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The relationship between landscape and meteorological parameters on COVID-19 risk in a small-complex region of Yogyakarta, Indonesia

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Abstract. As of the beginning of September 2021, the COVID-19 outbreak has lasted for more than 1.5 years in Indonesia, especially on Java and Bali islands. Yogyakarta Special Region, Indonesia, is one of the areas that continued to impose restrictions on community activities at the highest level for that period. This is due to the high rate of COVID-19 spread in this region. In this paper, the influence of landscape and meteorological parameters on the spread of COVID-19 risk in Yogyakarta is investigated. This study utilises primary and secondary data obtained from observation, remote-sensing-image interpretation, literature study and data documented by several agencies. The data were statistically analysed using simple linear regression and Geographic Information System (GIS) analysis utilising the average nearest neighbour. The results show that the variation in landscape and meteorological parameters in the Yogyakarta area does not have a significant impact on the spread of COVID-19. Ease of accessibility in various areas of Yogyakarta is able to overcome landscape barriers. This affects the random distribution pattern of COVID-19, clustering in plain areas that facilitate population mobility rather than in mountainous, volcanic or karst areas. Also, meteorological conditions with small variations do not impact the spread of COVID-19. In summary, this study shows that ease of mobility in a medium-wide area can encourage the spread of COVID-19 in various regions even though there are variations in its terrain and climate.

Key words:
COVID-19 outbreak,
landscape,
meteorological parameters,
Yogyakarta

Introduction

The COVID-19 pandemic, which was initially reported in Wuhan, China, in December 2019 (Santos 2020) and declared a global pandemic by the WHO on March 11, 2020 (Chaudhry et al. 2020) has had a wide impact on people's lives around the world. As of the beginning of September 2021, new cases with various variants are still being found in many different countries. WHO data on October 21, 2020 (World Health Organisation 2020) shows that more than 40 million cases had been confirmed around the world, with the death toll reaching 1.1 million. Meanwhile in Indonesia, data released on the same day by the COVID-19 Handling Task Force (Satuan Tugas Penanganan COVID-19 2020) showed that there had been 373,109 positive cases, with the death toll reaching 3.4%. Almost a year later, by early September 2021, the number of positive cases in Indonesia had increased to 4,089,801. In addition, data from the task force team showed that, worldwide, there had been more than 200 million cases with more than 4 million deaths.

During this period, the COVID-19 pandemic disrupted various sectors of life, including the economic (Tisdell 2020), the social (Santos 2020) and the cultural (Burgess and Sievertsen 2020). One of the efforts to fight the COVID-19 pandemic has been to break the virus spread chain. In Indonesia, the government imposed a macro-scale social restriction (locally known as PSBB) on April 2020, a restriction on communities' activity (locally known as PPKM) on January 2021, a micro-scale PPKM on February 2021, and an emergency PPKM on July 2021 that continued till August 2021. Spatio-temporal modelling that can accurately inform the distribution pattern between regions across time is badly needed for monitoring to help break this spread. Furthermore, findings in the form of spatio-temporal patterns also provide information about the behaviour of the outbreak's spread in an area so that it can be used as a reference in mitigating similar disasters in the future.

Many studies investigating the spread of COVID-19 cases have revealed the characteristics of the physical environment in an area where COVID-19 is spreading. Meteorological and landscape characteristics are determining factors of the physical environment. The results of the study show that positive cases are mostly found in areas with low air temperature (Rios et al. 2020); high air temperature and relative humidity are associated with reduced transmission of COVID-19, while low temperature, wind speed, dew point temperature, frost, rainfall and surface pressure are associated with a prolongation of the activation and infectivity of the virus (Sarkodie and Owusu 2020), and the increase in air temperature and relative humidity accompanies decreases in new cases and daily new deaths (Wu et al. 2020). In general, the influence of weather on the spread of COVID-19 is still poorly understood, even though vulnerable weather parameters will help classify risky geographic areas in various countries (Gupta et al. 2020).

Yogyakarta Special Region (DIY – for the Daerah Istimewa Yogyakarta) in Indonesia has a complex landscape and varied climatic conditions. In 2019, this area was inhabited by no fewer than 3.8 million people (Integration of Statistical Processing and Dissemination Sector 2020) spreading over various landforms, including volcanic foot, volcanic foot plains, fluviovolcanic plains, structural-denudational mountains, karst and coastal areas. Each landform has different terrain conditions that affect settlement patterns, accessibility and mobility, and even determine climate variations. In regard to this, it is interesting to thoroughly examine how the variation of the landscape and meteorological parameters in Yogyakarta relates to the spread of COVID-19.

This paper describes the influence of landscape and meteorological parameters on the spread of COVID-19 risk in the DIY. This research is urgently needed because studies on the characteristics of the spread of disease outbreaks, which are classified as non-natural disasters based on the Law No. 24 of 2007 of The Republic of Indonesia, are still relatively few compared to those relating to natural disasters. Also, studies that examine the role of the physical environment on the spread of the pandemic are still limited, even though Indonesia, and especially the DIY, has varied landscape and climatic characteristics. This paper attempts to provide alternative information on the influence of landscape and meteorological parameters on the spread of COVID-19 risk, rather than social factors of population mobility and activity in the DIY. This information can be used to support the action planning and implementation to deal with the COVID-19 pandemic, especially in the DIY.

Materials and methods

Data collection and analysis

This research is an exploratory study that employs a geographic approach, namely the regional complex. This study also utilised geographic themes in analysing problems, especially location, human–environment interaction, and movement. This study used primary and secondary data. The data in this study were obtained from the interpretation of remote-sensing imagery, modelling, a literature study, and document searches from various institutions (Table 1). Primary data in the form of geomorphological characteristics were gathered from field observations and collated into several samples, which were determined purposively based on the delineation results from ASTER Imagery. In the observation process, a geomorphological survey was carried out with a geomorphological-analytical

Table 1. Types of data, data collection techniques and data sources/instrument

No	Data	Collection method	Data sources/instrument
1	Landform characteristics	Observation	GPS, geological compass, digital camera
		Remote sensing imagery interpretation	Delineasi ASTER GDEM 30 meter spatial resolution
		Study literature	Srijono et al. (2008)
			Ashari (2017)
			Sutikno et al. (2007)
			Purwantara et al. (2020)
2	Precipitation	Remote sensing imagery interpretation	CHIRPS by USC Santa Barbara, USGS
3	Humidity		NOAA by NCEP
4	Wind (direction and velocity)		Era5 by Copernicus
5	Surface temperature		Era5 by Copernicus
6	COVID-19 risk in Yogyakarta	Documentation	Disaster Management Agency of Yogyakarta Special Province
7	Population data		Statistical Agency of Yogyakarta Special Province

survey (Verstappen 2014) to obtain detailed information about landform characteristics. These field observations are supported by information on landforms from the literature study. The secondary data includes data on climate conditions and COVID-19 risks obtained from the interpretation of remote-sensing images and documents published by several institutions.

The data analysis in this research was a statistical and GIS analysis. The first step in this analysis was to conduct a GIS analysis to find out the spatial distribution of the COVID-19 risk in each landform unit. All stages in this GIS analysis were carried out with the help of ArcGIS and Quantum GIS tools. The technique in GIS analysis utilised overlay and average nearest neighbour. The overlay process was carried out between the COVID-19 risk map obtained from the Disaster Mitigation Agency of DIY (BPBD for *Badan Penanggulangan Bencana Daerah*) and the landform map. The results of this overlay showed the distribution of COVID-19 risk levels in various formation units. This overlay analysis was further strengthened by the use of average nearest neighbour analysis to investigate the distribution pattern of COVID-19 risk in the DIY in relation to the landforms and meteorological parameters, whether they are random, clustered or dispersed. According to Nirwansyah et al. (2015), to determine this distribution pattern, the z-score and p-value are used as indicators. In addition, according to Aziz (2012), the formulas for nearest neighbour analysis are as follows.

$$R = \frac{r_{obs}}{r_{exp}} \quad (1)$$

$$r_{obs} = \sum_{i=1}^{N} \frac{\mathrm{Min}(d_{ij})}{N} \quad (2)$$

$$r_{exp} = \sqrt{\frac{A}{N}} \quad (3)$$

The second step was to perform a statistical analysis using simple linear regression. This analysis was conducted to examine how the various meteorological parameters influence COVID-19 risk in the Yogyakarta area. This analysis revealed the effects of any changes in air temperature, wind, humidity and precipitation conditions on the high or low risk of COVID-19. The analysis was carried out in Microsoft Excel. The formulas for simple linear regression are as follows.

$$Y = a + bX \quad (4)$$

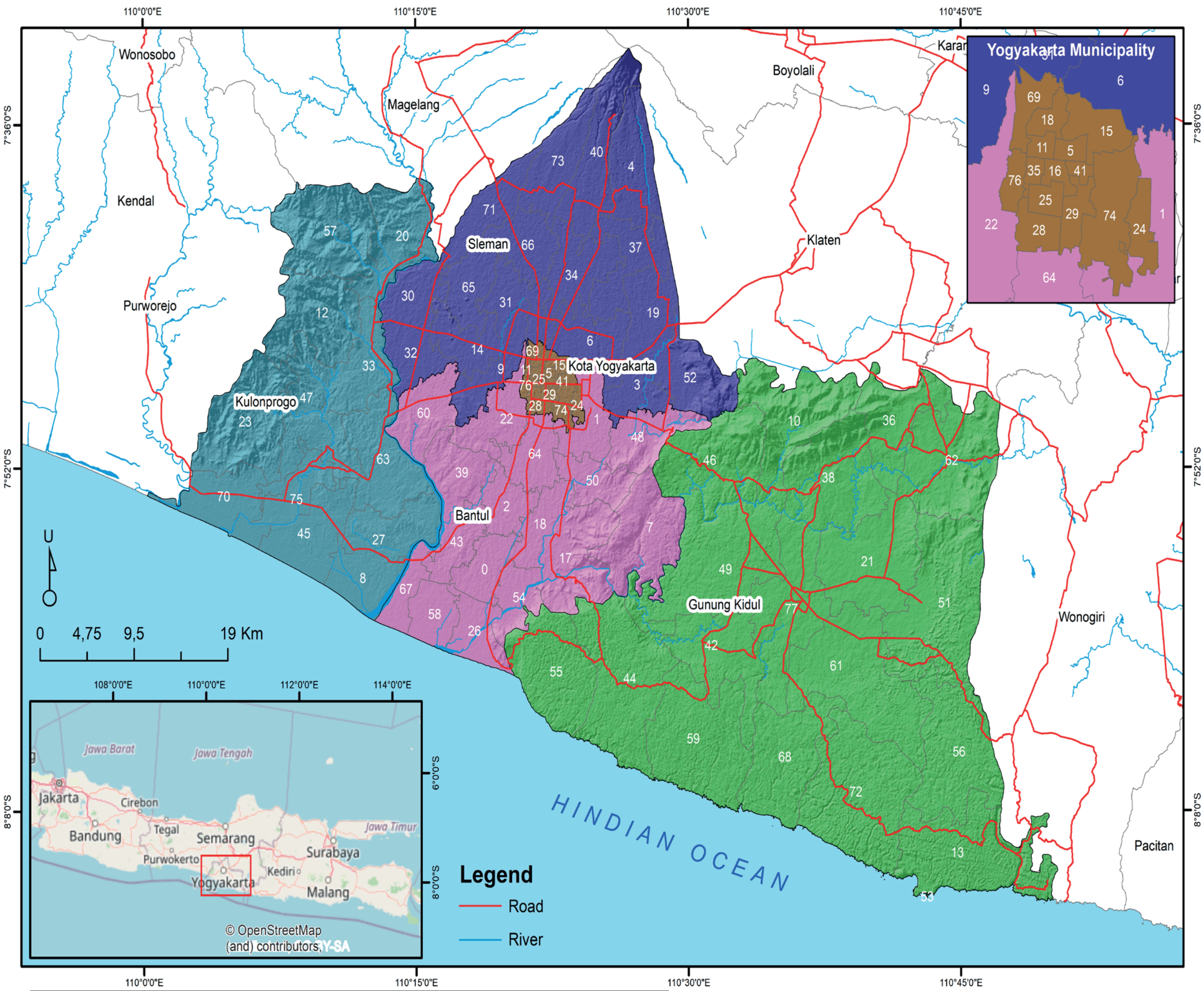
$$a = \frac{(\Sigma Y)(\Sigma X^2) - (\Sigma X)(\Sigma XY)}{n\,\Sigma X^2 - (\Sigma X)^2} \quad (5)$$

$$b = \frac{n\Sigma XY - (\Sigma X)(\Sigma Y)}{n\,\Sigma X^2 - (\Sigma X)^2} \quad (6)$$

Study area

This research was conducted in the DIY area, Indonesia. Yogyakarta Special Region (DIY) is one of the six provinces of Java island. Based on data from the Central Statistics Agency (2020), DIY has an area of 3,133 km² divided into five smaller administrative areas, namely four regencies and the provincial capital (Fig. 1). The area percentage of the four regencies in DIY are Gunungkidul (45.69%), Kulon Progo (18.71%), Sleman (18.35%) and Bantul (16.22%). The city of Yogyakarta is the provincial capital with an area of 32.50 km², or 1.04% of the total territory of the DIY. Based on the 2020 population census, DIY was inhabited by 3,668,719 residents. The distribution of the population in the regencies/cities from is, from highest to lowest, Sleman (31.7%), Bantul (26.5%), Gunungkidul (19.3%), Yogyakarta City (11.3%) and Kulon Progo (11.2%).

Physiographically, DIY has a varied landscape and is composed of various rock types. Volcanic,



No	Kecamatan	No	Kecamatan	No	Kecamatan	No	Kecamatan	No	Kecamatan	No	Kecamatan
0	Bambanglipuro	14	Godean	28	Mantrijeron	42	Paliyan	56	Rongkop	70	Temon
1	Banguntapan	15	Gondokusuman	29	Mergangsan	43	Pandak	57	Samigaluh	71	Tempel
2	Bantul	16	Gondomanan	30	Minggir	44	Panggang	58	Sanden	72	Tepus
3	Berbah	17	Imogiri	31	Mlati	45	Panjatan	59	Saptosari	73	Turi
4	Cangkringan	18	Jetis	32	Moyudan	46	Patuk	60	Sedayu	74	Umbulharjo
5	Danurejan	19	Kalasan	33	Nanggulan	47	Pengasih	61	Semanu	75	Wates
6	Depok	20	Kalibawang	34	Ngaglik	48	Piyungan	62	Semin	76	Wirobrajan
7	Dlingo	21	Karangmojo	35	Ngampilan	49	Playen	63	Sentolo	77	Wonosari
8	Galur	22	Kasihan	36	Ngawen	50	Pleret	64	Sewon		
9	Gamping	23	Kokap	37	Ngemplak	51	Ponjong	65	Seyegan		
10	Gedangsari	24	Kotagede	38	Nglipar	52	Prambanan	66	Sleman		
11	Gedongtengen	25	Kraton	39	Pajangan	53	Pulau Tidak Terdefinisi	67	Srandakan		
12	Girimulyo	26	Kretek	40	Pakem	54	Pundong	68	Tanjungsari		
13	Girisubo	27	Lendah	41	Pakualaman	55	Purwosari	69	Tegalrejo		

Fig. 1. Study area

karst, structural and denudational landforms are found in areas with rough relief; fluvial landforms exist on the plains; and marine, aeolian and organic landforms are found in coastal areas (Fig. 2). Based on the Geological Map of the Yogyakarta Sheet and the Surakarta-Giritontro Sheet, products from the eruption of the Merapi Volcano dominate the type of material on the surface ranging from volcanic areas to lowlands on the south side. The karst region is composed of limestone. Meanwhile, in the mountainous areas, structural and denudational landforms are composed of very complex types of material in the form of old volcanic rocks produced from various phases of ancient eruptions.

The DIY area, which is located on the south side of the central part of Java Island, is in a monsoon climate area characterised by two seasons per year. The rainy season occurs around the turn of the year, whereas the dry season occurs around the middle of the year. Data for the last three years from the Meteorology, Climatology and Geophysics Agency shows the average air temperature in this region at 26.07°C in 2018, 25.95°C in 2019 and 26.47°C in 2020. In that three-year period, the highest air temperatures always occurred in November and April. This is probably associated with the equinox, as Java Island lies slightly south of the equator. The climate in DIY is very good for supporting agriculture, which dominates land use in this region. Rice fields stretch from the volcanic footplain to the lowlands in the Graben area of Bantul and the alluvial plains of Kulon Progo. Meanwhile, land in structural-denudational, karst and mountainous areas is mostly used for dryland agriculture.

Results

The COVID-19 pandemic has been impacting Indonesia since March 2020. In response to this condition, the Indonesian government imposed the first restrictions on community activities in April 2020, which were referred to as "large-scale

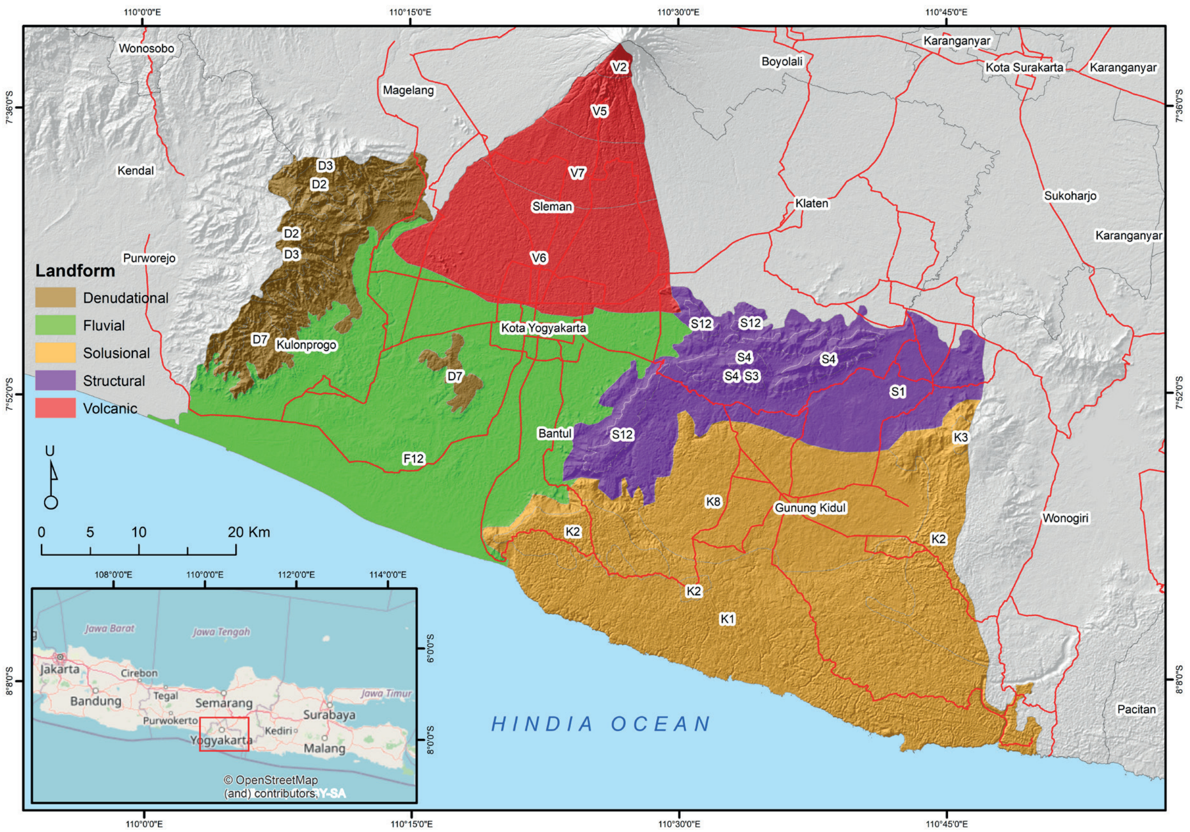


Fig. 2. Geomorphological situation of the study area

social restrictions". The DIY Provincial Disaster Management Agency (BPBD) began to map the risk of COVID-19 in July 2020. The map showed that there were some areas in DIY Province that were not affected by the pandemic in 2020. Entering 2021, the impact of the pandemic was becoming massive, and all sub-districts in DIY were affected. This is indicated by the lower number of low-risk and unaffected areas, while areas with medium and high risk were increasingly dominating (Fig. 3).

DIY is an area with complex landscape variations. It is even part of the area with the most diverse range of landforms in Indonesia. In this area, there are volcanic, structural, denudational, karst, fluvial, marine, aeolian and organic landforms (Fig. 2). Human settlements develop widely on volcanic, fluvial, karst, structural and denudational landforms. The results of field observations on volcanic landform samples show a maximum slope of 78%, with an average of 10.5%, and there are many small rivers. The sample on the karst landform shows a wavy relief and there is a dissolving depression with a sinkhole in it. Samples on fluvial landforms in Yogyakarta City show relatively flat topography, with river valleys along with natural levees and river terraces. Samples on structural landforms show hills with steep to very steep slopes. The maximum tilt of the slope is 85%, and the average is 26%. The samples on denudational mountains show geomorphic processes in the form of erosion and mass movement that have been going on for a long time.

In relation to the spread of COVID-19, there is no specific distribution pattern based on landforms. In other words, there is no tendency for landforms that have a high or low risk. High, medium and low risks can be found at the sub-district level within these various landforms. However, the structural-denudational landforms in the Kulon Progo regency include an area that shows a slow increase in risk ranging from unaffected, low to moderate risk. The same thing also occurs in karst landforms in the Gunungkidul region. During 2020, there were several sub-districts in this karst area that experienced a slow increase in risk or fluctuations in risk levels between unaffected, low, moderate and high. This is due to the number and low density of the population, and to terrain characteristics that hinder population mobility. In general, landforms have no effect on the spread of COVID-19. It is evident that on the same landform there are variations in risk level between sub-districts.

Meteorological conditions in the DIY also indicate variations. However, the spatial variation is not very significant, especially in the area occupied by the population. During this research period, namely from July 2020 to February 2021, the air temperature in the study area range from 19.52°C to 26.7°C. Spatially, the air temperature in the DIY region from July to October 2020 was dominated by temperatures close to the maximum (26.7°C). Low air temperature was only found in the Merapi Volcano and the Peak of the denudational mountains of Kulon Progo. Meanwhile, between November and February the air temperature was dominated by the low category (close to the minimum), whereas high temperatures were only found in the coastal areas. The wind speed during the study period ranges from 0 to 2 on the Beaufort scale. Wind speed with a scale of 2 Beaufort was recorded in July–August during the dry season. From July to the first half of November the wind is predominantly northerly from Merapi Volcano to the plains, where it becomes north-westerly, whereas in the second half of November to February 2021 the wind becomes north-easterly over DIY.

The monthly rainfall is also varied. The lowest rainfall is 0 mm, which was found during the three months of the dry season between July and September 2020, while the highest rainfall of 381 mm occurred in February 2021. Spatially, high rainfall is found in the Merapi Volcano and denudational mountains areas. The difference between high and low rainfall in a month was 169 mm in February 2021. Air humidity in DIY has low fluctuations, which is between 68% and 80%. Spatially, the relative humidity of the air does not vary much. Between July and October, most areas are at a moderate level of relative humidity. High humidity up to 80% is only found in the southern coast of Gunungkidul. From November to February, the relative humidity of the air was also dominated by the medium level. The coast of Gunungkidul, which previously had high humidity, showed the lowest humidity in this period. The most spatially variable relative humidity was only found in November 2020.

As with the influence of landforms, so too the effects of meteorological parameters on the spread of COVID-19 are not significant. The COVID-19 risk map published by the DIY Province BPBD shows that the risk of COVID-19 spreads in various regions with differences in air temperature, rainfall, humidity and wind. In other words, there is no pattern that shows the distribution of the risk level to be determined by certain weather conditions. In this study, we took a random sample of five sub-districts to represent each regency/city in DIY. The temporal meteorological parameter data and the risk level of COVID-19 in the five sub-districts were then plotted on a graph (Fig. 4). It shows that there is no consistent pattern between meteorological factors and risk level. For example, an increase in rainfall is not followed by an increase in risk for all samples. In some samples, the increase in rain

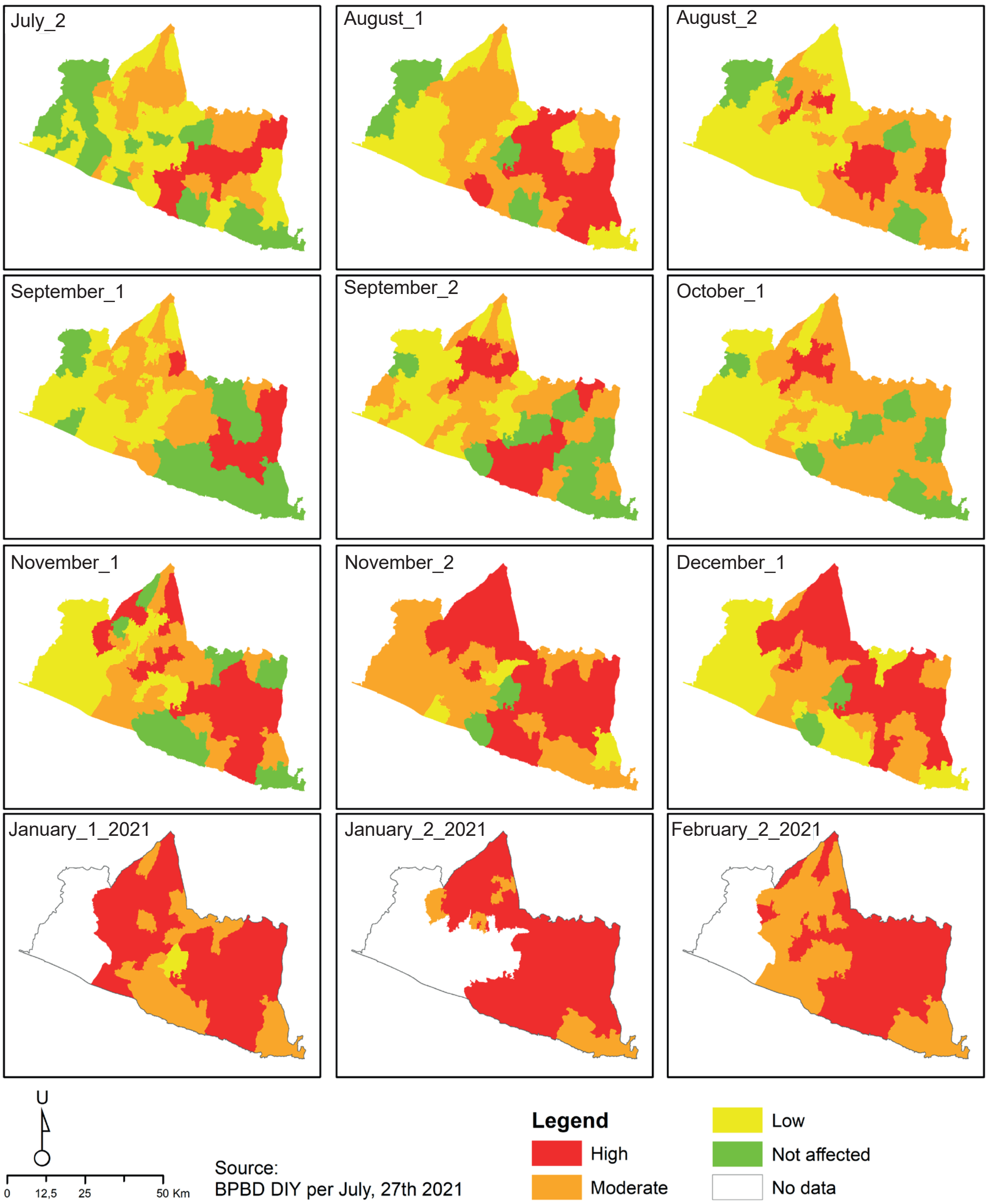


Fig. 3. Map of the zonation of COVID-19 risk in DIY

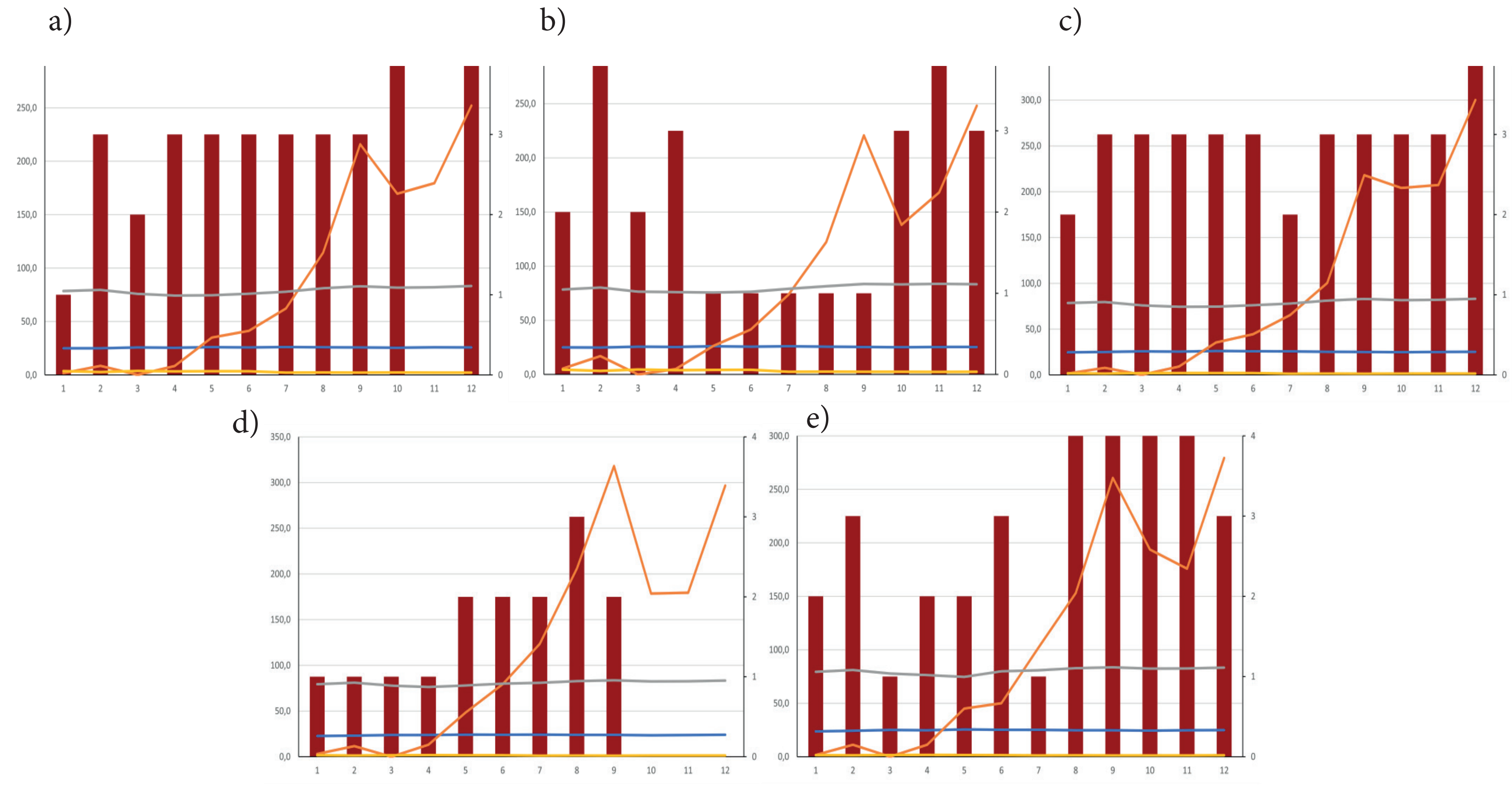


Fig. 4. The graph of COVID-19 risk and meteorological parameters in five sample area. (a) Bantul, (b) Purwosari, (c) Mantrijeron, (d) Samigaluh, (e) Seyegan. Right axis shows the risk, left axis shows the meteorological parameters, X-axis shows the period of data. Blue line: temperature, peach line: precipitation, grey line: relative humidity, yellow line: wind velocity

tends to be followed by an increase in risk. In addition, other samples indicate that the increase in risk occurs when the rainfall decreases. Also, other meteorological parameters tend to show no pattern with the level of COVID-19 risk.

To strengthen the research findings that show that there is no influence of meteorological parameters on the spread of COVID-19, we performed a simple linear regression analysis. The analysis was carried out to know the influence that the trend of increasing air temperature, humidity, rainfall and wind speed has on the risk of COVID-19. The results of the analysis show that there is no significant effect of these various parameters on the risk of COVID-19. A temperature increase has a positive effect on increasing risks but it only produces a maximum R^2 of 3.83 in September 2020. An increase in rainfall is also associated with an increased risk. This parameter has the strongest effect compared to other parameters, with a maximum R^2 of 34.29 in September 2020. Also, the increasing relative humidity of the air has a positive effect on the pandemic, but it only produces a maximum R^2 of 13.98 in July 2020. Meanwhile, the wind speed also shows the same symptoms, namely there are symptoms of increased risk when there is an increase in wind speed. However, this effect is also very small, being indicated with only an R^2 of 6.72 in August 2020. The results of the simple linear regression analysis of several climate parameters on the risk of COVID-19 in the DIY area are presented in Table 2.

Overall, the findings of this study indicate that in the DIY area, landscape conditions and meteorological parameters do not have a significant impact on the risk of COVID-19. Spatially, there is no pattern of the COVID-19 risk spread following certain landforms or weather zoning. This condition is supported by the results of the average nearest neighbour analysis conducted on COVID-19 risk data based on sub-districts in DIY. The distribution pattern of the COVID-19 risk in DIY between July 2020 and February 2021 tends to be random. The clustering pattern was found in the first half of August 2020, throughout September 2020, and the first half of October 2020. However, this grouping is also not based on the zoning (Table 3).

Discussion

Many studies on the influence of meteorological parameters in the COVID-19 spread have been carried out. Previous researchers have conducted studies in cross-country regions (Rios et al. 2020;

Table 2. The regression analysis of meteorological parameter and landform to COVID-19 risk

No	Year	Month	Period	R^2 to COVID19 risk				
				T	P	RH	WS	Landform
1	2020	July	2	0.24	1.26	13.98	1.54	1.74
2	2020	August	1	0.83	2.08	5.08	3.03	0.40
3	2020	August	2	1.72	0.00	1.62	0.45	1.67
4	2020	September	1	0.98	0.05	0.02	3.34	0.03
5	2020	September	2	3.83	34.29	0.02	5.51	0.22
6	2020	October	1	1.43	16.09	0.14	2.88	0.92
7	2020	November	1	0.62	5.22	2.08	0.19	0.01
8	2020	November	2	0.41	7.04	0.17	0.97	2.81
9	2020	December	1	0.11	12.22	0.11	2.21	0.93
10	2021	January	1	0.18	5.30	0.63	0.01	1.22
11	2021	January	2	2.39	10.92	5.41	0.47	6.82
12	2021	February	1	0.85	0.14	4.20	0.67	2.87
			Max	3.83	34.29	13.98	5.51	6.82
			Min	0.11	0.00	0.02	0.01	0.01
			Avr	1.13	7.88	2.79	1.77	1.64

Table 3. The p-value and z-score of spatial pattern of COVID-19 in DIY Province

No	Year	Month	Period	z score	p value	spatial pattern
1	2020	July	2	0.066912	0.946652	Random
2	2020	August	1	1.968924	0.048962	Moderate clustered
3	2020	August	2	1.593096	0.111139	Random
4	2020	September	1	1.655988	0.097724	Clustered – random
5	2020	September	2	2.795906	0.005175	Strong clustered
6	2020	October	1	3.719768	0.000199	Strong clustered
7	2020	November	1	0.466939	0.640543	Random
8	2020	November	2	-0.919694	0.357733	Random
9	2020	December	1	0.566759	0.570878	Random
10	2021	January	1	0.227628	0.819936	Random
11	2021	January	2	-0.214206	0.830387	Random
12	2021	February	1	0.237425	0.812327	Random

Sarkodie and Owusu 2020) in single regions, such as South America (Zhu et al. 2020) and Africa (Adekunle et al. 2020), in single countries such as the United States (Gupta et al. 2020; Chien and Chen 2020), Singapore (Pani et al. 2020), China (Lin et al. 2020; Huang et al. 2020; Lin et al. 2020), India (Kumar 2020), Saudi Arabia (Alkhowailed et al. 2020) and Bangladesh (Islam et al. 2021), as well as within single regions within a country, such as in New Jersey, United States (Dogan et al. 2020), Mumbai, India (Kumar and Kumar 2020), Delhi, India (Singh et al. 2021) and Jakarta, Indonesia (Tosepu et al. 2020).

In these studies, various meteorological parameters that affect the spread of COVID-19 have been identified, including: air temperature (ranging from −6 °C in China to 35 °C in India), relative humidity (11.39% to 88.42%), absolute humidity (4g/m^3 to 7g/m^3), wind direction and speed (0 to 10 m/s), rain (0 to 95.97 mm/day), frost and dew point (−45.14°C to 23.94°C). The analysis of the influence of meteorological parameters on the spread of COVID-19 refers to the assumption that the characteristics of COVID-19 are relatively the same as MERS, SARS and Influenza, where meteorological parameters greatly influence disease transmission. Therefore, the influence of meteorological parameters is very important, although in many discussions it is still debatable (Wu et al. 2020). Based on the various studies that have been carried out, temperature and humidity greatly affect the spread of COVID-19. Other meteorological parameters also have an effect, but their effects are not greater than the effect of temperature and humidity. The importance of air temperature and humidity effects in the spread of COVID-19 is also presented by various research results that specifically analyse these two meteorological parameters, where high temperature and humidity are able to suppress the spread of the pandemic (Wu et al. 2020). Another study examined the effect of air temperature and specific humidity. The conclusion of the study indicated that weather should be considered in the modelling of infectious diseases (Runkle et al. 2020).

Meanwhile, the influence of landscape has rarely been discussed in research. One study analysed the influence of rural landscape on the spread of COVID-19 (Agnoletti et al. 2020). However, the landscape examined in that study dealt with anthropogenic landscape in rural areas, rather than landscape in terms of terrain variations. In fact, terrain conditions greatly determine the distribution of settlements, mobility and the accessibility of an area, thus determining the spread of the pandemic through human-to-human contact.

The findings of this study show that in the DIY area the spread of COVID-19 is not much influenced by landscape factors and meteorological parameters. This can be seen in the pattern of COVID-19 risk spread, which tends to be random. An area of certain landforms and meteorological conditions may have a low risk at one time but turn out to be unaffected in the following month, and suddenly turn high in the next two weeks. Equally, there are some areas with the same landforms and meteorological conditions that initially show high risk, then change to moderate and then are unaffected by the COVID-19 pandemic. This finding is quite interesting compared to several previous studies that highlight the significant influence of meteorological factors on COVID-19 outbreaks. This inconsistency is similar to the findings from a study conducted by Goswami et al. (2020) in India that showed that the effect of temperature on COVID-19 differs between states.

Previous studies have shown that meteorological parameters have a significant effect on positive cases, mortality rate and transmissibility. Srivastava (2021) explains that local meteorology plays a crucial role in the spread of coronavirus and mortality. Meanwhile, Kumar and Kumar (2020) explain that there is a significant correlation between COVID-19 and temperature, dew point, relative humidity and surface pressure. In contrast to various previous studies, the findings of this study indicate that meteorological parameters do not have a great influence on the risk of COVID-19 in the DIY area.

Temperature parameters have been said to be negatively correlated with COVID-19 in various previous studies (Dogan et al. 2020; Lin et al. 2020). An increase in temperature has a negative effect on the emergence of new cases and deaths (Wu et al. 2020) – an increase in air temperature will result in a decline in number of cases (Srivastava 2021). In other words, high air temperatures reduce COVID-19 (Sarkodie and Owusu 2020). An increase in air temperature has effected a decrease in COVID-19, based on the results of studies conducted in Bangladesh (Haque and Rahman 2020), Saudi Arabia (Alkhowailed et al. 2020), Africa (Adekunle et al. 2020) and America (Chien and Chen 2020). Compared to various previous studies, the findings of this study show the opposite condition, namely an increase in temperature is positively correlated with an increased risk of COVID-19, even though the effect is very weak. This condition is the same as the results of research conducted by Pan et al. (2021) in eight countries, as well as research by Ladha et al. (2020) in New Delhi, India. The effect of the increasing air temperature on the decrease of COVID-19 does not always apply in all places. Other research results also show that air temperature is positively correlated with COVID-19 (Kumar 2020; Pani et al. 2020). Findings from studies in several cities in China (Guo et al. 2020; Huang et al. 2020), Bangladesh (Islam et al. 2021), and India (Ladha et al. 2020; Singh et al. 2021) show the same conditions as the findings in this study.

Relative humidity (RH) in this study shows the same symptoms as temperature, which indicates a positive relationship to the risk of COVID-19, but the effect is weak. This result is similar to the findings of Rios et al. (2020) and Runkle et al. (2020) showing that humidity has an effect on the spread of COVID-19, but the effect is very weak. Also, Srivastava (2021) explains that humidity has no effect on COVID-19 cases or, if it does, it tends to be negative and very weak. Air humidity has received much attention in various previous studies. There are studies that use absolute humidity (AH) parameters but most use relative humidity. The research results also vary from one region to another. Sarkodie and Owusu (2020), Haque and Rahman (2020) and Wu et al. (2020) explain that RH has a supressing effect on COVID-19. Meanwhile, Kumar and Kumar (2020) more specifically claim that RH and AH offers a suppressing effect. Findings that differ from other studies indicate that RH has a significantly escalating effect on COVID-19, including Alkhowailed et al. (2020), Pani et al. (2020), Islam et al. (2021) and Singh et al. (2021). Meanwhile, Lin et al. (2020) also show a positive correlation but the effect is very weak.

Other parameters tested in this study include rain and wind speed. Although the results of the analysis show no significant effect of these two parameters, the finding that increased wind speed is nonetheless positively correlated to the risk of COVID-19 strengthens the results of previous studies showing the effect of wind speed on COVID-19, including Lin et al. (2020), Sarkodie and Owusu (2020), Wei et al. (2020), Islam et al. (2021), Singh et al. (2021) and Srivastava (2021). However, in those previous studies, wind speed was shown to have a significant effect on COVID-19 risk, while in this study we do not find a strong influence between wind speed and the risk of COVID-19. Meanwhile, rainfall does not have an impact on COVID-19, as revealed by various previous studies, such as Srivastava (2021),

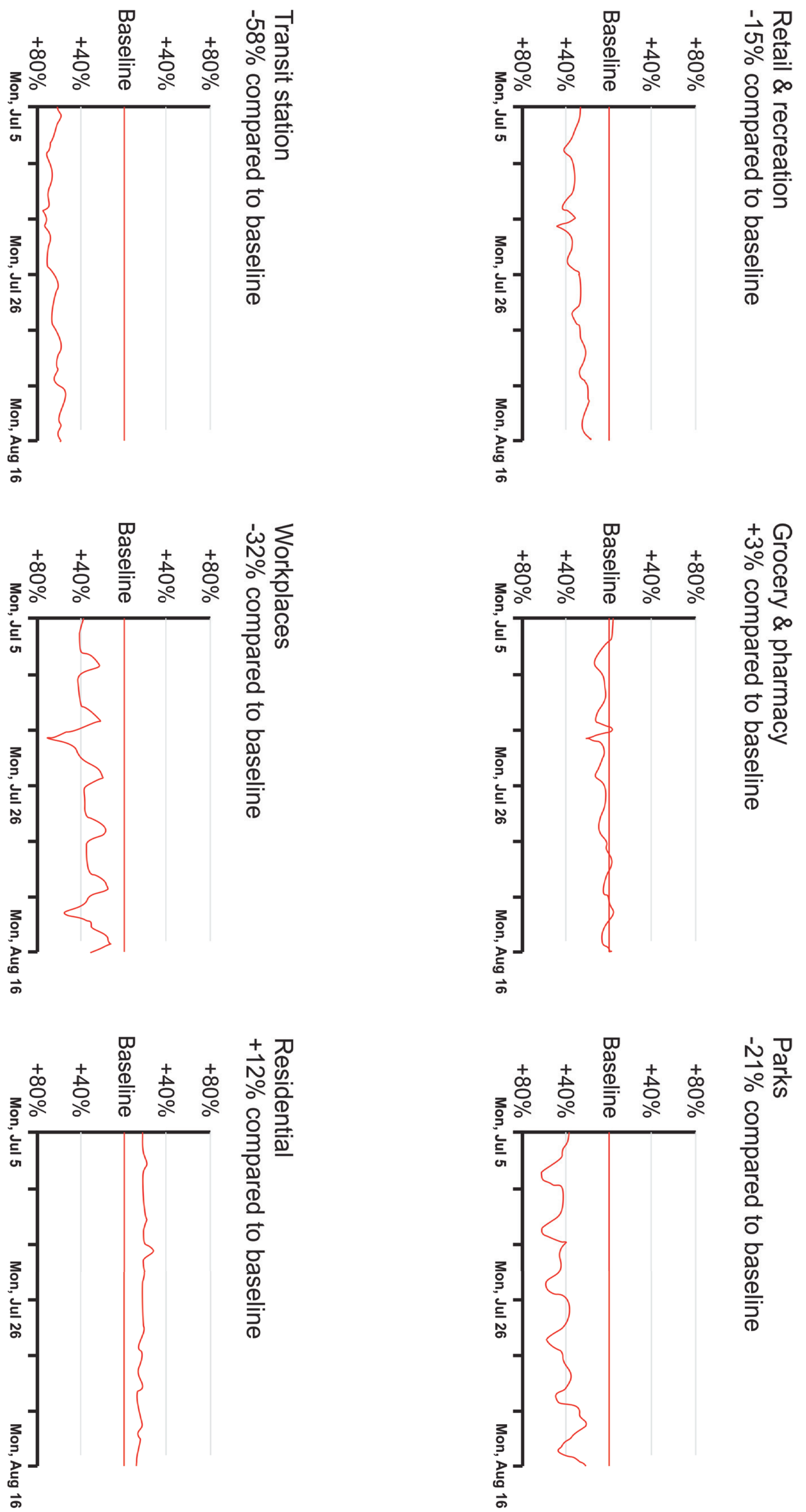


Fig. 5. Population mobility in DIY

Huang et al. (2020) and Singh et al. (2021). Wang et al. (2021) show an effect of rain on COVID-19.

In addition to meteorological parameters, this study also attempts to identify the effects of landform variations on the spread of COVID-19 risk. The results of the data analysis do not show an influence of landforms on the risk of COVID-19. It is assumed that landforms that have rough topography, are inundated or are located at a height will be difficult to reach so have low accessibility. This condition is thought to inhibit the spread of the risk of COVID-19. In general, geomorphological conditions correlate with settlements (Dibyosaputro 2015; Pan et al. 2020). The settlement development in various difficult terrains indicates that human civilisation can develop in many different landforms. If this is supported with accessibility in the form or good road conditions, mobility will no longer be hampered.

The weak influence of physical factors on COVID-19 risk in this study indicates that there are other factors that increase the risk of COVID-19 in the Yogyakarta area that must be examined. The factor in question is population mobility between regions (Adiga et al. 2020; Iacus et al. 2020; Linka et al. 2021). High mobility and interactions between populations have been proven to cause 92% of deaths in France and Italy with an R2 value of 0.91 (Iacus et al. 2020). Areas with good transportation indicated by the presence of airports, railways, national roads and toll roads tend to have a higher level of COVID-19 risk (Wei et al. 2020). The development of technology and transportation helps humans to move and reach various places easily, and even to reach difficult places. Mobility in difficult places is not a hindrance. Therefore, topographic factors do not affect mobility, but mobility is influenced by the social ties of individuals (Förster et al. 2012).

In this study, we find that difficult-to-access landforms are still at high risk for COVID-19. The accessibility constraints can be overcome by utilising advances in transportation technology and social relations. This suppresses the influence of landform variations on accessibility, where this accessibility is thought to affect the risk of COVID-19. Another growing opinion states that COVID-19 is no longer a pandemic, but has become a pandemic that synergises with other factors (pandemic-synergies) called syndemic/syndemy, mainly synergies with socio-ecological and biological factors (Lemke et al. 2020; Yadav et al. 2020). Thus, if we only consider the physical aspects, the symptoms in the field will be different and cannot be generalised. In addition, if we only consider social aspects, the symptoms in the field cannot determine the pattern of COVID-19 distribution in the particular area. It is explained by Sun et al. (2020) that population density is not an important factor in determining the distribution of COVID-19 under strict lockdown policies.

Next, we examine population mobility data in the DIY region. The data comes from personal data of Android-based cellular phone users who are tracked by Google. Mobility data shows that population mobility in DIY has decreased from the baseline data by 18% in retail and tourist areas, 2% in raw material stores and pharmacies, 5% in park recreation areas, 53% in transit stations and 62% in workplaces, but has seen an 18% increase in residential areas (Google 2021). The baseline for calculating the initial data as a comparison of this data is the median user movement data from January 3 to February 6, 2020, while the movement data is calculated until August 17, 2021. This means that 18% of people live in their homes. Although there has been a decrease in mobility, it does not mean that there is no movement. For example, the movement in the retail and recreation sector only fell 18% from the baseline. This number is still small. There is still 82% movement that occurred compared to the initial conditions. These movements and interactions have led to an increase in COVID-19 cases (Fig. 5). In addition, residents who are no longer mobile and stay in their homes but have been exposed to COVID-19 also have the potential to increase the risk in the area where they live.

Conclusion

The spread and risk of COVID-19 can be influenced by various factors, including meteorological and landform factors. The influence of these factors cannot be generalised from one place to another. The spread of COVID-19 risk in the Yogyakarta area, which is relatively narrow, with high population mobility and very good accessibility, tends to be random. The mobility of the population can overcome landform constraints. The spatially small variation of meteorological parameters also makes this factor unable to control the spread of COVID-19 risk in Yogyakarta. In fact, in general, the various meteorological parameters have almost no effect on the risk of COVID-19. There are several things that need to be carried out in further research, including spatial modelling of positive COVID-19 cases in Yogyakarta based on daily data containing information on living place. With this positive case point data, a temporal pattern of the development of the pandemic can be made from time to time in the Yogyakarta area. Future research is highly recommended to explore the effect of population mobility on the spatiotemporal pattern of positive COVID-19 cases in Yogyakarta. This study, which was conducted to analyse the various factors that influence the spread of COVID-19, is urgently needed to provide a comprehensive picture of the pandemic in the Yogyakarta area, which is influenced by the characteristics of the physical and social environment of the population. This information is useful for handling the pandemic and as a mitigation measure for similar problems that may occur in the future.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Study design: SP; data collection SP, AA, STP; statistical analysis: SP, AA, STP; result interpretation SP, AA, STP; manuscript preparation SP, AA, STP; literature review: AA, STP.

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