing; EDRI; Earthquake parameters; STDM distance

1. Introduction

Earthquake catastrophe bonds (ECB) are a reliable financial instrument for finding alternative funds for earthquake disaster management. However, it can provide a moral hazard to investors [11,21,47]. The examples are IBRD/Fonden2017 (investors lost all cash and coupon values due to an 8 Mw earthquake in Mexico in 2017), and IRBD/CAR120 (investors lost 30% of cash value due to an 8 Mw earthquake in Peru in 2018). If this continues, it will not attract investors in the future. In order to succeed in the market, a transparent and precise earthquake bond pricing model is required [14].

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The main participants in disaster bonds are sponsors, special-purpose vehicles (SPVs), investors, and trustees [23]. The sponsor is usually the insurance or reinsurance company or the state that signs the contract and pays the reinsurance premium to the SPV. The SPV converts the insurance premium into a catastrophe bond (CAT Bond), which is issued and offered to investors in the capital market. Funds raised from investors will be held in a trustee and will be invested in short-term, low-risk securities. When the triggering condition occurs, the SPV will provide compensation, namely the loss of all or part of the face value and coupons according to the contract. If the triggering event does not occur during the term of the bond, the investor will receive the face value plus the coupon [17,43]. The types of triggers for catastrophe bonds are indemnity, industrial loss, modelled loss, and parametric [15,19].

An essential part of the issue process for earthquake bonds is their pricing. The creation of a model for determining the price of earthquake bonds has been the subject of numerous studies. Zimbidis *et al.,* [48] developed a single and multi-period earthquake bond pricing model for the Greece area. The methods used are: a log-normal distribution to model the year's deposit interest rate; Cox Ingersoll Ross (CIR) to model coupons based on annual EURIBOR; Generalized Extreme Value (GEV) to model the maximum annual earthquake magnitude; Maximum Likelihood Estimation (MLE), and FORTRAN subroutine MLEGEV to estimate the parameters of the GEV distribution.

A multi-period earthquake bond pricing model with coupons was created by Tang and Yuan [40] using pricing measures together with a distorted probability function. The Poisson process is used to determine the number of disasters that will occur at time t; GEV and Generalized Pareto Distribution (GPD) are used to model the maximum annual loss taken on by earthquake; MLE and R functions are used to estimate parameters on GEV and GPD; Vasicek is used to model risk-free interest and coupons; and Wang's transformation is used to model premium disaster bond pricing. Modelled loss, which is modelled using a compound Poisson process depending on frequency and severity, is the sort of trigger that is employed. On the basis of severity alone, though, the probability measure is distorted.

Shao *et al.,* [37] developed a Cox & Pederson disaster bond pricing model and linked it to single and multi-period earthquakes. The model used in the payment function is a piecewise linear function. The method used in modelling interest rates and inflation is the Autoregressive Integrated Moving Average (ARIMA) (1,1,1); CIR to model coupons; The Maxima block is used to have a maximum annual earthquake magnitude; GEV is used to model the distribution of the magnitude of the annual earthquake disaster; Gamma distribution is used to model earthquake depth. The type of trigger used is a parametric type, namely the magnitude and depth of the magnitude, and the result is an earthquake in California.

Gunardi and Setiawan [13] developed a single and multi-period earthquake bond model for Indonesia. The model used in the payment function is a piecewise linear function. The methods used are CIR to model coupons; The Maxima block is used to select the maximum annual earthquake magnitude; GEV is used to model the distribution of the magnitude of the annual earthquake disaster. Kiohos and Paspati [20] used a model similar to Zimbidis *et al.,* [48]. However, the territory used in Romania.

The method or model used in developing the earthquake bond price model has limitations or weaknesses. The description is as follows:

i. The severity of an earthquake depends on the location, magnitude, and depth of the earthquake [3,4], but in the articles that have been discussed previously, it is not discussed.
ii. In the determination of interest rates and coupons that have been developed, there are some limitations, namely that Vasicek allows negative values [24,35], In addition, the

volatility of interest rate changes is assumed to be constant, so that it is not realistic for bond prices [32]. CIR is better than Vasicek but has the disadvantage of constant volatility and no jumps caused by monetary policy [32]. ARIMA [37] requires stationarity conditions on the data. However, this is not always possible in practice, as evidenced by African inflation from 1980 to 2009 [5] and Canadian and US interest rates [27].

iii. The selection of earthquake magnitude using the Block Maxima Method (BMM) can eliminate other extreme value data in a period [11].

Limitations in the previous model will be corrected by proposing alternative methods or models for determining the price of earthquake bonds, and this is the novelty of this study. The description is as follows:

i. Decompose the area based on EDRI, average earthquake parameters (depth and magnitude), and STDM distance using the K-Means method and the elbow method in determining the optimal number of clusters. The choice of the K-Means method is because it is simple and efficient [7], but it has the disadvantage that it sometimes produces a minimum local value [44], so it is necessary to have an optimal number of groups validity using the Elbow method.
ii. Fuzzy Time Series (FTS) does not require a data requirement test, making it simpler to predict interest rates and coupon rates [36].
iii. Selection of extreme magnitude values using Peaks Over Threshold (POT) in each area that has been decomposed based on EDRI, earthquake parameters, and STDM distance. Furthermore, the calculation of the trigger probability on the cash value function uses the total probability.

The proposed DECBP model for a single period is based on the decomposition of earthquake characteristics of an area cluster by EDRI, average earthquake parameters (depth, magnitude), and STDM distance. The proceeds will be combined together and offered to investors as a single bond. The steps carried out are modelling the decomposition of the deferred area, payment function, distribution of extreme earthquake magnitude values, prediction of interest and coupon rates, numerical simulations, analysis of the influence of interest rates, coupons, and many groups of earthquake areas.

The stages of numerical simulation carried out are: collecting extreme magnitude data using the POT method; the Kolmogorov-Smirnov (KS) test to determine the suitability of the data as an exponential distribution (needs to be done so that STDM distance calculations can be carried out); and GPD (extreme magnitude data as the basis for calculating probability); determining EDRI on risk/perils covered; calculate the average depth, magnitude, and distance of STDM between earthquake events; group the IRGB area based on the average depth, magnitude, and STDM distance between earthquake events; calculate the total probability of triggering earthquake disaster bonds; predict interest rates and coupons using FTS.

The resulting model in this study is expected to assist the Super Purpose Vehicle (SPV) in determining the price of earthquake bonds and serve as a reference for future researchers developing models for the price of earthquake catastrophe bonds.

2. Materials and Methods

2.1 Materials

The first material in this study is the DECBP mathematical model for a single period. The second material is the data used in the numerical simulation, namely: West Java Province EDRI data obtained from the National Disaster Management Agency (BNPB); earthquake parameter data obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG); Bank Indonesia interest rate data obtained from Bank Indonesia (BI); and the Libor interest rate obtained from http://www.fedprimerate.com. The data used is from the period 2009 to 2021. Meanwhile, the software used is EasyFit for distribution suitability testing and Rstudio for data visualization, prediction of interest rates, coupon rates, and regional decomposition.

2.2 Methods

The method in this research is Research and Development (R&D), which is pursued through the development of the DECBP mathematical model. The methods or models used in the development are as follows.

2.2.1 Space-time-depth-magnitude

The distance of the earthquake occurrence uses the nearest neighbourhood principle (η_{ij}) which is formulated as follows:

$$\eta_{ij} = \begin{cases} c\tau_{ij} r_{ij}^{k} \frac{1}{\varepsilon_i} 10^{-b(m_i - m_0)^2} & \tau_{ij} \geq 0 \\ \infty & \tau_{ij} < 0 \end{cases} \tag{1}$$

η_{ij} should be smaller if earthquake *j* is strongly related to earthquake i, and it may be large when earthquake i dan *j* have a weak connection. The notation in Eq. (1) are *c* is a constant; τ_{ij} is the time difference between two earthquakes such that $(\tau_{ij} = t_j - t_i)$; r_{ij} is haversine distance for the surface distance between two earthquake (full detail see (Patil and Atrey [34])), b is the Gutenberg-Ritcher parameter (full detail see (Aki [1]; Utsu [41])), *k* is a fractal ($k = \frac{3b}{c}, c \approx 1.5$ (Aki 1981)), ε_i and m_i are the epicentral depth and magnitude if the *i*th earthquake. The m_0 is the threshold value of the magnitude of interest. By taking common log_{10} from both side of Eq. (1):

$$log_{10}\eta_{ij} = -\frac{b(m_i - m_0)}{2} + log_{10}c + log_{10}\tau_{ij} + klog_{10}r_{ij} - log_{10}\varepsilon_i \tag{2}$$

If it is assumed that the value of c is 1, then the results of the rescale of the time, distance, and depth components are as follows:

$$T_{ij} = \tau_{ij} 10^{-\frac{b(M_i - M_0)}{2}}, R_{ij} = r_{ij}^{k} 10^{-\frac{b(M_i - M_0)}{2}}, E_i = \varepsilon_i 10^{-\frac{b(M_i - M_0)}{2}} \tag{3}$$

So that Eq. (2) becomes the following equation:

$$log_{10}\, \eta_{ij} = \begin{cases} log_{10}\, T_{ij} + log_{10}\, R_{ij} - log_{10}\, E_i & \tau_{ij} \geq 0 \\ \infty & \tau_{ij} < 0 \end{cases} \tag{4}$$

Equations (2), (3) and (4) define the empirical relationship of the nearest neighbourhood distance (η) to the joint distribution of (T, R, E) [4].

2.2.2 K-Means method

Clustering is the classification of a number of data points into a group that has similar characteristics [8]. The K-Means method, which iteratively searches for the cluster centre based on the distance of each data point to the cluster centre, is one of the effective and straightforward clustering strategies [39]. The steps are follow [30]:

i. First step
Identified the data to be grouped, $x_{ij}(i = 1,2, \dots, n; j = 1,2, \dots, m)$, *n* is number of data to be clustered, and *m* is amount of variable.

ii. Second step
The centres of each cluster are independently set at the beginning of the iteration, where $c_{kj} = (k = 1,2, \dots, K, j = 1, \dots, m)$

iii. Third step
The formula in the following Eq. (5) can be used to determine the distance between each data point and each cluster.

$$d_{ij} = \sqrt{\sum_{j=1}^{m}\left(x_{ij} - c_{kj}\right)^2}. \tag{5}$$

iv. Fourth step
The data that will become a member of cluster j is the data that has the smallest distance to the centre of cluster j when compared to the distance to the centre of other clusters.

v. Fifth step
Clustering the data into members in each cluster.

vi. Sixth step
The new cluster centre value is calculated using the formula in the following equation:

$$c_{kj} = \frac{\sum_{h=1}^{p} y_{hj}}{p}; y_{hj} = x_{hj}\epsilon, \text{cluster } kth, p \text{ is amount of cluster } kth \tag{6}$$

vii. Seventh step
Repeat steps two and five until no more members of the cluster centre have moved.

2.2.3 Elbow method

The optimal number of clusters in this study was determined using the Elbow Method. The procedure is to compare the percentage of the results to the number of clusters that will form an elbow at a point by using a graph as an information aid [22,39]. Use the Sum of Square Error (SSE) formula for each cluster in Eq. (7) below to determine the comparison value:

$$SSE = \sum_{k=1}^{K}\sum_{i=1}^{n}\left|x_{h,i} - V_{h,k}\right|^2 \tag{7}$$

Where K denotes the number of clusters in W_h, $x_{h,i}$ is the distance of the *i*th object data in the region that has the hth EDRI, and $V(h,k)$ is the center of cluster. Figure 1 shows a visual representation of the elbow method:

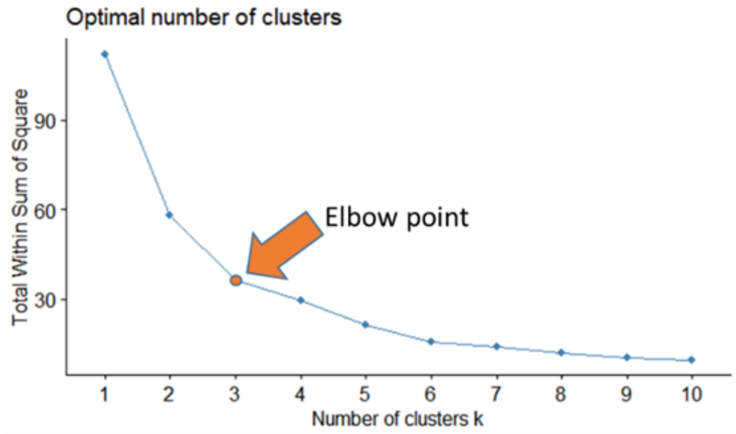


Fig. 1. Elbow Point Curve Illustration

In Figure 1, the orange elbow points indicate the optimal number of clusters is 3.

2.2.4 Fuzzy time series

Interest rates and coupon amounts are predicted using the fuzzy time series method. The approach is FTS Singh (FTSS). The following are the steps that were taken in FTSS fuzzy time series [38].

i. Using the range of historical time series data that are available, define the discourse universe (U) according to the formula $U = [D_{min} - D_1, D_{max} - D_2]$, where D_1 and D_2 are two proper positive numbers.
ii. Partition the U into equal length of intervals: $u_1, u_2, \dots, u_m$. The amount of interval will be in accordance with the number of linguistic variables (fuzzy sets($(A_1, A_2, \dots, A_m)$ to be considered.
iii. Apply the triangular membership rule to each interval in each set to generate the fuzzy sets A_i in accordance with the intervals from Step 2.
iv. Fuzzified the observed data and form a fuzzy logical relationship (FLR) using the following rules: if A_i is fuzzy production in year *n*th and A_j is fuzzy production in year $(n+1)$th, then FLR is denoted as $A_i \rightarrow A_j$. Pat this stage A_i, A_j are current state and *next state*.
v. Rules forecasting

The notation used in forecasting is as follows: $[A_j^*]$ corresponds to the interval u_j for which membership in A_j is a supremum, $L[A_j^*]$ is the lower limit of u_j, $U[A_j^*]$ is the upper limit of u_j, $l[A_j^*]$ is the interval of u_j, $M[A_j^*]$ is middle point of u_j, which have the supremum in A_j.

Notation for FLR is $A_i \rightarrow A_j$, A_i represents the fuzzified of interest rate or coupon in the year *n*th, A_j represents fuzzified of interest rate or coupon in year $(n+1)$th, E_i is the actual interest rate or coupon in the year *n*th, E_{i-1} is the actual interest rate or coupon in the year $(n-1)$th, E_{i-2} is the actual interest rate and coupon in the year $(n-2)$th, F_j is the result of forecasting. Forecasting in this method uses three years observational data sets: $n-2, n-1, n$ to implement FLR $A_i \rightarrow A_j$, the rules used in FTSS forecasting are as follows:

$for\ k = 3\ to\ \ldots.K$ (End of time series data)
Obtained FLR for year k to $k+1$
$A_i \rightarrow A_j$
Compute
$D_i = ||(E_i - E_{i-1}| - |E_{i-1} - E_{i-2}||$
$X_i = E_i + \frac{D_i}{2}$
$XX_i = E_i - \frac{D_i}{2}$
$Y_i = E_i + D_i$
$YY_i = E_i - D_i$
For $I = 1\ to\ 4$
$if\ X_i \geq L[A_j^*]$ and $X_i \leq U[A_j^*]$
Then $P_1 = X_i; n = 1$
Else $P_1 = 0; n = 0$
Next, I
If $XX_i \geq L[A_j^*]$ and $XX_i \leq U[A_j^*]$
Then $P_2 = XX_i; m = 1$
Else $P_2 = 0; m = 0$
Next, I
If $Y_i \geq L[A_j^*]$and $Y_i \leq U[A_j^*]$
Then $P_3 = Y_i; o = 1$
Else $P_3 = 0; o = 0$
Next, I
If $YY_i \geq L[A_j^*]$ and $YY_i \leq U[A_j^*]$
Then $P_4 = 0; p = 0$
$B = P_1 + P_2 + P_3 + P_4$
If $B = 0$ Then $F_j = M[A_j^*]$
Else $F_j = \frac{(B+M[A_j^*])}{m+n+o+k+l}$
Next k

2.2.5 Generalized pareto distribution

Let M be the ekstrim magnitude, which is known by the POT method, then the cumulative distribution function (CDF) can be approximated by GPD [10] with shape parameter $\kappa(\kappa \in \mathfrak{R})$, location scale $\boldsymbol{\xi}(\boldsymbol{\xi} \in \mathfrak{R})$ and scale parameter $\sigma(\sigma > 0)$ defined as follows:

$$F(M|\kappa, \xi, \sigma) = \begin{cases} 1 - \left(1 - \kappa\left(\frac{m-\xi}{\sigma}\right)\right)^{\frac{1}{\kappa}} & \kappa \neq 0 \\ 1 - e^{-\frac{M-\xi}{\sigma}} & \kappa = 0 \end{cases} \tag{8}$$

For $\kappa \leq 0$ $(\xi \leq M < \infty)$, $\kappa > 0(\xi \leq M < \xi + \frac{\sigma}{\kappa})$ [46]. Parameter estimation for GPD using EasyFit software.

2.2.6 Kolmogorov-Smirnov test

The KS test was conducted to determine the theoretical distribution of observational data. The KS test focuses on the larger deviation between the empirical distribution ($\mathrm{F_0(X)}$) and theoretical distribution ($\mathrm{S_N(X)}$) [31], which is calculated using the following equation as follows:

$$D_{count} = max\,|F_0(X) - S_n(X)| \tag{9}$$

H_0: the data fit the theoretical distribution
H_1: the data does not fit the theoretical distribution
If $D_{count} < D_{table}$, then accept the H_0, outside, and vice versa.

2.2.7 Regression analysis

Regression analysis is used to analyse the effect of interest rates and coupons on disaster bond prices. RStudio is used for regression analysis and classical assumption tests (normality, heteroscedasticity, multicollinearity, and linear regression).

3. Results and Discussion
3.1 DECBP Modelling
3.1.1 Decomposition of the disaster area using earthquake parameters and STDM distance

The characteristics of natural disaster risk by considering three basic components, namely exposure, vulnerability, and hazard, that can represent the impact of disasters such as losses and casualties [28]. This research uses the Earthquake Disaster Risk Index (EDRI), which can be modelled to take into account the Risk Index [29], in this research uses *Earthquake Disaster Risk Index* (EDRI). The severity of an earthquake depends on the location, magnitude, and depth of earthquake [3,6], In addition to the STDM distance, earthquake parameters can be used to reveal spatial temporal dependent earthquake characteristics [4]. The basic idea of the proposed DECBP Model for a single period is to decompose the region into groups that have similar characteristics based on EDRI, average earthquake parameters (depth, magnitude), and STDM distance, which are finally combined together and offered to investors as a single bond. Two steps to decompose the region are:

i. Region clustering based on EDRI data
It is assumed that W has different region ($w = 1,2,\dots,W$), where $w \in \Omega$ with Ω is region of perils covered. For $\forall w$, they will be included in the cluster that has the same EDRI category. Suppose K_r is a class group that has $r = 1,2,3$, where $r = 1$ (low category), $r = 2$ (medium category), $r = 3$ (high category). K_r^w denotes members of the class group K_r with the assumption are: $\bigcap_{r=1}^{3} K_r^w = \emptyset, w = 1,2,\dots,W; \bigcup_{r=1}^{w} K_r^w = \Omega: P(K_r^w) > 0$.

ii. Region clustering based on earthquake parameter (depth and magnitude), and STDM distance
The first step, we determine average of depth ($\bar{D}_r^w$), average of magnitude ($\bar{M}_r^w$), and average of STDM distance($\overline{\eta_{\iota J}}_r^w$), $\forall K_r^w$. Next will be grouping using the K-Means method, which has been described in Section 2.2.2, to obtain the optimal number of clusters using the elbow method in Section 2. 2.2.3. The result of this stage will be denoted $K_{rp}^w, w = 1,2,\dots,W, r = 1,2,3, n = 1,2,\dots,P$, where P is amount of cluster K_r^w, with the

assumption are $\bigcap_{p=1}^{P} K_{rp}^{w} = \emptyset; w = 1,2,\dots,W; \bigcup_{p=1}^{P} K_{rp}^{w} = \Omega, P\left(K_{rp}^{w}\right) > 0$. The purpose of this step is to classify areas based on the similarity of the average depth, earthquake magnitude, and STDM distance between earthquakes in each region in the *r* class group. Eq. (4) is used to calculate the STDM distance. For additional implications of notation, K_{rp}^{w} will be denoted $R_j, j = 1,2,3,\dots,J$, where *J* is the number of grouping areas, R_j is a group of earthquake areas that have been grouped based on EDRI, earthquake magnitude, depth of earthquake, and STDM distance. The order of the regional groups is sorted by non-earthquake prone areas to the earthquake-prone areas.

3.1.2 DECB payoff function

The payoff function depends on the trigger condition that occurs. In previous studies, the payoff function on Cat Bond was modelled in the form of a binary linear function [12,18,20,23,25,33,42] and *piecewise linear function* [20,23,33,48]. In the proposed model, the payoff function model uses piecewise linear because it can better describe the damage conditions caused by the earthquake. The payment diagram from DECBP for a single period is presented in Figure 2.

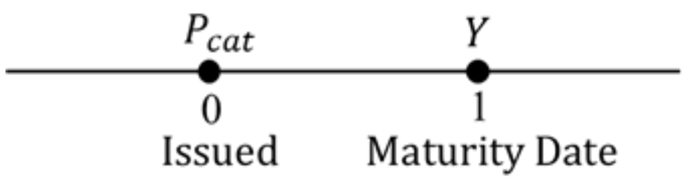


Fig. 2. Cash Value Diagram of Single Period

The scenario of a single period is that, at the time of issue, investor will buy earthquake catastrophe bond (P_{cat}) and will get a cash value (Y) at the end period. Which is defined as follows:

$$Y = \begin{cases} FV(1+C) & M \in (0,5) \\ FV(J_1+C) & M \in [5,6) \\ FV(J_2+C) & M \in [6,7) \\ FV(j_3+C) & M \in [7,8) \\ 0 & M \in (8,\infty) \end{cases} \tag{9}$$

FV is face value, $j_i, i = 1,2,3$ is the fractional of the face value ($j_3 < j_2 < j_1$), C is coupon rate, the value of j_i and *C* determined by the SPV. The determination of the limit in Eq. (9) is based on the trigger limit for the disaster bond following the Richter Scale of earthquake, which is presented in Table 1.

Table 1
Richter scale of earthquake magnitude

Magnitude level (SR)	category	effect
1.0 – 2.9	Micro	Generally not felt by people, though recorded on local instrument
3.0 – 3.9	Minor	Felt by many people, no damage
4.0 – 4.9	Light	Felt by all; minor breakage of objects
5.0 – 5.9	Moderate	Some damage to weak structure
6.0 – 6.9	Strong	Moderate damage in populated areas
7.0 – 7.9	Major	Serious damage over large areas; loss of life
> 8	Great	Severe destruction and loss of live over large areas

Source: https://www.britannica.com/science/Richter-scale

The amount of cash value (Y) received by the earthquake catastrophe bondholder at the end of the period depends on the trigger of the earthquake that occurred. If there is no trigger until the end of maturity, the boxholders will get $FV + R$. If the earthquake trigger occurs in the interval [5,6), then the bondholders get $j_1 FV + R$. If the trigger occurs in interval [6,7), then the bondholder will get $j_2 FV + R$. If the trigger occurs in interval [7,8), then the bondholders will get $j_3 FV + R$. If the triggers more than 8 SR, then the bondholders will lose all face value and coupon.

3.1.3 Modelling the calculation of the total probability of an earthquake trigger

This model focuses on the extreme value of the earthquake magnitude obtained using POT method. In this study, the threshold used is $m_0 > 2.9\ Sr$, because the earthquake that can be felt in 3 SR. The data of magnitude earthquake from each regional will be approximated by the GPD defined in Eq. (8). The calculation of the probability of each trigger interval in Eq. (9) uses the concept of probability where the conditional condition of the decomposition region variables is assumed to be independent. Let $\{X_1, X_2, \dots X_n\}$ is different set from the *X* population, all of which are represented in sample *I*, then the probability of X, defined $P(X) = \sum P(I)P(X|I)$ (Zangeneh and Little 2015). In this research X_i defined by $X_1 = 0 < M < 5, X_2 = 5 \leq M < 6, X_3 = 6 < M \leq 7, X_4 = 7 \leq M < 8, X_5 = M \geq 8$, so the total probability of the events accordance to X_i, defined as follows:

$$P(X_i) = \sum_{j=1}^{J} P\left(R_j\right) P(X_i|R_j) \tag{10}$$

3.1.4 Interest and coupon rate prediction

Interest and coupon rate will be prediction using FTS, which has been describe in Section 3.2.1

3.1.5 DECB single period model

The notation used in the DECB single period model as follows:

FV : Face Value
R : free risk interest rate (in this study, using the result of Bank Indonesia's interest rate prediction using FTS)
e : extra premium burden to bear earthquake risk (usually positive quantity reflecting each buyer risk aversion)
C : coupon rate (in this study, using the result of the annual LIBOR interest rate prediction using FTS)
M : maximum earthquake magnitude, calculated by local magnitude
Y : *cash value* according to Eq. (9)
The DECB for a single period was formulated by:

$$P_{cat} = E_Q\left(e^{-(r+e)}.Y\right) \tag{11}$$

Q is the probability of an event corresponding to the M distribution. Due to the observed area being decompose into several groups based on EDRI, earthquake depth, and STDM distance denoted R_i , then the Eq. (11) become tod Eq. (12) as below:

$$P_{cat} = e^{-(r+e)}\left(\sum_{i=1}^{5} P(X_i)\, Y_{X_i}\right) \tag{12}$$

3.2 Illustrative Example

3.2.1 Decomposition region based on EDRI

Indonesia's West Java Province consists of 27 regencies, or cities. Based on the EDRI score, the region is divided into areas with a high, medium, and low earthquake risk index. The regions with high, medium, and low EDRI categories are presented in Table 2.

Table 2
The results of the grouping of the West Java Province based on EDRI

EDRI Category	Cluster member
High	Banjar City, Tasikmalaya City, Sukabumi Regency, Bekasi City, Bandung Regency, Purwakarta Regency, Tasikmalaya Regency, Sukabumi City, Cirebon City, Bogor Regency, Depok City, West Bandung Regency, Cianjur Regency, Garut Regency, and Bandung City
Medium	Sumedang Regency, Kuningan Regency, Cimahi City, Majalengka Regency, Ciamis Regency, Subang Regency, Pangandaran Regency, Karawang Regency, Bogor City, Bekasi Regency, and Cirebon Regency
Low	Indramayu Regency

Source: BNPB

The value of the EDRI for each regency/city in West Java Province is presented in Figure 3.

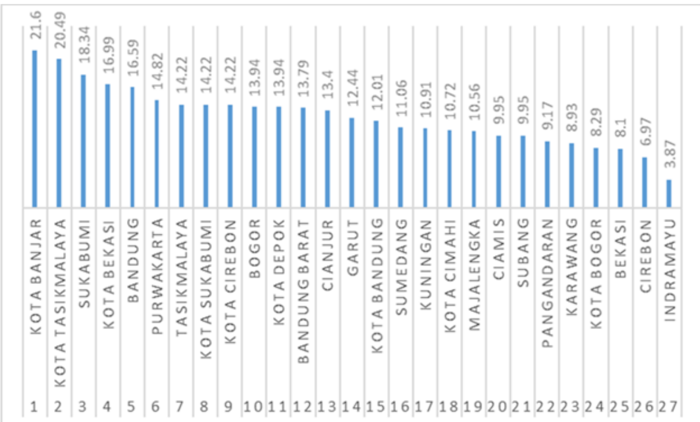


Fig. 3. EDRI of Jawa Barat Province 2021

Figure 3 shows that the EDRI score of Banjar City is the highest, while the lowest is Indramayu Regency. EDRI areas with a high category are in the interval 12.01 to 21.6; a medium category is in the interval 6.97 to 11.06; and a low category of 3.87, $K_1 = \{1,2,3,\ldots,15\}, K_2 = \{16,17,18,\ldots,26\}, K_3 = \{27\}$.

3.2.2 Clustering of regions based on depth, earthquake magnitude and distance STDM

At this stage, for each $K_r, r = 1,2,3$ will be clustered according to the average depth of the earthquake, the average magnitude of earthquake, and the average of STDM distance. The result of clustering for each region based on depth, magnitude and STDM distance represented in Figure 4, 5, and 6.

The point in Figure 4 shows the magnitude of the earthquake and the depth of the earthquake in an area that has a low EDRI score (Indramayu Regency). The earthquake with the highest strength occurred in 2021 at 4.6 on the Richter Scale. Based on the depth of the earthquake, this area was dominated by medium earthquakes; 1 deep earthquake, 4 medium earthquakes, and 2 shallow earthquakes.

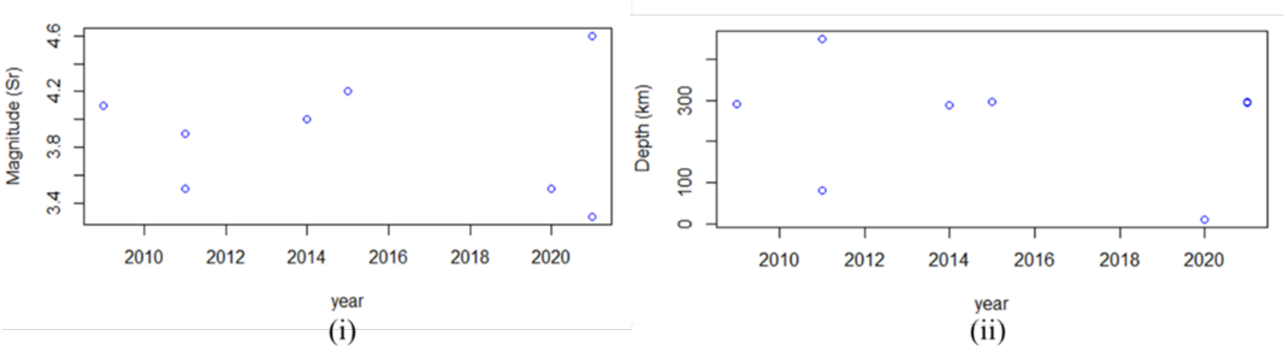


Fig. 4. Magnitude of earthquake plot (i), depth of earthquake plot (ii) in regions that have low ERDI

Figure 5 shows that there has been an earthquake with a magnitude of more than 5 SR with a shallow depth type. The number of earthquakes in the period 2009 to 2021 that were more than 2.9 on the Richter Scale is 244 earthquakes; 20, 21, 17, 2, 25, 11, 13, 22, 31, 13, 29, 23 (number of consecutive earthquakes from 2009 to 2021). The most earthquakes occurred in 2018, with 31 incidents. The highest earthquakes occurred in 2009 and 2017 at 5.8 on the Richter scale with a medium depth of 109.32 km (108.67 km). The highest frequency of earthquakes occurred in 2018, namely 75 earthquakes. When viewed from the depth of the earthquake, the EDRI area is being dominated by shallow earthquakes.

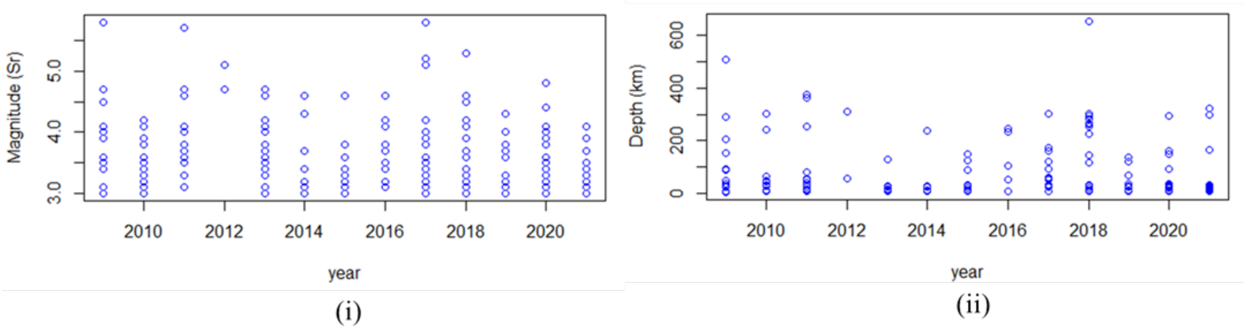
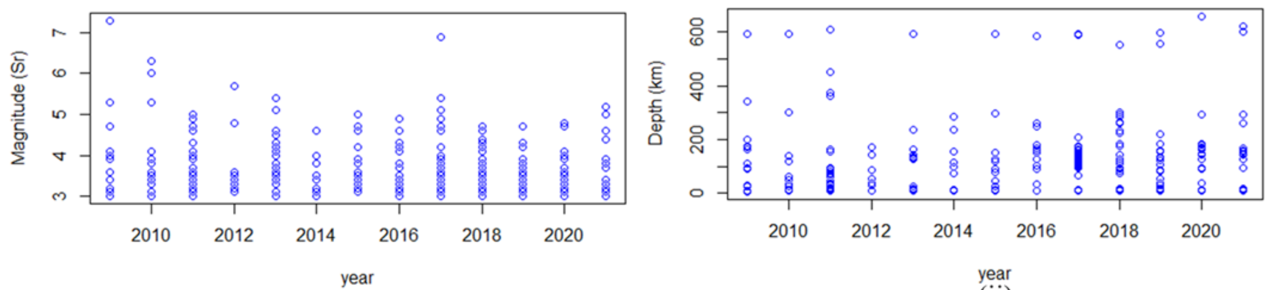


Fig. 5. Magnitude of earthquake plot (i), depth of earthquake plot (ii) in regions that have low ERDI

Figure 6 shows that earthquake occurrences in the high EDRI area are dominated by shallow earthquakes. Based on available data, this region has experienced an earthquake measuring 7.3 SR (shallow earthquake category) in 2009, 6.9 SR in 2017 (medium earthquake category), and 6.3 SR in 2010 (medium earthquake category). The earthquake that occurred in the high EDRI area caused high economic losses and caused casualties.



(i) (ii)

Fig. 6. Magnitude of earthquake plot (i), depth of earthquake (ii) in region that have medium EDRI

The number of earthquakes of more than 2.9 on the Richter Scale in the period 2009 to 2021 is 499 events; 25, 27, 43, 16, 35, 28, 23, 31, 49, 75, 40, 62, and 45 (number of earthquakes in sequence from 2009 to 2021). An STDM distance calculation can be done if the earthquake magnitude has an exponential distribution, which is defined as follows:

$$f(M,b') = b'e^{-b'(m-m_0)}, m \leq m \tag{13}$$

$b' = \frac{1}{\sum_{i=1}^{n}\frac{M_i}{n} - M_0}$, m_0 is the threshold [1,41], in illustration, we use m_0 is 2.9 SR. The result of KS test represented in Table 3.

Table 3
Kolmogorov-Smirnov Test

w	K_r	D_{hitung}	D_{Tabel}	b'
1		0.22313	0.842	5
2		0.118352	0.275568	1.100917
3		0.11288	0.228192	1.495726
4		0.143571	0.177264	0.90625
5		0.329193	0.842	2.101266
6		0.09675	0.389711	2.222222
7		0.118352	0.275568	1.100917
8	3	0.11288	0.228192	1.495726
9		0.071831	0.318	1.2223022
10		0.031246	0.178812	1.553134
11		0.031246	0.178812	1.553134
12		0.111403	0.409	1.66667
13		0.030955	0.128717	1.617647
14		0.044513	0.129307	1.679507
15		0.329193	0.842	2.222222
16		0.129672	0.483	1.590909
17		0.141997	0.375	1.276596
18		0.329193	0.842	2.222222
19		0.120961	0.483	0.886076
20	2	63802	0.139242	1.61235
21		0.113524	0.43	1.363636
22		0.075758	0.164929	1.522727
23		0.128261	0.318	1.14094
24		0.031246	0.178812	1.553134

25		0.28149	0.483	1.590909
26		0.071831	0.318	1.2223022
27	1	0.208065	0.4777297	1.22449

Based on the results of the calculations in Table 3, the earthquake magnitude data in each regency/city in West Java Province follows an exponential distribution because $D_{count} < D_{table}$. Next is the calculation of the average depth of the earthquake, earthquake magnitude, and STDM distance, which is summarized in Table 4.

Table 4
The value of *b*, *k,* the average of depth, magnitude and STDM distance

w	K_r	b	k	$\bar{D}$	$\bar{M}$	$\bar{\eta}$
1		2.17472	4.342945	116	3.1	24.35235
2		0.478122	0.956245	120.5833	4.095833	8.767356
3		0.649586	1.299172	39.536	3.568571	10.30031
4		0.393579	0.78159	259.7414	4.003448	7.465173
5		0.912568	1.825136	48.03614	3.375904	12.38068
6		0.965099	1.930198	30.08333	3.35	13.63105
7		0.478122	0.956245	120.5833	4.095833	8.767356
8	3	0.649586	1.299172	39.536	3.568571	10.30031
9		0.531152	1.062303	126.7647	3.717647	9.687361
10		0.674517	1.349035	78.14035	3.54386	10.246331
11		0.674517	1.349035	78.14035	3.54386	10.24633
12		0.723824	1.447648	81.77778	3.522222	11.29698
13		0.702535	1.40507	68.3211	3.505505	10.32763
14		0.729401	1.458801	47.87097	3.515054	10.73713
15		0.965099	1.930198	30	3.35	12.38068
16		0.690923	1.381846	89.91667	3.683333	10.42869
17		0.554418	1.108837	89.91667	3.683333	10.42869
18		0.965099	1.930198	18	3.35	14.78276
19		0.384818	0.769636	117.4286	4.028571	9.08751
20		0.700235	1.4000469	35.6381	3.485714	10.45767
21	2	0.59222	1.184439	105.6667	3.633333	10.30608
22		0.661312	1.322624	29.17647	3.554412	10.56207
23		0.495504	0.991008	204.4706	4.4382355	7.455105
24		0.674517	1.349035	78.14035	3.54386	10.24633
25		0.508217	1.016434	65.52344	3.600781	9.23
26		0.531152	1.062303	126.7647	3.717647	9.687361
27	1	0.531789	1.063578	224.2222	3.7	8.893394

Table 4 shows that Banjar City has the highest b value. This is due to the very small number of earthquakes of more than 2.9 on the Richter scale, namely 2 events. Meanwhile, Majalengka Regency has the lowest b value. The value of b shows the slope of the Frequency Magnitude Distribution (FMD) in the log plots that reflect the physical state of the observation area. The calculation of the value of b in each district/city in West Java Province has been calculated. A high b value indicates material heterogeneity and high stress can be endured. Conversely, a low value of b reflects high stiffness, so the area can accumulate higher stresses and release them suddenly. This issue is not clear and the variation in the value of b is still under discussion by experts [38]. Usually, the value of b is 1. For small-scale areas over a few to tens of kilometres, the spatial and temporal variations in the value of b can be very large. There are many factors that cause the deviation of the b value from its normal value. 1. An increase in material heterogeneity or crack density results in a high b value; an increase in the applied shear stress; or an increase in the effective stress decreases the b value. In addition, the accuracy of the b value is influenced by the low number of events.

i. Clustering of High ERDI Region

The clustering of high EDRI regions uses the K-Means method and the Elbow method to determine the optimal number of clusters with the help of RStudio software. Figure 7 shows that the optimal number of clusters is 3.

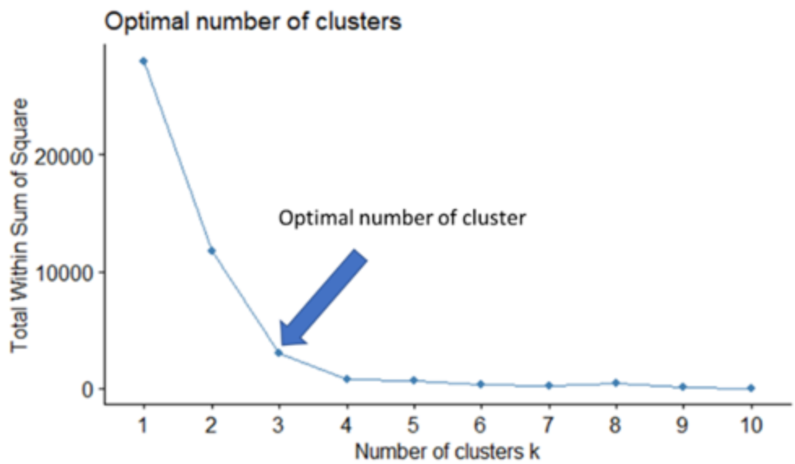


Fig. 7. Calculation of the optimal number of clusters in high EDRI areas using the Elbow method

The members of each cluster are presented in Table 5 below.

Table 5
The results of grouping high EDRI regions using the K-Means method

Cluster	Member of cluster
1	Sukabumi City, Bandung City, Purwakarta City, Sukabumi City, Cianjur Regency, Garut, Bandung City
2	Banjar City, Tasikmalaya City, Tasikmalaya Regency, Cirebon City, Bogor Regency, Depok City, West Bandung Regency
3	Bekasi City

The cluster centre is presented in Table 6 below. Table 6 shows that the data in cluster 1 is categorized as having low depth. The type of earthquake depth in cluster 2 is categorized as medium, while cluster 3 also has a medium earthquake category. But deeper than cluster 2. The order of STDM distance from shallowest to deepest is cluster 3, 1, and 2.

Table 6
The cluster centre of low EDRI region

Cluster	Depth	Magnitude	STDM distance
1	43.34051	3.461944	11.436827
2	103.14140	3.659894	11.909152
3	259.74140	4.003448	7.465173

ii. Clustering of medium EDRI region

The number optimal of cluster is 3, it shown in Figure 8.

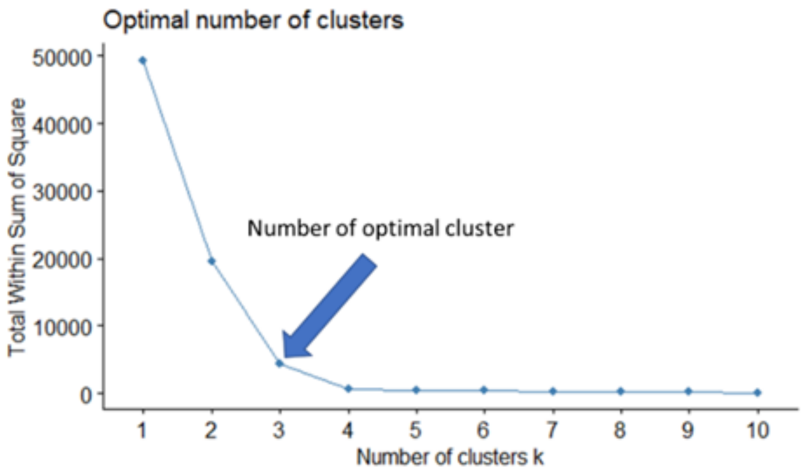


Fig. 8. Calculation of the optimal number of clusters in medium EDRI areas using the Elbow method

The member of cluster represented in Table 7.

Table 7
The results of grouping high EDRI regions using the K-Means method

cluster	The member of cluster
1	Cimahi City, Ciamis Regency, Pangandaran Regency, Cirebon Regency
2	Karawang Regency
3	Sumedang Regency, Kuningan Regency, Majalengka Regency, Subang Regency, Bogor City, Cirebon Regency

The cluster centre is presented in Table 8 below:

Table 8
The cluster centre of medium EDRI region

Cluster	Depth	Magnitude	STDM distance
1	37.0845	3.497727	11.258125
2	204.4706	4.438236	7.455105
3	101.3056	3.715013	10.030777

Based on Table 8, it shows that earthquakes in the EDRI category are categorized as shallow to medium. Cluster 1 has a shallow earthquake category, Cluster Two is medium, and Cluster Three has a medium earthquake category, but is deeper than the second cluster. The order of earthquake magnitude from smallest to largest is clusters 1, 2, and 3. The STDM distance from closest to furthest is clusters 2, 3, and 1.

iii. Clustering of low EDRI region

In low EDRI areas, no grouping is carried out because the members are only from one region, namely Indramayu Regency.

Based on the results of the grouping using the EDRI grouping and the K-means method, it was found that 7 regions consisting of districts/cities have similar earthquake characteristics. The members of the final cluster are as follows:

Table 9
The final region

R_j	Member of cluster
1	Indramayu Regency
2	Karawang Regency
3	Sumedang Regency, Kuningan Regency, Majalengka Regency, Subang Regency, Bogor City, Cirebon Regency
4	Sumedang Regency, Kuningan Regency, Majalengka Regency, Subang Regency, Bogor City, Cirebon Regency
5	Bekasi city
6	Banjar City, Tasikmalaya City, Tasikmalaya Regency, Cirebon City, Bogor Regency, Depok City, West Bandung Regency
7	Sukabumi City, Bandung City, Purwakarta City, Sukabumi City, Cianjur Regency, Garut, Bandung City

The final cluster results are in Table 9, sorted from the areas with the lowest to highest EDRI and the smallest to the largest possible losses due to earthquakes.

3.3 Total Probability

Before calculating the total probability, the first step is to test the fit of the data using the KS test with the help of EasyFiT. The significant level used is 0.01.

3.3.1 KS test

The KS test was carried out to determine the theoretical distribution of the earthquake magnitude data distribution in each grouping area according to Table 9. Processing the data in this test using EasyFit software. The theoretical distributions to be tested are GPD, Exponential, Pareto, and Beta.

i. **First region**
The result of the KS test is shown by Table 10.

Table 10
KS test for data magnitude in first region

No	Distribution	Statistik value	$\alpha = 0.01$
1	GPD	0.13756	0.51332
2	Exponential (2p)	0.2601	0.51332
3	Pareto	0.27601	0.51332
4	Beta	0.21844	0.51332

Based on Table 10, the statistical value of the KS test in all the distributions has a value less than the critical value of 0.513221. This indicates that the two distributions are suitable for approaching earthquake magnitude data. However, the most suitable one should be chosen. The most suitable theoretical distribution has the smallest statistical value. GPD has the smallest statistical value of 0.24567. Therefore, the GPD distribution was chosen as the most suitable theoretical distribution to describe the distribution of extreme earthquake magnitude data.

ii. **Second Region**
The result of the KS test is shown by Table 11.

Table 11
KS test for data magnitude in second region

No	Distribution	Statistic value	$\alpha = 0.01$
1	GPD	0.12851	0.33666
2	Exponential (2p)	0.18525	0.33666
3	Pareto	0.21218	0.33666
4	Beta	0.18182	0.33666

Table 11 reveals that all theoretical distributions' statistical test values are lower than their statistical values (0.33666). However, GPD, which has a statistical value of 0.12851, is the theoretical distribution that was selected as the most appropriate to reflect the distribution of extreme earthquake magnitude data in region 2.

iii. Third region

The result of the KS test is shown by Table 12.

Table 12
KS test for data magnitude in third region

No	Distribution	Statistic value	$\alpha = 0.01$
1	GPD	0.10815	0.21768
2	Exponential (2p)	0.13798	0.21768
3	Pareto	0.16613	0.21768
4	Beta	0.15952	0.21768

As shown in Table 10, the statistical test value of all theoretical distributions is less than the statistical value (0.18144). However, the theoretical distribution that has the smallest statistical value is GPD, which is 0.21768, so it was chosen as the most suitable theoretical distribution to describe the distribution of extreme earthquake magnitude data in region 3.

iv. Fourth region

The result of the KS test is shown by Table 12.

Table 13
KS test for data magnitude in fourth region

No	Distribution	Statistic value	$\alpha = 0.01$
1	GPD	0.07985	0.12568
2	Exponential (2p)	0.10119	0.12568
3	Pareto	0.11863	0.12568
4	Beta	0.18013	0.12568

Based on Table 13, the statistical value of the KS test distribution of all theoretical distributions is less than the statistical value (0.12568). However, the theoretical distribution that has the smallest statistical value is GPD, which is 0.07985, so it was chosen as the most suitable theoretical distribution to describe the distribution of extreme earthquake magnitude data in region 4.

v. Fifth region

The result of the KS test is shown by Table 14.

Table 14
KS test data magnitude in for fifth region

No	Distribution	Statistic value	$\alpha = 0.01$
1	GPD	0.08914	0.21019
2	Exponential (2p)	0.20912	0.21019
3	Pareto	0.24076	0.21019
4	Beta	0.09633	0.21019

Table 14 shows that the statistical value of the KS test for the Pareto distribution, exponential (2p), and GPD is less than the statistical value (0.17519). However, GPD, which has a statistical value of 0.2109, is the theoretical distribution that was selected as the most appropriate to reflect the distribution of extreme earthquake magnitude data in region 5.

vi. Sixth Region

The result of the KS test is shown by Table 15.

Table 15
KS test for data magnitude in sixth region

No	Distribution	Statistic value	$\alpha = 0.01$
1	GPD	0.0772	0.16846
2	Exponential (2p)	0.14859	0.16846
3	Pareto	0.14286	0.16846
4	Beta	0.14802	0.16846

Based on Table 15, the statistical value of the KS test throughout the theoretical distribution is less than the statistical value (0.168469). However, the theoretical distribution that has the smallest statistical value is GPD, which is 0.07729, so it was chosen as the most suitable theoretical distribution to describe the distribution of extreme earthquake magnitude data in region 6.

vii. Seventh Region

The result of the KS test is shown by Table 16.

Table 16
KS test for the data magnitude in region seventh

No	Distribution	Statistic value	$\alpha = 0.01$
1	GPD	0.08978	0.08848
2	Exponential (2p)	0.13754	0.08848
3	Pareto	0.13754	0.08848
4	Beta	0.09281	0.08848

The statistical value of the KS GPD test was chosen as the best appropriate theoretical distribution to reflect the distribution of extreme earthquake magnitude data in region 7 based on Table 16's statistical value being less than the statistical value (0.08848).

3.3.2 GPD distribution parameter estimated value

Using the EasyFit software, the following results were obtained. Table 17, shows that the value of each parameter from each region is different and has a different M domain. If $\kappa < 0$, then the domain is $M \geq \mu$. If, $\kappa < 0$, then the domain is $\mu \leq M \leq \mu + \frac{\sigma}{\kappa}$.

Table 17
Parameter estimation of GPD distribution

No	Region	κ	σ	μ	Domain of M
1	Region 1	-2.2547	5.3852	2.0454	$M \geq 2.0454$
2	Region 2	-0.61016	0.80344	3.6856	$M \geq 3.6856$
3	Region 3	-0.3266	0.95237	2.9802	$M \geq 2.9802$
4	Region 4	-0.2043	0.67942	2.971	$M \geq 2.971$
5	Region 5	-0.79413	1.9312	2.927	$M \geq 2.927$
6	Region 6	0.15227	0.61706	2.9501	$2.9501 \leq M$ <4.130624
7	Region 7	-0.0740	0.53185	2.9862	$M \geq 2.9862$

3.3.3 Total probability

The notation used in the total probability calculation is $P(R_i)$, which is the probability of an earthquake occurring in $R_i, i = 1,2,\ldots,7$, where the calculation is obtained by dividing the number of earthquakes that are more than 3 SR in the R_i region by the number of earthquakes in $P\ (m_a \leq M < m_z|R_i)$ denotes the likelihood of an earthquake occurring in the interval $[m_a, m_z]$ in R_i.Table 18 shows the results of the $P\ (m_a \leq M < z|R_i)$ calculation.

Table 18
The result of $P(m_a \leq M < m_z|R_i)$ dan $P(R_i)$

Region	$P(0 < x \leq 5)$	$P(5 < x \leq 6)$	$P(6 < x \leq 7)$	$P(7 < x \leq 8)$	$P(x > 8)$	$P(R_i)$
1	0.300298	0.051266	0.040764	0.033454	0.574218	0.011984
2	0.404933	0.157615	0.099805	0.067646	0.270001	0.029294
3	0.8004	0.08614	0.043021	0.0238401	0.046599	0.071904
4	0.902841	0.055135	0.021474	0.00954	0.01101	0.223702
5	0.539907	0.102648	0.067761	0.047737	0.241947	0.07723
6	0.990239	0.009657	0.000104	0	0	0.121172
7	0.964492	0.026701	0.006318	0.001705	0.000784	0.464714

The notation used in calculating the total probability is as follows:
A : $M \in (0,5)$
B : $M \in [5,6)$
C : $M \in [6,7)$
D : $M \in [7,8)$
E : $M \in [8,\infty)$
The total probability of each event A, B, C, D, or E is as follows:
$P(A) = \sum_{i=1}^{7} P(R_i).P(0 < M < 5) = 0.884879$
$P(B) = \sum_{i=1}^{7} P(R_i).P(5 \leq M < 6) = 0.045265$
$P(C) = \sum_{i=1}^{7} P(R_i).P(6 \leq M < 7) = 0.019491$
$P(B) = \sum_{i=1}^{7} P(R_i).P(7 \leq M < 8) = 0.000792$
$P(B) = \sum_{i=1}^{7} P(R_i).P(M \geq 8) = 0.039654$

3.3.4 Interest and coupon rate prediction using FTSS
3.3.4.1 Interest rate prediction

The monthly BI interest rate statistics issued by Bank Indonesia between 2009 and 2010 are the data utilized in the interest rate projection. The following are the outcomes of the interest rate forecast computation performed by FTS Singh:

Step 1. Defines the universal discourse of interest rates, $U = [3,9]$
Step 2. Partitioning the set *U* into 9 intervals (linguistic values)

$$u_1 = [3,3.66667], u_2 = [3.66667,4.33333], u_3 = [4.33333,5], u_4 = [5,5.66667], u_5 = [5.66667,6.33333], u_6 = [6.33333,7], u_7 = [7,7.66667], u_8 = [7.66667,8.33333], u_9 = [8.33333,9]$$

Step 3. Define the nine fuzzy sets $A_1, A_2, \ldots A_9$ as linguistic variables in the universal set U, which is defined as follows:

Table 19
Linguistic variable interest rate

A_1	Smaller interest rate
A_2	Smallest interest rate
A_3	Small interest rate
A_4	Below average interest rate
A_5	Average interest rate
A_6	Upper interest rate
A_7	High interest rate
A_8	Highest interest rate
A_9	Higher interest rate

The membership function of the linguistic variable is defined as follows:

$$\begin{aligned}
A_1 &= \frac{1}{u_1} + \frac{0.5}{u_2} + \frac{0}{u_3} + \frac{0}{u_4} + \frac{0}{u_5} + \frac{0}{u_6} + \frac{0}{u_7} + \frac{0}{u_8} + \frac{0}{u_9} \\
A_2 &= \frac{0.5}{u_1} + \frac{1}{u_2} + \frac{0.5}{u_3} + \frac{0}{u_4} + \frac{0}{u_5} + \frac{0}{u_6} + \frac{0}{u_7} + \frac{0}{u_8} + \frac{0}{u_9} \\
A_3 &= \frac{0}{u_1} + \frac{0.5}{u_2} + \frac{1}{u_3} + \frac{0.5}{u_4} + \frac{0}{u_5} + \frac{0}{u_6} + \frac{0}{u_7} + \frac{0}{u_8} + \frac{0}{u_9} \\
A_4 &= \frac{0}{u_1} + \frac{0}{u_2} + \frac{0.5}{u_3} + \frac{1}{u_4} + \frac{0.5}{u_5} + \frac{0}{u_6} + \frac{0}{u_7} + \frac{0}{u_8} + \frac{0}{u_9} \\
A_5 &= \frac{0}{u_1} + \frac{0}{u_2} + \frac{0}{u_3} + \frac{0.5}{u_4} + \frac{1}{u_5} + \frac{0.5}{u_6} + \frac{0}{u_7} + \frac{0}{u_8} + \frac{0}{u_9} \\
A_6 &= \frac{0}{u_1} + \frac{0}{u_2} + \frac{0}{u_3} + \frac{0}{u_4} + \frac{0.5}{u_5} + \frac{1}{u_6} + \frac{0.5}{u_7} + \frac{0}{u_8} + \frac{0}{u_9} \\
A_7 &= \frac{0}{u_1} + \frac{0}{u_2} + \frac{0}{u_3} + \frac{0}{u_4} + \frac{0}{u_5} + \frac{0.5}{u_6} + \frac{1}{u_7} + \frac{0.5}{u_8} + \frac{0}{u_9} \\
A_8 &= \frac{0}{u_1} + \frac{0}{u_2} + \frac{0}{u_3} + \frac{0}{u_4} + \frac{0}{u_5} + \frac{0}{u_6} + \frac{0.5}{u_7} + \frac{1}{u_8} + \frac{0.5}{u_9} \\
A_9 &= \frac{0}{u_1} + \frac{0}{u_2} + \frac{0}{u_3} + \frac{0}{u_4} + \frac{0}{u_5} + \frac{0}{u_6} + \frac{0}{u_7} + \frac{0.5}{u_8} + \frac{1}{u_9}
\end{aligned} \tag{14}$$

Step 4. Defuzzification interest rate data and build fuzzy logical relations, and then define Fuzzy Relation Groups (FRG). The FRGs are as follows:

$$A_1 \rightarrow A_1; A_2 \rightarrow A_1; A_2, A_3, A_3 \rightarrow A_2; A_3, A_4; A_4 \rightarrow A_3, A_4, A_5; A_5 \rightarrow A_4, A_5, A_6; A_6 \rightarrow A_4, A_5, A_6, A_6, A_7; A_7 \rightarrow A_6, A_7, A_8; A_8 \rightarrow A_7, A_8; A_9 \rightarrow A_8 \tag{15}$$

Step 5. Doing forecasting using the rules that have been discussed in section 3.2.1. Visualization of interest rate forecasting results using FTS Singh is presented in Figure 9.

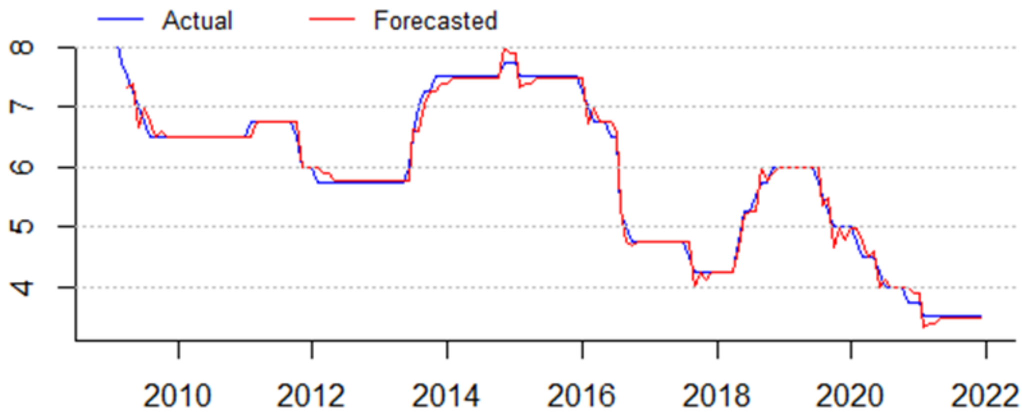


Fig. 9. Actual VS Forecasting Interest Rate

The forecasting results in Figure 9 show that the curve of the forecasting interest rate is almost similar to the actual curve, with a Means Square of Error value of 1.4%. This shows that the forecasting results using FTS Singh are very good. The predicted interest rate yield is 3.48719%. The predicted interest rate will be used in determining the price of earthquake bonds for a single period.

3.3.4.2 Coupon rate prediction

Coupon rate predictions use monthly Libor data for the period 2009 to 2021. The results of the calculation of interest rate predictions using FTS Singh are as follows:

Step 1. Defines the universal discourse of interest rates, $U = [0,4]$.
Step 2. Partitioning the set U into 9 intervals (linguistic values)

$$u_1 = [0, 0.4444], u_2 = [0.4444, 0.8889], u_3 = [0.8889, 1.3333], u_4 = [1.3333, 1.7778], u_5 = [1.7778, 2.2222], u_6 = [2.2222, 2.6667], u_7 = [2.6667, 3.1111], u_8 = [3.1111, 3.5556], u_9 = [3.5556, 4]$$

Step 3. Define the nine fuzzy sets $A_1, A_2, \ldots A_9$ as linguistic variables in the universal set U, which is defined as follows:

Table 20
Linguistic variable interest rate

A_1	Smaller coupon rate
A_2	Smallest coupon rate
A_3	Small coupon rate
A_4	Below average coupon rate
A_5	Average coupon rate
A_6	Upper coupon rate
A_7	High coupon rate
A_8	Highest coupon rate
A_9	Higher coupon rate

The membership function of the linguistic variable is defined as follows:

$$\begin{aligned}
A_1 &= \frac{1}{u_1}+\frac{0.5}{u_2}+\frac{0}{u_3}+\frac{0}{u_4}+\frac{0}{u_5}+\frac{0}{u_6}+\frac{0}{u_7}+\frac{0}{u_8}+\frac{0}{u_9}\\
A_2 &= \frac{0.5}{u_1}+\frac{1}{u_2}+\frac{0.5}{u_3}+\frac{0}{u_4}+\frac{0}{u_5}+\frac{0}{u_6}+\frac{0}{u_7}+\frac{0}{u_8}+\frac{0}{u_9}\\
A_3 &= \frac{0}{u_1}+\frac{0.5}{u_2}+\frac{1}{u_3}+\frac{0.5}{u_4}+\frac{0}{u_5}+\frac{0}{u_6}+\frac{0}{u_7}+\frac{0}{u_8}+\frac{0}{u_9}\\
A_4 &= \frac{0}{u_1}+\frac{0}{u_2}+\frac{0.5}{u_3}+\frac{1}{u_4}+\frac{0.5}{u_5}+\frac{0}{u_6}+\frac{0}{u_7}+\frac{0}{u_8}+\frac{0}{u_9}\\
A_5 &= \frac{0}{u_1}+\frac{0}{u_2}+\frac{0}{u_3}+\frac{0.5}{u_4}+\frac{1}{u_5}+\frac{0.5}{u_6}+\frac{0}{u_7}+\frac{0}{u_8}+\frac{0}{u_9}\\
A_6 &= \frac{0}{u_1}+\frac{0}{u_2}+\frac{0}{u_3}+\frac{0}{u_4}+\frac{0.5}{u_5}+\frac{1}{u_6}+\frac{0.5}{u_7}+\frac{0}{u_8}+\frac{0}{u_9}\\
A_7 &= \frac{0}{u_1}+\frac{0}{u_2}+\frac{0}{u_3}+\frac{0}{u_4}+\frac{0}{u_5}+\frac{0.5}{u_6}+\frac{1}{u_7}+\frac{0.5}{u_8}+\frac{0}{u_9}\\
A_8 &= \frac{0}{u_1}+\frac{0}{u_2}+\frac{0}{u_3}+\frac{0}{u_4}+\frac{0}{u_5}+\frac{0}{u_6}+\frac{0.5}{u_7}+\frac{1}{u_8}+\frac{0.5}{u_9}\\
A_9 &= \frac{0}{u_1}+\frac{0}{u_2}+\frac{0}{u_3}+\frac{0}{u_4}+\frac{0}{u_5}+\frac{0}{u_6}+\frac{0}{u_7}+\frac{0.5}{u_8}+\frac{1}{u_9}
\end{aligned} \tag{16}$$

Step 4. Defuzzification interest rate data and build fuzzy logical relations, and then define Fuzzy Relation Groups (FRG). The FRGs are as follows:

$$\begin{aligned}
&A_1 \to A_1, A_2; A_2 \to A_1, A_2, A_3; A_3 \to A_2, A_3, A_4, A_5; A_4 \to A_3, A_4, A_5; A_5 \to A_4, A_5, A_6;\\
&A_6 \to A_5, A_6, A_7; A_7 \to A_6, A_7, A_8; A_8 \to A_7, A_9 \to NA
\end{aligned} \tag{17}$$

Step 5. Doing forecasting using the rules that have been discussed in section 3.2.1. A visualization of the results of interest rate forecasting using FTS Singh is presented in Figure 7.

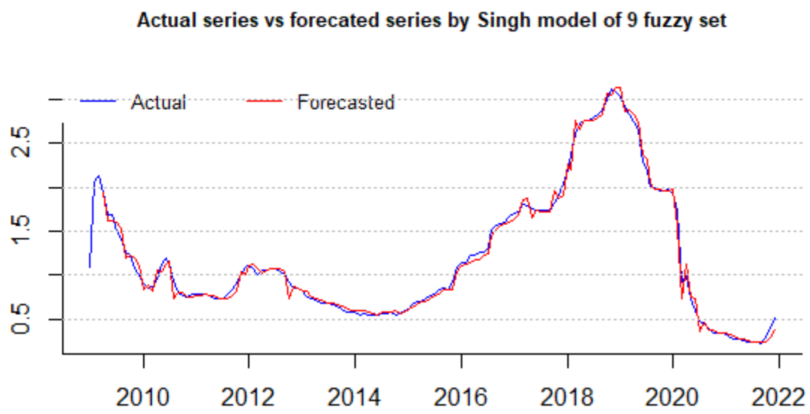


Fig. 10. Actual VS Forecasting Coupon Rate

The forecasting results in Figure 10 show that the curve of the forecasting coupon rate is similar to the actual curve, with a Means Square of Error value of 0.4%. This shows that the forecasting results using FTS Singh are very good. The predicted coupon rate result is 0.535. The amount of the predicted coupon rate will be used in determining the price of earthquake disaster bonds for a single period.

3.3.5 Calculation of catastrophe bond prices by region decomposition

We use $r = 3.48719\,\%, \mathrm{e} = 5\%, \mathrm{C} = 0.535\%, \mathrm{FV} = \mathrm{Rp}1{,}000{,}000, \mathrm{j}_1 = 67\%, j_2 = 33\%, j_3 = 22\%$, Then the price of earthquake catastrophe bonds for a single period by decomposition is RP.

909,131. The payoff function to be received by disaster bondholders at the end of the period as follows:

$$Y = \begin{cases} Rp. 1{,}005{,}350 & M \in (0,5) \\ \text{Rp.} 675{,}350 & M \in [5,6) \\ Rp. 335{,}350 & M \in [6,7) \\ Rp. 225{,}350 & M \in [7,8) \\ 0 & M \in (8, \infty) \end{cases} \tag{18}$$

3.3.6 Analysis of the effect of interest rates, coupons and number of seismic regions on earthquake bond prices

i. **Analysis of the effect of interest rates on bond prices for earthquake disasters**
An analysis of the effect of interest rates on DECBP using a Monte Carlo simulation by generating a random number of 1000 times, which represents the interest rate. The simulation results using Rstudio are presented in Figure 11.
Figure 11 shows that interest rates have a negative relationship with earthquake bond prices. The higher the interest rate, the lower the price of disaster bonds, and vice versa. The results of the analysis are in line with (Burnecki, Giuricich, and Palmowski [9]; Chao and Katina [10]; Tang and Yuan [40]).

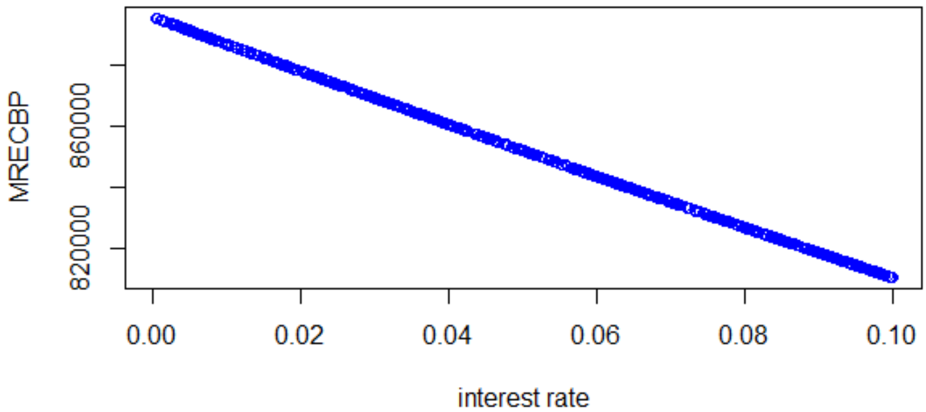


Fig. 11. Single period DECBP results for $r = (0{,}0.1), e = 0.05, C = 0.535\ \%$

ii. **Analysis of the effect of coupon rates on bond prices for earthquake disasters**
The analysis of the effect of the coupon rate on DECBP uses a Monte Carlo simulation by generating a random number of 1000 times, which represents the coupon rate. The simulation results using Rstudio are presented in Figure 12. Figure 12, shows that coupon rates have a positive relationship with earthquake bond prices. The higher the coupon rate, the higher the price of disaster bonds, and vice versa. The results of the analysis are in line with [9,10,40].

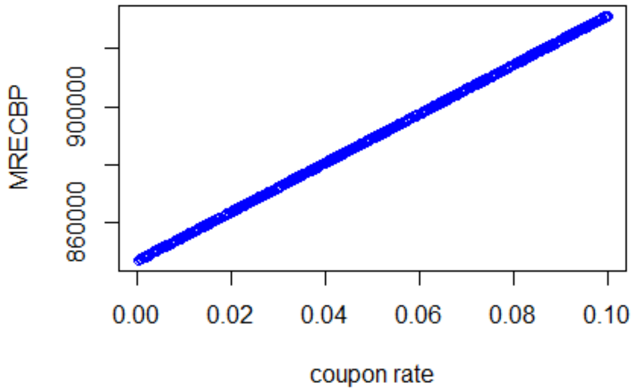


Fig. 12. DECBP single period for $C = (0, 0.1), e = 0.05, r = 3.48719$ %,

iii. Analysis of the effect of interest rates and coupons on earthquake bond prices

An analysis of the effect of interest rates and coupons on DECBP using a Monte Carlo simulation by generating 1000 random numbers for interest rates and coupons. The simulation results are presented in Figure 10. Figure 13, shows that the magnitude of interest rates and coupons affects the price of catastrophic bonds, because movements in high interest rates and coupons cause price changes. To analyse the effect of interest rates and coupons on disaster bond prices using simple regression analysis. The classical assumption test for simulation data is met. Analysis of the effect of interest rate and coupon variables on bond prices and a classical assumption test using Rstudio software. The results of the regression using the obtained are as follows:

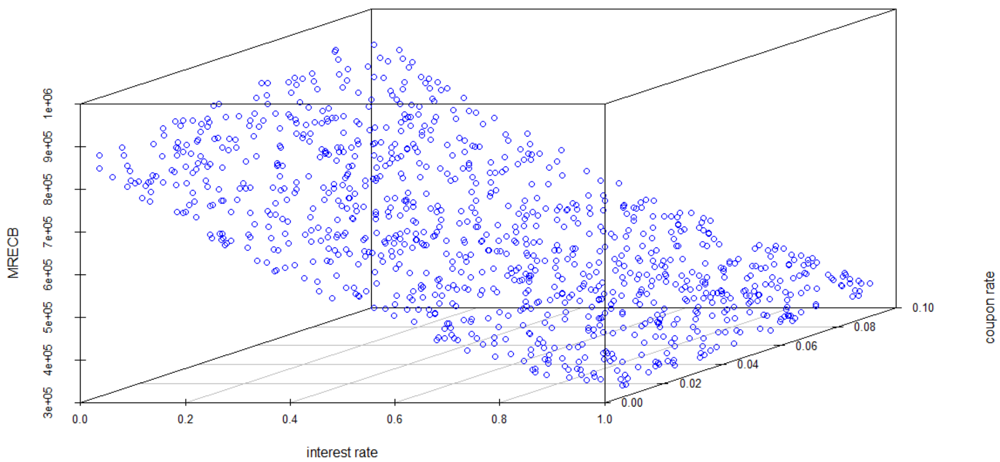


Fig. 13. DECBP single period for $r = (0,0.1), C = (0,0.1), e = 0.05$

$$P_{cat} = 955659.7 - 812753.1r + 554658C \tag{18}$$

Based on the results of the analysis, it is concluded that there is a significant effect between interest rates and coupons simultaneously on earthquake disaster bond prices ($p_{value} = 0 < 0.05$), coupon interest rates have a negative effect on earthquake bond prices ($p_{value} = 0 < 0.05$), and the coupon rate has a positive effect on the price of earthquake bonds ($p_{value} = 0 < 0.05$). The magnitude of the effect of interest rates and coupons is 96.21%. In the simulation data, the elasticity of the interest rate is 0.687, while the coupon rate is 0.048. This means that the increase or decrease in the value of the earthquake disaster bond price is smaller than the percentage value of the addition or subtraction of the interest rate or coupon rate.

iv. Analysis of the effect of the amount of regional decomposition on the price of earthquake bonds

The model proposed in this study is an earthquake disaster bond price model for a single period by decomposing the coverage area based on EDRI, earthquake depth, earthquake magnitude, and STDM distance. In this section, an analysis of the effect of the amount of regional decomposition on the price of earthquake disaster bonds is carried out, taking as an example the number of decompositions of 1 (without any grouping), 3 (areas grouped by IRBG), and 7 (regions grouped by EDRI, earthquake parameters, and STDM distance). The probabilities for each triggering event are presented in Table 21.

Table 21
The probability of trigger events for $n = 1,3,7$

The number of regional	$P(0 < x \leq 5)$	$P(5 < x \leq 6)$	$P(6 < x \leq 7)$	$P(7 < x \leq 8)$	$P(x > 8)$
1	0.937213	0.043627	0.012758	0.00409	0.002313
3	0.927348	0.042109	0.01332	0.005157	0.012066
7	0.884879	0.045265	0.019491	0.000792	0.039654

Based on Table 19, the probability of an earthquake with a magnitude of less than 5 SR is the highest compared to the probability of other earthquakes. The probability of an earthquake occurring more than 8 on the Richter scale with the number of decompositions in the 7 region has the highest probability compared to others, which is 0.039654. The results of the calculation of disaster bonds for the number of decompositions 1, 3, and 7 are presented in Figure 14.

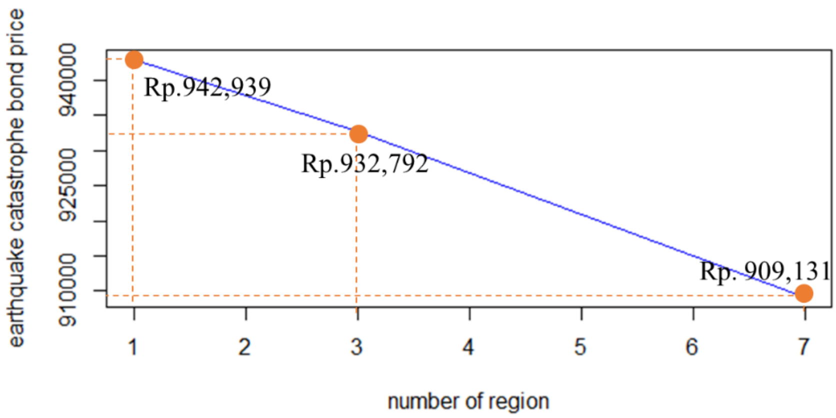


Fig. 14. Earthquake catastrophe price for $n = 1,3,7$

Figure 14 shows that the number of decomposition regions has an inverse relationship with bond prices; the more regions the decomposition results from, the lower the disaster bond prices. The results of the analysis show that the decomposition of the area based on EDRI, earthquake parameters, and STDM distance can provide lower bond prices and attract investors. Besides, the results of the decomposition of the insured area obtained can provide an overview of the earthquake conditions in the area. The findings obtained in this study are in line with previous research, namely that regional decomposition can provide a better alternative for calculating prices in reducing moral hazard [16,25,26].

4. Conclusions

Historical data on seismicity in West Java Province shows that an earthquake with a magnitude of 7.3 on the Richter Scale has occurred and caused high losses and fatalities. The disaster management contingency fund of the incident could not cover the actual loss, so it was necessary to find alternative funds, one of which could be using the earthquake disaster bond instrument. The multi-regional model of earthquake disaster bonds for a single period can be used by the Indonesian government in determining the price, because the price is lower than the single-regional one so it can attract investors. In addition, it is more transparent than the single-regional model because the areas that are guaranteed bonds are described in detail from the order that is not earthquake-prone to earthquake-prone and which group of areas has a high seismic potential. However, in this case, it is necessary to pay attention to the amount of interest rates and coupons that are set because they affect the price of catastrophe bonds. Additionally, it is more transparent than the single-regional model because the places that are guaranteed bonds are specified in detail, including which group of locations have a high seismic potential and in what order they are earthquake-prone from least to most. However, because they have an impact on the cost of disaster bonds in this instance, it is important to pay attention to the specified interest rates and coupons.

The results of the analysis of the influence of financial risk, namely interest rates and coupons on bonds, are in line with DECB price [9,10,40]. Interest rates have an inverse relationship with disaster bond prices; the lower the interest rate, the higher the earthquake disaster bond price. Therefore, the issuer needs to pay attention to the magnitude of the interest rate. If the interest rate is low, it will cause the bond price to be catastrophically high. This will cause investor interest to decline. Likewise, with the determination of coupons, the issuer must be able to carefully determine the amount of the coupon. A high coupon rate does attract investors, but on the other hand, it causes high earthquake bond prices as well. The thing that needs to be considered for investors who want to buy MRECB is to pay attention to the threshold value of the set trigger so as not to lose cash and coupon values. In MRECB, cash value is modelled in a piecewise linear form, so investors can easily calculate how much profit they expect to get if the opportunities from the trigger interval are presented transparently.

The constraint found in the bond calculation is that the probability value of the trigger is more than 8. This is not in accordance with the real condition, namely Region 1 has the greatest chance of triggering more than 8. This reflects that the higher the parameter of GPD, the greater the opportunity. On the other hand, Region 6 has the least chance of triggering more than 8. This reflects that the value of >0 causes an extremely low trigger chance. In the actual earthquake data, Region 1 is an area that has a low EDRI and its seismic history has never been more than 5 SR. In contrast, Region 8 has a high EDRI score and an earthquake history of 7.3 SR. For this reason, in the future, researchers will try to model the distribution of earthquakes with a distribution that is more suitable for actual conditions.

The proposed DECBP is only for a single period, so it is necessary to develop an MRECB model for multiple periods. Therefore, for further research, a multi-period MRCB model will be developed. The model developed in this study is expected to assist the Super Purpose Vehicle (SPV) in determining the price of earthquake bonds and become a reference for other researchers in developing a model for earthquake disaster bond prices.

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