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BUILDING DAMAGE HAZARD ZONATION USING FKCN AND IDW ALGORITHM

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ABSTRACT

The objective of this study is to create building damage hazard zonation area using fuzzy kohonen clustering network (FKCN) for physical parameter data clustering and inverse distance weighting (IDW) for data interpolation in Banda Aceh city, Indonesia. IDW algorithm is used alongside FKCN because of its simplicity. The physical parameter in this study consists of lithology, topographic zone and peak ground acceleration value (PGA). The result is Banda Aceh city divided into 3 zones which are low, medium, and high building damage area, based on the combination of physical parameter on each area.

Keywords: *Building Damage, Earthquake, Fuzzy Kohonen Clustering Network, Hazard Zonation, Inverse Distance Weighting*

1. INTRODUCTION

Indonesia is a country with high earthquake intensity. The 1983 Banda earthquake (8.5 Mw), 2004 Sumatera-Andaman Island earthquake (9.1 Mw), 2005 North Sumatera/Nias earthquake (8.6 Mw) and West Coast Sumatera earthquake were 4 big earthquake occurrences in Indonesia [1]. An earthquake with a certain intensity and magnitude as a response to the movements of plates can result in physical infrastructure damage as happened at Banda Aceh in 2004 with total of physical infrastructure damage reached approximately 35% [2] and caused total approximated to the hundred thousand of death in Indonesia, Sri Lanka and Thailand [3].

Escobar et al, 2008 [4] proposed a method using torsion amplification factors, P-TAF to simplify the current static seismic torsion design procedure for buildings. In the previous research, in order to evaluate the building damage due to an earthquake, Silva and Garcia, 2001 [5] combined artificial neural network and fuzzy system, Carreno et al, 2010 [6] implemented neuro-fuzzy system based on a special three-layer feed-forward artificial neural network and fuzzy rule bases and self-organizing Map (SOM) algorithm has been applied by Irwansyah and Hartati, 2012 [7] in evaluating the building damage caused by the earthquake event.

FKCN had been applied to construct the building damage hazard zonation with Kriging algorithm for the data interpolation [8]. According to Largueche, F.Z.B, 2006 [9] Kriging algorithm is difficult to understand and implement but actually this method is generally better than IDW. The original Kriging method requires the preliminary modeling step of a variance distance relationship, meanwhile IDW does not involve such step, simple and quick [10]

Based on those previous researches, we use FKCN as the clustering data algorithm and IDW algorithm for data interpolation to construct the building damage hazard zonation area in Banda Aceh city Indonesia.

2. RELATED WORKS

FKCN is an unsupervised learning clustering analysis method which integrated Fuzzy C-Means (FCM) model [11] and Kohonen network [12]. This algorithm was introduced by Bezdek et al, 1992 [13] in order to improve convergence rate and reduce labelling errors problem on FCM.

de Almeida et al, 2012 [14] applied FKCN to an interval of data and proved that FKCN is better than FCM. Another study combined FKCN and motion control algorithm [15]. Fan et al, 2013 [15] improved the original FKCN [13] by divide FKCN into two parts, which are training phase and application phase in order to develop intelligent wheelchair. The improvement is lower error rates and less iterations compared to the original FKCN.

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Jabbar et al, 2009 [16] proved FKCN has the ability to segment the color image with HSV as color representation, [17] introduced Adaptive Fuzzy Kohonen Clustering Network that reduce computation process of FKCN in image segmentation and [18] determine cluster membership values in short times by doing some improvements from the original FKCN.

3. METHODOLOGY

Manuscripts This study consists of (1) PGA calculation, (2) lithology and topography data extraction (3) clustering data using FKCN and (4) data interpolation using IDW algorithm.

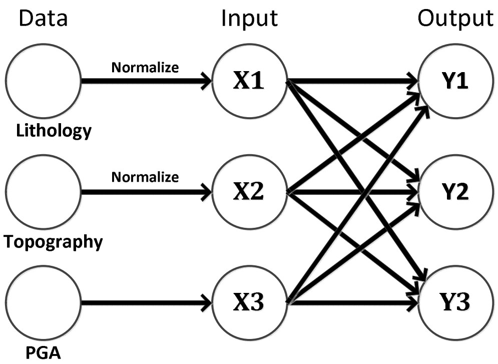

Figure 1: Building Damage Hazard Data Clustering Architectur

3.1 PGA Calculation

PGA value of Banda Aceh city is computed with the following formula [19]:

$$\ln(PGA) = 0.2418 + 1.414M + C1 + C2(10-M)^3 + C_3 \ln(r_{rup}+1.^{7818e0.554M}) + 0.0060H + 0.3846Z_r \quad (1)$$

Where PGA is peak ground acceleration (gals); M is earthquake magnitude (Richter scale); rrup is horizontal distance from earthquake epicentrum to centroid grid; H is depth of the epicenter (Km); Zr indicates rock sites (0 for interface and 1 for intraslab) and C1, C2, C3 are coefficient from the function (C1 = 0, C2 = 0, and C3 = -2.552).

3.2 Data Extraction

The conversion process of lithology data and topographic zoning obtained from map into data as shown in Table 1. The class value is based on each contribution on each level of building damage.

Table 1: Lithology and topography class [7]

No	Lithology		Topography	
	Class	Value	Class	Value
1	Sand	6	Inland Plain	7
2	Clayey Sand	5	Inland Deep	6
3	Sandy Clay	4	Coastal Plain	5
4	Sand	3	Coastal Low	4
5	Swamp	2	Coastal Deep	3
6	Non	1	River/Seabed/Lake	2
7	-	-	No Data	1

3.3 Data Normalization

Min-max normalization [20] transform data into a new minimum and maximum value but preserves the relationships among original data values by computing:

$$v' = \frac{v - \min A}{\max A - \min A} * (new_{\max A} - new_{\min A}) + new_{\min A} \quad (2)$$

Where
$\min A$ = minimum value from attribute A,
$\max A$ = maximum value from attribute A,
$new_{\max A}$ = maximum value on the new scale, and
$new_{\min A}$ = minimum value on the new scale.

3.4 FKCN Algorithm

The physical parameter is computed by FKCN algorithm for data clustering analysis. The algorithm of FKCN is summarized as follow:

Step 1: Fix c, sample space and threshold error ε > 0 some small positive constant.

Step 2: Initialize $v_0 = (v_{10}, v_{20}, \ldots, v_{c0})$ choose $m_0 >$ 1 and iteration limit ($t_{\max}$)

Step 3: For t = 1,2…, $t_{\max}$

a. Compute all learning rates:

$$m_t = m_0 - t * \Delta m, \quad \Delta m = \frac{1}{t_{\max}} \quad (3)$$

Where m_t is the fuzzy membership for the t iteration and Δm: fuzzy membership differences for each iteration

For each member, update its membership function:

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$$u_{ik,t} = \left(\sum \left(\frac{\|X_k - V_{i,t-1}\|}{\|X_k - V_{j,t-1}\|} \right)^{\frac{2}{m-1}} \right)^{-1} \quad (4)$$

Where $u_{ik,t}$ is the membership function of the *k-th data of i-th cluster for each t-iteration*; X_k is the k-th data; $V_{i,t-1}$ is the i-th cluster center for t-1 iteration; $V_{j,t-1}$ is the j-th cluster center for t-1 iteration and m is weighting exponent on each fuzzy membership.

Compute learning rate

$$\alpha_{IK,\tau} = (\upsilon_{IK,\tau})^{\mu_\tau} \quad (5)$$

Where $\alpha_{ik,t}$ is the learning rate of the *k-th data* of *i*-th cluster for t iteration.

b. Update all weight vectors:

$$v_{i,t} = v_{i,t-1} + \frac{\sum_{k-1}^{n} \alpha_{ik,t}(x_k - v_{i,t-1})}{\sum_{j=1}^{n} \alpha_{ij,t}} \quad (6)$$

Where v_i is i-th cluster center and $v_{i,t}$ is i-th cluster center for t iteration

c. Compute the function

$$E_t = \|V_t - V_{t-1}\| \quad (7)$$

Where E_t is error for each t iteration; V_t is cluster center for t iteration and V_{t-1} and cluster center for t-1 iteration.

d. If $E_t < \varepsilon$ stop. Else t = t + 1 goto step 3

3.5 IDW Algorithm

Inverse distance weighting [21] is one of the simplest spatial prediction techniques by computing the formula bellow:

$$Z_0 = \frac{\sum_{i=1}^{N} Z_i - d_i^{-n}}{\sum_{i=1}^{N} d_i^{-n}} \quad (8)$$

Where Z_0 is estimation value of variable z in point I, Z_i is sample value in point I, d_i is distance of sample point to estimated point, N is coefficient that determines weigh based on a distance and n is total number of predictions for each validation case.

4. RESULT

Building damage hazard data clustering in this study is conducted using FKCN with m = 2, ε = 0.001, t_{max} = 50 and c = 3 by 10th iteration. Figure 2 shows FKCN had achieved small number of error by 10 or more iteration and is similar to the experiment by Bezdek et al (1992).

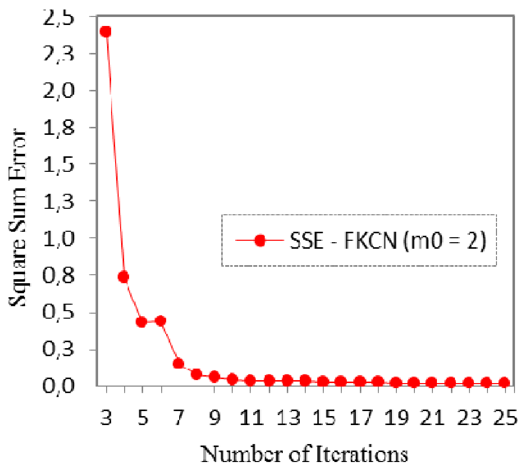

Figure 2: FKCN Square Sum Error Plot

Table 2: Data Characteristics on each class of clustering result

Class	Data Characteristic		
	PGA Range	Dominant Lithology	Dominant Topography
Class 1	0,8767 – 0,8806	Sand Clay, Clay and Clayey Sand	Inland Plain, Coastal Plain and Inland Deep
Class 2	0,8773 – 0,8797	Sand, Clayey Sand and Swamp	River, Coastal Deep and Coastal Plain
Class 3	0,8775 – 0,8796	Swamp	River and Coastal Deep

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Banda Aceh city is divided into 3 classes as described in Table 2 Class 3 (green) as seen in Figure 3 represents low building damage area, which constructed by swamp for lithology class and dominated by river/seabed/lake and coastal deep for topography zone with 0.8775-0.8796 gals PGA range value.

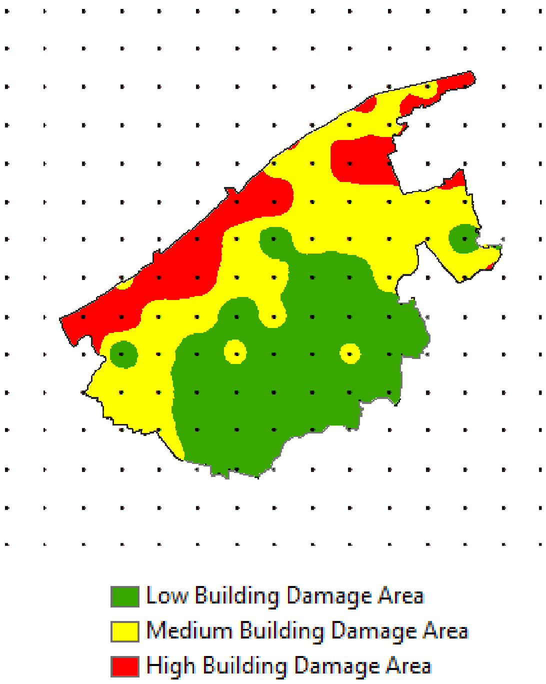

Figure 3: Building Damage Hazard Zonation in Banda Aceh

Class 2 (yellow) is medium building damage area and class 1 (red) is high building damage area which constructed by the same method.

Using same data and location with different methodology, [8] conducted clustering data and zonation building damage hazard area caused by earthquake. Zoning resulting from these studies showed that the pattern is almost different where coastal area relatively consist of high building damage and medium damage hazard zone (north west) and low building damage hazard zone which is located relatively further away towards the inland (Figure 4).

5. CONCLUSION

FKCN algorithm which is implemented in this study had performed well in data clustering analysis, based on the small number of error since the 10th iteration. According to the zonation result using IDW algorithm, most of the research area in Banda Aceh city, Indonesia located at the low and medium building damage hazard area. The result also indicates high damage zones only cover a small area in the northwest part of the city, near and relatively parallel with coast line. Zoning differences with previous research showing the importance of developed models that can represent nearly ideal conditions

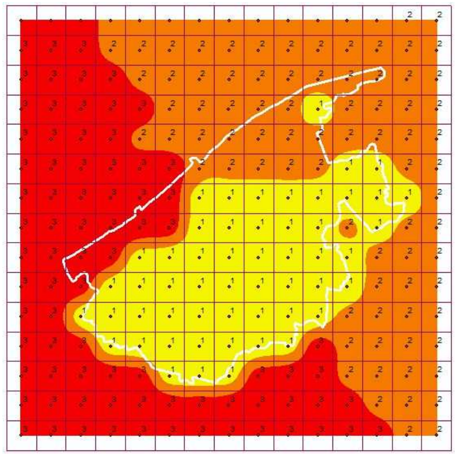

Figure 4: Building Damage Hazard Zonation in Banda Aceh (Red: High Building Damage Hazard Area; Orange: Medium Building Damage Hazard Area; Yellow: Low Building Damage Hazard Area) (Irwansyah and Hartati, 2014)

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