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Estimating the Flood, Landslide, and Heavy Rainfall Susceptibility of Vaccine Transportation after 2021 Flooding in South Kalimantan Province, Indonesia

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Abstract: Vaccine accessibility and availability has been shown to be one of the key factors to ensure rapid responses to the COVID-19 pandemic. Increased vaccine coverage is, however, dependent on vaccine supply and transportation, in particular ensuring that road networks have as minimal disruption as possible. In Indonesia, the most common and imminent threats affecting transport flows are due to frequent disasters such as floods, landslides, and high rainfall. This research is novel because it fills in the gap between health and disaster studies in COVID-19-related studies published since 2021. This study presents an analysis of susceptibility of various hydro-meteorological disasters on the trans-provincial roads that span over 856.014 km and cover an area of 38,744.23 km^2 over 13 districts in South Kalimantan Province, Indonesia. The floods that occurred in January and November 2021 inundated an area of around 4000 km^2 (10 percent of the total study area) that spans along 13 sub-provincial/district areas. Data collected are analyzed using the geographical information system (GIS) to quantify and classify the impacts in the 13 districts, utilizing different indicators such as topography, road conditions and characteristics, amount of rainfall, and types of disasters that occurred (floods and landslides). The results show that the trans-provincial road, which is also the only road available for transporting vaccines in the South Kalimantan Province, was highly susceptible to various hydro-meteorological disasters. Around 20 percent of the total road length was disrupted by the floods, close to 4% of the road section passes through mountainous areas that make it susceptible to landslides, and about 13% to 23% of the road section is vulnerable to slip risks due to the extreme rainfall. The results presented here demand an overarching solution involving multiple stakeholders from public works and local disaster management offices in terms of disaster mitigation and preparedness strategies, and environmental protection in terms of disaster risk reduction implementation. This research contributes to the health sector particularly through future preparedness to pandemics and wider vaccine distribution and coverage through the identification and mapping of sections of roads impacted by multiple disasters.

Keywords: flood; landslide; rainfall; road; transportation; vaccine

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1. Introduction

Flooding has been one of the most common and costly hazards over the last decade, resulting in significant losses in both lives and economic costs [1]. In the context of transportation, flooding has caused road network damage and transportation system closures as well as delays, disruptions, and finally, economic losses [2]. Since transportation systems are required for society to function [3], any disruption of these systems endangers safety and security and can result in significant financial loss and generate direct and indirect adverse consequences, including losing access to essential services [4].

Transportation susceptibility, including assessing the likelihood of disruption, has received increased attention. Several studies have looked into the effects of flooding on transportation disruptions [5], such as assessing transportation network exposure to coastal tsunami-induced disruptions [6], learning from weather event dynamics to assess transportation resilience [7], and modelling the impacts of tornado and hurricane wind-induced flooding on transportation networks. To assist the transportation susceptibility assessment, the use of geographic information system (GIS) analysis is required, which has been used. Transportation has played an important role in pandemic mitigation through vaccination distribution [8], and the assessment of the impacts of disaster magnitude in the form of flooding on vaccine distribution is required immediately.

An important measure to address the pandemic is through vaccinations. The COVID-19 local transmission rates can be mitigated by increasing vaccination coverage. At the same time, the expansion of vaccination coverage depends on vaccine transport. Nature, in the form of extreme rainfall, which leads to extreme floods, has caused a burden on vaccine coverage. The disruptions to vaccine transport due to nature's causes, in this case, flood events, have been widely reported. In January 2021, storm-induced flooding in the United Kingdom threatened the vaccine factory in Wrexham, North Wales. In February 2021, FEMA identified a major winter storm continuing to spread from the Southern Plains into the Northeast that had the potential to cause significant vaccine distribution disruptions as winter weather extended from Maine to Texas and into the South [9].

In March 2021, it was reported that widespread flooding had disrupted the rollout of COVID-19 vaccinations in Australia. This flooding was caused by the overflowing of water from rivers. High rainfall led to potential flooding and caused the closure of transportation networks ranging from trains to roads in New South Wales (NSW) state. As a result, the flood prevented the vaccines' delivery to respiratory clinics and some general practitioners across regional NSW. Similar disruptions in vaccine transport have been observed in Asian regions; the Asian continent has experienced floods due to monsoon torrential rains. In India [10], monsoon rains have caused vaccine transport disruptions and disruptions to people's access to the nearest health facilities to obtain vaccinations.

Current studies have highlighted how natural disasters can potentially disrupt the supply chain of medical logistics, in which the impacts on the supply chain can be classified as direct costs, indirect costs, and secondary effects [11]. Within the medical supply chain and particularly for vaccine distribution, the vaccines can be directly damaged due to the exposure on the roads. Related to the indirect cost, this can disturb the root levels of health facilities that manage and provide the vaccine at grass-roots levels. For secondary effects, delayed vaccine distributions can lead to an epidemic among unprotected people and accelerate the spread of the disease. Learning from past Hurricane Maria [12], this meteorological disaster caused at least 17% of the population to have no access to medications. This disaster hindered the transportation of urgent medical supplies, including dialysis equipment. Regarding the natural hazard disruptions on vaccine transportation, De Boeck et al. [13] has estimated the loss of vaccination coverage due to these disruptions: using GIS and spatial modelling, it was estimated that 37% more facilities are being affected by this flooding.

The COVID-19 vaccination rollout in Indonesia started in January 2020. At the time, the vaccination campaign was primarily aimed at the elderly. The vaccination program for the public started in June 2021. From June to 21 October 2021, the vaccination rate in South Kalimantan Province only reached 34.37% for the first dose and 20.53% for the second dose. As of December 2021, the coverage of dose 1 vaccination in South Kalimantan province reached 62.02%. This figure equals 1.96 million vaccine participants from the set target of 3.16 million people. Meanwhile, for the second dose of vaccination until recently, 38.21% of the target was achieved. Despite this achievement, the dose 1 and 2 vaccination rates in South Kalimantan Province are still below the average vaccination coverages at the provincial level.

Vaccines are distributed to local health facilities in Indonesia via land transportation. To transport the vaccine, a medium-sized truck that has a custom-made box container is used. This container has an air conditioner since the vaccine transport requires a low temperature. The truck used was a medium-sized one that has a low ground clearance of 25 cm, and this makes the truck vulnerable in flood areas. If the vehicle passes through the flood, it will be submerged. Another issue is that South Kalimantan has a limited road network and does not have other ways or routes if the selected routes were submerged.

In January 2021, floods and landslides occurred in South Kalimantan Province, Indonesia and impacted 11 of the 13 districts and cities. Water levels were varied and ranged from 30 cm to 50 cm, and 2 m to even 3 m. The floods occurred from 9 January to 29 January, or 20 days, as a result of the Martapura River's overflow, high rainfall, and environmental degradation. This heavy flood likely occurred due to similar events that occurred in 1928. Flooding was associated with high rainfall intensity, which triggered an overflow of river water beginning 9 January 2021. In another nearby location, the Lulut River, located 1 km from the Martapura River, there was also a flood in 2006, but only a foot. In 2021, floods occurred frequently in March, May, August, September, and November of that year.

Floods in January 2021 in South Kalimantan were caused by multiple causal factors of natural and anthropogenic origins. Prior to the floods, South Kalimantan experienced extreme weather conditions [14]. The movement of water vapor supply from the East Pacific to the West Pacific (known as La Niña) as well as the sea surface temperature, which was warmer than normal, resulted in more significant activity for the formation of rain clouds in Indonesia, especially in the South Kalimantan area. In addition, the presence of closed wind eddies around Kalimantan resulted in the formation of a convergence area in the Java Sea off the southern and eastern parts of Kalimantan. This condition had the potential to increase the mass of water vapor from the Java Sea, which caused the growth of massive convective clouds around South Kalimantan. As a result, in January 2021, the rainfall increased from as low as 15.9 mm to as high as 255.3 mm [15].

The South Kalimantan floods were also driven by land use changes from intact rainforests to plantations that are very vulnerable to floods. For the period of 2010–2020, there was a decline in the area of primary forest by 13,000 hectares and secondary forest by 116,000 hectares, which resulted in the plantation area expansion being sized at 219,000 hectares. In total, 304,225 hectares of intact forest were converted into oil palm plantations between 2001 and 2019.

The floods in South Kalimantan caused a great loss. It was estimated that 633,273 people were affected, 135,656 families were displaced, 46 people died, and 123,410 houses were flooded due to this flood. In regard to transportation effects, the floods disrupted the South Kalimantan trans highway networks that connected the district within South Kalimantan Province to other provinces [16].

Despite growing research on disaster assessments in transportation, our understanding of how disasters can impact specific routes of vaccine transportation is still limited. This information is very crucial, especially for a country such as Indonesia that is threatened equally by meteorological and hydrological hazards. At the same time, the government of Indonesia has used those routes within disaster-prone areas to transport the COVID-19 vaccine to remote areas. A lack of immediate assessments on how the vaccine route is prone to multi-hazard risks can cause a significant delay in COVID-19 nationwide mitigations and responses activities.

This research is intended to capture the transportation-related challenges that impeded COVID-19 vaccine distributions during Indonesia's vaccine rollout, particularly in South Kalimantan Province, which was simultaneously affected by floods and landslides due to the rainfall. The novelty of this study is that it utilizes GIS, which included multi-hazards of flood, rainfall, and landslides and analyzed the combined impacts of those multi-hazards on COVID-19 distributions. Our study focused on addressing three main questions. First, how far have floods, rainfall, and landslides affected the length of primary road networks? Second, how many vaccine recipients will be impacted? Third, which districts will be impacted the most? The results will contribute significantly to plan future COVID-19 vaccine transportation distribution with a maximized coverage area and with the least distribution cost.

2. Materials and Methods

2.1. Study Site

South Kalimantan Province (Figure 1) is a part of Kalimantan Island with a total area of 38,744.23 km^2 divided into 13 districts. The districts include Tabalong, Balangan, Kotabaru, Hulu Sungai Utara, Hulu Sungai Tengah, Hulu Sungai Selatan, Tapin, Barito Kuala, Banjarmasin, Banjar, Banjarbaru, Tanah Bumbu, and Tanah Laut. Kotabaru is the largest district in South Kalimantan, covering an area of 13,044.50 km^2, while Banjarmasin is the smallest, covering only 72.00 km^2. South Kalimantan is geographically located in the southeastern part of the island of Kalimantan, which has a low-lying area on the west and east coasts and a plateau formed by the Meratus Mountains in the center. South Kalimantan is divided into two geographical regions: the lowlands and the highlands. Lowland areas are mostly made up of peatlands and swamps, which are rich in biodiversity and home to a variety of freshwater animals. A few highland areas are still natural tropical forests and are protected by the government.

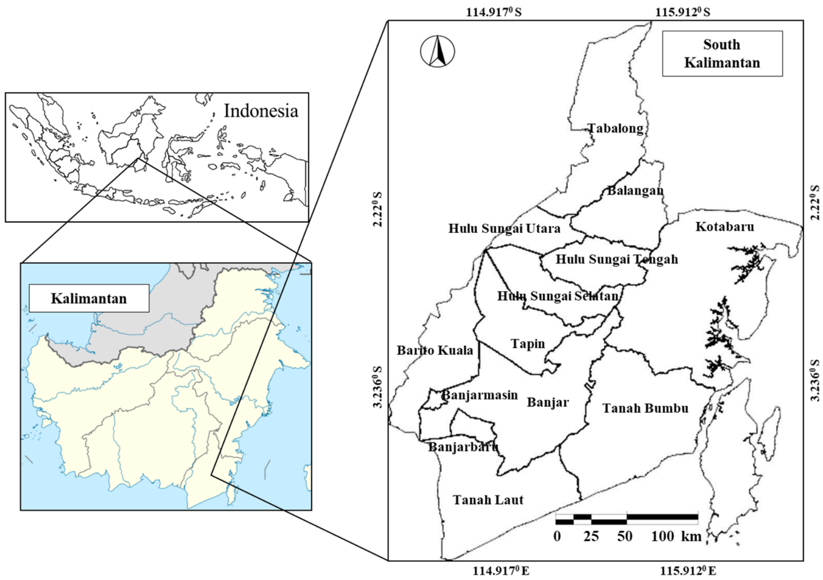

Figure 1. Thirteen districts in South Kalimantan Province, Indonesia.

The landscape of South Kalimantan is characterized by extensive intact forests totaling 139,315 ha, of which 1,325,024 ha are production forests and 139,315 ha are protected forests. South Kalimantan is also known as the land of a thousand rivers due to the large number of rivers in the region. One of the well-known rivers from these rivers is the Barito River, which is upstream, including Central Kalimantan, but is often used to name the entire watershed up to its mouth at the Java Sea in South Kalimantan and is known as Muara Banjar or Kuala Banjar. The Barito River is frequently used for floating markets. In addition, there is the Martapura River, a tributary of the Barito, which is located in the Banjarmasin City and in the Martapura City, the capital of Banjar District, in its upper part.

South Kalimantan, like most other Indonesian provinces, has a tropical monsoon climate. From June to September, winds from Australia carry little water vapor, resulting in a dry season. During the rainy season, however, many wind currents carry water vapor from Asia and the Pacific Ocean. Such conditions occur every half-year following the passage of the transition period between April and May and October and November. Rainfall ranges from 350–210 mm/day from January to April, then drops to 110–200 mm/day from May to August before rising again from 130–290 mm/day from September to December.

2.2. South Kalimantan District, Topography, and Road Classification Mapping

Geographical information system (GIS) methods with ArcView 3.2 were used to classify districts, topography, and roads on South Kalimantan [17] (Figure 2). The method began with the retrieval of the boundaries of South Kalimantan as well as Landsat 8

Operational Land Imager (OLI) images of this province with a spatial resolution of 30 m per pixel. The province Landsat 8 OLI imagery was then identified as district, topography, or road. The result obtained is a shapefile (shp) representing the thematic layer of the South Kalimantan district represented as polygons, road represented as polylines, and topography represented as raster. The elevation data to develop the topography draped over the true color of South Kalimantan were retrieved from World Imagery (WGS84) and included 15 m Terra Colour imagery at small and mid-scales.

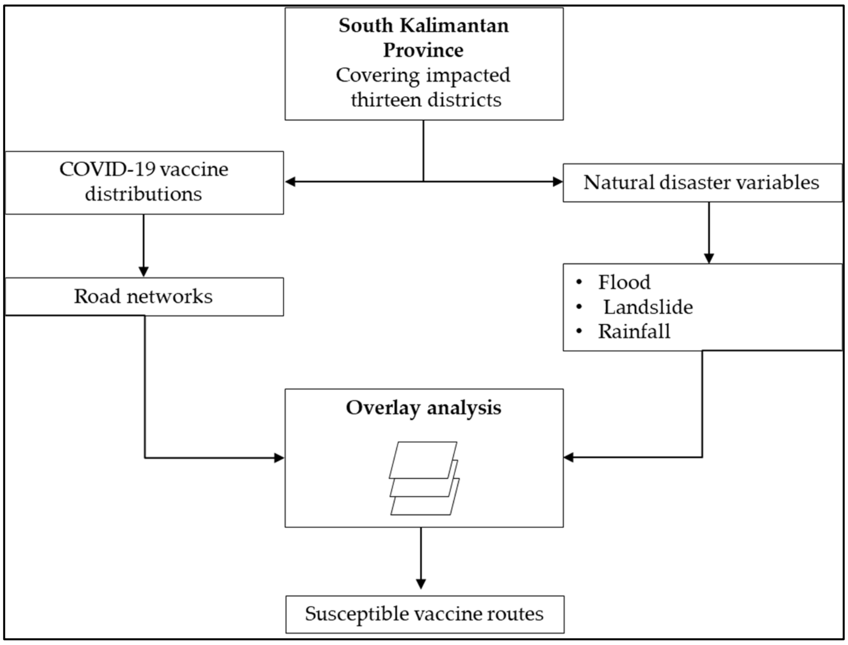

Figure 2. Research workflows.

2.3. South Kalimantan Flood Mapping

The flood mapping method used in this study is similar to that used by Uddin and Matin (2021) for flood events in South Kalimantan in January and November 2021 [18]. The mapping steps make use of publicly available satellite imagery provided by Sentinel-1 Copernicus, which works during cloudy weather to map flood inundation. Sentinel-1 data were processed using the Google Earth Engine (GEE) to distinguish and classify floods for flood mapping throughout South Kalimantan. Sentinel-1 IW GRD images were visualized using VV polarization for flood mapping. The visualization enabled one to quickly determine the extent of the damaged areas regardless of weather conditions, recognize flood patterns, and distinguish between flooded areas and permanent water bodies. The classification results are available in both GeoTiff and raster format. For further mapping and analysis, the flood raster data were then converted to vector format to create a shapefile (shp) that represented the thematic layer of the South Kalimantan flood occurrence as polygons. The flood polygon was then superimposed on the road layer to obtain the lengths of road affected by the flood.

2.4. South Kalimantan Landslide Mapping

The landslide data and base map of South Kalimantan were retrieved from the Centre for Volcanology and Geological Mitigation Disaster, Indonesia (https://vsi.esdm.go.id/) in the format of GeoTIFF raster. The raster data were then converted into vector format to generate a shapefile (shp) representing the thematic layer of the South Kalimantan landslide occurrence represented as polygons. The landslide polygon was then overlaid with the road layer to obtain the lengths of road that were affected by the landslide.

2.5. South Kalimantan Rainfall Mapping

The rainfall data of South Kalimantan were retrieved from the provincial Office of Meteorology, Climatology, and Geophysics (https://http://iklim.kalsel.bmkg.go.id/, accessed on 25 February 2023). The rainfall data were denoted in mm/day and tabulated in the GIS table along with their coordinates of latitude and longitude. To estimate rainfall coverage, the rainfall data were tabulated. The rainfall data were classified into 3 classes including low for <200 mm/day, medium for 200–300 mm/day, and high for >300 mm/day.

2.6. Statistical and Quantitative Analysis

The relationship between vaccine transportation and affecting hazard variables such as floods, landslides, and heavy rainfall was analyzed using statistical and quantitative analysis. In this analysis, the included variables were the numbers of vaccine receivers and the length of roads impacted by floods, landslides, and rainfall, divided into <200, 200–300, and >300 mm/day classes. The quantitative analysis aimed to determine the relationship between transportation and the impacted vaccine receivers. Beyond that, this analysis aimed to determine which hazard variables were the most important and had significant contributions to the vaccine receiver numbers. The quantitative analysis was performed using correlation analysis, and the most important variables were determined based on permutation importance [19], denoted as an increase in percent mean square (%IncMSE).

3. Results

3.1. Flood impacts on Road and Vaccine Distribution

A flood occurred twice in 2021, in January and November (Figure 3). Most floods in those periods occurred in the lowland areas of South Kalimantan. Those areas are in the western and eastern parts of the Meratus Mountains, located in the central part of the South Kalimantan Province landscapes. There were no floods observed in the highlands. In January, the flood area equaled 4256 km^2 and in November it was 3738 km^2, a decrease of 12.17%. Despite the reduction in flood areas, floods have happened in areas where there were no floods before. In January, floods only occurred in the western parts of South Kalimantan. There were no floods observed in the eastern parts of South Kalimantan that bordered directly with the coastal areas. In contrast, in November 2021, there were floods in eastern parts of the country near the coasts. Floods continue to occur in the western areas, with some areas experiencing a reduction and others experiencing an increase.

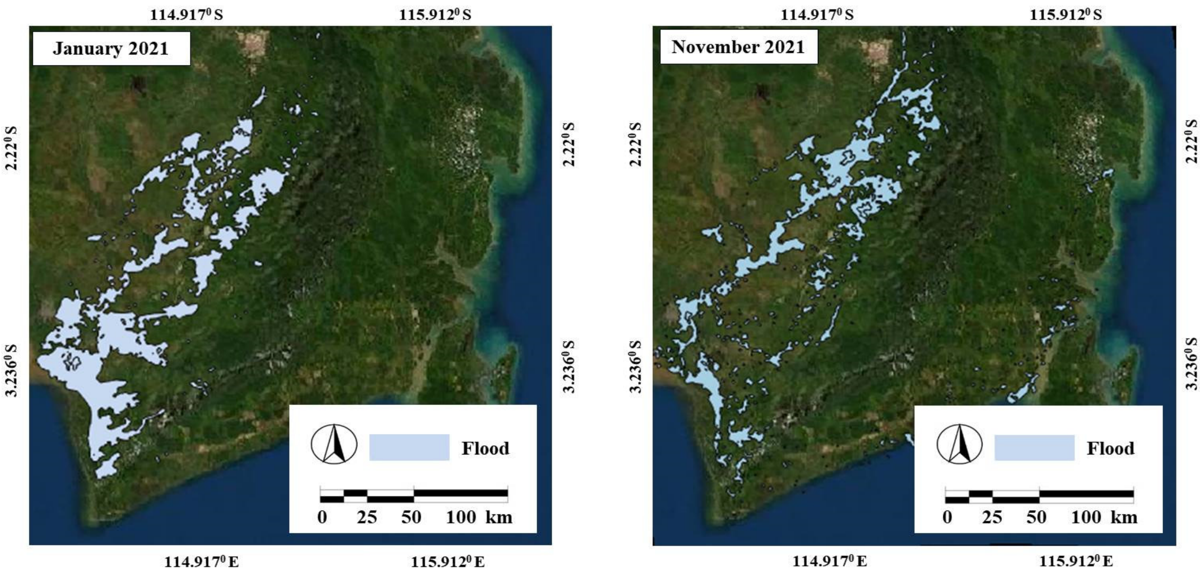

Figure 3. Floods in January and November 2021 in South Kalimantan; topography with Meratus Mountains in the center.

Floods in January and November 2021 impacted the roads used for transporting vaccines (Figure 4). In January 2021 (Figure 5), only 2 out of 13 districts that had roads were not affected by the flood. In contrast, 4 out of 13 districts had more than 50% of the road length affected by the flood. In November, only one out of 13 districts that had more than 50% of their road length was affected by the flood. In contrast to January 2021, roads in all districts in November 2021 were affected by the floods. To summarize, floods disrupted 19.67% of the roads used for vaccine transportation in January 2021, and this figure was expected to rise to 19.95% in November 2021. Some roads in the eastern parts of the South Kalimantan that were previously not affected by the floods were disrupted in November.

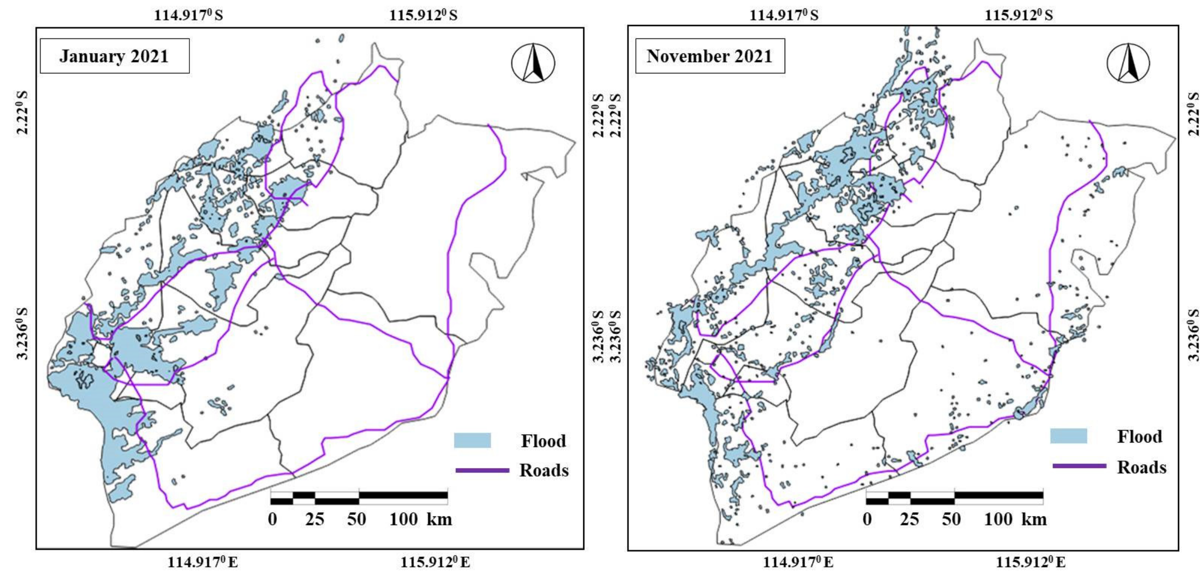

Figure 4. Flood impacts on roads used for distributing vaccines in January and November 2021 in South Kalimantan.

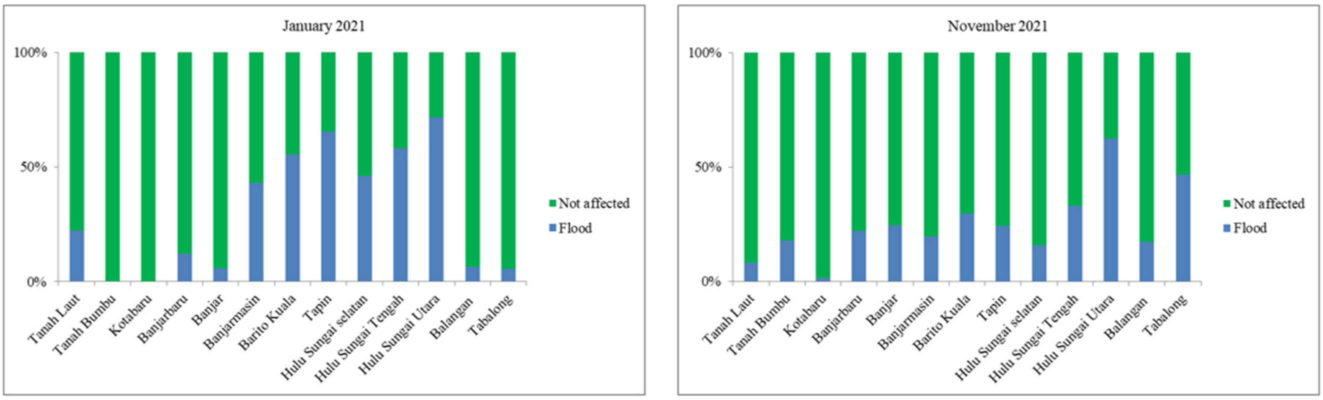

Figure 5. Compositions of road lengths impacted by floods for distributing vaccines in January and November 2021 in South Kalimantan.

3.2. Landslide Impacts on Road and Vaccine Distribution

Apart from massive areas affected by flooding, South Kalimantan was also at massive risk due to landslides. The result is shown in Figure 6, which shows areas having a risk of landslide spanning from south to north, mostly located in the central part of South Kalimantan. The area that is at a landslide risk is estimated to be 4,833 km^2, or equal to 12.47% of the South Kalimantan area. The presence of areas prone to landslides will impact roads used for vaccine transportation of around 30.758 km, or 3.58% of all road total lengths (Figure 7). In contrast to the flood risks, most areas vulnerable to landslides in South Kalimantan were observed in the Meratus Mountains or on high land.

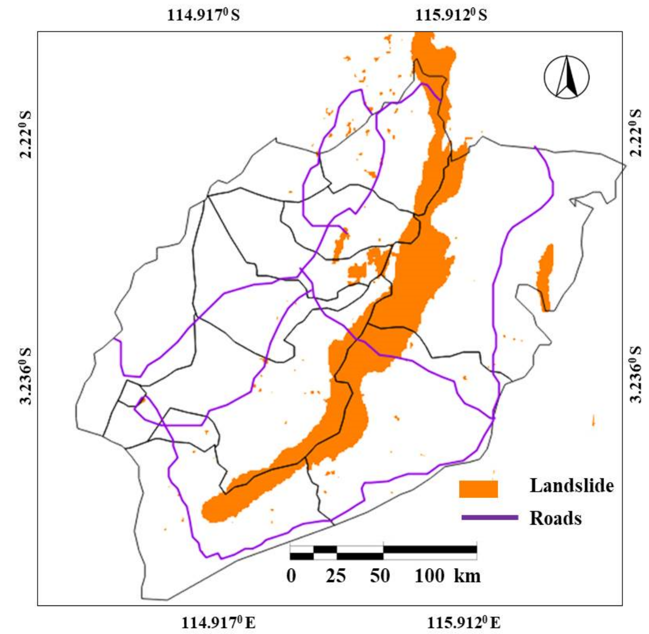

Figure 6. Landslide hazards on roads used for distributing vaccines in South Kalimantan.

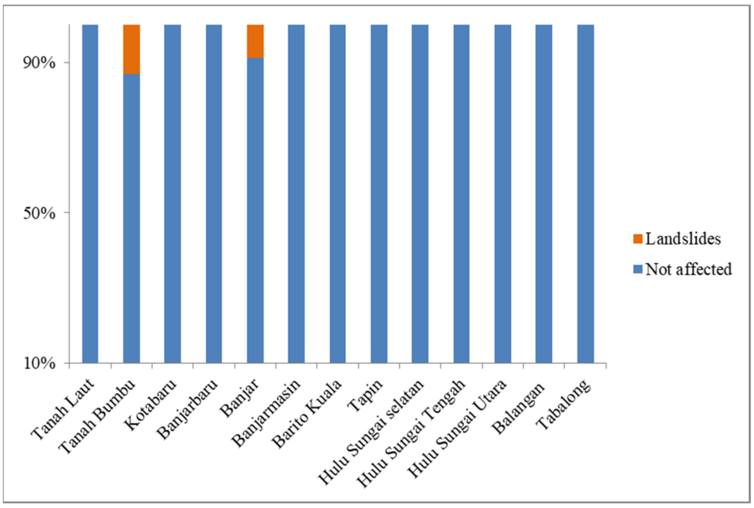

Figure 7. Compositions of road lengths impacted by landslides for distributing vaccines in January and November 2021 in South Kalimantan.

3.3. Rainfall Impacts on Road and Vaccine Distribution

Figure 8 depicts the areas in districts of South Kalimantan that experienced precipitation according to the rainfall classifications, including 200, 200–300, and >300 mm/day. It is obvious that the presence of precipitation was overlapping and correlating with the flood events. Rainfall in this study impacted the roads used for distributing the vaccine (Figure 9). In January 2021, extreme rainfall with values of more than 300 mm/day impacts 1.87% of the roads, or 16.601 km. In November 2021, extreme rainfall was observed in two locations. A total of 1.25% of roads were impacted, and another location had an impacted a road with a length of 11.029 km, or 1.28% of roads that received extreme rainfall. Despite the fact that the road length that received extreme rainfall was considered less, the length of the road that received precipitation with a range of 100–300 mm/day was almost 12.68% in January and increased to 22.28% in November 2021. Those roads that received precipitation were also flooded.

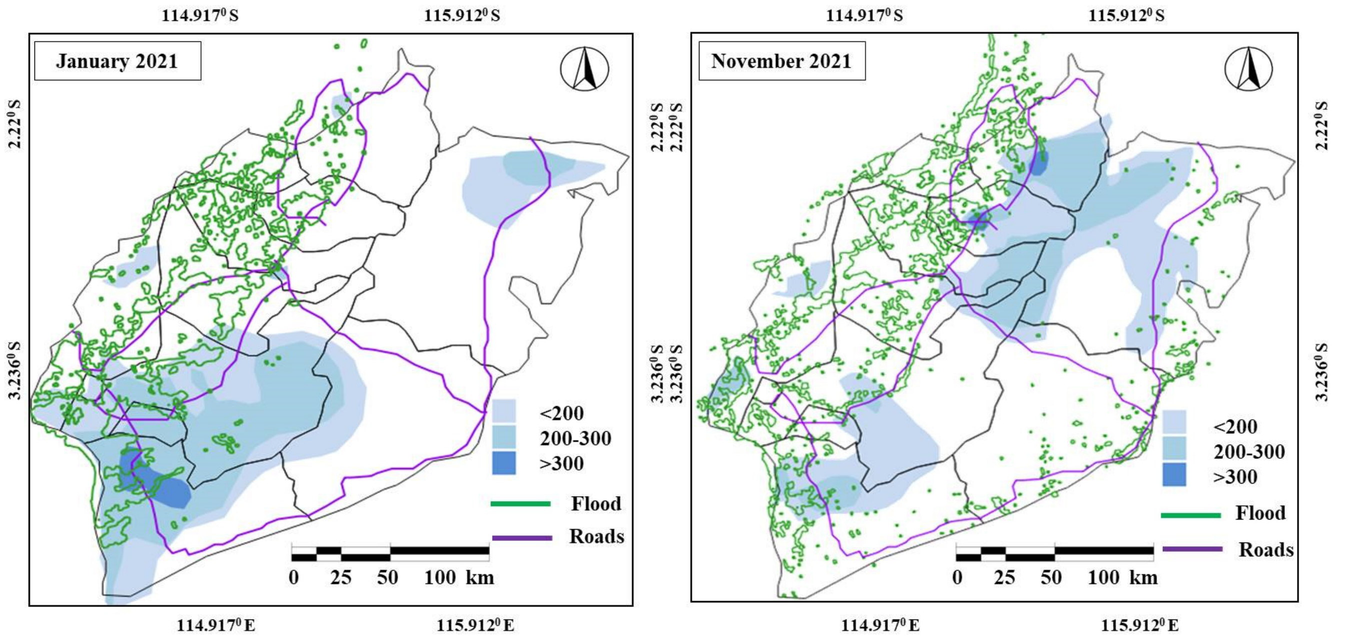

Figure 8. Rainfall (<200, 200–300, >300 mm/day) impacts on roads used for distributing vaccines in South Kalimantan.

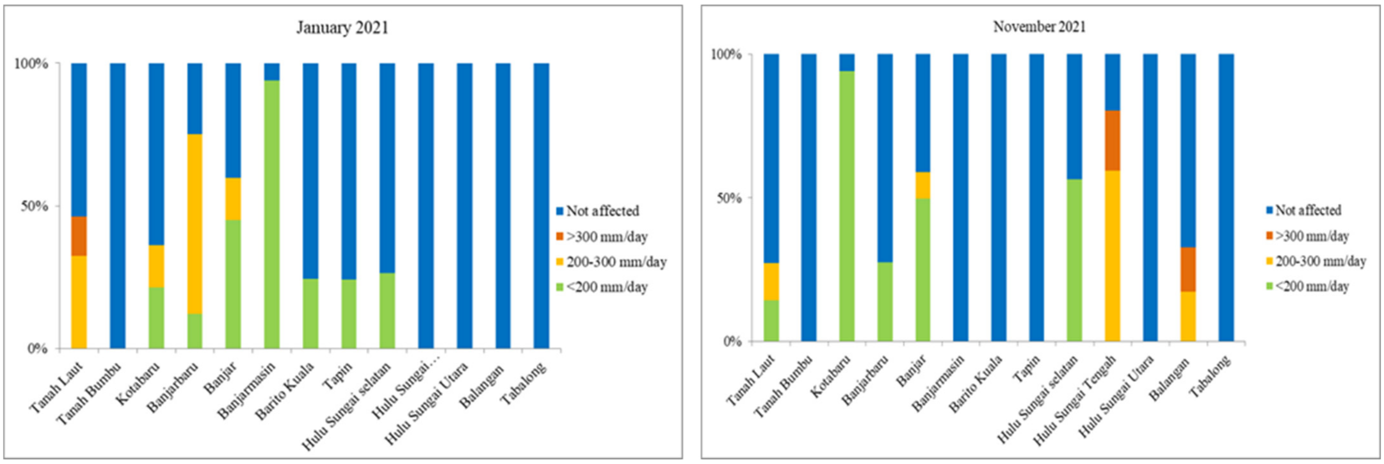

Figure 9. Compositions of road lengths impacted by rainfall (<200, 200–300, >300 mm/day) for distributing vaccines in January and November 2021 in South Kalimantan.

Figure 10 describes daily rainfall data for South Kalimantan Province provided by Indonesia's Agency of Meteorology, Climatology, and Geophysics. The floods in 2021 were related to the anomaly in the annual trends of province-level rainfall. South Kalimantan has several anomalies in rainfall trends in which the daily rainfall fluctuated suddenly, exceeding average rainfall. A significant increase in rainfall was observed in 2021. This rainfall value is recorded as the highest so far for the last 10 years. This explains the magnitude of the current floods in South Kalimantan in 2021.

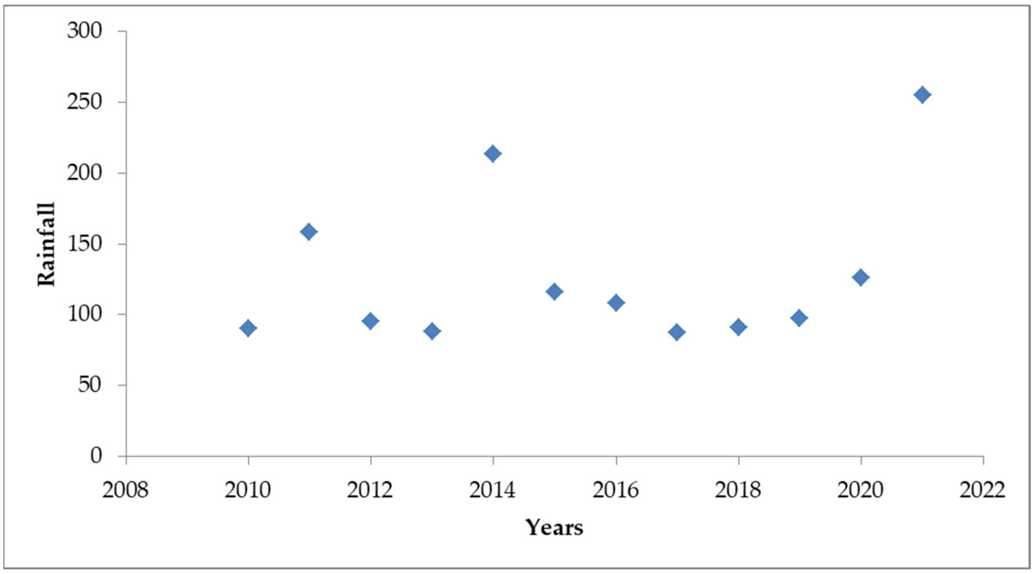

Figure 10. Daily rainfall data of South Kalimantan Province.

3.4. Numbers of Affected Vaccines Due to the Impacted Roads by Floods and Landslides

Based on data provided by the health agencies of each studied district, the government of South Kalimantan distributed 96,924 to 508,780 COVID-19 vaccines to vaccine receivers living in each district (Figure 11). Banjarmasin had the highest number of people to be vaccinated, and Balangan had the fewest people to be vaccinated, but the vaccine transportation to those people living in those areas may have been disrupted due to the natural disasters. Vaccine distributions due to the high demands in Tanah Laut, Tanah, Kotabaru, and Banjar were theoretically less impacted since less than 20% of their roads were impacted by the floods. Balangan is considered a less susceptible district since it has the lowest vaccine demands and impacted roads. Banjarmasin can be categorized as the most vulnerable district since it had the highest vaccine demands and, at the same time, one-third of its road was inundated. Despite the fact that Tanah Bumbu and Banjar were least impacted by the floods, vaccine distribution in these areas may have experienced delays due to the presence of landslides.

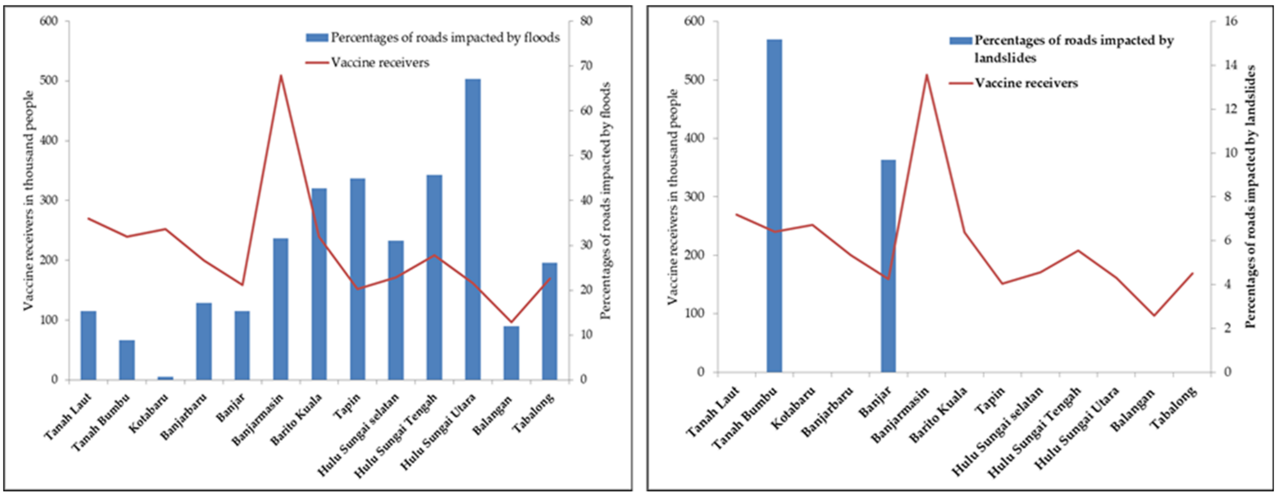

Figure 11. Numbers of COVID-19 vaccines distributed in thousands impacted by floods and landslides as expressed by percentages of roads affected by floods in the left and landslides in the right graphs.

3.5. Influential Hazards

Figure 12 provides results of permutation importance and aims to elaborate on the relationship between the numbers of impacted vaccine receivers and floods, landslides, and rainfall variables. This analysis also confirmed which natural hazard variables mostly affected the vaccine distributions. Among the input environmental hazards, flood was the most influential and contributed more than other hazards to disrupting vaccine distributions. Low rainfall, less than 200 mm/day, was the second most important hazard variable, with a permutation importance of 15%, followed by high rainfall, more than 300 mm/day (13%). Moderate rainfalls of 200–300 mm/day combined with the landslide were hazard variables that had less impact on vaccine distribution. Those hazard variables accounted for 12%.

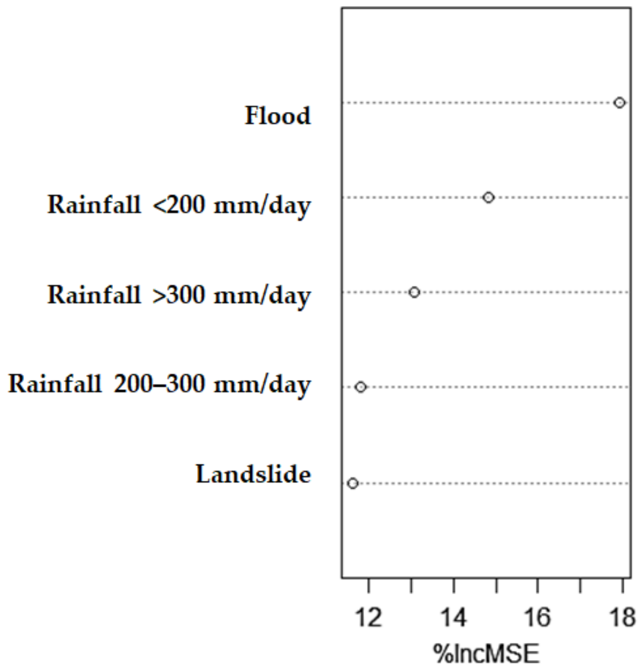

Figure 12. The permutation importance ranking of variables with a percent mean squared error (%IncMSE) increase, indicating the permutation importance score of each hazard variable, is shown. The larger the values of %IncMSE, the more important the hazard variables affecting the vaccine distributions.

4. Discussion

In general, the landslide risks were caused by several factors, ranging from the hydrology aspect (water level changes, ground water changes, stream erosion), the meteorology aspect (rainfall, snowmelt), the geology aspect (earthquakes, volcano eruptions), the anthropogenic aspect (lack of vegetation covers due to deforestation), or any combination of these factors. Like other parts of Indonesia, the landslides in this study, as reported by current studies [20], were mostly caused by the combination of slopes and a lack of vegetation cover on those slopes. The absence of vegetation on the slope was due to land clearing and deforestation activities in the forest of the Meratus Mountains. The deforestation and land clearing activities aim to provide land for agricultural purposes, including plantations [21].

Roads established in mountain ranges are very vulnerable to landslides. The findings in this study are in agreement with the results from the previous study. The road network in the mountainous landscape of Scotland has 34% of the strategic road network, or 152 road segments, identified as being vulnerable to landslide activity [22]. The landslide-induced road disruption was also observed in South Asian regions, including in Lao PDR [23] and Uttarakhand. The Uttarakhand region in the Himalayan mountainous range has 22% of areas that are prone to landslides [24]. Despite the fact that the percentage of road segments vulnerable to landslides is lower in South Kalimantan, because the road connects the western and eastern parts of the island, a landslide on this road can pose a significant problem, particularly when transporting vaccines.

It is obvious that the presence of precipitation is overlapping and correlating with the flood events. In January 2021, precipitation mostly fell in the southern parts of Kalimantan, with less rainfall in the northern, central, and eastern parts. At the same time, those areas that were experiencing floods in January, particularly in the southern parts of Kalimantan, had more areas affected by floods. Similar patterns were also observed in November 2021. Areas that receive precipitation were observed in two areas. The first areas were in the southern parts, which are similar to January 2021, and other areas were observed in the northern and eastern parts. Simultaneously, floods were observed in the eastern parts of Kalimantan, and this flood was absent during the flood incident in January 2021. The correlations of precipitation with high rainfall and flood incidents as observed in this study are in agreement with previous studies [25,26]. Flood properties are related to the combination of precipitation characteristics, including intensity, or rainfall, amount, duration, and spatial distribution. Therefore, floods originated from combinations of high intensity, short-duration storms or longer duration, low-intensity rainfall. Most floods tended to occur in certain months ranging from May or June to September, which coincides with the presence of wetter months of the year, usually September, October, December, and even May.

Rainfall appears as extreme rainfall, which can also contribute to the disaster. The rainfall is categorized as heavy and extreme if it exceeds the normal rate of 250 mm/day [27]. In China, rainfall exceeding 250 mm/day and reaching a range of 350–377 mm/day led to heavy downpour and torrential rains that caused floods in 4 villages and towns and displaced 4906 people. In Indonesia, heavy rainfall occurs frequently. The presence of torrential rains is usually followed by flood disasters due to the flood area, damaged infrastructure, and a number of people affected. The occurrence and peak of heavy rainfall in January is related to the El Nina phenomenon that happens simultaneously. The peak of La Nina coincides with the peak of the rainy season in the period of January–February, causing heavy rainfall across Indonesia, and is followed by floods and landslides. The flood was caused by the overflow of the river. The overflown river then inundated lower land nearby.

Floods and landslides are not the disasters that should be considered as consequences of extreme rainfall in the context of transportation disruption. In some road networks with proper hydrology and drainage management, flooding might not be a significant issue. Due to the working drainage system and networks, the road surface will be free from inundation. Despite the lack of inundation, extreme rainfall can still disrupt transportation since the rainfall causes roads to be very slippery and even visibility is obstructed due to fog and smoke [28], and these lead to vehicle accidents [29]. Based on the study in 2008, weather-related crashes were observed in the United Kingdom, Canada, and the United States, and that rainfall contributed to the 31%–111% increase in overall automobile crash rates, accompanied by injury crash rates increasing from 28% to 70% [30]. Then in 2013, it was confirmed that a combination of meteorological phenomena including precipitation [31,32] and non-meteorological events can contribute to a wide range of risks. This has raised an awareness that extreme annual rainfall in South Kalimantan should be taken into account to decrease the number of transportation accidents and crashes during vaccine distribution, considering that 12.68–22.28% of the roads in South Kalimantan receive precipitation with extreme rainfall. The relative accident risks were increased for poor road weather conditions and were also the highest for rain and slippery or very slippery road conditions [33].

This research has significantly contributed to the particular mitigation of geological disasters that bottleneck medical logistic transport and the sustainability of healthcare services in general. This study is the first that has delivered multi-hazard risks of transportation and can contribute to the mitigation of these risks. This study recommends a broader consideration of deforestation and calls for reforestation to the land area surrounding the route that has been used for transporting vaccines. A study in 2013 highlights the need for public health and transportation to be integrated, with a focus on the most vulnerable and at-risk transportation routes and operators [34].

The sustainability of pandemic management depends on the sustainability of transporting medical supplies, including vaccines. Vaccine transportation to vulnerable areas and people can only be ensured upon the mapping of the most effective and efficient vaccine distribution route that considers potential disruption risks from disasters or other natural and societal risks.

Despite the fact that this study has delivered a multi-hazard risk assessment for vulnerable vaccine transports, there are some limitations to this study. Due to the study area's magnitude, the analysis' measure only highlights a small number of variables that are thought to have a major influence. As a result, several variables were overlooked. First, this study has limited the types of roads. This should be incorporated into a future study since the roads in Indonesia are made of two distinct materials: asphalt and concrete. Those road materials have distinct characteristics in response to hydrology-induced disasters and will affect transport vulnerability significantly and differently. Besides the road conditions, one variable that is highly recommended to be included in the further study is the type of vaccine itself. Each vaccine has distinct characteristics and responses due to the transportation physical conditions, including temperatures and expirations. Natural disasters will lead to a significant delay in vaccine transportation, which will directly increase the exposure of vaccines to unsuitable conditions.

5. Conclusions

The trans-provincial roads spanning over 856.014 km are an important asset for accelerating the vaccine distribution and coverage to cope with the COVID-19 pandemic in the South Kalimantan Province. Despite their importance, these roads are highly susceptible to multiple disasters as shown in the above analysis. It was found that around 20 percent of the total road lengths were disrupted by the floods, close to 4% of the road sections pass through mountainous areas that make it susceptible to landslides, and about 13% to 23% of the road section is vulnerable to slip risks due to the extreme rainfall.

To the best of our knowledge, the flood susceptibility analysis presented in this study is relevant for transportation system planners, emergency responders and managers, and, most importantly, others working to reduce pandemic risk by increasing vaccine transportation system resilience. The analysis, which was designed as a flexible planning and decision-support tool, could also be adapted to plan for other types of hazards that could threaten and disrupt vaccine transportation and distribution, such as landslides and tsunamis, as well as storm surge-induced flooding. The map of impacted transportation networks will contribute to achieving Sustainable Development Goals, in particular SDG 3, to improve vaccine coverage in an effective manner.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved under the Ethics Approval Letter from the Ethics Committee Faculty of Public Health, Universitas Indonesia Number: Ket- 435/UN2.F10.D11/PPM.00.02/2020.

Informed Consent Statement: Informed consent was obtained from respondents by agreeing to fulfil the terms and conditions to participate in the study. The researchers applied the informed consent during the study with the principles of beneficial, no harm, confidentiality, justice, and voluntary participation. Hence, several pieces of information should be agreed to by participants prior to data collection. Particularly, those participants under 18 years old have to ask permission from their parent or legal guardian. If they do not meet the criteria, the system automatically stops the survey.

Data Availability Statement: The datasets utilized and/or analyzed during the present study are available on reasonable request from the corresponding author.

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