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Model Framework for Analysis and Visualization of Climate Disaster Patterns

Dian Pratiwi

Trisakti University
Jln. Kyai tapa No. 1, Grogol, Jakarta Barat, Indonesia

Corresponding author: dian.pratiwi@trisakti.ac.id
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Abstract - Extreme climate change has almost begun to show symptoms just about in all countries, including Indonesia. At the beginning of 2020, some parts of Indonesia were flooded due to high rainfall intensity. In fact, in DKI Jakarta area the potential for flooding often arrive early. For this reason, an appropriate disaster pattern analysis system needs to be developed and implemented to prevent the incident from recurring by planning better handling. The model framework that was built to create a visualization system for disaster patterns in this study consisted of five stages, namely the image processing stage in the map image, the placement of the coordinates of the affected area, interpolation with the B-Spline method, extrapolation with the Von-Neumann law, and the accurate evaluation of the formed disaster pattern mapping. Through this model framework, it is expected to produce a system design for informative disaster pattern mapping.

Keywords: climate, B-Spline, extrapolation, interpolation, Von-Neumann law

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Introduction

Background

Indonesia, which is famous for its rich natural resources, is the largest archipelago country in the world and has a tropical climate because of its position in-between the latitude of 6° N - 11° S (equator). This position causes the average temperature in Indonesia tends to be high, where the lowest temperature is above 18° C. The highest temperature normally occurs between March - April, which is marked as the dry season. While the lowest temperature or the rainy season usually occurs from October to December. However, in recent years there has been climate change in Indonesia, where the root cause is due to an increase in the level of greenhouse gas emissions in several areas, especially in the capital city of Jakarta. The increase in CO_2 emissions on the average was caused by an increase in the number of motor vehicles, forest fires in several areas such as Riau, Sumatra, and Kalimantan, and the reduction of peatlands due to land degradation.

The impact of climate change has begun to be seen in the symptoms felt by the majority of the population, such as rain with high intensity which suddenly occurs during the dry season to cause flood, hot temperatures that have been felt even in the morning, tidal waves, landslides, drought with longer periods, and others. Of the various impacts of climate change, one of the most frequently occurring and significant losses is the flood disaster.

Flooding is the most common disaster in Indonesia and has quite a detrimental impact on many parties. Various ways to deal with floods have been carried out by the government of Indonesia, including preparing rescue facilities for victims who regularly experience disasters. Such preparation must be supported by the results of observations and analysis from climatologists regarding when the possibility of high-intensity rain and regional points in Indonesia that have the potential to flood. This is not enough though if it is not supported by adequate technology in analyzing it. Therefore, researchers try to develop one of the computer-based technologies in this study to analyze disaster patterns, so that it can produce the information needed in flood disaster management planning, as well as predicting areas in Indonesia that are potentially affected by floods later in life form of mapping the daily, monthly, and yearly map time patterns. This pattern will provide information as well as an overview to the regional governments which have the potential for a disaster within the selected mapping period, so that it can be prevented early.

Methods and Materials

Methods

In this study, two main methods were applied, namely the B-Spline method for interpolation and Von-Neumann for extrapolation. Both methods are part of Cellular Automata (Neumann, 1966).

B-Spline Method

B-Spline is a development of the Spline method, both of which are commonly used to make curves and surfaces. In making curves, laying down the basic points/initials become the initial foundation to produce new points (called knots) to form curved lines or surfaces. This technique is called interpolation. In theory, interpolation in curves consists of polynomial interpolation and quadratic interpolation. Both can be used by applying the Spline or B-Spline function. The Spline is a polynomial type that has segments. This is the advantage, so the curves formed can be adjusted to the local characteristics of the data. The following is B-Spline interpolation formula (1) by (Brezinski and Zaglia (2002):

$$T\,(u, v) = \sum_{i=0}^{n} \left\{ \sum_{j=0}^{m} P_{ij} B_i^d(u) \right\} B_j^d(v) \;\cdots\cdots\cdots\; (1)$$

where:
T is a new knot point (a new pixel),
d is degree,
B is basis,
P_{ij} defines i,j-th control points (i=0...n ; j=0...m),
n and m defines control points,
u and v are the knots.

In the research by Budiantara *et al.* (2006), the Spline technique used to model the entrance examination scores for the student GPA was B-Spline and MARS (Multivariate Adaptive Regression Spline). These studies obtained that both had relatively small MSE results. However, in B-Spline modeling for linear regression analysis, quadratic, and cubic tends to be better than the results of MARS modeling. This is the reason why B-Spline was chosen in this study as an interpolation method, to map patterns of flood conditions with the hope that the error/MSE value obtained will be as small as possible.

Von-Neumann Method

Von-Neumann model is a mathematical model that is often used to analyze and to produce patterns in Cellular Automata (CA) science. The CA provides a way of trackling problems by focusing on local behaviours then studying their global behaviour. Von Neumann showed that a CA can be a universal model (Sahin *et al.*, 2015). A new type of CA can be found in many different real life applications in special cases, *e.g.* mathematical modeling, theoretical biology and chemistry, DNA research, image science, textile design, *etc.*

(Uguz *et al.*, 2019). The CA type used in this study is the 2D Von Neumann type, where the rule transition took is based on a discrete model that is a map model of Indonesian territory with discrete-time. One of Von Neumann's schemes is shown on Figure 1 below.

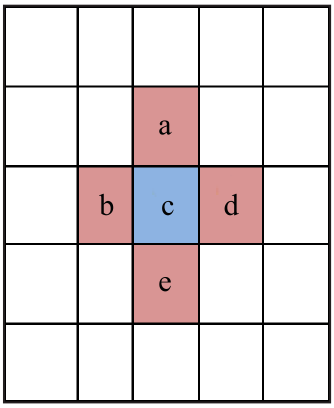

Figure 1. Von Neumann's scheme.

Whereas the formula (2) for obtaining rules from the Von Neumann scheme above is:

$$S_{ij}(t+1)=(a.S_i-1_j(t)+b.S_{ij}-1(t)+c.S_{ij}(t)+d.S_{ij}+1(t)+e.S_{ij}+1_j(t) \ldots\ldots (2)$$

The formula was also used in a research performed by (Macal and North (2009) to present the interaction of social agents, and a study by Muslimah and Pratiwi (2018) to display the distribution pattern of cattle disease through the Von Neumann R1 method. The results in the study take three transition rules and show life simulation in the case of stock markets, supply chains, and consumer markets. This simulation can be used to predict the spread of the epidemic and also to understand the various factors that cause failure (Figure 2).

The stages carried out in this study comprised data collection. The data needed is climate disaster one that has been recorded historically in the form of a digital map (picture), and has detailed information as in Figure 3.

The number of sample images used can be taken annually, monthly, or daily with a minimum sample as the basis for interpolation of four area maps with flood disaster conditions.

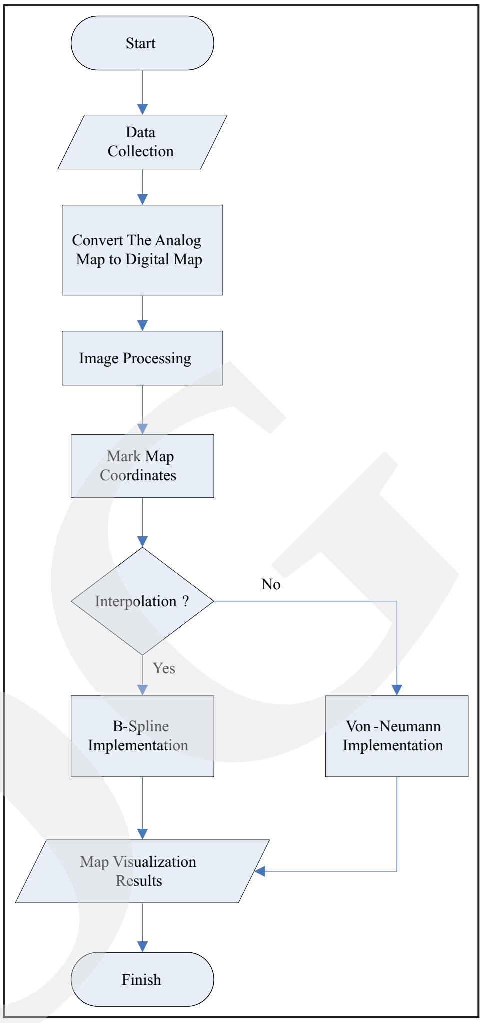

Figure 2. Research flowchart.

The data was collected from the Climatology and Geophysics Meteorology Agency (BMKG) and the National Disaster Management Agency (BNPB), in the form of historical data from various regions in Indonesia that experienced flooding due to climate change from 2005 to 2013. The data can be in-depth information flood, flood location, and length of time flood experienced by an area.

In visualizing flood disasters, the map used in this study is a map of several regions of Indonesia which are still in the form of analog maps. The map was then converted into a digital map with a scanner, which was then segmented automatically by an application system .

After the climate disaster map had finished, the image processing was carried out to mark

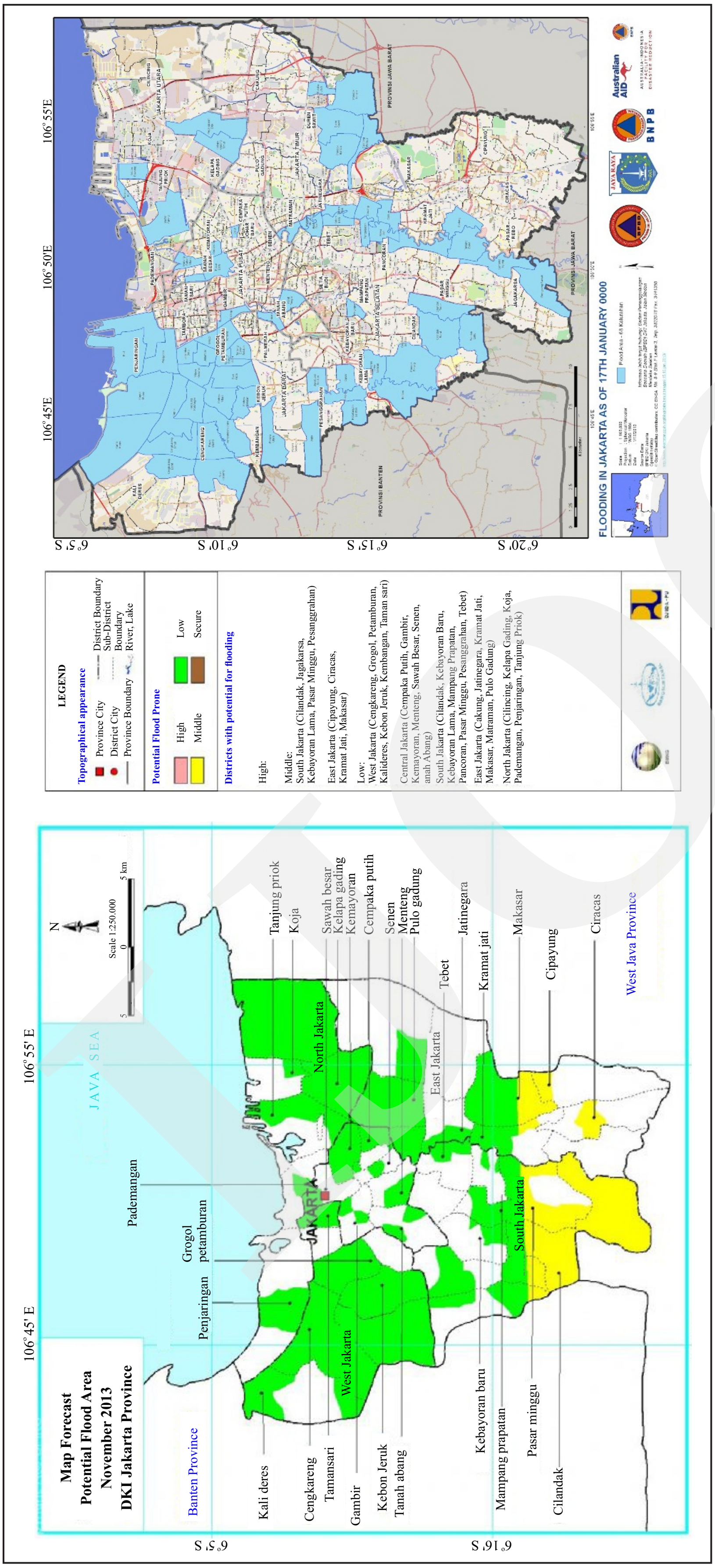

Figure 3. Digital map of flood patterns in Jakarta, DKI Jakarta Province. a) November 2013; b) January,17, 2000.

and separate/segment areas that had experienced disasters or not. Then, the separated areas were marked with coordinates and colours that represent the severity of the disaster (Figure 4).

After marking the coordinates of the area affected by the disaster, then the width and the flood height were measured, where the height of the flood can be categorized as Figure 5.

The area is then calculated according to the ratio of the total area to produce a percentage of the area in the application (Formula 3).

$$\text{Area (application)} = \frac{\text{Mapped area } (km^2)}{Total\ area(km^2)} x100\% \cdots \quad (3)$$

After the stage of mapping the coordinates and categorizing the area were completed, it then entered the interpolation and extrapolation stages. The interpolation stage visualizes the condition of the map region between the time intervals entered, while the extrapolation stage visualizes the condition of the map region outside the time interval. To calculate the accuracy of the visualization, the visualization map is compared to the actual map by matching the colour of the area formed.

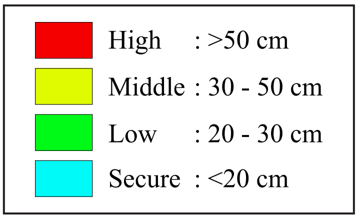

Figure 5. Categorized flood scale.

Result and Discussion

In this study, a framework for visualizing climate disaster mapping has been established, using data from flood disasters in Indonesia. The disaster maps collected were those from BMKG in 2013 and 2014 where the 2013 map comprised November, October, December, while the 2014 map consisted of January, February, and March. From the minimal amount of data, it was used to produce new maps (as a result of visualization) both within and outside the time interval. B-Spline Interpolation method in this study was used to form a map model between regional maps with known time intervals, so that it can be used to analyze disaster patterns from time to time as well as knowing the time of change from one condition to another. Figures 6 and 7 are the forms of visualization results by using the colour categorization in Figure 5.

Whereas the Von Neumann extrapolation method was used to construct transitional rules from mapped areas, so that it could be used to find out how the condition of an area was in the following year or month or day (Figure 7).

Basically, the results of applying the B-Spline method can also be used to model or to produce the data needed due to loss or damage between time intervals of flood disaster condition maps. The model is based on the results of experiments previously conducted by research-

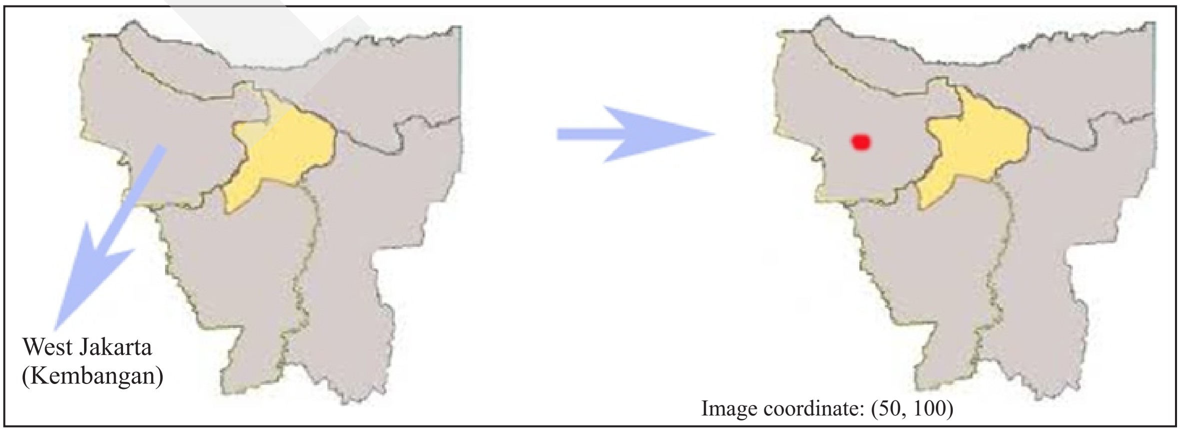

Figure 4. Marking the coordinates of the event area.

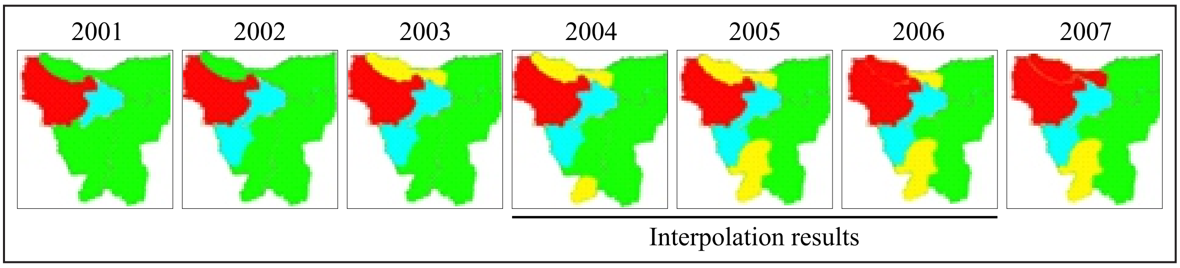

Figure 6. Visualization of interpolation result (flood scale see Figure 6).

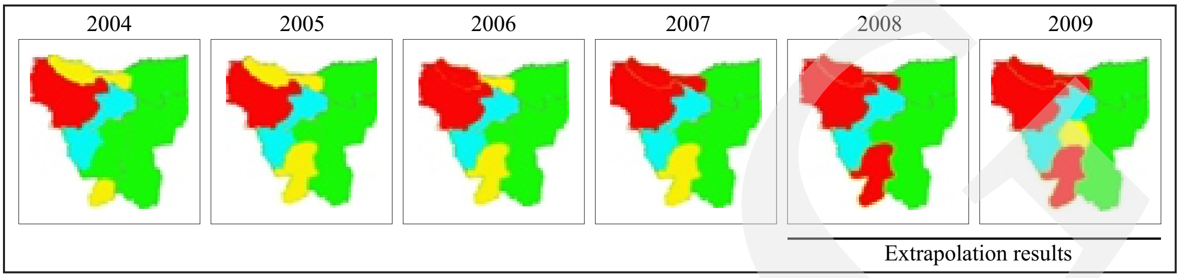

Figure 7. Visualization of extrapolation result (flood scale see Figure 6).

ers (Pratiwi, 2013), where new points that form curves are produced from laying only four basic control points. The formation of the new point is based on the transition rule generated from the Bernstein Polynomial formula, where the rule is obtained by computing neighbouring values from the condition map between these intervals. Similar as in a research by Sahin *et al.* (2015) which uses Cellular Automata Von Neumann to produce 2460 rules to see the behaviour of changing patterns in the image. This method was later adapted in this study to form a new map from known flood disaster maps. The results of the new map can have a high accuracy because the rule-taking procedure is obtained by calculating pixel values between the conditions before and after the map time sought. The number of maps produced depends on the number of LOD (Level of Detail) inputs. The more LOD, the more maps produced. The LOD in this study is a representative of the time interval of occurrence, which can be worth years, months, or days. This method can prove its accuracy by calculating the difference between the original map pixel and the new map that results from interpolation or extrapolation.

Based on the graph at Figure 8, the difference between the interpolated result value and the real value is not significant. Similar to the extrapolated value in graph b, the map pattern is formed using one of the rules extracted by the Von Neumann and B-Spline rules, resulting in a pattern that almost matches the original value. If the difference is calculated, its value in the average is only around of 5% for interpolation and 8% for extrapolation. This means, it has the same accuracy results with the research conducted by Eosina *et al.* (2016) where the study that mapped the distribution pattern of DHF based on Von Neumann and Hidden Markov models reached an accuracy percentage of 95%. The success of this CA model is also proven in researches by (Umoh and Hart (2016) and (Umrikar *et al.* (2011) in simulating the pattern of changes in urban growth from LANDSAT image data from 2003 to 2020, with quite good and representative results. Thus, it can be taken as a report that the CA model is a method for generating visualization patterns against discrete data capable of forming future patterns or patterns at certain time intervals with a fairly high degree of accuracy.

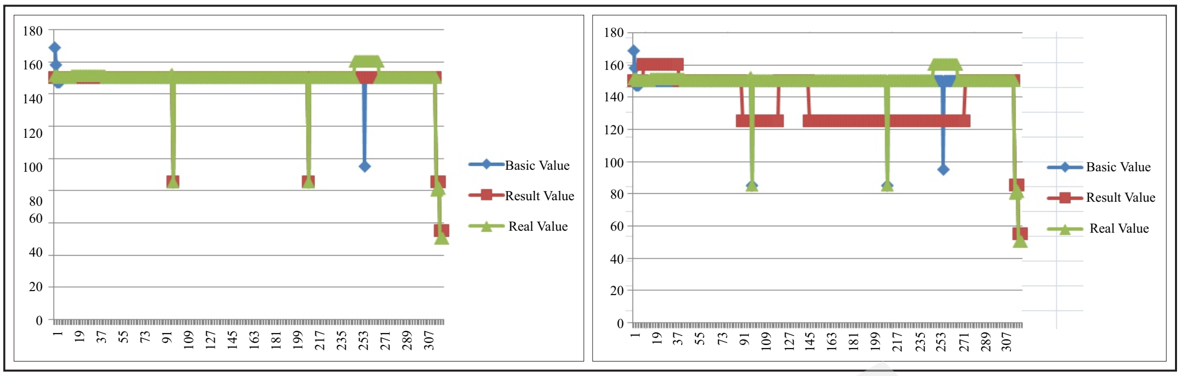

Figure 8. Graph of the pixel value of the interpolation result (left) and the pixel value of the extrapolation result (right) of the climate disaster pattern using one rule.

Conclusions

In writing the framework of this research model, the conclusions that can be drawn are:

- The Cellular Automata method with Von Neumann rules and B-Spline is able to create visualization patterns against discrete data to form predictions of future patterns, either in the form of years, months, weeks, or days.
- The form of mapping pattern results from interpolation and extrapolation of flood climate disasters depend on the time interval of the data used. The greater the amount of data used to form rules, the more variations in the form of interpolation and extrapolation.
- The accuracy of mapping results using Cellular Automata depends on the accuracy of determining the selected rule.

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