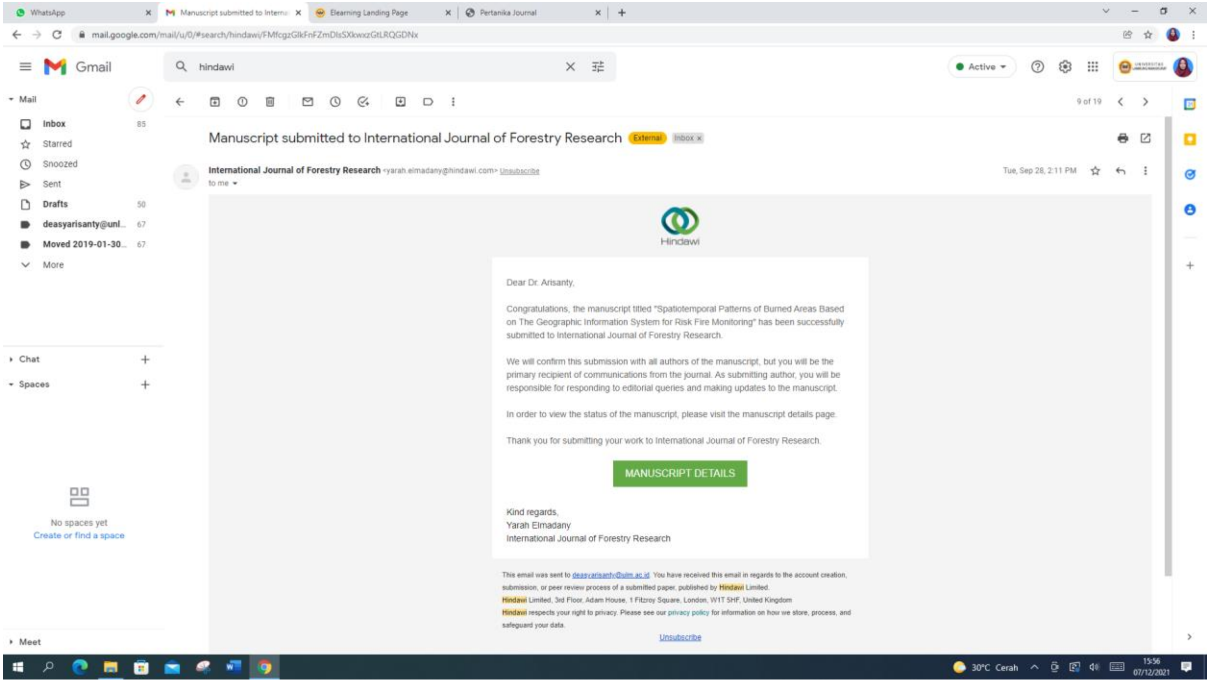
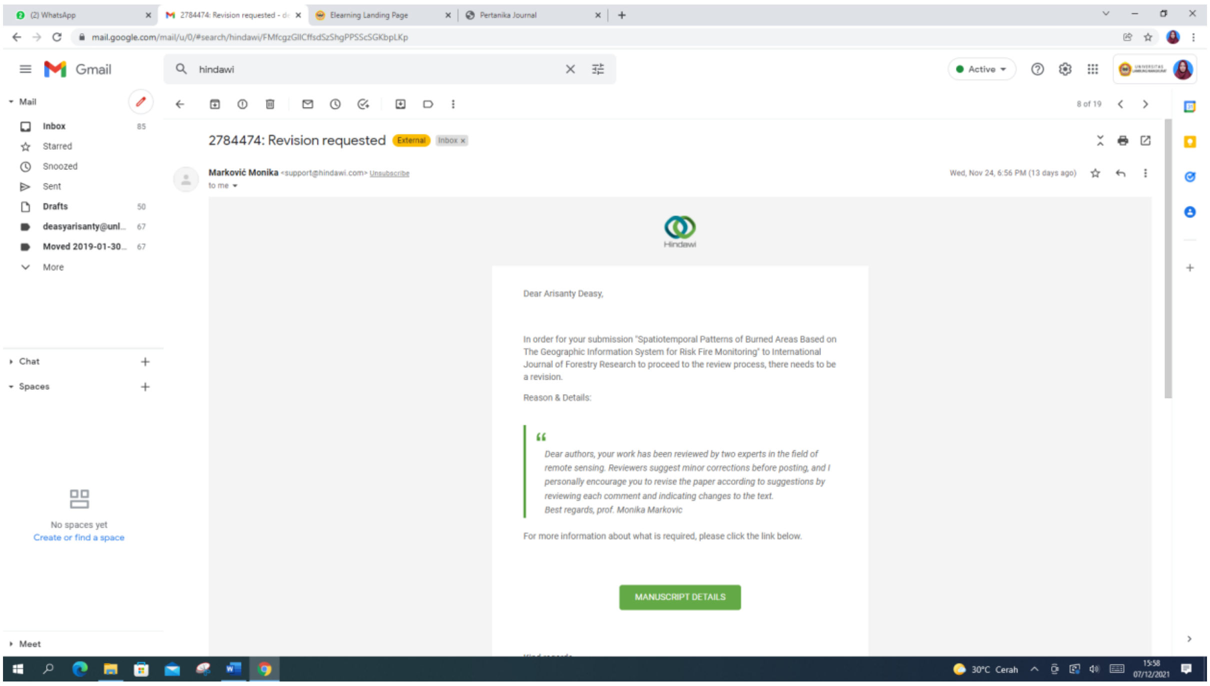
Bukti Corresponding Artikel

1. Tanggal 28 September 2021 dilakukan submitted artikel melalui sistem: https://sso.hindawi.com/auth/realms/Hindawi/protocol/openid-connect/logout?redirect_uri=https%3A%2F%2Freview.hindawi.com%2F



2. Proses review berlangsung dari tanggal 28 September 2021-24 November 2021 (2 bulan). Tanggal 24 November 2021 keluar hasil review artikel dengan **minor revision**, dengan perbaikan sebagai berikut:



Major issues

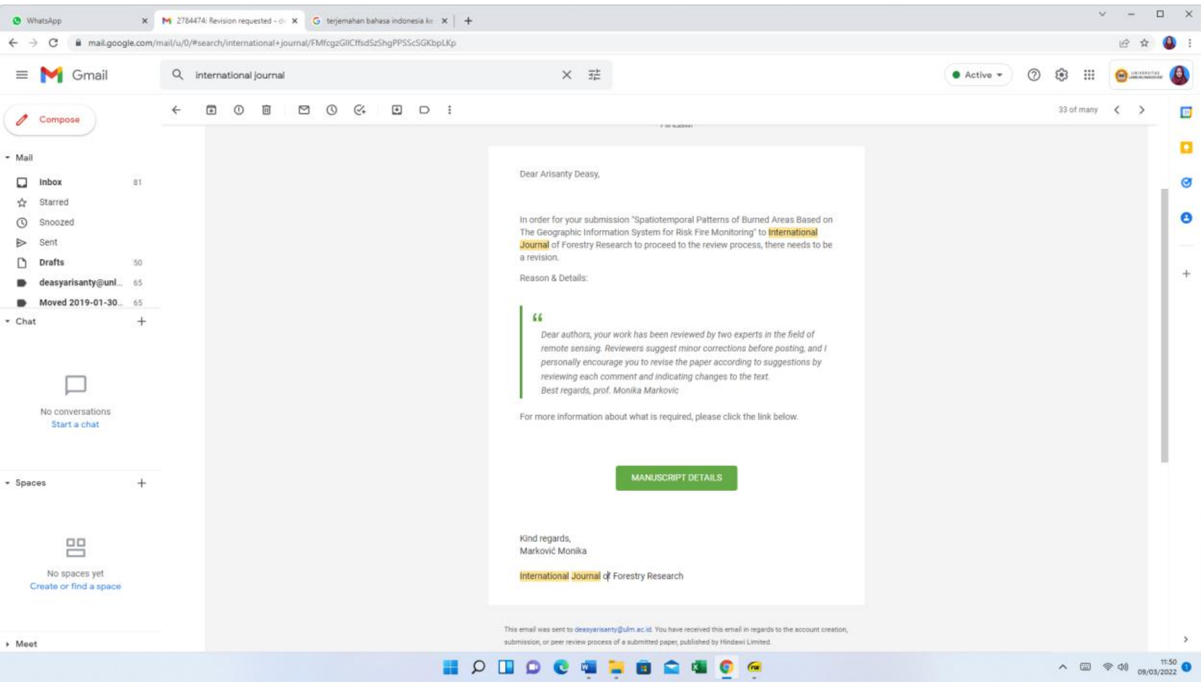
Authors should highlight what is main novelty in their manuscript (i.e. methodology or in obtained results).

Minor issues

- introduction: some sentences are confusing; an explanation can be added regarding the relationship between paragraphs
- Figure 1 and figure 4 should be in higher resolution.
- Page 7 last paragraph:
  „Other regions belonged to the non-significant category. (Figure 3)." Authors should delete "." before "(Figure 3)."
- what does each number in the result mean? give a more detailed explanation about it
- add a discussion about the spatial pattern of land fires in the discussion section
- some tables need to be cited in the script.
- Some references can be considered for replacement, see notes on your manuscript

Reviewer 2

1. novelty needs to be clarified again in the introduction
2. Somehow it seems to me that within this part of the introduction the text is not fluid. Perhaps, if possible, to try to create more coherent text, according to the current layout, most sentences seem like separate thoughts.
3. the table goes beyond the paper frame. It is not clear what the given rows (10 rows) of values in the table refer to
4. some figure not clear, need to higher resolution



3. Perbaikan disubmit pada tanggal 28 November 2021. Adapun perbaikan yang saya lakukan adalah sebagai berikut (warna kuning menggambarkan perbaikan konten dan tata tulis yang telah saya lakukan) antara lain:

Reviewer 1:

a. Menambahkan novelty empirik dan metode pada bagian pendahuluan dan saya tambahkan juga pada bagian pembahasan
b. Memperbaiki semua gambar peta dengan melakukan penajaman resolusi
c. Tabel yang belum disitasi saya sitasi
d. Menambahkan pembahasan mengenai pola spasial kebakaran hutan dan lahan
e. Saya menambahkan dengan beberapa artikel baru pada bagian pendahuluan dan pembahasan

Reviewer 2:

a. Menambahkan novelty pada bagian pendahuluan
b. Perbaikan kalimat untuk menyambungkan antar kalimat pada dua paragraf
c. Memperbaiki tata tulis yang masih kurang jelas, bahasa yang kurang tepat, dan nomor tabel.

Perbaikan novelty

Reviewer meminta pernyataan novelty ini untuk ditambahkan pada pendahuluan atau pada bagian pembahasan (Novelty dari aspek empirik). Berikut adalah bagian yang saya perjelas pada bagian pendahuluan mengenai novelty empirik. Saya menjelaskan secara detil bahwa dengan adanya analisis spasiotemporal maka dapat menentukan prioritas area yang akan ditangani dalam kebakaran lahan terutama pada lahan basah. Kajian tentang kebakaran lahan basah secara spasiotemporal yang selalu terjadi setiap tahun menjadi dasar dalam monitoring dan evaluasi dari sejarah kebakaran hutan dan lahan. Kajian tentang kebakaran lahan banyak dilakukan, tetapi di Indonesia khususnya pada lahan basah jarang dilakukan.

Pada bagian pendahuluan (halaman 2 pada jurnal):

"Forest and land fires are included in the geographical data, so they can be analyzed using Getis Ord Gi* analysis and kernel density. The analysis helps reveal the spatial pattern of forest and land fires so that strategies for fire management, mitigation, and prevention can be designed [28, 29]. Unfortunately, studies on spatial patterns of land and forest fires and fire density at various national and regional scales are still rarely carried out [30], including in Indonesia. Kernel density analysis has been proven to be accurate for analyzing the spatiotemporal pattern of land fires [31, 32], so it is appropriate to use it in analyzing forest and land fires in fire-prone areas in Indonesia, such as South Kalimantan dominated by wetlands and peatlands.

The pattern and density of forest and land fires are useful for determining priority areas in handling forest and land fires in South Kalimantan since forest and lands fires have increased every year in the region. Based on data from http://sipongi.menlhk.go.id, fires covered 2,331.96 hectares of land in 2016, 8,290.34 hectares in 2017, 9,8637.99 hectares in 2018, and increased to 137,848.00 hectares in 2019. The increasing land fires were due to the long dry season and the suboptimal handling [33]. Programs to manage burned forests and land areas, especially peatlands, have been widely carried out, such as by the Peat and Mangrove Restoration Agency (Badan Restorasi Gambut dan Mangrove – BRGM) from 2016 to the present time, including in South Kalimantan [31, 32]. However, such programs were suboptimal because they could only restore limited areas while fires happened in such vast areas. This study focuses on areas with the densest fires based on the results of the spatiotemporal analysis and fire density, so responsible government agencies like BRGM can set up a priority in handling fires. This study aims to analyze the spatiotemporal pattern of fires and fire density in fire-prone areas in Indonesia."

Pada bagian pembahasan (Halaman 8 pada jurnal):

"Utilization of data from the findings of this study is very important in the management of forest and land fires disaster management in South Kalimantan. especially for the Regional Disaster Management Agency. Monitoring and evaluation of fire history can be predicted by making a model of fire and land hazard maps and placing fire posts in fire and forest prone areas."

Saya juga telah menambahkan novelty mengenai metode bahwa kajian pola spasial yang dilakukan bukan hanya menggunakan analisa statistik (Getis Ord Gi*) tetapi juga dilengkapi dengan analisa secara kualitatif dengan kernel density dalam melihat pola spasial kebakaran lahan. Kombinasi kedua metode ini dalam melihat kebakaran hutan dan lahan saya gunakan karena melihat metode ini dapat digunakan untuk menganalisis data geografi hanya sangat sedikit riset yang menggunakan metode ini untuk kajian kebakaran hutan dan lahan **(Novelty dari aspek teoritik/metodologi).**

Pada bagian pendahuluan (halaman 2 pada jurnal)

"Forest and land fires are included in the geographical data, so they can be analyzed using Getis Ord Gi* analysis and kernel density. The analysis helps reveal the spatial pattern of forest and land fires so that strategies for fire management, mitigation, and prevention can be designed [28, 29]. Unfortunately, studies on spatial patterns of land and forest fires and fire density at various national and regional scales are still rarely carried out [30], including in Indonesia. Kernel density analysis has been proven to be accurate for analyzing the spatiotemporal pattern of land fires [31, 32], so it is appropriate to use it in analyzing forest and land fires in fire-prone areas in Indonesia, such as South Kalimantan dominated by wetlands and peatlands.

Pada bagian pembahasan (halaman 8 pada jurnal)

Overall. the Getis Ord Gi* analysis (hot spot analysis) and kernel density can analyze the spatial pattern of land fires in South Kalimantan. Several studies using Getis Ord Gi* analysis and kernel density confirm that both methods effectively measure the level of spatiotemporal clustering patterns [48]. However. the map generated by the kernel density analysis must be analyzed together with the hot spot analysis to be statistically significant [49]. Other studies show that kernel density analysis is quite accurate for analyzing spatiotemporal patterns even though it is considered a non-statistical approach [44].

Secara umum pada naskah sebagai berikut (naskah yang direvisi), warna kuning revisi yang telah dilakukan:

Spatiotemporal Patterns of Burned Areas Based on The Geographic Information System for Risk Fire Monitoring

Deasy Arisanty[1*], Muhammad Muhaimin[1], Dedi Rosadi[2], Aswin Nur Saputra[1], Karunia Puji Hastuti[1], Ismi Rajiani[3]

[1]*Department of Geography Education, Faculty of Teacher Training and Education, Lambung Mangkurat University, H. Hasan Basry Street, 70123 Banjarmasin, Indonesia*
[2]*Department of Mathematics, Faculty of Mathematics and Natural Sciences, Gadjah Mada University, North Sekip, 55281 Yogyakarta, Indonesia*
[3]*Department of Social Science Education, Faculty of Teacher Training and Education, Lambung Mangkurat University, Hasan Basry Street, 70123 Banjarmasin, Indonesia*

Corresponding author: deasyarisanty@ulm.ac.id; ORCID ID: 0000-0001-5937-2309

Abstract
Forest and land fires occur every year in Indonesia. Efforts to handle forest and land fires have not been optimal because fires occur in too many places with unclear patterns and densities. The study analyzed the spatiotemporal patterns of burned areas and fire density in fire-prone areas in Indonesia. Data of burned areas were taken from http://sipongi.menlhk.go.id/. The website collected its data from NOAA (National Oceanic and Atmospheric Administration) images. Data were analyzed using the hot spot analysis to determine the spatiotemporal patterns of the burned areas and the kernel density analysis to examine the density of land fires. Findings showed that the spatiotemporal pattern from 2016 to 2019 formed a hot spot value in the peatland area with a confidence level of 90-99%, meaning that land fires were clustered in that area. In addition, the highest density of land fires also occurred in the peatland areas. Clustered burned areas with high fire density were found in areas with low-medium vegetation density—it was the peatland areas. The peatland areas must become the priority to prevent and handle forest and land fires to reduce risk fires.

Keywords: burned area, spatiotemporal pattern, fire density

1. Introduction

Forest and land fires are recurring events in Indonesia and are the main contributors to climate change [1–3]. Various methods have been carried out to overcome forest and land fires, yet they do not show satisfying results [4]. The traditional method to monitor fires employing the community is still practiced in Indonesia, including in South Kalimantan [5, 6]. This method, however, has made fire management less effective and dangerous. Electronic and computer technology has enabled the development of methods for handling forest and land fires through computer-based geospatial systems [6].

Geospatial technology is the most appropriate and easier method in analyzing geographical phenomena, including monitoring land fires [7]. As fires often occur in spatially vast and dangerous areas, the use of geospatial technology is considered the most appropriate choice to handle such fires [8]. Geospatial technology allows analyzing forest and land fires at various spatial and temporal scales [9]. Geospatial analysis can also prevent future fires and help conserve forest and land resources [10]. A Geographic Information System (GIS) enables efficient analysis of geographic phenomena, including spatial pattern analysis or spatial relationship modeling [9, 11–14].

Spatial autocorrelation analysis is an analysis in GIS. Spatiotemporal autocorrelation refers to the correlation of events within themselves over space and through time. It reflects the extent to which events with similar properties are clustered or dispersed [15, 16]. Spatial autocorrelation analysis aims to analyze whether the variables are spatially correlated and how relevant they are—and how they generate hot spots [17, 18]. Hot Spot Analysis, an autocorrelation analysis, refers to calculating the Getis-Ord Gi* statistic for each element in the dataset. The Getis-Ord Gi* value can be used to detect the spatial distribution of clustering high-value or low-value spatial units [19]. The Getis-Ord Gi* value based on the normal distribution hypothesis test is more sensitive than the LISA (Local Indicators of Spatial Association) method based on the random distribution hypothesis test [20].

In addition to using Getis-Ord Gi*, spatial temporal analysis can use the kernel density. Kernel density in the Geographic Information System is a method to determine whether or not an occurring phenomenon forms a cluster [21]. Kernel density analysis characterizes the horizontal pattern using spectral value information [22]. Kernel density is used to describe temporal and spatial heterogeneity [23]. The kernel method has been used in region analysis only since the 1990s. In the context of area analysis, this method describes the probability of observed objects in an area. This method begins by centering a bivariate of a density probability function with a unit volume (kernel) over each sample point [24]. A regular grid is then superimposed on the data, and a probability density estimate is calculated at each grid intersection by summing the volume of overlapping kernels. The density estimation at each grid intersection is used for the calculation of the bivariate kernel density estimation. The resulting kernel density estimation will have a relatively large value in areas with many sample points and low values in areas with few sample points. Predicted region estimates are obtained by drawing contour lines (isopleths) based on the number of kernel volumes at grid intersections. This isopleth defines predictive polygons at different probability levels whose area can be calculated.

Many autocorrelation analyses, such as Getis Ord Gi* and kernel density, have been carried out to rehabilitate forest areas. Results of autocorrelation analysis in these studies are clusters of forest damage so that adaptive forest rehabilitation actions can be planned [25]. Studies on the spatial pattern of soil erosion risk on agricultural land show the impact of soil erosion, including problems of agricultural soil fertility [26]. Ord Gi* and kernel density analysis can also analyze clusters and densities of earthquake events to examine clusters with various magnitudes [27]. Kernel density analysis has also been used to estimate the temporal and spatial patterns of carbon emissions—the results are used to plan efforts to achieve carbon emission reduction [23].

Forest and land fires are included in the geographical data, so they can be analyzed using Getis Ord Gi* analysis and kernel density. The analysis helps reveal the spatial pattern of forest and land fires so that strategies for fire management, mitigation, and prevention can be designed [28, 29]. Unfortunately, studies on spatial patterns of land and forest fires and fire density at various national and regional scales are still rarely carried out [30], including in Indonesia. Kernel density analysis has been proven to be accurate for analyzing the spatiotemporal pattern of land fires [31, 32], so it is appropriate to use it in analyzing forest and land fires in fire-prone areas in Indonesia, such as South Kalimantan dominated by wetlands and peatlands.

The pattern and density of forest and land fires are useful for determining priority areas in handling forest and land fires in South Kalimantan since forest and lands fires have increased every year in the region. Based on data from http://sipongi.menlhk.go.id, fires covered 2,331.96 hectares of land in 2016, 8,290.34 hectares in 2017, 9,8637.99 hectares in 2018, and increased to 137,848.00 hectares in 2019. The increasing land fires were due to the long dry season and the suboptimal handling [33]. Programs to manage burned forests and land areas, especially peatlands, have been widely carried out, such as by the Peat and Mangrove Restoration Agency (*Badan Restorasi Gambut dan Mangrove* – BRGM) from 2016 to the present time, including in South Kalimantan [31, 32]. However, such programs were suboptimal because they could only restore limited areas while fires happened in such vast areas. This study focuses on areas with the densest fires based on the results of the spatiotemporal analysis and fire density, so responsible government agencies like BRGM can set up a priority in handling fires. This study aims to analyze the spatiotemporal pattern of fires and fire density in fire-prone areas in Indonesia.

2. Materials and Methods

Research Location

The study took place in South Kalimantan Province with coordinates 5° 20' - 1° 10'latitude, 114° 0' - 117° 40'east longitude with an area of 36.985 km^2. South Kalimantan experiences land fires every year and is a priority area for peat restoration [33, 34]. The research location is shown in Figure 1.

Figure 1. Research Location

Data

The primary data for this research is the burned areas for four years from 2016 to 2019. The data comes from the website http://sipongi.menlhk.go.id/, the official website of the Ministry of Forestry and Environment of the Republic of Indonesia. The fire data on the website comes from NOAA (National Oceanic and Atmospheric Administration) data. The number of burned areas each year is shown in Table 1.

TABLE 1: Data on Burned Areas

Number	Year	Number of Burned Area (dots)
1	2016	43
2	2017	63
3	2018	191
4	2019	424

Source: http://sipongi.menlhk.go.id/

Analysis of Spatiotemporal Patterns with Hot Spot Analysis (Getis-Ord Gi*)

The analysis used to determine the pattern of land fires was the hot spot analysis. The hot spot analysis is used to calculate Getis-Ord Gi* statistics on each data set feature [35]. The calculation results will show the z-score and p-value in each feature with a high or low value in the spatial cluster. This analysis considers each adjacent feature. Features with a high value are attractive but not necessarily statistically significant. A statistically significant hot spot has a high value and is surrounded by other features with a high value as well. The number of local features and their neighbors is compared proportionally to the sum of all features—when the local number is very different from the expected local number, and the difference is too large to be the result of a random chance, the z-score results are statistically significant [36]. The larger the positive z-score value, the more intense the grouping to form a hot spot, and vice versa—the smaller the negative z-score value, the more intense the grouping to form a cold spot [36, 37]. The formula of the Getis Ord Gi* is as follows.

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \quad (1)$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (3)$$

Gi* : Ord Gi* value
Xj : Value or j feature attributes
Wij : Spatial weight between i and j features
$\bar{X}$: Average value
S : Standard deviation
N : Number of features

Hot spot analysis identifies significant hot spots and cold spots using the Getis-Ord Gi* statistics using a set of weighting features. Weighting features are based on the field attribute selected from the analyzed layer. The neighborhood of each feature is compared with the study area to determine the value of each feature [37].

TABLE 2: Guideline in Interpreting the Z-score Value in Hot Spot Analysis

No	Z-Score	Interpretation
1	< -2.58	Cold Spot - 99% Confidence
2	-2.58 to -1.96	Cold Spot - 95% Confidence
3	-1.96 to -1.65	Cold Spot - 90% Confidence
4	-1.65 to 1.65	Not Significant
5	1.65 to 1.96	Hot spot - 90% Confidence
6	1.96 to 2.58	Hot spot - 95% Confidence
7	> 2.58	Hot spot - 99% Confidence

Source: [38]

Analysis of Burned Area Density (Kernel Density)

The probability density function is a fundamental concept in statistics. Consider a random number X with a probability density function f. The specific f function gives an overview of the distribution of X and allows the probability associated with X to be found in that relationship. Kernel density calculates the density of features in the surrounding environment. One feature can be heavier than another due to the meaning of the feature itself [39].

The algorithm used to determine the default search radius is also known as bandwidth. First, calculate the center mean of the input point if a population field other than none is selected, and the value of that field will weigh all the following calculations. Then, calculate the distance from the mean center for all points. Next, calculate the median of the distance (Dm). Finally, calculate the Standard Distance (SD) and the bandwidth with the radius search formula, as presented follows [39].

$$searchRadius = 0.9 \times \min\left(SD, \sqrt{\frac{1}{\ln(2)}} \times Dm\right) \times n^{-0.2} \quad (4)$$

SD = Standard distance
Dm = Median distance
N = Number of points analyzed

The steps taken to make a density analysis at the burned areas can be formulated as an analysis model shown in Figure 2.

Figure 2. Analysis Model of the Burned Area Density

3. Result and Discussion

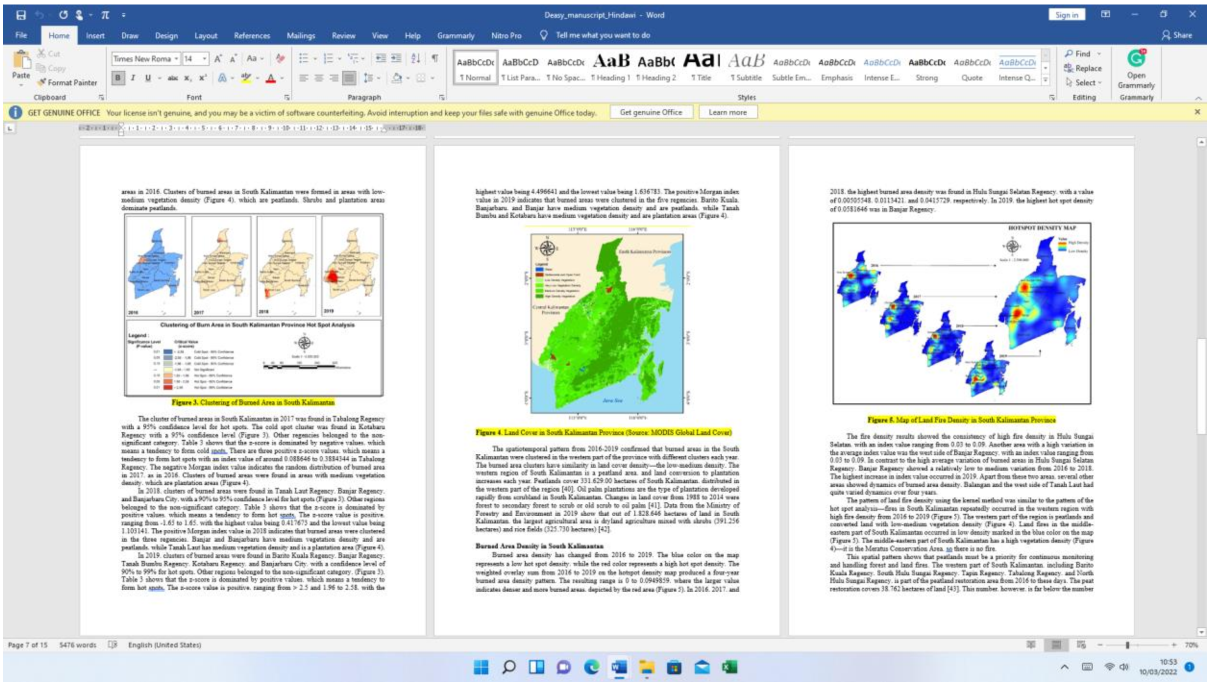
The Spatiotemporal Pattern of Burned Areas in South Kalimantan

Burned areas in South Kalimantan Province continue to increase even though efforts have been made to reduce forest and land fires. There were 42 burned points in 2016, 63 in 2017, 191 in 2018, and 424 in 2019. The spatiotemporal pattern analysis helps identify fire patterns in an area and the risk of fire recurrence in the same area. Hot spot analysis can be used to analyze the spatial pattern of the burned area. Table 3 and Figure 3 describe the clusters of burned areas in South Kalimantan from 2016 to 2019.

TABLE 3: Data of the Global Moran's I Summary of 2016-2019

2016		2017		2018		2019	
Moran's Index	z-score	Moran's Index	z-score	Moran's Index	z-score	Moran's Index	z-score
-0.0093	0.1572	-0.0629	-0.8369	0.0394	1.3508	0.0447	1.6368
-0.0162	0.1039	-0.0654	-0.9152	0.0275	1.1115	0.0317	2.5255
-0.0395	-0.1256	-0.0495	-0.6322	0.0277	1.2250	0.0359	3.0498
-0.0338	-0.0536	-0.0442	-0.5269	0.0214	1.3051	0.0427	2.7914
-0.0331	-0.0705	-0.0362	-0.3633	0.0213	1.2236	0.0438	3.3055
-0.0496	-0.0270	-0.0275	-0.1604	0.0224	1.4065	0.0428	3.6308
-0.0551	-0.0270	-0.0447	-0.5968	0.0186	1.3422	0.0043	4.0809
-0.0788	-0.0270	-0.0174	0.0886	0.0111	1.0278	0.0399	4.1955
-0.0872	-0.0270	-0.0062	0.3848	0.0121	1.3631	0.0370	4.2885
-0.1056	-0.0270	-0.0066	0.3884	0.0149	1.4177	0.0351	4.4996

In 2016, clusters of burned areas with hot spots (90%) were found in South Hulu Sungai Regency, Central Hulu Sungai Regency, and North Hulu Sungai Regency. Other regencies had cold spots with a confidence level of 99% (Figure 3). Table 3 shows that the z-score is dominated by negative values, which means a tendency to form cold spots. The two positive z-score values confirm a tendency to form hot spots with a value of 0.011871 to 0.157192 in three regencies. The negative Morgan index value indicates a random distribution of burned



areas in 2016. Clusters of burned areas in South Kalimantan were formed in areas with low-medium vegetation density (Figure 4), which are peatlands. Shrubs and plantation areas dominate peatlands.

Clustering of Burn Area in South Kalimantan Province Hot Spot Analysis

Figure 3. Clustering of Burned Area in South Kalimantan

The cluster of burned areas in South Kalimantan in 2017 was found in Tabalong Regency with a 95% confidence level for hot spots. The cold spot cluster was found in Kotabaru Regency with a 95% confidence level (Figure 3). Other regencies belonged to the non-significant category. Table 3 shows that the z-score is dominated by negative values, which means a tendency to form cold spots. There are three positive z-score values, which means a tendency to form hot spots with an index value of around 0.088646 to 0.3884344 in Tabalong Regency. The negative Morgan index value indicates the random distribution of burned area in 2017, as in 2016. Clusters of burned areas were found in areas with medium vegetation density, which are plantation areas (Figure 4).

In 2018, clusters of burned areas were found in Tanah Laut Regency, Banjar Regency, and Banjarbaru City, with a 90% to 95% confidence level for hot spots (Figure 3). Other regions belonged to the non-significant category. Table 3 shows that the z-score is dominated by positive values, which means a tendency to form hot spots. The z-score value is positive, ranging from -1.65 to 1.65, with the highest value being 0.417675 and the lowest value being 1.103141. The positive Morgan index value in 2018 indicates that burned areas were clustered in the three regencies. Banjar and Banjarbaru have medium vegetation density and are peatlands, while Tanah Laut has medium vegetation density and is a plantation area (Figure 4).

In 2019, clusters of burned areas were found in Barito Kuala Regency, Banjar Regency, Tanah Bumbu Regency, Kotabaru Regency, and Banjarbaru City, with a confidence level of 90% to 99% for hot spots. Other regions belonged to the non-significant category. (Figure 3). Table 3 shows that the z-score is dominated by positive values, which means a tendency to form hot spots. The z-score value is positive, ranging from > 2.5 and 1.96 to 2.58, with the highest value being 4.496641 and the lowest value being 1.636783. The positive Morgan index value in 2019 indicates that burned areas were clustered in the five regencies. Barito Kuala, Banjarbaru, and Banjar have medium vegetation density and are peatlands, while Tanah Bumbu and Kotabaru have medium vegetation density and are plantation areas (Figure 4).

Figure 4. Land Cover in South Kalimantan Province (Source: MODIS Global Land Cover)

The spatiotemporal pattern from 2016-2019 confirmed that burned areas in the South Kalimantan were clustered in the western part of the province with different clusters each year. The burned area clusters have similarity in land cover density—the low-medium density. The western region of South Kalimantan is a peatland area, and land conversion to plantation increases each year. Peatlands cover 331.629.00 hectares of South Kalimantan, distributed in the western part of the region [40]. Oil palm plantations are the type of plantation developed rapidly from scrubland in South Kalimantan. Changes in land cover from 1988 to 2014 were forest to secondary forest to scrub or old scrub to oil palm [41]. Data from the Ministry of Forestry and Environment in 2019 show that out of 1.828.646 hectares of land in South Kalimantan, the largest agricultural area is dryland agriculture mixed with shrubs (391.256 hectares) and rice fields (325.730 hectares) [42].

Burned Area Density in South Kalimantan

Burned area density has changed from 2016 to 2019. The blue color on the map represents a low hot spot density, while the red color represents a high hot spot density. The weighted overlay sum from 2016 to 2019 on the hotspot density map produced a four-year burned area density pattern. The resulting range is 0 to 0.0949859, where the larger value indicates denser and more burned areas, depicted by the red area (Figure 5). In 2016, 2017, and 2018, the highest burned area density was found in Hulu Sungai Selatan Regency, with a value of 0.00505548, 0.0113421, and 0.0415729, respectively. In 2019, the highest hot spot density of 0.0581646 was in Banjar Regency.

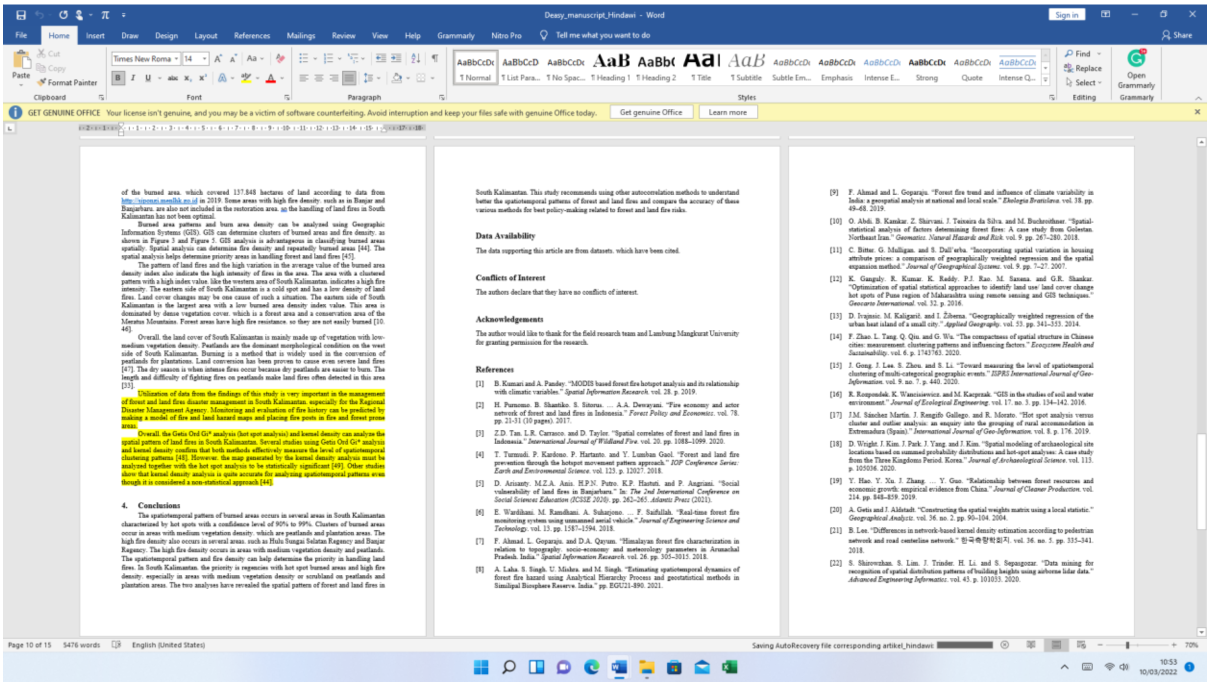
HOTSPOT DENSITY MAP

Figure 5. Map of Land Fire Density in South Kalimantan Province

The fire density results showed the consistency of high fire density in Hulu Sungai Selatan, with an index value ranging from 0.03 to 0.09. Another area with a high variation in the average index value was the west side of Banjar Regency, with an index value ranging from 0.03 to 0.09. In contrast to the high average variation of burned areas in Hulu Sungai Selatan Regency, Banjar Regency showed a relatively low to medium variation from 2016 to 2018. The highest increase in index value occurred in 2019. Apart from these two areas, several other areas showed dynamics of burned area density. Balangan and the west side of Tanah Laut had quite varied dynamics over four years.

The pattern of land fire density using the kernel method was similar to the pattern of the hot spot analysis—fires in South Kalimantan repeatedly occurred in the western region with high fire density from 2016 to 2019 (Figure 5). The western part of the region is peatlands and converted land with low-medium vegetation density (Figure 4). Land fires in the middle-eastern part of South Kalimantan occurred in low density marked in the blue color on the map (Figure 5). The middle-eastern part of South Kalimantan has a high vegetation density (Figure 4)—it is the Meratus Conservation Area, so there is no fire.

This spatial pattern shows that peatlands must be a priority for continuous monitoring and handling forest and land fires. The western part of South Kalimantan, including Barito Kuala Regency, South Hulu Sungai Regency, Tapin Regency, Tabalong Regency, and North Hulu Sungai Regency, is part of the peatland restoration area from 2016 to these days. The peat restoration covers 38.762 hectares of land [43]. This number, however, is far below the number



of the burned area, which covered 137.848 hectares of land according to data from http://sipongi.menlhk.go.id in 2019. Some areas with high fire density, such as in Banjar and Banjarbaru, are also not included in the restoration area, so the handling of land fires in South Kalimantan has not been optimal.

Burned area patterns and burn area density can be analyzed using Geographic Information Systems (GIS). GIS can determine clusters of burned areas and fire density, as shown in Figure 3 and Figure 5. GIS analysis is advantageous in classifying burned areas spatially. Spatial analysis can determine fire density and repeatedly burned areas [44]. The spatial analysis helps determine priority areas in handling forest and land fires [45].

The pattern of land fires and the high variation in the average value of the burned area density index also indicate the high intensity of fires in the area. The area with a clustered pattern with a high index value, like the western area of South Kalimantan, indicates a high fire intensity. The eastern side of South Kalimantan is a cold spot and has a low density of land fires. Land cover changes may be one cause of such a situation. The eastern side of South Kalimantan is the largest area with a low burned area density index value. This area is dominated by dense vegetation cover, which is a forest area and a conservation area of the Meratus Mountains. Forest areas have high fire resistance, so they are not easily burned [10, 46].

Overall, the land cover of South Kalimantan is mainly made up of vegetation with low-medium vegetation density. Peatlands are the dominant morphological condition on the west side of South Kalimantan. Burning is a method that is widely used in the conversion of peatlands for plantations. Land conversion has been proven to cause even severe land fires [47]. The dry season is when intense fires occur because dry peatlands are easier to burn. The length and difficulty of fighting fires on peatlands make land fires often detected in this area [33].

Utilization of data from the findings of this study is very important in the management of forest and land fires disaster management in South Kalimantan, especially for the Regional Disaster Management Agency. Monitoring and evaluation of fire history can be predicted by making a model of fire and land hazard maps and placing fire posts in fire and forest prone areas.

Overall, the Getis Ord Gi* analysis (hot spot analysis) and kernel density can analyze the spatial pattern of land fires in South Kalimantan. Several studies using Getis Ord Gi* analysis and kernel density confirm that both methods effectively measure the level of spatiotemporal clustering patterns [48]. However, the map generated by the kernel density analysis must be analyzed together with the hot spot analysis to be statistically significant [49]. Other studies show that kernel density analysis is quite accurate for analyzing spatiotemporal patterns even though it is considered a non-statistical approach [44].

4. Conclusions

The spatiotemporal pattern of burned areas occurs in several areas in South Kalimantan characterized by hot spots with a confidence level of 90% to 99%. Clusters of burned areas occur in areas with medium vegetation density, which are peatlands and plantation areas. The high fire density also occurs in several areas, such as Hulu Sungai Selatan Regency and Banjar Regency. The high fire density occurs in areas with medium vegetation density and peatlands. The spatiotemporal pattern and fire density can help determine the priority in handling land fires. In South Kalimantan, the priority is regencies with hot spot burned areas and high fire density, especially in areas with medium vegetation density or scrubland on peatlands and plantation areas. The two analyses have revealed the spatial pattern of forest and land fires in South Kalimantan. This study recommends using other autocorrelation methods to understand better the spatiotemporal patterns of forest and land fires and compare the accuracy of these various methods for best policy-making related to forest and land fire risks.

Data Availability

The data supporting this article are from datasets, which have been cited.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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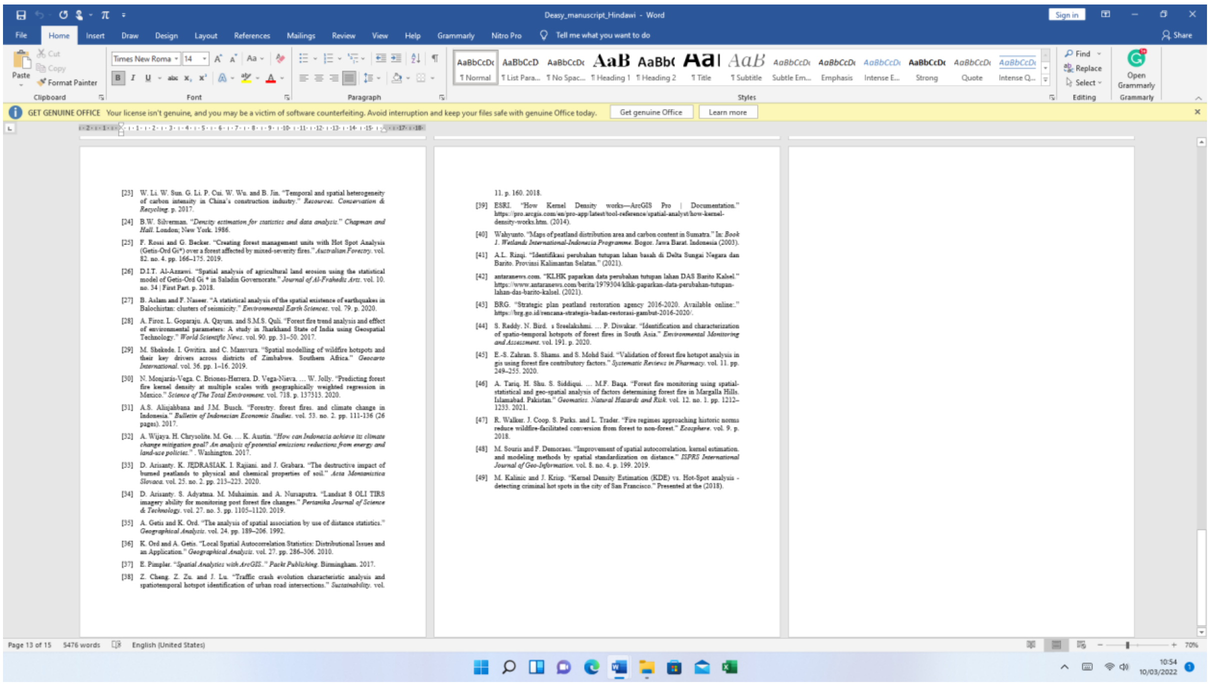

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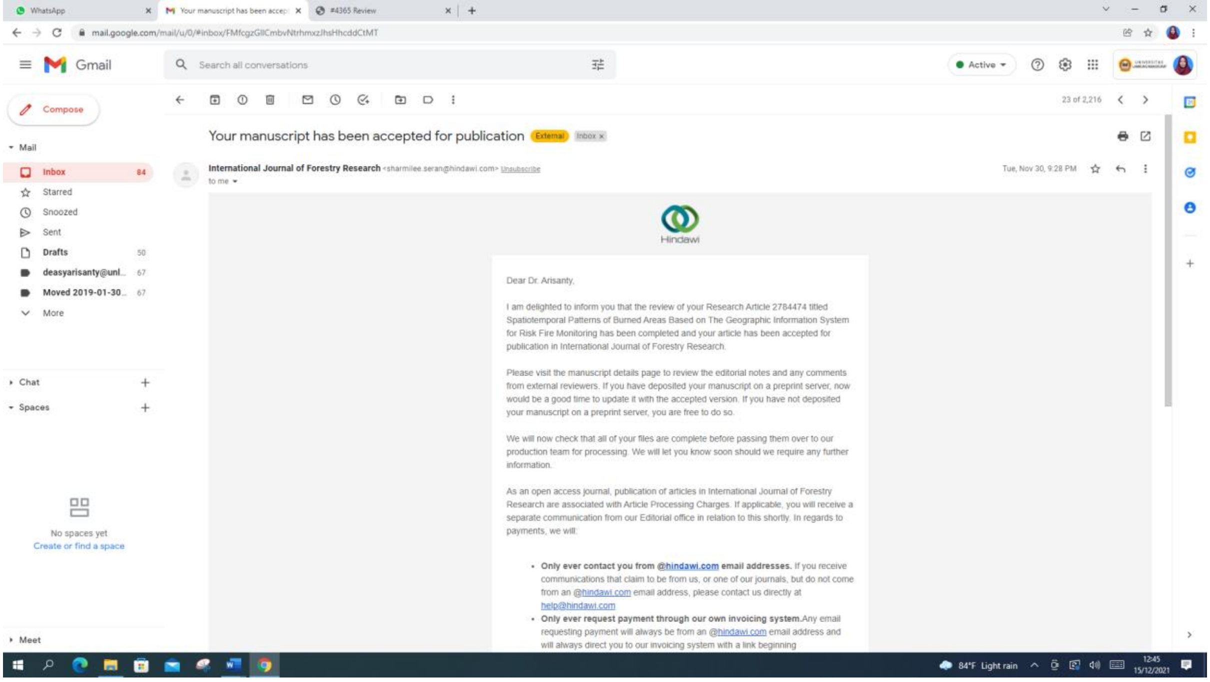

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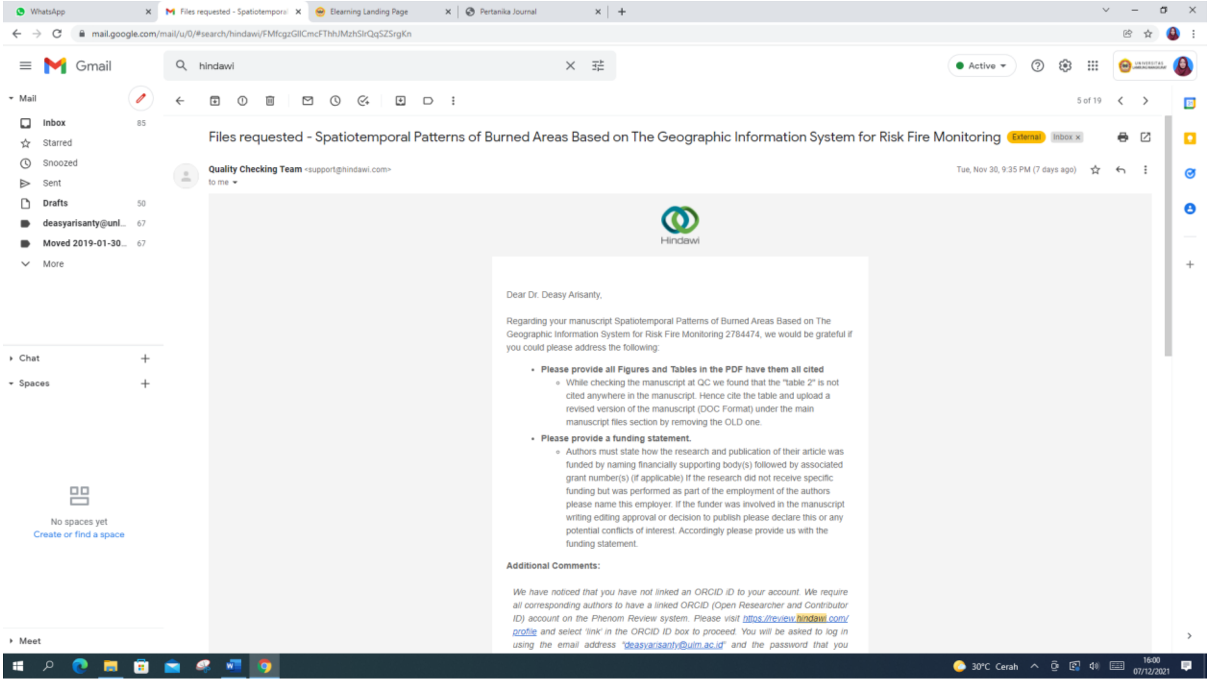

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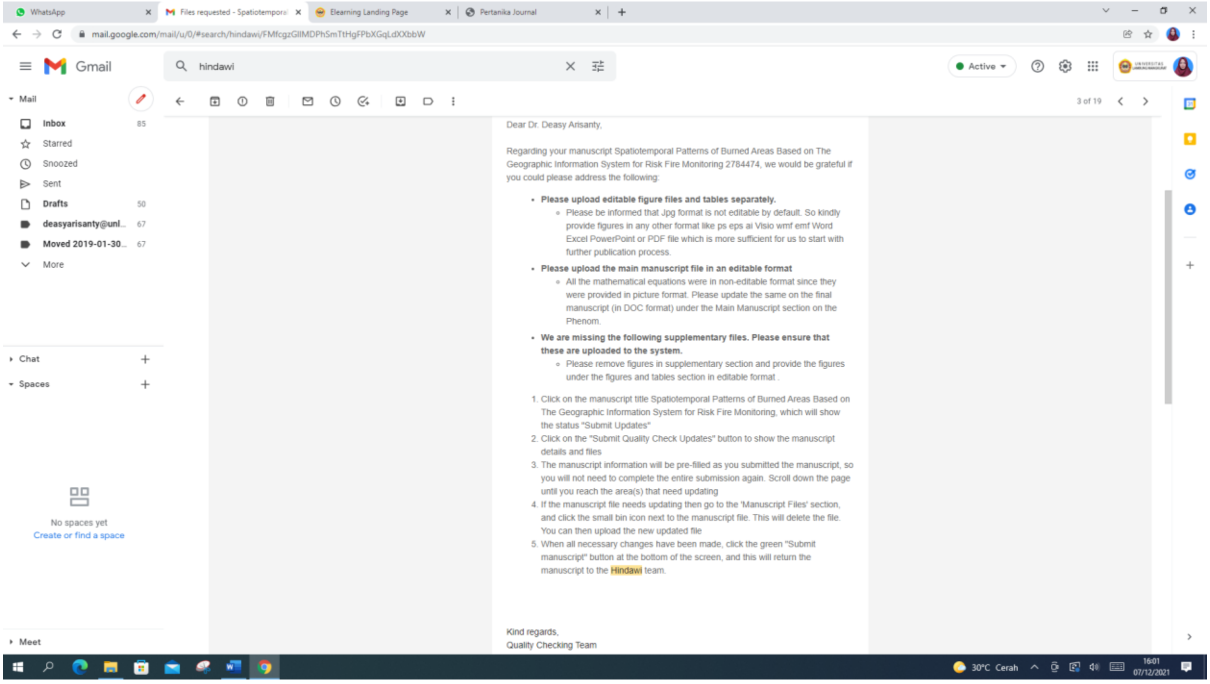

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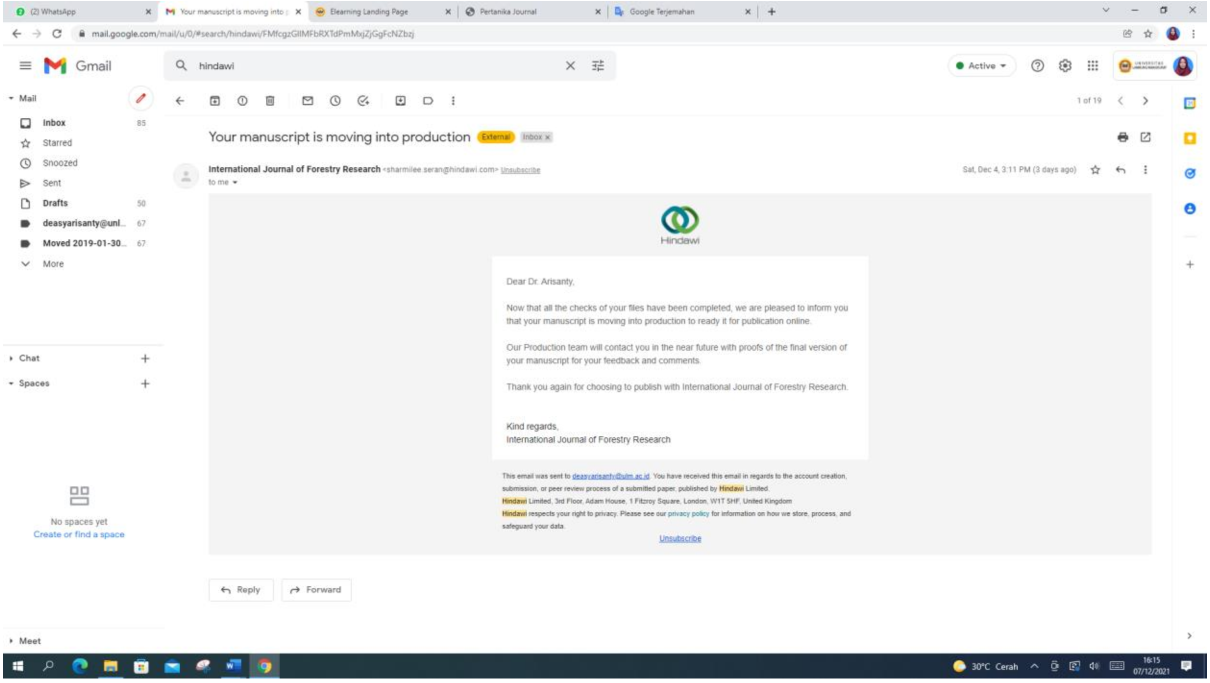

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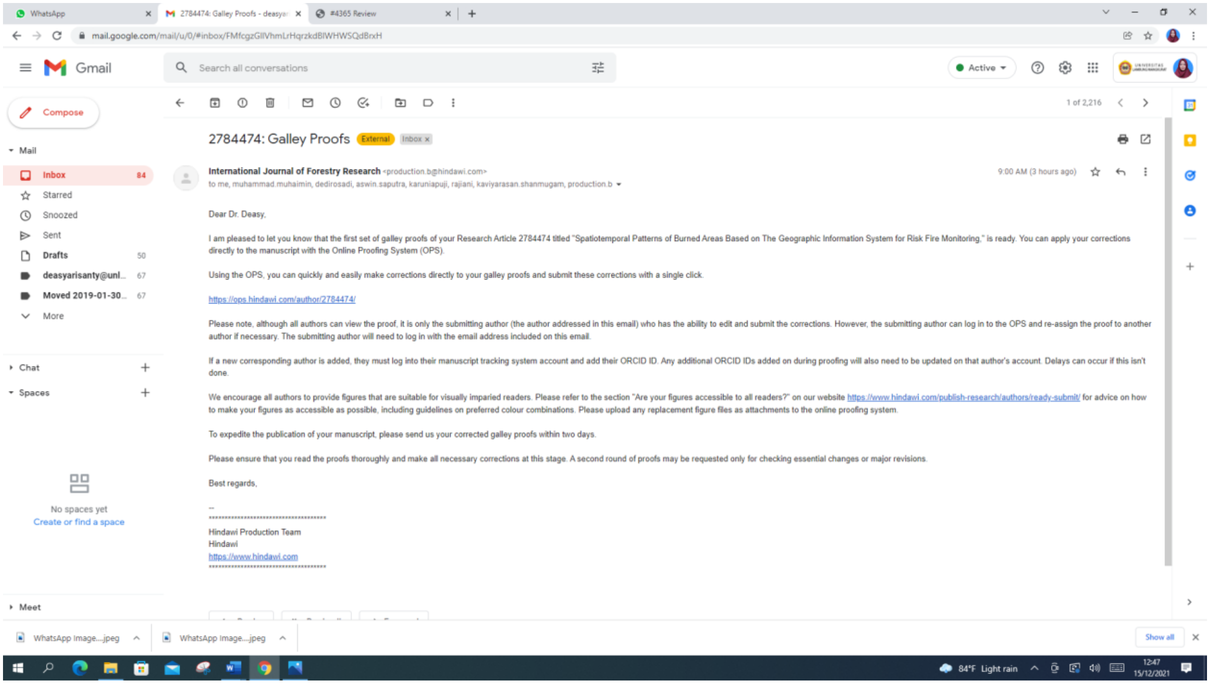

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Research Article

Spatiotemporal Patterns of Burned Areas Based on the Geographic Information System for Fire Risk Monitoring

Deasy Arisanty,[1] Muhammad Muhaimin,[1] Dedi Rosadi,[2] Aswin Nur Saputra,[1] Karunia Puji Hastuti, and Ismi Rajiani[3]

[1]Department of Geography Education, Faculty of Teacher Training and Education, Lambung Mangkur University, H. Hasan Basry Street, Banjarmasin 70123, Indonesia
[2]Department of Mathematics, Faculty of Mathematics and Natural Sciences, Gadjah Mada University, North Sekip, Yogyakarta 55281, Indonesia
[3]Department of Social Science Education, Faculty of Teacher Training and Education, Lambung Mangkurat University, Hasan Basry Street, Banjarmasin 70123, Indonesia

Correspondence should be addressed to Deasy Arisanty

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Abstract

Forest and land fires occur every year in Indonesia. Efforts to handle forest and land fires have not bee optimal because fires occur in too many places with unclear patterns and densities. The study analyz the spatiotemporal patterns of burned areas and fire density in fire-prone areas in Indonesia. Data burned areas were taken from http://sipongi.menlhk.go.id/. The website collected its data from NOA (National Oceanic and Atmospheric Administration) images. Data were analyzed using the hot sp analysis to determine the spatiotemporal patterns of the burned areas and the kernel density analysis examine the density of land fires. Findings showed that the spatiotemporal pattern from 2016 to 20 formed a hot spot value in the peatland area with a confidence level of 90–99%, meaning that land fir were clustered in that area. In addition, the highest density of land fires also occurred in the peatlar areas. Clustered burned areas with high fire density were found in areas with low–medium vegetatic density—they were the peatland areas. The peatland areas must become the priority to prevent ar handle forest and land fires to reduce fire risks.

1. Introduction

Forest and land fires are recurring events in Indonesia and are the main contributors to climate chan [1–3]. Various methods have been carried out to overcome forest and land fires, yet they do not sho satisfying results [4]. The traditional method to monitor fires employing the community is still practice in Indonesia, including in South Kalimantan [5, 6]. This method, however, has made fire manageme less effective and dangerous. Electronic and computer technology has enabled the development methods for handling forest and land fires through computer-based geospatial systems [6].

Geospatial technology is the most appropriate and easier method in analyzing geographical phenomen including monitoring land fires [7]. As fires often occur in spatially vast and dangerous areas, the use geospatial technology is considered the most appropriate choice to handle such fires [8]. Geospati technology allows analyzing forest and land fires at various spatial and temporal scales [9]. Geospati analysis can also prevent future fires and help conserve forest and land resources [10]. A geograph information system (GIS) enables efficient analysis of geographic phenomena, including spatial patte analysis or spatial relationship modeling [9, 11–14].

Spatial autocorrelation analysis is an analysis in GIS. Spatiotemporal autocorrelation refers to t correlation of events within themselves over space and through time. It reflects the extent to whic events with similar properties are clustered or dispersed [15, 16]. Spatial autocorrelation analysis aims analyze whether the variables are spatially correlated and how relevant they are and how they genera hot spots [17, 18]. Hot spot analysis, an autocorrelation analysis, refers to calculating the Getis–Ord statistic for each element in the dataset. The Getis–Ord G_i^* value can be used to detect the spati distribution of clustering high-value or low-value spatial units [19]. The Getis–Ord G_i^* value based the normal distribution hypothesis test is more sensitive than the LISA (Local Indicators of Spati Association) method based on the random distribution hypothesis test [20].

In addition to using Getis–Ord G_i^*, spatial-temporal analysis can use kernel density analysis. Kern density in the geographic information system is a method to determine whether or not an occurri

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