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COVID-19 vaccine prioritization based on district classification in Yogyakarta Province, Indonesia

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Abstract

Due to limited availability, Indonesia's coronavirus disease 2019 (COVID-19) vaccination will be done in 4 stages until herd immunity has been reached. Yogyakarta, an education and tourist destination, needs to get a specific, spatial estimation of the exact need for COVID-19 vaccination without delay. This study sheds light on identifying which districts should be prioritized at each vaccination phase. Secondary data collected from provincial, and county-level statistical agencies were quantitatively calculated by the Z-Score method. The results indicate that the first phase of vaccination should prioritize Pengasih and Sentolo districts in Kulon Progo Regency, which have a large number of health workers; the districts of Depok, Banguntapan, Piyungan, Sewon, Wonosari, Gamping, Mlati and Ngaglik should be done in the second phase based on the fact that these districts have many public service officials as well as elderly people; Umbulharjo and Depok districts will be approached in the third phase since they have more vulnerable groups and facilities that may promote COVID-19 transmission during their daily activities; while the fourth phase should focus on the districts of Banguntapan, Sewon, Kasihan, Gamping, Mlati, Depok, and Ngaglik due to the intensity of COVID-19 clusters discovered there. Overall, vaccination would be given the priority in the districts with the largest number of people in need, *i.e.*, public service officers, elderly people and those likely to be exposed to the coronavirus causing COVID-19.

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Introduction

On 31 December 2019, 27 cases of an unusual type of pneumonia were reported had been collected in Wuhan Hubei Province, the People's Republic of China (Ali *et al*., 2020). The findings indicated a new disease that was eventually confirmed as coronavirus disease 2019 (COVID-19) (Li *et al*., 2020; Zhu *et al*., 2020; Sajed *et al*., 2020). Despite uncertainty of its origin, market sales of raw meat were believed to be the original exposure of this virus (Giesen *et al*., 2020). China responded quickly by embarking on several proactive public health approaches to fight the disease (Guo *et al*., 2020), which nevertheless rapidly spread all over the globe and was therefore declared a global pandemic by the World Health Organization (WHO) as early as 11 March 2020 (Stahel, 2020; Ali *et al*., 2020). At this time, more than 90 countries had declared lockdown of areas at various degrees to fight further rapid transmission (Di Domenico *et al*., 2020). Still, the virus spread so fast that 1000 patients tested positive two weeks after the first case had been diagnosed (Spinelli and Pellino, 2020). The virus, which primarily caused respiratory malfunction, made exposed countries limit social activities, which impacted strongly on the performance of their economy (Butt *et al*., 2020). Various strategies and efforts were made by affected countries, including Indonesia, to prevent transmission, with vaccine development initiated in several research centres around the world (Alshaabi *et al*., 2020; Pennycook *et al*., 2020; Harapan *et al*., 2020).

COVID-19 is generally caused by human-to-human transmission by droplets suspended in the air after heavy breathing and particularly coughing or sneezing (Shereen *et al*., 2020). Indonesia was badly struck by COVID-19. The first case was reported on 2

March 2020 in Depok City (Brahma, 2020) and confirmed by President Joko Widodo. Soon after, there were already two people infected by the new virus (Djalante, *et al*., 2020). The first case made the government look for clusters to prevent further spread (Ifdil *et al*., 2020). Still, it was not possible to contain the virus as many cases started to be reported in the city, and it was soon also found in all provinces in Indonesia underlining that the healthcare system was not ready to face the new disease (Setiati and Azwar, 2020). Areas with high human mobility thus carry a high risk of spreading the virus. Yogyakarta Province is such typical place, known as 'The City of Students' and 'The City of Tourism'.

Vaccine research made rapid progress and various vaccines, such as those produced by AstraZeneca (Cambridge, UK), Janssen Pharmaceutica (Beerse, Belgium), Moderna, Inc. (Cambridge, MA, USA) and Pfizer-BioNTech. Also, China and Russia manufactured their own vaccines with Sinopharm (Beijing, China) and Sinovac Biotech (Beijing, China) in the former country and the Russian Gam-COVID-Vac in the latter (WHO, 2021). They have all been passed by regulatory authorities based on emergency needs so that, amazingly, effective vaccines were available within a year from the first report of the new virus. Planning for vaccine distribution is an urgent issue as it is critical to optimize allocation. Studies by the National Academies of Sciences, Engineering, and Medicine (NASEM) in the U.S. (2020) recommend that vaccine access should be prioritized for geographic areas identified by a specific index, such as the Social Vulnerability Index (SVI) developed by the Agency for Toxic Substances and Disease Registry (ATSDR) and the Centres for Disease Control and Prevention (CDC) in the U.S. A rational vaccine distribution strategy based on the SVI should contribute to the multifaceted mitigation needs the world requires and also satisfy priorities assigned for high-vulnerability areas that could potentially be hard hit by COVID-19 (Arling *et al*., 2021). The question of vaccination priority is intertwined with various issues, *e.g*., health equity, age, occupation, geography, race and politics. Many attributes are correlated with high social vulnerability and low socioeconomic status, such as old age, manual work and individual co-morbidities (Chen *et al*., 2021). Distribution clusters and location of potential vaccine delivery facilities can be calculated by spatial statistics and mapping techniques to support strategies aimed at elimination of travel barriers for access to COVID-19 vaccination centres (Whitehead *et al*., 2021).

In accordance with the urgency of vaccine distribution in an emergency, it is paramount to rethink the spatial aspects in order to get the most optimal distribution to the targets. Vaccine distribution is important for building herd immunity, but the scarcity of vaccines, both nationally and regionally, is a concern for governments. Attention is therefore paid to effective distribution at all levels based on prevailing socio-demographic conditions. At the time of writing, research on COVID-19 vaccine distribution planning based on spatial aspects is rarely found. However, Krzysztofowicz and Skotak (2021) have proposed an approach using geographical information systems (GIS) to evaluate the proximity of vaccination sites to elderly people's houses. Zhou *et al.* (2021) modelled vaccine distribution by comparing various strategies, such as those done randomly or based on age, spatial availability as well as space and age together. They found that among these four strategies, vaccine distribution considering age and a spatial approach effectively lowered transmission (flattening the curve) in situations with limited access to vaccines. Even though both studies solely assessed the performance of vaccine distribution by one demography aspect (the elderly), Zhou *et al.* (2021) considered added mobility aspects as well as other socio-economic aspects that might trigger movement of people. Other researchers (Pacheco *et al.,* 2019; Mosser *et al.,* 2019; Gromis *et al.,* 2020) also studied spatio-temporal vaccine distribution, though without proposing any model for targeting priority vaccine coverage. Due to its role in education and tourism Yogyakarta Province has massive migration flows. Based on the data from the Civil Registry Agency, 78.7% of college students came from outside the province. Meanwhile, the Office of Tourism for reports rising numbers of tourists every year, with about 5.7 million tourists for 2018 and around 6.6 million for 2019 (Tourism Agency, 2019). These matters have made the province a potential area of high COVID-19 transmission (Vidal *et al*., 2020). Hence, it has become one of the government-prioritized provinces for vaccination. In late June 2021, COVID-19 in Yogyakarta Province surpassed 50,000 cases. The distribution of confirmed COVID-19 cases dominated in Sleman Regency followed by Bantul Regency, Yogyakarta City, Gunung Kidul Regency and Kulon Progo Regency. However, due to the limited number of doses available, vaccine administration has to be done in phases until it can be given to all citizens. Vaccination is done by involving all public and private sectors (Geraghty, 2020) and as stated by the government, carried out with considerations of all parties.

The overall aim of vaccination in Indonesia is to meet the criteria of herd immunity at the very least. This has been set at 73% within Indonesia based on SAGE (2020) and the 'Decree of the Director-General of Disease Control and Prevention of the Ministry of Health Number HK. 02.02/4/1/2021 concerning Technical Instructions for the Implementation of Vaccinations to control the COVID-19 Pandemic'. Based on these indicators, at least 2,800,526 of Yogyakarta Province's residents should be vaccinated against COVID-19.

The vaccination priority levels are set so that the most vulnerable will be vaccinated first. This study aimed to identify which districts should be prioritized at each vaccination phase. To advance towards this goal, the focus was set on geographical planning based on health, spatial and socioeconomic characteristics.

Materials and methods

This study analysed the geospatial distribution of the priority community groups for each vaccination stage at the district level in Yogyakarta Province. Each priority stage of vaccination in Indonesia considers the level of risk based on vulnerable groups and location factors with a high transmission rate of severe acute respiratory syndrome-related coronavirus 2 (SARS-CoV-2), the virus causing COVID-19. The vaccine intervention policy in Indonesia is divided into four stages based on the availability and allocation of vaccines, their timely arrival and safety profile as well as the priority level of the vaccine recipients.

Study area and population

The study area comprised all districts of Yogyakarta Province in Indonesia, which has a tropical climate. The spatial layout was obtained from the Ina-Geopartal, GIS platform made officially by Government of Indonesia, in shapefile form (Figure 1). The file contains polygons or territorial areas of each district, and their attributes cover all geographical locations and administrative positions within the province. As stated in demography data provided

by the local government in 2020, Yogyakarta has 3,842,932 residents, 1,219,640 from Sleman Regency (32%), 1,018,402 from Bantul Regency (27%), 742,731 from Gunung Kidul Regency (19%) and 431,939 from Kulon Progo Regency (11%) (Badan Pusat Statistik Yogyakarta, 2020).

Research design

Health, demographic and socio-economic variables were used for analysing COVID-19 vaccine prioritization in Yogyakarta Province, with targets based on socio-spatial vulnerability conditions and effective scenarios to achieve herd immunity. Each variable has an indicator gathered from statistical data publicly provided by the government. Those variables are adapted from four prioritized targets by SAGE (2020) and the Ministry of Health (2021). The different units of some variables led us to use the Z-score method adopted from Muta'ali (2014), Bathi and Das (2016) as well as Mirza *et al.* (2020). The Z-score was used to normalize the aggregate of health-socio demographic vulnerability values. Using the data available would represent the level of prioritized group based on the actual conditions before the pandemic.

The overall process of COVID-19 vaccine prioritization was done in five steps. First, the input indicator data were fed into a Microsoft Excel table for each variable based on district classification and this was done for every phase. Secondly, the numeric data were summed for each indicator to obtain the aggregate value of each variable. Thirdly, we calculated the aggregate value of each variable to get the Z-score by using the following formula:

$$\text{Z-score} = \frac{(X_i - \overline{X})}{Sd} \quad (1)$$

where X_i is the term for the observational data (the indicators); $\overline{X}$ the average of observation data; and Sd the standard deviation.

Fourthly, in every prioritization phase, we summed up all Z-score values for each district which produced positive and negative numbers. We classified each value according to Muta'ali (2014), who states that positive and negative Z-score values should be classified differently. The higher Z-scores indicate the district that should receive a higher priority since it consists of a greater number of vulnerable people and vice versa.

Finally, we classified the total Z-scores of the districts into five classifications: 'Very Low'; 'Low'; 'Medium'; 'High': and 'Very High' prioritizations considering the average Z-score value or 0.00 as limit between positive and negative values. The positive scores fell into the High and Very High classes, whilst the negative ones fell into the Very Low: Low; and Medium classes. This was done consecutively for every phase so that the districts to be prioritized for each vaccination phase were obtained.

Data collection

All data were derived from the official website of Statistic Bureau Centres of Yogyakarta. We used health data for 2019 and 2020 in the form of the number of health workers available, *i.e.*, doctors, nurses, midwives and health facilities (public and private hospitals, public health centres (Puskesmas), clinics, integrated healthcare centres (Posyandu) in each district. We also collected socio-economic data for these two years regarding the population density, including the number of elderly (≥60 years) persons, and the number of people working in the social or public service sector, *i.e.* military staff, police officers, state officials, state civil apparatus, state-owned enterprise workers, higher educators and teachers,

Code	Districts
B1	Srandakan
B2	Sanden
B3	Kretek
B4	Pundong
B5	Bambanglipuro
B6	Pandak
B7	Bantul
B8	Jetis
B9	Imogiri
B10	Dlingo
B11	Pleret
B12	Piyungan
B13	Banguntapan
B14	Sewon
B15	Kasihan
B16	Pajangan
B17	Sedayu
G1	Panggang
G2	Purwosari
G3	Paliyan
G4	Saptosari
G5	Tepus
G6	Tanjungsari
G7	Rongkop
G8	Girisubo
G9	Semanu
G10	Ponjong
G11	Karangmojo
G12	Wonosari
G13	Playen
G14	Patuk
G15	Gedangsari
G16	Nglipar
G17	Ngawen
G18	Semin
Y1	Mantrijeron
Y2	Kraton
Y3	Mergangsan
Y4	Umbulharjo
Y5	Kotagede
Y6	Gondokusuman

Code	Districts
Y7	Danurejan
Y8	Pakualaman
Y9	Gondomanan
Y10	Ngampilan
Y11	Wirobrajan
Y12	Gedongtengen
Y13	Jetis
Y14	Tegalrejo
K1	Temon
K2	Wates
K3	Panjatan
K4	Galur
K5	Lendah
K6	Sentolo
K7	Pengasih
K8	Kokap
K9	Girimulyo
K10	Nanggulan
K11	Kalibawang
K12	Samigaluh
S1	Moyudan
S2	Minggir
S3	Seyegan
S4	Godean
S5	Gamping
S6	Mlati
S7	Depok
S8	Berbah
S9	Prambanan
S10	Kalasan
S11	Ngemplak
S12	Ngaglik
S13	Sleman
S14	Tempel
S15	Turi
S16	Pakem
S17	Cangkringan

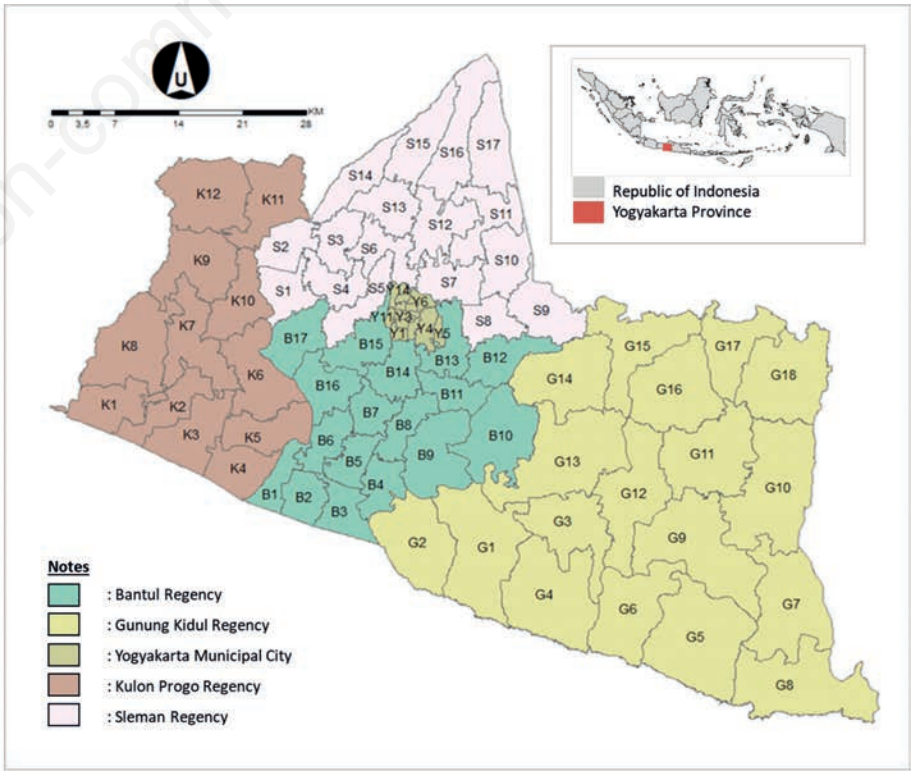

Figure 1. The study area comprising the whole Yogyakarta Province in Indonesia.

housekeepers, college students, craftsmen, private workers and entrepreneurs. We also utilized the number of public facilities in 2020, such as traditional markets, minimarkets, industries, restaurants/food stalls, tourism objects and hotels/hostelries.

Data analysis

The Z-score values at each phase were determined by the accumulation of several indicators available as follows: Phase 1 - based on the availability of health workers and health facilities indicators; Phase 2 - based on public service officers and the elderly; Phase 3 - based on indicators of education personnel and facilities as well as population; and Phase 4 - based on employment indicators. Districts with a high accumulation of available indicators would receive higher Z-score values, while districts with a low accumulation of data would have lower Z-scores.

Variables analysed

The variables used by each stage can be seen in Table 1. These variables were intended to focus on reducing the mortality rates and maintaining the stability of the capacity of health facilities and other critical facilities to keep running amid a pandemic. This study used data on health, population, social, educational, and economic data in 2019. The data were used to describe conditions and activities of community groups before the COVID-19 pandemic started to affect the level of risk of virus transmission and infection. The spatial distribution of the Z-Score value was divided into 5 priority classes: Very Low, Low, Medium, High, and Very High as seen in Table 1. This method proportionally distributed the number of priority targets (districts) and the percentage of priority classes of each district at each stage and discussed according to the decree as mentioned above. The range was calculated based on the reduction of the highest and lowest Z-scores produced, thus divided by the number of priority classes. As stated above, the positive scores fell into the High and Very High classes, whilst the negative ones fell into the Very Low; Low; and Medium classes. Each phase had different range values, so the priority classes for each regency could be different at each phase too.

Subsequently, the distribution of prioritized districts was presented in a choropleth, thematic map that represents the scale of prioritization within the 78 districts according to spatial-demography approach in each phase. The darker the shade of colour of a district in the map, the higher the Z-score value produced, which indicates that there are more vulnerable people and that consequently a greater number needs to be vaccinated in the district in question. For the districts represented by brighter shades of colour, the reverse situation is indicated. Indicators related to priority targets in total could only be aimed at ages above 18 years in accordance with the requirements stated in the decree. Consideration of

Table 1. Summary of indicators used in this study.

Phase	Priority target*	Variable	Indicator (number of)	Z-score range	Level
1	Health workers, health worker assistants, supporting staff of health sector	Health worker	Doctors	–2.29 to –1.52:	Very low
			Nurses	–1.51 to –0.76:	Low
			Midwives	–0.75 to 0.00:	Medium
		Health facility	Public hospitals	0.00 to 3.75:	High
			Private hospital	3.76 to 7.49:	Very high
			Public health centres (Puskesmas)		
			Clinics		
			Integrated healthcare centres (Posyandu)		
2	Public service staff and people older than >60 years	Public service staff	Military armies	–1.71 to –1.14:	Very low
			Police officers	–1.13 to –0.57:	Low
			State officials	–0.56 to 0.00:	Medium
			State civil apparatus	0.00 to 1.59:	High
			State-owned enterprise workers	1.60 to 3.19:	Very high
		Age	Elderly people		
3	Vulnerable communities according to geospatial, social, and economic aspect	Education facility	Higher education	–2.68 to –1.79:	Very low
		Education workers	Kindergarten teachers	–1.78 to –0.89:	Low
			Elementary school teachers	–0.88 to 0.00:	Medium
			Middle school teachers	0.00 to 8.05:	High
			High school teachers	8.06 to 16.11:	Very high
		Demography	Population density		
		Trade and Industry	Traditional markets		
			Minimarkets		
			Medium and large industries		
			Restaurants and food stalls		
		Tourism	Tourism objects		
			Hotels and hostelries		
4	Other community and workers based on cluster	Non-workforce	Housekeepers	–2.16 to –1.44:	Very low
			College students	–1.43 to –0.72:	Low
		Workforce	Craftsmen/labours	–0.71 to 0.00:	Medium
			Private workers	0.00 to 3.30:	High
			Entrepreneurs	3.31 to 6.60:	Very high
			Other workers		

*Based on Director General of Disease Prevention and Control Decree HK.02.02/4/1/2021 in terms of Technical Guideline on Vaccination to Control COVID-19 Pandemic.

the determining indicators was based on the probability of exposure to COVID-19 during daily activities. Specifically, the total dataset obtained was then calculated using the Z-scores so that the hierarchy of priority at the district level was classified according to five levels, namely Very Low (1), Low (2), Medium (3), High (4) and Very High (5).

Results

The relationship between priority targets according to the Decree of the Director-General of Disease Control and Prevention of the Ministry of Health Number HK. 02.02/4/1/2021, variables, indicators, and hierarchy of priority based on the Z-score in each phase is stated in Table 1. We obtained the Z-score on each phase sequentially by calculating the indicator values and produced a range of Z-score for each phase as stated in Table 2. The table explains that SD and also the average values were part of the calculation process in order to arrive at the Z-score values. It must also be emphasized that all Z-score values for each phase consist of either positive or negative values.

Figure 2 shows the priority for Phase 1 COVID-19 vaccination focused on the capacity of the health sector, in this study defined as the number of health workers and health facilities in the study area. The results of the Z-score calculation indicate that the districts of Wates and Sentolo should be prioritized and be placed in the 1st vaccination phase as the health capacity of Kulon Progo Regency attained up to 33% of health workers, the highest propor-

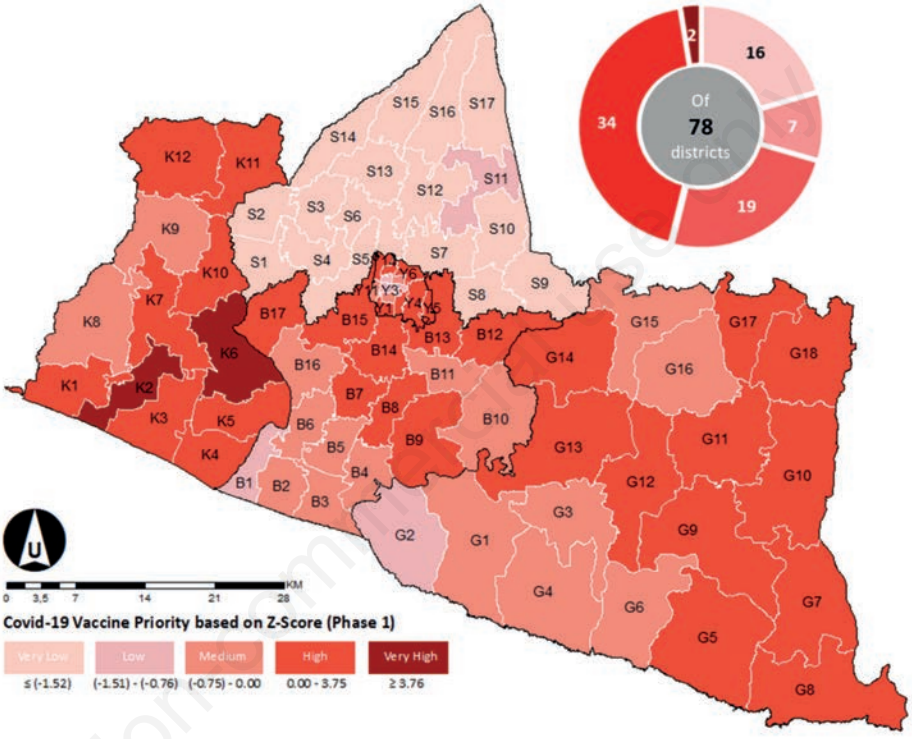

Figure 2. COVID-19 vaccination prioritization at the first phase at the district level.

Table 2. Summary of Z-score values.

Phase	Priority target	Variable	Average value	Standard deviation	Z-score value	
					Min	Max
1	Health workers, health worker assistants, supporting staff of health sector	Health workers Health facilities	48.45 59.04	52.16 35.54	–0.79 –1.52	6.87 1.97
2	Public service staff and people older than >60 years	Public service staff Age	1400.74 7570.79	1189.66 3157.01	–1.04 –1.90	3.49 2.82
3	Vulnerable communities according to geospatial, social, and economic aspect	Education workers Education facilities Demography Trade and industry Tourism	553.17 1.86 3814.93 298.77 26.03	4.72 578.37 5608.77 367.23 40.98	–0.76 –0.39 –0.63 –0.79 –0.64	7.78 4.90 3.35 6.34 4.32
4	Other community and workers based on cluster	Non-workforce Workforce	10,491.97 15,518.86	6824.55 10,739.57	–1.11 –1.10	3.79 3.16

tion of the Phase 1 vaccination priority target. Yogyakarta City was sorted into the second place with a proportion of 21%, while the Gunung Kidul and Bantul regencies obtained the third and fourth ranks due to the proportional values of 18% and 15%, respectively. The lowest priority in the Phase 1 vaccination scheme was Sleman Regency with 12%.

Priority for the COVID-19 Phase 2 of vaccination was aimed at public service workers and the elderly (>60 years old). Public service officers as intended in the decree consist of the army staff, police officers, state officials, civil servants and state-owned enterprise employees. As a result of the calculations, the greater the number of public service personnel and elderly (>60 years old) in a district, the higher the Z-score. Hence, the districts of Depok, Banguntapan, Piyungan, Sewon, Wonosari, Gamping, Mlati and Ngaglik should be placed in Phase 2 due to their high number of public servants. Figure 3 explains that with respect to vaccine needs, the proportional percentage of vaccines per regency should be dominated by Sleman Regency (29%) followed by the regencies of Bantul and Gunung Kidul, with 24% each, Kulon Progo Regency (13%) and Yogyakarta City (10%).

COVID-19 vaccination Phase 3 is for communities that are socially, economically, and geospatially vulnerable. In terms of Figure 4, vulnerable groups are defined as people related to activities or infrastructures that can increase exposure to COVID-19, such as schools and higher education, population density, trade, industry facilities and tourism. Thus, the higher the number of this kind of vulnerable groups and facilities within a district, the higher the possibility of prioritization in this phase. Based on the Z-score calculation, it was found that districts of Depok and Umbulharjo should be placed in Phase 3. The needs during Phase 3 consisted of Gunung Kidul Regency (29%), Bantul Regency (25%), Sleman Regency (19%) plus Yogyakarta City and Kulon Progo Regency with 14% and 13%, respectively.

Phase 4 focuses on aspects of the community and economic actors according to the economy, generally divided between people who have an occupation and those who are not in the workforce. The former consists of workers/craftsmen with special skills, private employees, and entrepreneurs, while the latter includes students and household managers. The greater the number of those groups, the higher the priority of the district. As seen in Figure 5, the districts of Banguntapan, Sewon, Kasihan, Gamping, Mlati, Depok and Ngaglik have the highest priority in this phase. Regionally, the need for vaccination, Sleman Regency had the highest priority (33%) followed by Bantul Regency (28%), Gunung Kidul Regency (18%), Yogyakarta City (14%) and Kulon Progo Regency (8%).

Based on the calculations to determine the regional priority of the phases (Figure 6), it can be stated that 3.9% of all districts in Yogyakarta Province have a very high priority, 32.1% high priority, 20.5% medium priority, 29, 5% low priority and 14.1% very low priority for COVID-19 vaccination. We also estimated the prioritized districts within each region in Yogyakarta Province. Generally, according to health, demography, socio-economy and spatial characteristics, Depok (Sleman Regency), Banguntapan and Kasihan (Bantul Regency), Wonosari (Gunung Kidul Regency), Sentolo and Wates (Kulon Progo Regency) and Umbulharjo (Yogyakarta City) had the highest need for vaccine allocation.

Figure 7 explains the scale of vaccine necessity among the districts classified as Very high and High. The inner circle shows the regencies and the outer the districts. The colours of the inner circle in the figure represent the needs of each regency whilst the graded colours in the outer circle visualize the percentage of COVID-19 needs compared to other districts within the regency. The darker the shade of colour of a district in the diagram, the higher the vaccination priority. Among all of the districts shown, Depok District comes out as the one with the highest number of people that should be targeted for COVID-19 vaccination due to this district's top achievements with respect to all the different indicators.

Depok District in Sleman Regency received high achievements based on all indicator applied (Figure 7), and Wonosari District had a strong impact on account of its core role of Gunung Kidul Regency's development (Kuswantoro and Pramono, 2020). For example, people in the districts of Semin, Playen, Karangmojo, Semanu and Ponjong tend to build a new settlement located close to Wonosari because of cheaper land prices, while the districts of Wates and Sentolo are located in the most vibrant area of Kulon Progo Regency, which provides ease of connections thanks to a superior road infrastructure (Setiadi, 2016). Moreover, each of the districts belonging to Sleman Regency, Bantul Regency and Yogyakarta City are part of the Yogyakarta Municipality agglomeration as stated by Putra and Muta'ali (2014). In addition, Sleman Regency dominated with respect to necessity of the COVID-19 vaccination in all phases (Figure 8).

Discussion

Yogyakarta Province has a high risk of COVID-19 transmission. At the end of 2020, it was one of the five provinces with the highest mortality rate due to COVID-19 (Katadata, 2020). However, when reviewed at the district level, it appeared that the level of transmission varied and that clusters in nearby locations are influenced by social, educational and economic conditions that existed before the pandemic. Indeed, the results of this study show that districts with a high rate of COVID-19, and consequently with pronounced vaccination needs, corresponded to areas previously shown to have strong economic, social and educational activities (Sharifi and Khavarian-Gamsir, 2020). Further, districts with very high to moderate priority classifications with respect to vaccine needs were found to be those known to either have large numbers of health workers (Wu *et al*., 2007), high social and economic activities, such as those related to tourism and trade (Yu, *et al*., 2021; Mirzaee *et al*., 2021); those associated with educational facilities such as universities and schools (Buckner *et al*., 2021) or those with a high daily migration.

Healthcare workers were found to be the most vulnerable population group due to their high level of SARS-CoV-2 exposure and should therefore belong to vaccination Phase 1. For example, Kulon Progo Regency occupied the highest priority in this connection and Wates District in this regency has a high number of nurses, doctors and midwives that should be prioritized compared to other districts. We assessed the level of vulnerability by measuring the number of health facilities from a spatial point of view (Ministry of Health, 2021b), as they can result in high-risk areas by attracting infected people (Glauser, 2020). Nonetheless, the results showed that the number of health facilities did not have a major impact on the classification level of the groups targeted for vaccination. It is proven that indicator of health facilities is not always directly proportional to the assessment results of the priority level of vaccination.

Phase 2 should focus on public service workers and the elderly.

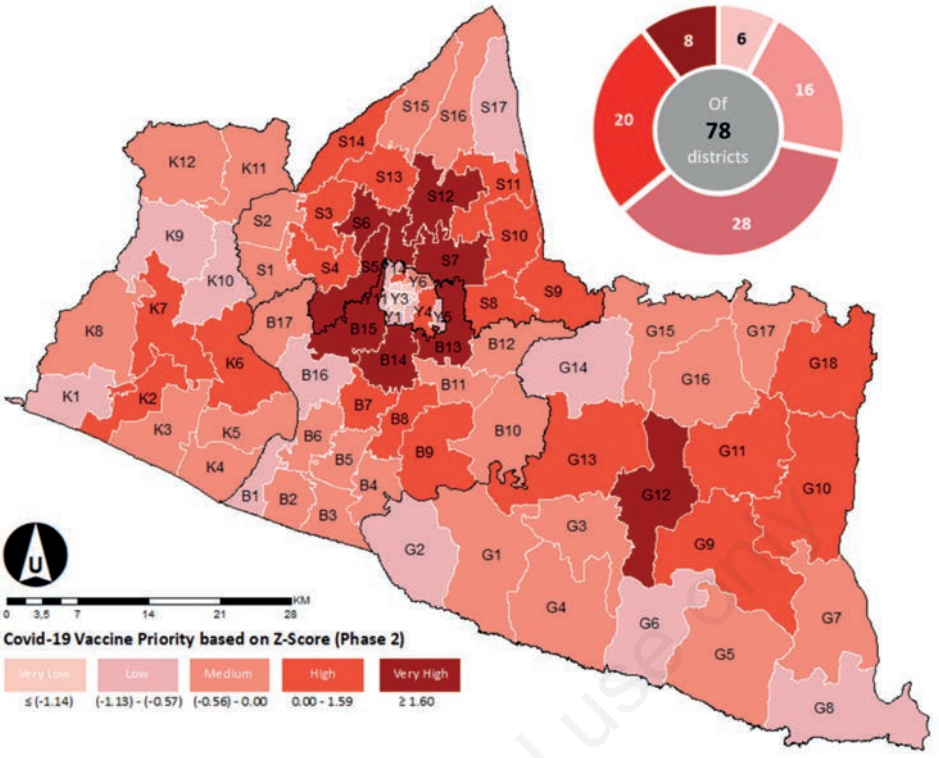

Figure 3. COVID-19 vaccination prioritization at the second phase at the district level.

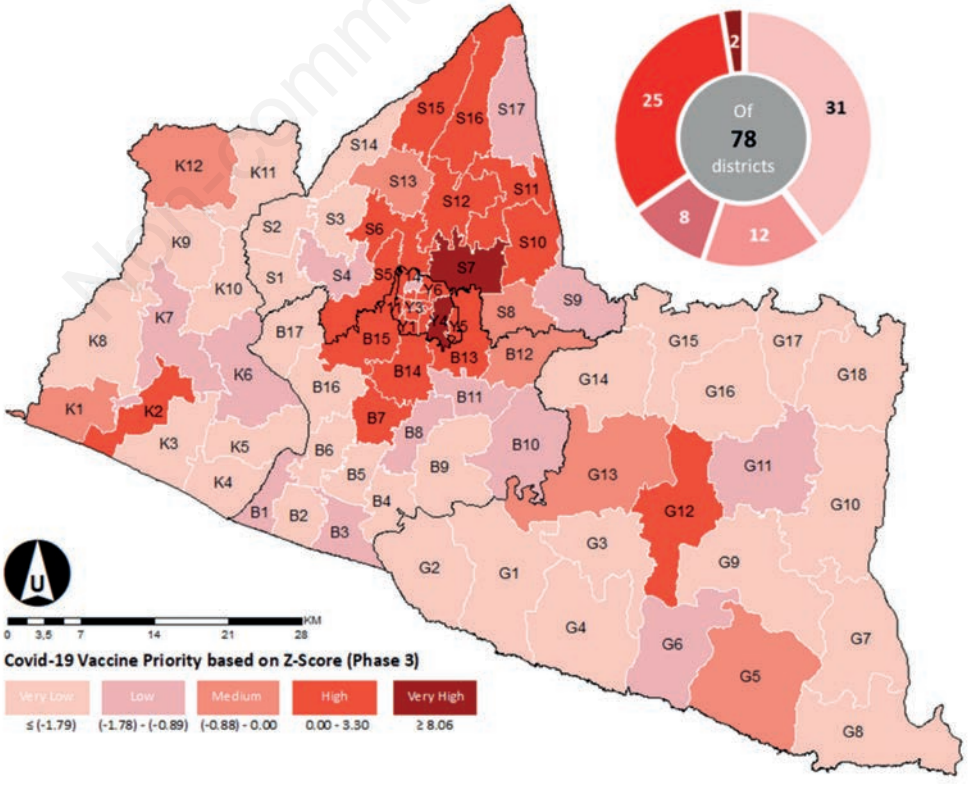

Figure 4. COVID-19 vaccination prioritization at the 3rd phase at the district level.

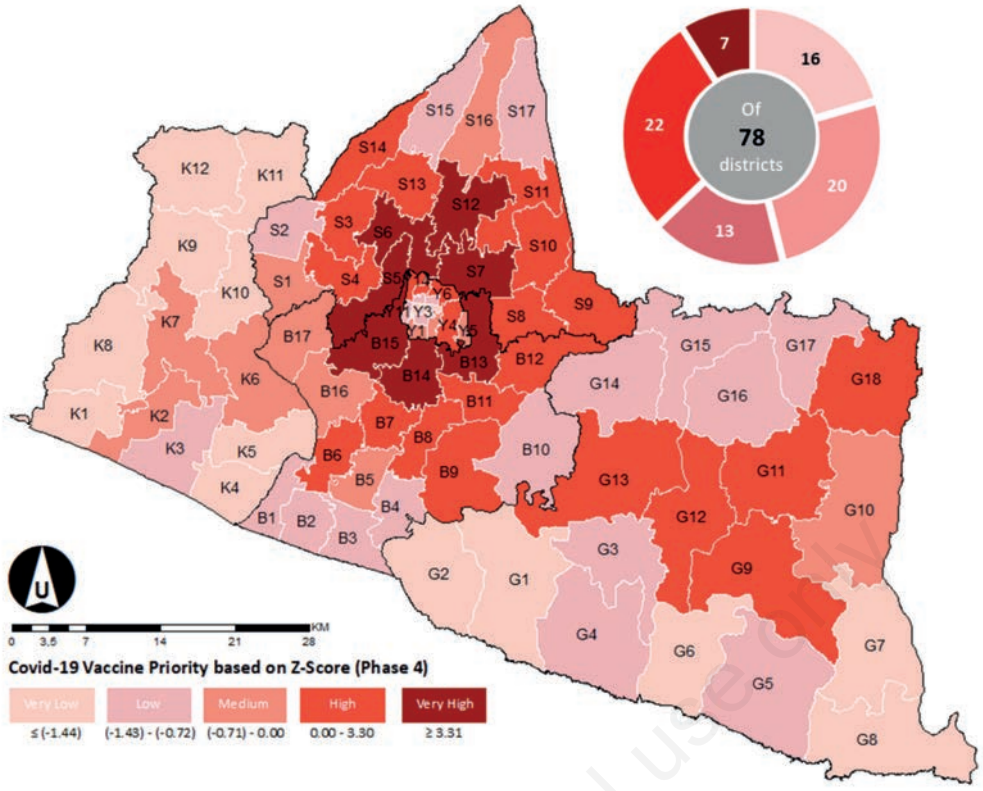

Figure 5. COVID-19 vaccination prioritization at the 4th phase at the district level.

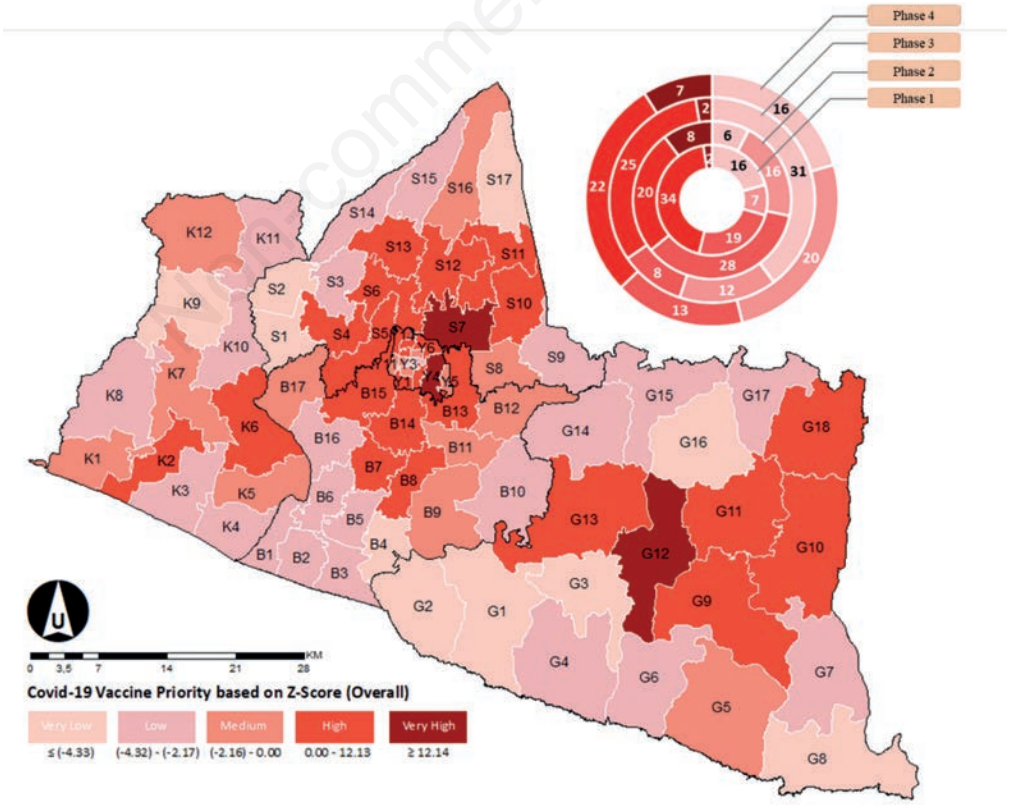

Figure 6. The overall COVID-19 vaccination prioritization at the district level.

Figure 7. Prioritized districts within region in Yogyakarta Province for COVID-19 vaccination.

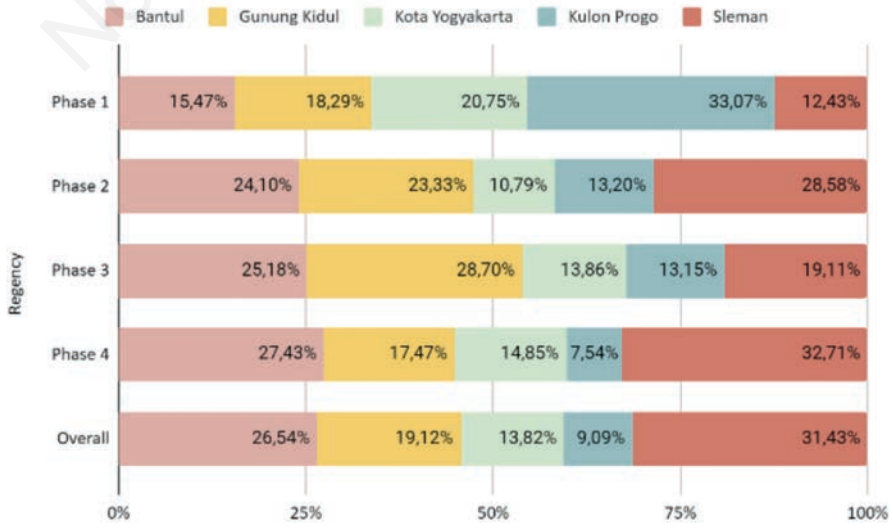

Figure 8. Percentage of each region's place in the COVID-19 vaccination phases.

Although CDC (2020) tells us that people over 60 years of age have a higher mortality risk, the Indonesian Ministry of Health placed the elderly in Phase 2, since clinical trials of the new vaccines had not yet been examined for this age group, while the results for the 18-59 years old were available (BBC Indonesia, 2021). Public service officers, such as military and police officers and civil servants, who intersect with vital public needs to reduce social and economic disruption and help protect the functioning of health facilities (SAGE, 2020), also belong to this priority group. Taking a look at the overall number of vaccine recipients, this is in line with the main employment data by Statistic Bureau Centres of Sleman Regency, which shows a dominant number of people working in the fields of administration, education services, health care and social services.

Phase 3 focused on the geospatial, social, educational, and economic aspects of vulnerable groups. The municipality and regencies within Yogyakarta Province, dominated by educational, economic, as well as tourism activities, have already reduced the number of people prone to COVID-19, especially in highly populated districts with a large number of universities and economic facilities (trade and tourism). The number of targeted recipients in this phase focuses on the number of teachers at all levels of education due to their direct contact with children and college students from outside the region (Edmunds, 2020; Naubedum *et al*., 2021). Hence, vaccinated teachers would contribute to a lower risk of infection and mortality among children due to COVID-19 (Gostin *et al*., 2021; Prasetya, 2021). Sometimes teachers need to provide home education (Wibowo, 2020) that leads to a higher risk of virus transmission. The results of the vaccine classification in Phase 3 show that districts surrounded by a greater number of institutions dealing with higher education and economy will get a higher vaccination classification.

To cover the overall vaccination target at the age range of 18-59 years (Table 1), the priority scale of Phase 4 vaccination is focused on remaining clusters which have a high probability for infection. Districts with the highest priority vaccine classification are districts with a high number of the labour force clusters as a result of its high number of productive populations. Districts that become part of Yogyakarta Municipality agglomeration by their rapid development are districts with the highest rate of land-use change due to widening urban expansion at the outskirts of Yogyakarta City (Devi *et al*., 2020). The highest number and percentage are supposed to be found for districts, with workforces in manufacturing and trade as well as in the hotel and restaurant sectors (BPS Bantul Regency, 2020).

On the whole, this research was limited with regard to data collection. More data could have been included to obtain prioritized regions. However, data on low-income residents, the number of underprivileged, residents in slums and homeless people are not publicly accessible in Indonesia. The unavailable data could have improved this research in relation to functionality. but we were forced to focus on the administrative scope. Data on high and low risk for the elderly could also have been more detailed and helped to determine exactly which group to vaccinate with a minimum of side effects. We could also have accommodated more detailed information on social groups and co-morbidities characteristics, but we were limited by inaccessible or unavailability data.

For further research, it will be utterly important to have real-time evaluation of vaccine administration to compare the ideal conditions based on priority needs and actual condition in local areas. By using proximity analysis, the distance between prioritized target locations (such as persons being at home or in the workplace) and spatial research should be developed to recommend particularly suitable vaccination sites. It would also be useful to document real-time evaluation of vaccine administration to compare ideal condition based on priority and actual conditions in every district of Yogyakarta. Lastly, since it is proven that district prioritization regarding vaccination necessity could be developed by harnessing publicly available data from the government, it is strongly recommended for as many regions as possible to consider the proposed approach as a tool to evaluate vaccination effectiveness and efficiency.

A spatial approach could help to understand vaccination effectiveness and efficiency for the prioritized target at each stage. That certain districts, *e.g*., Depok, Wonosari, Wates and Sentolo, have large numbers of people targeted for COVID-19 vaccination can be accounted for by their wide and strong relations with other districts (Figure 7). This also explains why many districts belonging to the regencies of Sleman Bantul and Yogyakarta City were in a similar situation. As seen in Figure 8, Sleman Regency had a strong need for COVID-19 vaccination in all phases. This is in line with the number of COVID-19 confirmed cases in the Yogyakarta Province, which is dominated by Sleman Regency's citizens (Regional Government of The Yogyakarta Province, 2021). It can thus be stated that the higher the number of cases within a region, the higher the need for vaccination, a statement supported by one of the findings by Zhou *et al.* (2021), who found that vaccination would be optimally distributed when planned according to the distribution of the COVID-19 hotspots.

In relation to the relevance of the Ministry of Health (2021a) to the implementation of vaccination in Yogyakarta, there are still things that are not relevant when referring to the research findings that analyse vaccination targets according to demographic and spatial characteristics. Based on our calculations, according to Figure 8, vaccinations should be given sequentially to Sleman Regency, Bantul Regency, Gunung Kidul Regency, Yogyakarta City, and Kulon Progo Regency. In practice, the level of vaccination coverage within each area consecutively are Yogyakarta City (160.51%), Kulon Progo Regency (57.23%), Sleman Regency (56.7%), Gunung Kidul Regency (47.30%), and Bantul Regency (40.31%) of the total provincial target (Indonesia Ministry of Health, 2021c). Thus, it could be stated that vaccination in Yogyakarta Province has not fully considered the spatial aspect within its implementation.

Conclusions

Districts with high numbers of vaccination priority groups are those with the highest distribution of health workers, elderly, and public service officers. They are also spatially associated with educational areas and those with a vibrant economy as exemplified by trade and tourism. Overall, districts with high-priority groups were found to dominate throughout all phases of COVID-19 vaccinations amounting to 32% of all districts in Yogyakarta Province. There is thus a link between demographic and spatial conditions that can be used as a reference in determining the priority scale for COVID-19 vaccination.

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