Classification of security quality level using Fuzzy Logic study case: Balikpapan City

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Abstract. A liveable city is a city with a comfortable environment that gives its residents a sense of perfection to live and ease to do various activities. Balikpapan is one of major cities whose has the third-largest population in the province of East Kalimantan consisting of 6 districts namely, South Balikpapan, East Balikpapan, North Balikpapan, West Balikpapan, Central Balikpapan, and Balikpapan City. The consequence that arises from the large population is the increase in crime that affects the liveability in terms of security quality. In this study, Mamdani Fuzzy Logic is used to investigate the level of security quality of each sub-district in this city based on the crime figures. Moreover, the types of criminalities are categorized into four kinds, namely fraud, theft, immoral violence, and other crimes. Based on the result, it was found that the order of sub-districts with the best level of security is Central Balikpapan which is followed by Northern and Eastern Balikpapan with fairly good security status. Meanwhile, sub-districts with lax security are Western Balikpapan, Balikpapan City and Southern Balikpapan.

1. Introduction
Study of the sustainable and liveable city has received increased attention since it has multi aspects to consider [1]. Liveability of a city has become an essential concept in the field of planning by both researchers and government since it is requisite to have a comfortable environment such that the residents feel a sense of perfection to live and can do various activities. Yadav and Patel in [2] stated that the city’s functions for boosting economy, well-providing employment, better health service, and many more things have been perceived as a solution for the community. Many previous researchers had conducted studies of the liveable city toward sustainable development which can be found in [3], [4], and [5].

In deciding whether a city is categorized as liveable or not, one of the methods that can be used is the Fuzzy Inference System (FIS). Rizki and Tipa in [6] employed this method to find the criminality level in Batam City, while Yenni and Utناسari in [7] used Fuzzy Logic to predict the city’s criminality rate. Meanwhile, the inconsistent result of the liveability of a city can be occurred according to the variables that are used in the research. Hence, Chen in [8] proposed to use the Multi-MCDM and Hopfield Neural Network which combines some methods to measure the sustainable liveable city. The other results can be seen in [9] and [10].

According to this topic, on the other hand, Balikpapan is one of the most crowded city with the third-largest population in East Kalimantan Province, Indonesia. Based on the data in [11], this city
consists of six sub-districts which have been occupied by 667,118 people in 2019. The number of residents’ growth implies not only increasing demand for living space but also some unfavorable side impacts such as the decrease of socio-economic quality and the rise of criminality number. Regarding criminality, Hardianto in [12] stated that the insufficient wage rate may have a negative strong correlation to this problem. Additionally, the supporting data from [13] stated that there were 11,509 number of crime in Balikpapan. Although there was a slight decrease in 2017, the main types of criminality in the city which need utmost attention are fraud, theft, and (immoral) violence. These problems surely bring impact to the liveability of Balikpapan City. The study of liveable in the city was previously done by [14] who investigated the rating level of each sub-district by the education sector. Therefore, it is interesting to investigate further this liveability based on another sector. Hence, this research is aimed to implement the Mamdani Fuzzy Logic that focuses on the number of criminality to derive the rank of sub-district based on its security quality.

2. Fuzzy Logic implementation
In this section, the rank of security quality of each sub-district in Balikpapan City is processed using Mamdani Fuzzy Logic method as follow:

2.1. Data collection
Data was acquired from the Report of Police Office which includes criminality reports in Balikpapan City along 2019. This data, then, is classified into four classes of criminality as shown as in table 1.

| Sub-District          | Type of Criminality |
|-----------------------|---------------------|
|                       | Theft    | Fraud | Immoral Violence | Other Crimes |
| Northern Balikpapan (NB) | 41      | 15    | 27               | 1            |
| Eastern Balikpapan (EB)  | 46      | 12    | 27               | 0            |
| Southern Balikpapan (SB) | 73      | 27    | 42               | 5            |
| Balikpapan City (BC)    | 22      | 22    | 38               | 5            |
| Western Balikpapan (WB)  | 61      | 15    | 65               | 3            |
| Central Balikpapan (CB) | 41      | 11    | 32               | 3            |

*Source: Report of Resort Police Office of Balikpapan City 2019*

2.2. Fuzzification
In this step, the crisp value is transformed into a fuzzy set. The variable inputs which are used in this research are fraud, theft, immoral violence, and other crimes, while the fuzzy set contains three categories, namely high, fair, and low. Firstly, the number of theft of each sub-district from table 1 is categorized into three types of membership function, those are low theft ($\mu_{LT}$), fair theft ($\mu_{FT}$), and high theft ($\mu_{HT}$), which defined as:

\[
\mu_{LT}(t) = \begin{cases} 
1, & 0 \leq t \leq 38 \\
\frac{42 - t}{4}, & 38 < t < 42 \\
0, & 42 \leq t < 75 
\end{cases}
\]  \quad (1)

\[
\mu_{FT}(t) = \begin{cases} 
0, & 0 \leq t < 38 \text{ or } 62 \leq t \leq 75 \\
\frac{t - 38}{4}, & 38 < t < 42 \\
1, & 42 \leq t < 58 \\
\frac{62 - t}{4}, & 58 \leq t \leq 62 
\end{cases}
\]  \quad (2)
Three are three types of membership function for fraud, those are low fraud ($\mu_{LF}$), fair fraud ($\mu_{FF}$), and high fraud ($\mu_{HF}$):

\[
\mu_{LF}(f) = \begin{cases} 
0, & 17 \leq f < 27 \\
\frac{17 - f}{3}, & 14 < f < 17 \\
1, & 11 \leq f < 14
\end{cases}
\]  

\[
\mu_{FF}(f) = \begin{cases} 
0, & 24 - f \leq f \leq 27 \\
\frac{f - 14}{3}, & 14 < f < 17 \\
1, & 17 \leq f < 21
\end{cases}
\]  

\[
\mu_{HF}(f) = \begin{cases} 
0, & 21 - f \leq f \leq 27 \\
\frac{f - 21}{3}, & 21 < f < 24 \\
1, & 24 \leq f \leq 27
\end{cases}
\]

As the previous type of criminality, the number of immoral violence of each sub-district is then classified into three types of membership function, those are low immoral violence ($\mu_{Li}$), fair immoral violence ($\mu_{Fi}$), and high immoral violence ($\mu_{Hi}$):

\[
\mu_{Li}(i) = \begin{cases} 
1, & 43 - i \leq i \leq 36 \\
\frac{43 - i}{7}, & 36 < i < 43 \\
0, & 43 \leq i < 65
\end{cases}
\]  

\[
\mu_{Fi}(i) = \begin{cases} 
0, & 62 - i \leq i \leq 36 \\
\frac{i - 36}{7}, & 36 < i < 43 \\
1, & 43 \leq i < 55
\end{cases}
\]  

\[
\mu_{Hi}(i) = \begin{cases} 
0, & 55 - i \leq i \leq 55 \\
\frac{i - 55}{7}, & 55 < i < 62 \\
1, & 62 \leq i \leq 65
\end{cases}
\]

Moreover, the three types of membership function for the other crimes of each sub-district are low other crimes ($\mu_{LC}$), fair other crimes ($\mu_{FC}$), and high other crimes ($\mu_{HC}$):

\[
\mu_{LC}(c) = \begin{cases} 
1, & c < 2 \\
3 - c, & 2 \leq c < 3 \\
0, & 3 \leq c \leq 5
\end{cases}
\]
Lastly, the quality of security is also classified as bad ($\mu_{BQ}$), fair ($\mu_{FQ}$), and good ($\mu_{GQ}$) as follow:

\[
\mu_{GQ}(q) = \begin{cases}
1, & 0 \leq q < 3 \\
4 - q, & 3 \leq q < 4 \\
0, & 4 \leq q \leq 10
\end{cases}
\]

\[
\mu_{FQ}(q) = \begin{cases}
0, & q < 3 \text{ or } q > 7 \\
q - 3, & 3 \leq q \leq 4 \\
1, & 4 \leq q \leq 6 \\
7 - q, & 6 \leq q \leq 7
\end{cases}
\]

\[
\mu_{BQ}(q) = \begin{cases}
0, & 0 \leq q < 6 \\
q - 6, & 6 \leq q \leq 7 \\
1, & 7 < q \leq 10
\end{cases}
\]

Figure 1. Graph of security level.

After defining the membership function, the number of criminality in Table 1 is substituted into the defined membership functions. Hence, the result is summarized in table 2.

Table 2. The value of criminality based on the membership function

| Sub-district | $\mu_{LT}$ | $\mu_{FT}$ | $\mu_{HT}$ | $\mu_{LF}$ | $\mu_{HF}$ | $\mu_{LI}$ | $\mu_{HI}$ | $\mu_{LC}$ | $\mu_{FC}$ | $\mu_{HC}$ |
|--------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| NB           | 0.25       | 0.75       | 0          | 0.67       | 0.33       | 0          | 1          | 0          | 0          | 1          |
| EB           | 0          | 1          | 0          | 1          | 0          | 0          | 1          | 0          | 0          | 0          |
| SB           | 0          | 0          | 1          | 0          | 0          | 1          | 0.14       | 0.86       | 0          | 0          |
| BC           | 1          | 0          | 0          | 0          | 0.67       | 0.33       | 0.71       | 0.29       | 0          | 0          |
| WB           | 0          | 0.25       | 0.75       | 0.67       | 0.33       | 0          | 1          | 0          | 0          | 1          |
| CB           | 0.25       | 0.75       | 0          | 1          | 0          | 0          | 1          | 0          | 0.5        | 0.5        |

2.3. Fuzzy rules

In this step, the set of rules which contains all the combination of linguistic value are defined. There are some considerations to define the rules:
1. If one of criminality is high, except for the other crime, then the security quality is bad;
2. If one of criminality is fair and low, except for the other crime, then the security quality is fair;
3. If there are three types of criminality which are fair, and the rest is low, then the security quality is bad; and
4. If there are two types of criminality which are fair, and the rest is low, then the security quality is fair.

Therefore, all the rules are explicitly listed in Table 3.

| Table 3. Fuzzy rules |
|----------------------|
| criminal kind | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ | $R_6$ | $R_7$ | $R_8$ | $R_9$ |
| theft | low | low | low | low | low | low | low | fair | high |
| fraud | low | low | low | low | low | low | fair | low | low |
| immoral violence | low | low | low | fair | high | low | low | low | low |
| other crime | low | fair | high | low | low | low | low | low | low |
| security quality | good | good | fair | fair | bad | fair | bad | fair | fair |

| criminal kind | $R_{10}$ | $R_{11}$ | $R_{12}$ | $R_{13}$ | $R_{14}$ | $R_{15}$ | $R_{16}$ | $R_{17}$ | $R_{18}$ |
| theft | low | low | low | low | low | low | low | low | low |
| fraud | high | low | low | low | fair | fair | high | high | fair |
| immoral violence | fair | high | high | low | low | low | low | low | fair |
| other crime | fair | high | fair | high | fair | high | fair | high | low |
| security quality | fair | bad | bad | fair | bad | bad | bad | bad | bad |

| criminal kind | $R_{19}$ | $R_{20}$ | $R_{21}$ | $R_{22}$ | $R_{23}$ | $R_{24}$ | $R_{25}$ | $R_{26}$ | $R_{27}$ |
| theft | low | low | low | fair | fair | high | high | fair | high |
| fraud | high | high | low | low | low | low | low | low | low |
| immoral violence | fair | high | high | low | low | low | low | low | fair |
| other crime | low | low | low | fair | high | fair | high | low | low |
| security quality | bad | bad | bad | fair | bad | bad | bad | bad | bad |

| criminal kind | $R_{28}$ | $R_{29}$ | $R_{30}$ | $R_{31}$ | $R_{32}$ | $R_{33}$ | $R_{34}$ | $R_{35}$ | $R_{36}$ |
| theft | fair | high | fair | fair | high | high | low | low | low |
| fraud | low | low | fair | high | high | fair | low | low | low |
| immoral violence | high | high | low | low | low | low | fair | fair | high |
| other crime | low | low | low | low | low | low | high | low | low |
| security quality | bad | bad | fair | bad | bad | bad | fair | bad | bad |

| criminal kind | $R_{37}$ | $R_{38}$ | $R_{39}$ | $R_{40}$ | $R_{41}$ | $R_{42}$ | $R_{43}$ | $R_{44}$ | $R_{45}$ |
| theft | low | low | high | low | low | low | low | low | high |
| fraud | fair | high | high | high | high | low | low | high | low |
| immoral violence | high | fair | high | high | high | fair | fair | fair | high |
| other crime | high | fair | fair | high | fair | high | fair | fair | fair |
| security quality | bad | bad | bad | bad | bad | fair | bad | fair | bad |

| criminal kind | $R_{46}$ | $R_{47}$ | $R_{48}$ | $R_{49}$ | $R_{50}$ | $R_{51}$ | $R_{52}$ | $R_{53}$ | $R_{54}$ |
| theft | high | fair | fair | high | high | fair | fair | fair | high |
| fraud | low | low | low | low | low | fair | high | fair | high |
| immoral violence | high | fair | high | high | fair | high | fair | high | fair |
| other crime | fair | high | high | high | high | fair | high | fair | fair |
| security quality | bad | bad | bad | bad | fair | bad | bad | bad | bad |
Next, we can find the $\alpha$ values for every rule of each sub-district using (16) and substitute the value of criminality to the relevant membership function.

$$\alpha_i = \min(R_i).$$ (16)

For example, since $R_1$ indicates “low” for all type of criminality, so it gives $\alpha_1 = \min(R_1) = \min(0,0,0.14,0) = 0$ for Southern Balikpapan. In this article, we enlist only the $\alpha$ values which are not zero. Consequently, Table 2 and 3 altogether yield table 4.

Table 4. $\alpha$-Value

| Sub-district | $\alpha_i \neq 0$ | Sub-district | $\alpha_i \neq 0$ | Sub-district | $\alpha_i \neq 0$ |
|--------------|-----------------|--------------|-----------------|--------------|-----------------|
| EB           | $\alpha_8 = 0.25$ | WB           | $\alpha_{28} = 0.25$ | NB           | $\alpha_1 = 0.25$ |
| SB           | $\alpha_{58} = 0.14$ | $\alpha_{29} = 0.5$ | $\alpha_6 = 0.25$ |
|              | $\alpha_{80} = 0.86$ | $\alpha_{45} = 0.25$ | $\alpha_8 = 0.67$ |
| BC           | $\alpha_{15} = 0.67$ | $\alpha_{46} = 0.5$ | $\alpha_{30} = 0.33$ |
|              | $\alpha_{17} = 0.33$ | $\alpha_{60} = 0.25$ | CB             | $\alpha_1 = 0.25$ |
|              | $\alpha_{35} = 0.29$ | $\alpha_{64} = 0.33$ | $\alpha_2 = 0.25$ |
|              | $\alpha_{41} = 0.29$ | $\alpha_{69} = 0.25$ | $\alpha_8 = 0.5$ |
|              |                   | $\alpha_{77} = 0.33$ | $\alpha_{22} = 0.5$ |

2.4. Rule composition

From table 4, we summarized the rules which give $\alpha \neq 0$ for each sub-district. This is performed in table 5.
Table 5. Rule composition

| Sub-district | \{\alpha_i \neq 0\} | The output of Security quality based on the rule | Maximum value \(v = \max(R_i(\alpha_i \neq 0))\) |
|--------------|-----------------|-----------------------------------------------|-----------------------------------------------|
| EB | \{\alpha_6\} | \(R_8 \Rightarrow \) fair | 1 |
| SB | \{\alpha_{50}, \alpha_{80}\} | \(R_{50}, R_{80} \Rightarrow \) bad | 0.86 |
| BC | \{\alpha_{15}, \alpha_{17}, \alpha_{35}, \alpha_{41}\} | \(R_{15}, R_{17}, R_{35}, R_{41} \Rightarrow \) bad | 0.67 |
| WB | \{\alpha_{20}, \alpha_{29}, \alpha_{45}, \alpha_{46}, \alpha_{60}, \alpha_{64}, \alpha_{69}, \alpha_{77}\} | \(R_{20}, R_{29}, R_{45}, R_{46}, R_{60}, R_{64}, R_{69}, R_{77} \Rightarrow \) bad | 0.5 |
| NB | \{\alpha_1, \alpha_6\} or \{\alpha_b, \alpha_{30}\} | \(R_1, R_6 \Rightarrow \) good; or \(R_8, R_{30} \Rightarrow \) fair | 0.25 or 0.67 |
| CB | \{\alpha_1, \alpha_2\} or \{\alpha_b, \alpha_{22}\} | \(R_1, R_2 \Rightarrow \) good; or \(R_6, R_{22} \Rightarrow \) fair | 0.25 or 0.5 |

From Table 5 and membership functions in (13) to (15), then we derive new functions which figure out the solution region of each sub-district. First of all, since the quality of security for Sub-district of Eastern Balikpapan is fair, we define a new function \(\mu_{EBFQ}(q)\) as follow:

\[
\mu_{EBFQ}(q) = \min \left(1, \mu_{FQ}(q)\right) = \begin{cases} 
0, & q < 3 \text{ or } q > 7 \\
q - 3, & 3 \leq q \leq 4 \\
1, & 4 < q \leq 6 \\
7 - q, & 6 < q \leq 7 
\end{cases}
\]  

(17)

Then, the function for Sub-district of Southern Balikpapan which has a bad quality of security is \(\mu_{SBBQ}(q)\) as shown in (18).

\[
\mu_{SBBQ}(q) = \min \left(0.86, \mu_{BQ}(q)\right) = \begin{cases} 
0, & 0 \leq q < 6 \\
q - 6, & 6 \leq q \leq 6.86 \\
0.86, & 6.86 < q \leq 10 
\end{cases}
\]  

(18)

After that, the function for Sub-district of Balikpapan City which has a bad quality of security is \(\mu_{BCBQ}(q)\) which is given in (19).

\[
\mu_{BCBQ}(q) = \min \left(0.67, \mu_{BQ}(q)\right) = \begin{cases} 
0, & 0 \leq q < 6 \\
q - 6, & 6 \leq q \leq 6.67 \\
0.67, & 6.67 < q \leq 10 
\end{cases}
\]  

(19)

Moreover, the function for Sub-district of Western Balikpapan which has a bad quality of security is \(\mu_{WBBQ}(q)\) which can be seen in (20).

\[
\mu_{WBBQ}(q) = \min \left(0.5, \mu_{BQ}(q)\right) = \begin{cases} 
0, & 0 \leq q < 6 \\
q - 6, & 6 \leq q \leq 6.5 \\
0.5, & 6.5 < q \leq 10 
\end{cases}
\]  

(20)

The next is the function for Sub-district of Northern Balikpapan which has the fair quality of security is \(\mu_{NBGQ}(q) = \min \left(0.25, \mu_{GQ}(q)\right)\) or \(\mu_{NBFQ}(q) = \min \left(0.67, \mu_{FQ}(q)\right)\), therefore Northern Balikpapan has the quality function \(\mu_{NBGQ}(q) \cup \mu_{NBFQ}(q)\) which is given in (21).
Lastly, the function for Sub-district of Central Balikpapan which has a good quality of security is $\mu_{CBGQ}(q) = \min \left( 0.25, \mu_{GQ}(q) \right)$ or $\mu_{CBFQ}(q) = \min \left( 0.5, \mu_{FQ}(q) \right)$, therefore Central Balikpapan has the quality function $\mu_{CBGQ}(q) \cup \mu_{CBFQ}(q)$ is given in (22).

$$\mu_{CBGQ}(q) \cup \mu_{CBFQ}(q) = \begin{cases} 
0.25, & 0 \leq q < 3.25 \\
q - 3, & 3.25 \leq q \leq 3.67 \\
0.67, & 3.67 < q \leq 6.33 \\
7 - q, & 6.33 < q \leq 7 \\
0, & q > 7 
\end{cases} \quad (22)$$

All figures for each sub-district are presented in Figure 2.

2.5 Defuzzification

Defuzzification is a process to produce a quantifiable result in crisp from the corresponding membership function. In this research, the centroid method is used to find the center of the area $\bar{q}$ from the derived function in (18) to (22). Let $f(q)$ is a function defined on the interval $[a, b]$, then the center this area is given by
\[ \bar{q} = \frac{\int_{a}^{b} q f(q) \, dq}{\int_{a}^{b} f(q) \, dq} \] 

(23)

From the figure 2 (a), it is evident that the centroid of Sub-district of Eastern Balikpapan based on (17) is 5 which mean that it has a fair quality of security (see figure 1). Furthermore, the centroid of the Southern Balikpapan using the function in (18) is

\[ \bar{q} = \frac{\int_{6}^{6.86} (q^2 - 6q) \, dq + \int_{6.86}^{10} 0.86q \, dq}{\int_{6}^{6.86} (q - 6) \, dq + \int_{6.86}^{10} 0.86 \, dq} \approx 8.20 \]

which infer that the security in this sub-district is bad. The rest scores and level of each sub-district are given in table 6.

**Table 6. Defuzzification Result and Level of Security Quality**

| Rank | Sub-District         | Value | Level |
|------|----------------------|-------|-------|
| 1    | Central Balikpapan   | 3.93  | Fair  |
| 2    | Northern Balikpapan  | 4.10  | Fair  |
| 3    | Eastern Balikpapan   | 5.00  | Fair  |
| 4    | Western Balikpapan   | 8.12  | Bad   |
| 5    | Balikpapan City      | 8.16  | Bad   |
| 6    | Southern Balikpapan  | 8.20  | Bad   |

From table 6, we can observe that Central Balikpapan ranks first and the laxest security level is experienced by Southern Balikpapan.

3. Conclusion

As Balikpapan City is one of the largest city in East Kalimantan Province, it is not entirely free of crime which may reduce the quality of security for its inhabitants. The crimes are then categorized into four types, those are fraud, theft, immoral violence, and other crimes. Based on the analysis using Mamdani Fuzzy Logic Method, it can be concluded that the sequence of Sub-District in Balikpapan from the top security level to the worst one is Central Balikpapan, Northern Balikpapan, and Eastern Balikpapan where the quality is fair and followed by Western Balikpapan, Balikpapan City, and Southern Balikpapan with their bad quality of security.

4. Acknowledgments

Authors sincerely wishing to acknowledge the meaningful support from the Directorate of Research and Community Service Institut Teknologi Kalimantan (LPPM ITK) and the encouragement from colleagues in the Department of Mathematics ITK.

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