# MAXIMUM ENTROPY BASED URBAN FIRE RISK DISTRIBUTION MODELING UNDER CLIMATE INFLUENCES IN NORTH, WEST, AND SOUTH OF JAKARTA CITY

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## ABSTRAK

Insiden kebakaran di perkotaan dipengaruhi oleh banyak faktor mulai dari populasi, kepadatan bangunan hingga variabel iklim. Saat ini, kejadian kebakaran dapat diperkirakan dengan menggunakan berbagai variabel dan metode pemodelan termasuk pendekatan entropi maksimum. Kemudian tujuan dari penelitian ini adalah untuk memodelkan kemungkinan sebaran spasial wilayah di Kota Jakarta terutama di Kecamatan Utara, Barat, dan Selatan yang rawan terhadap risiko kebakaran. Model dikembangkan menggunakan pendekatan entropi maksimum dengan menggunakan variabel iklim sebagai prediktor yang diperoleh dari database WordClim. Model kemudian dikonfirmasi menggunakan nilai area under the curve (AUC). Model iklim menunjukkan bahwa bagian utara dan barat Jakarta menerima curah hujan lebih rendah daripada bagian selatan. Berdasarkan distribusi probabilitas risiko kebakaran yang dimodelkan, bagian Utara dan Barat memiliki distribusi probabilitas risiko kebakaran tertinggi dengan nilai 50%. AUC memvalidasi distribusi probabilitas model risiko kebakaran dengan nilai AUC 0,64 ± 0,07. Hasil yang diperoleh dari penelitian ini selanjutnya dapat digunakan perencanaan pencegahan kebakaran.

**Kata kunci**        : AUC, kebakaran, entropi maksimum, perkotaan, WorldClim.

## ABSTRACT

*Fire incidents in urban setting were influenced by many factors ranging from population, building density to climatic variables. Currently, fire incident can be estimated using various variables and modeling methods including maximum entropy approach. Then the aim of this study is to model the probable spatial distribution of areas in Jakarta City mainly in North, West, and South districts that are prone to the fire risks. The model was developed using maximum entropy approach using climatic variables as predictors obtained from WordClim database. The model then was confirmed using area under the curve (AUC) values. The climatic models show that North and West parts of Jakarta receiving lower rainfall than South parts. Based on modeled probability distributions of fire risks, North and West parts were having highest probability distributions of fire risks with value of 50%. The AUC validates the probability distributions of fire risks model with AUC value of 0.64 ± 0.07. The results obtained from this study then can be used planning fire prevention.*

*Keywords*        : *AUC, fire, maximum entropy, urban, WorldClim.*

## INTRODUCTION

Rapid developments of economy and urbanization process have extended rapidly the city scale. The consequence of this is the growing urban fire risk in city. Recently, urban fire accidents have become one of the significant urban problems for city fire managements. This problem is related to the highly population density. Besides population density, urban fire risk was also driven by climate factors. Climate change is estimated to accelerate the likelihood and severity of a wide range of extreme weather events. Those extreme weathers combined with climate change will affect urban area, considering high population densities and high concentrations of vulnerable people in urban areas that lead to increasing urban

fire risk indicating the adverse climate change impacts. One of adverse climate change impacts in the form of extreme weather is the reduced rainfall. Based on study by Holden et al. (2018), it confirms that decreases in summer precipitation and wetting rain days were most likely a primary cause of the increment in urban area burned.

Following growing urban fire incidents, numerous urban fire management methodologies have been developed and upscaled. Those methods to assess the urban fire incidents are ranging from Urban Fire Simulation Model that has been applied in Calfornia (Li & Davidson 2013), Event pattern Markup Language (He et al. 2020), Monte Carlo based numerical model (Himoto & Tanaka 2010) to geographic information system (GIS) based cellular automaton (Patac & Vicente 2019). In the nexus of GIS alone, since 2000 GIS has become versatile tool to manage urban fire. The development of GIS has provided a powerful tool for managing and solving urban safety problems. GIS has capability to collect, store, manage, retrieve, transform, analyze, and display spatial data with their fire attribute data (Gai et al. 2008). Following GIS applications (Klimešová & Ocelíková 2005), a spatial data modeling method based on maximum entropy has been developed. The principle of maximum entropy is based on statistical deducing and underlines that the probability distribution should be in accordance with known information.

Fires are very likely to occur in urban areas with high population density4, especially in urbanized areas such as Jakarta. The highly dense South Jakarta area that ranks first in the areas with the most fires in 2020 is no exception. Fires that occur in buildings and residential areas are among the major disasters for these areas due to the high population density and the economic value of the buildings and properties that are destroyed by fires.5 Fires occur due to

interactions between the components of fuel, oxygen, heat sources, and chemical chain reaction (fire tetrahedrons). Components that can be used as fuel include flammable materials in solid, liquid, or gaseous forms. Some solid materials in the household that can also become fuel in fires are house frames made of wood, bamboo, or other non-permanent building materials. Furthermore, it takes a minimum of 16% oxygen in the air to create a fire reaction. Then, a sufficient energy source is required until a fuel component reaches the ignition temperature.6,7 The use of electric cables that are not in accordance with standards and the behavior of using unsafe gas stoves can trigger fires. Fire is detrimental because it can cause fatalities and economic losses. The density of population, crowded buildings, and difficult access roads will make the evacuation process and firefighting operations to be constrained so that it takes a long time to put out the fire.

Jakarta, as a capital large city with its dense population, is prone to the fires. Fire incident studies mainly in Jakarta City are growing recently and have led to increasing literature (Sudiana et al. 2018a). This city is consisting of 5 districts including North, East, West, Central, and South. According to Sudiana et al. (2018b), the order of districts that prone to fire from the most to the least vulnerable districts were East, West, South, Central, and North Districts. Besides experiencing fire risks, Jakarta City is also prone to the extreme weather. The annual mean temperature in Jakarta has increased about 1.6 ∘C (Siswanto et al. 2015). Jakarta also has number of hot days with increasing trends (Khoir et al. 2018). It causes the temperature in Jakarta to get more warmer than previous year recently. Considering the urban risk and combined with extreme weather and climate change trends in Jakarta, then this paper aims to model the potential spatial distribution of areas in Jakarta City mainly in North, West, and

South Districts that prone to the fire risks. The model was developed using maximum entropy approach using climate determinant variables.

**METHODS**

The study area was a capital city of Jakarta (Figure 1). This city has size of 661.5 km$^2$ and population of 11063324 people with density of 16704 individuals/km$^2$. According to statistic of Jakarta (https : // statistik . jakarta .go .id / kejadiankebakaran-di–dki -jakarta - tahun-2020/), there were about 60 fire incidents distributed in 5 districts. In last 2020, there were in total 6249 cases of fire incidents. South Jakarta has the highest cases with 397 cases followed by East district (349 cases), West (333), North (266) and the lowest was Central District with 160 cases. Jakarta was coastal city located in low land with average of altitude of 79 m above sea level. The temperature range in Jakarta was 21.1-37.8 $^0$C with humidity of 33-74% and mean rainfall of 377 mm/day especially during La Nina period.
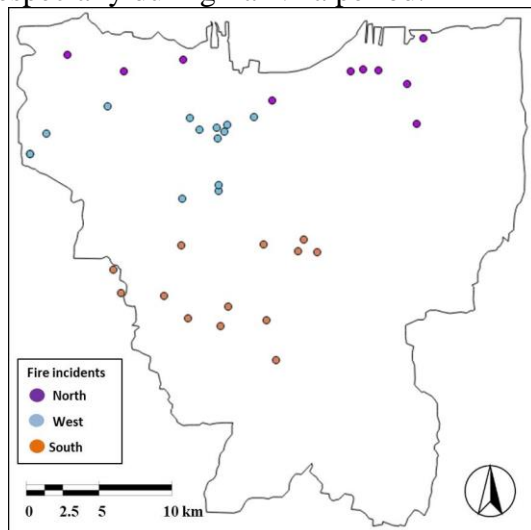


**Figure 1. Fire incidents in North, West, and South districts of Jakarta City.**

**Climatic envelope variables**

This study's fire distribution modeling was established on fire incident association with climate at the regional scale and the climatic envelope concept. Climatic envelope modeling is utilized to define an object's current and future distribution based on suitable climate conditions. Niche theory, which defines the climatic niche as a practical or intangible space described on several axes of climatic parameters, is used to support the model's improvement and subsequent application. When inferring from recent distributions to future potential, the climatic niche is one variable of an object's essential niche. It is expected to stay stationary and does not take dispersion ability or evolutionary adaptation into account. Climatic envelopes are most appropriate at local scales where there is a dominance of climate influence on an object, and geographically adjusted climatic envelopes are a fundamentally conventional instrument to model an object's spatial distribution. Even if the delineation of all acceptable climates is partial, it allows for the stable identification of some known adequate climatic parameters.

There are 15 climatic variables that have been modeled in this climatic-based distribution modeling using WorldClim's database with high spatial resolution global weather and climate data (Table 1). Those climatic parameters consisting temperature seasonality, annual mean temperature, mean temperature in wettest quarter, mean temperature in driest quarter, mean temperature in warmest quarter, mean temperature in coldest quarter, maximum temperature in warmest month, minimum temperature in coldest month, mean diurnal range, isothermality, temperature annual range, precipitation seasonality, annual rainfall, rainfall in wettest month, rainfall in driest month, rainfall in wettest quarter, rainfall in driest quarter, rainfall in warmest quarter, and rainfall in coldest quarter.

Weather data were retrieved from several station data when developing a climatic envelope (Nitschke & Innes 2006) with WorldClim (Fick & Hijmans 2017, Marchi et al. 2019). The correspondence between a station's reported elevation and the elevation retrieved from a global

elevation raster data was checked. Stations with significant differences (>several hundred meters) between reported and actual elevation were mapped and evaluated in relation to available spatial data and geographic information from neighboring stations. The mean temperature was calculated by taking the average values of the maximum and minimum monthly temperatures from the tabulated station-by-station data.

**Table 1. Technical information of the**

| Factor | Source | Format |
|---|---|---|
| Fire incidents | Reports | Point, shape file |
| Jakarta City | Base map | Polygon, shape file |
| Climatic variables | WorldClim | GeoTiff |
| **data** | | |

**Maximum entropy distribution modeling**

First, the presence of fire was recorded in the designated study area using fire incident reports. The geocoordinate positions of observed fire incidents, consisting longitude and latitude, were recorded. The geographic distribution of fire incidents was then mapped into thematic layers of study areas. In order to generate more significant variables, maximum entropy distribution modeling was developed from climatic data including monthly temperature and precipitation values. Annual trends, seasonality, and extreme or limiting environmental factors are all represented by these climatic variables. The climatic data for this study were obtained from the WorldClim database. This database is presented as a single raster that spans the continents and is available in WGS84 longitude and latitude geocoordinates . In this paper, all 15 climatic variables were retrieved with a spatial resolution of 1 km$^2$ were acquired in defined Jakarta City.

All selected fire incidents and climatic parameters for modeling were transformed to ASCII format for modeling in the following step by maximum entropy modeling, which takes a list of fire incident locations as input, often referred to as presence-only data, as well as a set of climatic parameters acting as predictors, such as temperature and rainfall variables. The conclusive result is a thematic layer with fire incident environmental suitability classifications ranging from high to low.

**Area under the Curve (AUC) validation**

Maximum entropy distribution modeling yield a predicted and potential distribution of fire incidents beyond observed fire incidents. The model and potential distribution were validated using values of Area under the Curve (AUC) of Receiver Operating Characteristic (ROC). AUC of ROC is a versatile visualization and diagnostic instrument that can plot the model's true positive rate opposed to the false positive rate. The true positive rate is defined as the model's likelihood of correctly classifying fire incidents-only instances. While the false positive rate is the likelihood of misclassifying background incidents as fire incidents only. AUC values ranged from 0 to 1, with AUC close to 1 indicating that the model performed well.

**RESULTS**

Figure 2 presents the distribution model of annual precipitation in Jakarta City. It can be seen from the model that the annual precipitation distribution was varied. Central and northern parts of Jakarta were lower annual precipitation with minimum values were more common observed in northern parts. The precipitation was increasing towards South Jakarta. On the contrary, during the wettest months, North parts of Jakarta were receiving more rainfall in comparison to other parts of Jakarta City. North east parts of Jakarta were having the highest rainfall.

While the lowest rainfalls were observed in South parts of Jakarta (Figure 3). In contrast to precipitation rates during wettest months, rainfalls in driest months were decreasing in most parts of Jakarta. North parts of Jakarta were having the lowest rainfall and decreasing to 50 mm (Figure 4).
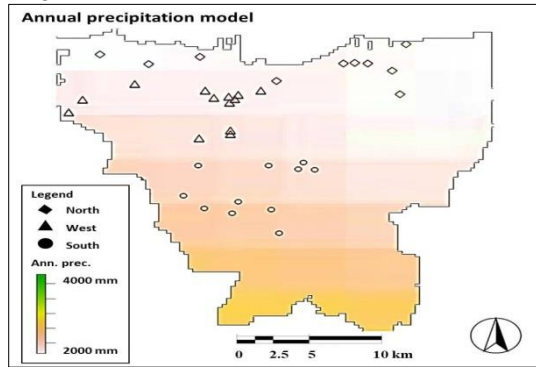


**Figure 2. Annual precipitation model within fire incidents in North, South, and West districts of Jakarta City.**
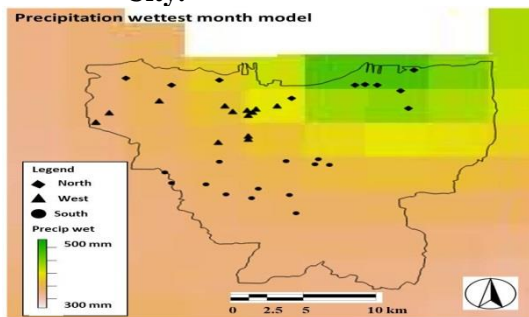


**Figure 3. Precipitation wettest month model within fire incidents in North, South, and West districts of Jakarta City.**
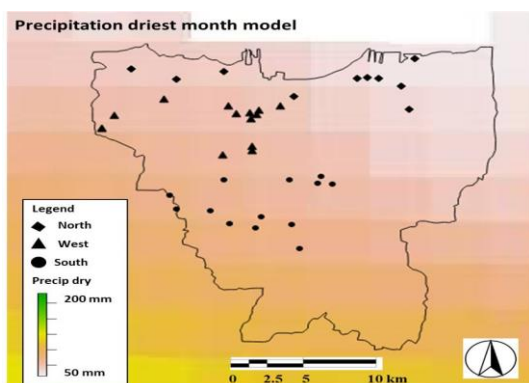


**Figure 4. Precipitation driest month model within fire incidents in North, South, and West districts of Jakarta City.**
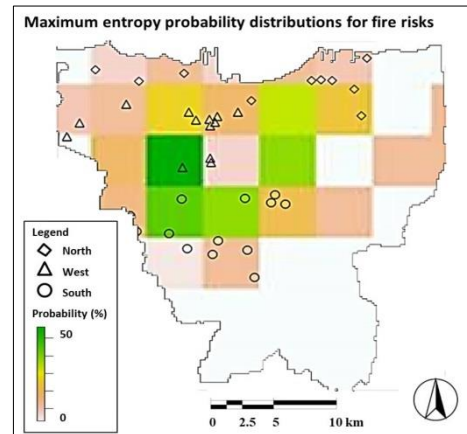


**Figure 5. Maximum entropy probability distributions (%) for fire risks developed from reported fire incidents based on climatic variable predictors in North, South, and West districts of Jakarta City.**

The values of modeled climatic variables in the forms of annual precipitation, rainfall in wettest and driest months combined with the observed fire incidents then were used to estimate the maximum entropy probability distributions for fire risks. From Figure 5, it can be seen that parts of Jakarta between North and West parts were having highest probability distributions of fire risks with value of 50%. North parts were also having high fire risk distributions (30-40%). Probability distributions of fire risks were decreasing in West and South parts of Jakarta.

Figure 6 shows the validations of modeled probability distributions of fire risks. The validations were measured as area under the curve (AUC). The average area under the curve (AUC) value was $0.64 \pm 0.07$ for maximum entropy model of fire risks in North, West, and South districts of Jakarta City. The mean AUC value of 0.64 indicates a moderate model.
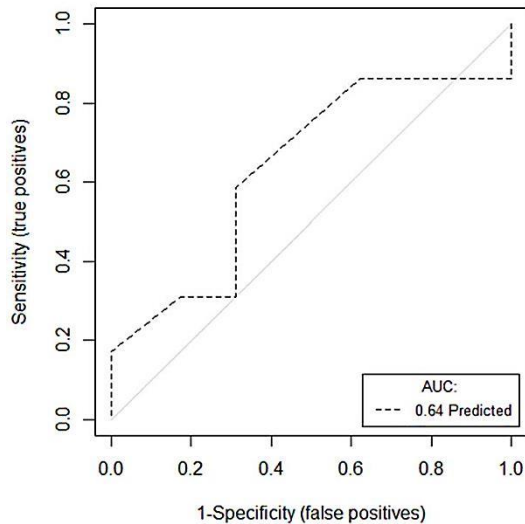
**Figure 6. The average area under the curve (AUC) (0.64 ± 0.07) for maximum entropy model of fire risks in North, West, and South districts of Jakarta City. The mean AUC value of 0.64 indicates a moderate model.**

## DISCUSSION

The use of maximum entropy in this study was in agreement with other studies in modeling the probability of fire risks (Syphard et al. 2019). Modeling using the maximum entropy prediction model has been applied to predict fire risks in Siberia (Janiec & Gadal 2020), USA (Parisien et al. 2012), and Ghats mountain (Renard et al. 2012) with satisfactory result. The accuracy of the model depends on the data used and it was including the climatic variables. In the few last years, an increase in the number of fire risks has been observed as has more years following extreme climate and affected by climate change.

According to Bekar et al. (2020), anthropogenic factors (Kim et al. 2019) and land use and/or land cover are significant at the regional level for discerning the incidences of fires at this spatial scale. Climate variables, on the other hand, gain importance and contribute to significant effects at the cross-regional and/or continental scale. Climate change can pose and increase two-folds of fire

vulnerability of urban inhabitants (Vilà et al. 2020). Climate change leads to the more drought conditions experienced by city. This dry weather causes structures in city becomes more vulnerable to fire and can increase the spread of fires within in urban settings (Bo et al. 2020). Climate change is also led to the scarcity of water that is needed to extinguish fires in city. Yananto and Sibarani (2016) have reported that recent climate change phenomenon has caused severe impacts on Jakarta City including decline rainfall.

Urban environments, like other ecosystem processes, are extremely vulnerable to climate change and following fire hazards. This is due to the fact that fire behavior reacts quickly to climate change characteristics. Fuel humidity, which is influenced by air temperature, relative humidity, wind speed, and rainfall, is one of these characteristics. Global warming and temperature rises will result from climate change. The projected increase in temperature as a result of climate change will rise fuel aridness and decrease relative moisture, and this consequence will be more pronounced in urban areas where precipitation declines and temperature rises (Howden et al. 1999). Surges in climate extreme events have the potential to cause a significant consequence on fire incidence. Moriondo et al. (2006) found that climate change caused a general increment in fire occurrence, as evidenced by an increment in the frequency of years with fire incidence, an increment in the extent of the season with fire incidences, and an increment in severe fire events, including the total sum of days.

The AUC obtained in here with value of 0.64 is comparable to AUC value from other studies. For fire risks in Sikkim, Banerjee (2020) obtain an AUC of 0.957. Higher AUC value was due to numbers of the predictors that have been used in the model. Similar to our study, Martin et al. (2018) reported AUC values from 0.7 to 0.85 indicating influences of climatic

variables that more significant during summer months in contributing the human induced fire risks (Martín et al. 2019).

## CONCLUSION

Based on modeled probability distributions of fire risks, North and West parts were having highest probability distributions of fire risks with value of 50%. North parts were also having lowest rainfall. This may confirm the influences of climatic variables in amplifying the probable fire incidents in Jakarta City. The AUC validates the probability distributions of fire risks model with AUC value of 0.64 ± 0.07. The results obtained from this study then can be used planning fire prevention. To the best of our knowledge, this study is the first that employ the maximum entropy method to model the probability of fire occurrence at city scale.

## ACKNOWLEDGEMENT

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