economies

Article

Inter-District Road Infrastructure and Spatial Inequality in Rural Indonesia

Ribut Nurul Tri Wahyuni [1,2,*], Mohamad Ikhsan [1], Arie Damayanti [1] and Khoirunurrofik Khoirunurrofik [1]

1 Faculty of Economics and Business, Universitas Indonesia, Depok 16424, Indonesia
2 STIS Polytechnic of Statistics, Jakarta 13330, Indonesia
* Correspondence: rnurult@stis.ac.id

Abstract: Road quality plays an important role, especially in rural areas where most poor households are situated. This study aims to calculate the Rural Access Index (RAI), an indicator of rural road quality (SDG indicator 9.1.1), at the district level, to evaluate the implementation of the Nawacita programme in Indonesia from 2014–2020. The RAI describes the proportion of rural residents who live within 2 km of an all-season road. This study recommends the utilisation of road network maps, urban–rural boundary maps, three road network condition datasets, and WorldPop data to calculate the RAI. The results show that during this period, the RAI increased and its inequality decreased, specifically in the regions of priority for this programme (Papua and West Papua). The results also capture a strong pattern of regional convergence. To ensure the future success of this implementation, the government can create regulations to designate several road infrastructure projects as a national strategy, as well as increase tax collection and private sector investment as sources of road infrastructure development funding.

Keywords: Rural Access Index; all-season road; inequality; regional convergence

Citation: Wahyuni, Ribut Nurul Tri, Mohamad Ikhsan, Arie Damayanti, and Khoirunurrofik Khoirunurrofik. 2022. Inter-District Road Infrastructure and Spatial Inequality in Rural Indonesia. *Economies* 10: 229. https://doi.org/10.3390/economies10090229

Academic Editor: Ralf Fendel

Received: 29 July 2022
Accepted: 14 September 2022
Published: 16 September 2022

1. Introduction

Limited road connectivity can result in high transportation costs and long travel times, which may impact sectoral productivity (Bell and van Dillen 2014; Haughton and Khandker 2009), employment (Mu and Van de Walle 2011) and poverty (Dercon et al. 2012; Khandker and Koolwal 2011). A lack of access to the outside market, for instance, makes it difficult for people to find new jobs and discourages investment, especially in rural areas where most poor households are situated.

Roberts et al. (2006) estimated that 68.3 per cent of rural residents lack access to the global road network. Almost a billion people reside in rural areas without access to paved national roads (Asher and Novosad 2020). As shown in Table 1, in 2011, 43.27 per cent of Indonesia's rural areas did not have access to paved road networks. Rural road construction was also unequal. In eastern Indonesia, 77 per cent of rural areas lacked access to paved roads connecting villages. Similarly, 62.16 per cent of Borneo Island's rural areas lacked access to paved roads connecting villages. Other islands had paved roads connecting villages in less than 46 per cent of rural areas.

The government has been implementing the Nawacita programme by reducing fuel subsidies since 2014 to boost infrastructure development (Salim and Negara 2018). This policy prioritises accelerating connectivity between peripheries and growth centres so that inter-regional inequality can be reduced, particularly in rural areas and eastern Indonesia (Bappenas 2014). State spending on infrastructure has increased significantly, from 8 per cent of the total state budget in 2014 to 19 per cent of the total state budget in 2017. Moreover, the President of Indonesia has created the Committee for the Acceleration of Priority Infrastructure Delivery (KPPIP), a special task force with the responsibility of coordinating policies among various stakeholders and unblocking stalled national strategic projects and priority projects (Salim and Negara 2018). In the 2015–2019 National

Medium-Term Development Plan, the government committed to building 2600 km of roads. To balance the geographic concentration of investment, at least half of the government expenditure went to areas outside the capital region (Bappenas 2014), such as outside Java.

Table 1. The percentage of Indonesian rural areas by inter-village road condition and regional group.

Regional Group		2011		2014		2020	
	Zone	Paved	All-Season	Paved	All-Season	Paved	All-Season
Sumatra	Western	54.16	88.30	58.86	84.11	78.05	91.23
Java	Western	78.80	97.69	84.04	97.00	95.21	98.63
Bali and Nusa Tenggara	Central	57.16	88.40	61.71	85.98	75.53	92.87
Borneo	Central	37.84	68.92	42.27	66.96	57.40	72.10
Sulawesi	Central	60.04	87.55	65.66	88.47	82.09	91.93
Moluccas and North Moluccas	Eastern	39.49	55.70	54.21	65.80	61.96	68.74
Papua and West Papua	Eastern	16.84	32.51	26.39	39.40	29.59	39.32
Indonesia		56.73	83.34	63.56	83.87	77.76	87.78

Source: Author's calculation from The Potensi Desa (Podes) survey data, BPS-Statistics Indonesia.

After the Nawacita programme's implementation, access to paved inter-village roads in rural areas grew significantly. The percentage of Indonesia's rural areas that did not have access to paved road networks fell to 43.27, but road inequity persisted. Eastern Indonesia has lagged behind western Indonesia in terms of rural road infrastructure development. Unfortunately, information about Indonesian rural roads' connectivity and inequality to support this opinion, other than the data in Table 1, is currently unavailable.

Few regional indicators measure rural road connectivity correctly. Conventional measurements are total road length and the proportion of paved roads (Iimi et al. 2016), which are not good predictors for rural roads (World Bank 2016). These indicators barely change over time, although the government has spent a lot of money upgrading the road network (Iimi et al. 2016). The quality of roads is often unknown and a matter of concern in developing countries (World Bank 2016). In Indonesia, besides total road length and the proportion of paved roads, the government uses steady-road condition data to indicate road connectivity. These data are only available for the national road network by province, without rural–urban separation. They are calculated from the International Roughness Index (IRI) and used as an indicator of sustainable development goals (SDGs), namely 9.1.1 (Bappenas 2017, 2020), even though the United Nations (UN) recommendation uses the Rural Access Index (RAI).

The objectives of this study were to calculate the RAI and its regional inequality. The RAI was used as an indicator of rural road connectivity in Indonesia. It shows the proportion of rural residents who live within 2 km, usually equal to a walk of 20–25 min, of an all-season road. The term "all-season road" refers to a road that is drivable all year round by the prevailing rural transport mode (Iimi et al. 2016; Roberts et al. 2006; Workman et al. 2019; World Bank 2016). The RAI is a new rural road connectivity measurement method based on Geographic Information Systems (GIS) data. This method resolves the limitations of conventional measurements. Iimi et al. (2016) and Mikou et al. (2019) calculated the RAI by utilising rural population distribution data from WorldPop or LandScan and road network data from the government or OpenStreetMap (OSM).

The best policies for rural road access improvement require estimates for local regions, such as at the district level. This is the first study conducted in Indonesia to provide such estimates. Because the Nawacita policy places a high priority on reducing inequality in certain areas (e.g., eastern Indonesia), this study also provides rural road connectivity inequality by regional group. Indonesia is divided into seven regional groups, each with multiple provinces. Each province has a number of districts, and each district consists of several subdistricts, which include rural and urban areas. National roads are under the authority of the central government and connect the capitals of the provinces. The provincial government has the jurisdiction to construct provincial roads connecting provincial capitals to district capitals. Finally, the district government is responsible for managing local roads. Because of data limitations, this study used only national and provincial roads to calculate the RAI.

This study aims to identify districts with poor rural road quality and regional groups with high rural road inequality. With these data, the government can evaluate the effects of the Nawacita programme and determine priority regions for rural road construction.

2. Methodology

The first step was to calculate the RAI at the district level. The RAI needs several datasets: population distribution maps, urban–rural classification data, village maps, road maps, and road network condition data. Step-by-step procedures for calculating the RAI are shown in Figure 1.

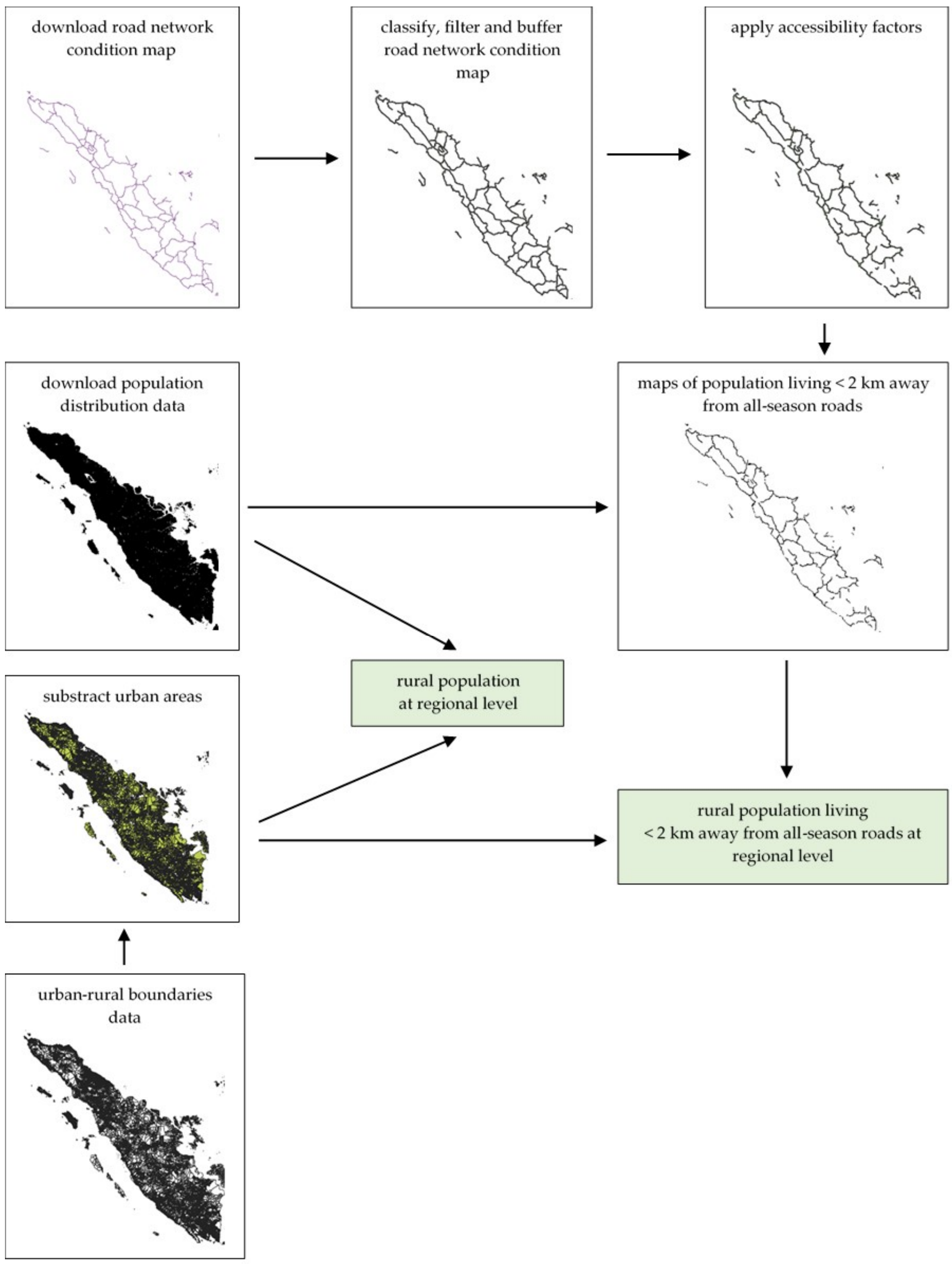


Figure 1. Overview of step-by-step procedures for calculating the RAI.

We used population distribution maps from WorldPop, which is the most robust dataset available, according to Mikou et al. (2019) and World Bank (2016). WorldPop uses the latest national census data and other data from countries to produce 100 m × 100 m of population distribution data. It can be downloaded freely and used in QGIS software (Workman et al. 2019). This study also conducted a robustness check by using 1 km × 1 km of population distribution data from LandScan.

We applied the urban–rural classification data from the Regulation of the Head of BPS-Statistics Indonesia Number 37 Year 2010. Then, we combined the village map with the urban–rural classification data. From this combination, we chose only rural areas to create the rural map. The intersection of the population distribution data and the rural map results in the total rural population.

This study utilised a road map from the Directorate General of Highways. Although Iimi et al. (2016), Li et al. (2022), Mikou et al. (2019) and Workman et al. (2019) recommend using OSM data, this study did not utilise it because Indonesian OSM data from 2014 to 2020 were inconsistent. This inconsistency is shown in Figure A1. We then buffered the road map with a 2-km radius.

All-season road identification uses data from the Directorate General of Highways and refers to paved roads with an IRI of less than 6 m per kilometre, unpaved roads with an IRI of less than 13 m per kilometre, paved roads in excellent, good, or fair condition, and unpaved roads in excellent or good condition (Workman et al. 2019). We also used Podes survey data from BPS-Statistics Indonesia for all-season road identification, specifically the existence of inter-village roads that can be traversed by motorised vehicles with four or more wheels throughout the year. This study applied all methods to specify all-season national roads in 2018. The results show that when data on the surface type and roughness of regional roads are not available, we can use the last method as a substitute to identify all-season roads in Indonesia.

The intersection between the road map with a 2-km radius and all-season road data produced the all-season road map. In the next step, we overlaid this map with a population layer, removed urban areas, and counted the population in the buffer (World Bank 2016). This resulted in the total rural population living within 2 km of all-season roads. Finally, the ratio between the total rural population living within 2 km of all-season roads and the total rural population resulted in the RAI.

The next step was to examine the impact of the Nawacita programme, which is part of the second objective. This study employed the variance coefficient (Equation (1)), the Gini coefficient (Equation (2)), the Lorenz curve, and the Theil index (Equation (3)) to measure rural road inequality. These methods are frequently used to quantify inequity in the transportation sector (e.g., Jang et al. 2017; Mestre 2021; Simon and Natarajan 2017; Zimm 2019). By analysing the inequality values of these different approaches, we can understand how well Indonesia's rural roads are being constructed. In addition, this study also used the decomposition of the inequality indicator (Equation (4)) and convergence analysis (Equations (5) and (6)) to evaluate the implementation of the Nawacita programme.

$$CV_t = \frac{se(RAI_t)}{\overline{RAI}_t} \text{ where } se(RAI_t) = \sqrt{\frac{\sum_{i=1}^{n}\left(RAI_{it} - \overline{RAI}_t\right)^2}{n}} \tag{1}$$

$$Gini_t = 1 - \sum_{i=1}^{n}\left(X_{it} - X_{(i-1)t}\right)\left(Y_{it} + Y_{(i-1)t}\right) \tag{2}$$

$$T_t = \sum_{i=1}^{n}\frac{1}{n}\frac{RAI_{it}}{\overline{RAI}_t} ln \frac{RAI_{it}}{\overline{RAI}_t} \tag{3}$$

$\overline{RAI}_t, se(RAI_t), CV_t, Gini_t$ and T_t are the mean, standard deviation, coefficient of variance, Gini coefficient and Theil index year t, respectively. X_{it} is the cumulative proportion of the population variable in the smaller region i = 1, . . . , n year t with $X_{0t} = 0$ and $X_{nt} = 1$. Y_{it} is the cumulative proportion of the RAI variable in the smaller region i = 1, . . . , n year t with

$Y_{0t} = 0$ and $Y_{nt} = 1$. Y_{it} should be indexed in non-decreasing order ($Y_{it} \geq Y_{(i-1)t}$) and X_{it} is generated by arranging regions in ascending order based on the RAI values. A lower variation coefficient value indicates a more equitable distribution.

The Gini coefficient is a simple mathematical metric representing the overall degree of inequality, whereas the Lorenz curve is a visual representation of equality. The Gini coefficient is usually calculated from the Lorenz curve. The Gini coefficient is the ratio of the segment between the 45° line of equality and the Lorenz curve over the entire segment under the 45° line. It has a value from 0 to 1, where 0 stands for perfect equality and 1 denotes perfect inequality. The higher the Gini coefficient, the further away the Lorenz curve is from the 45° line. The Lorenz curve is a valuable and essential visualisation tool because different Lorenz curves can have the same Gini coefficient (Zimm 2019). A Gini value of less than 0.20 stands for low inequality, a value from 0.20 to 0.50 shows medium inequality, and a value above 0.50 indicates high inequality.

The Theil index is part of a larger family of measures referred to as the general entropy class. If the Gini coefficient computes the deviation, the Theil index describes the entropic distance between a situation and the ideal egalitarian situation (Mestre 2021). Like the Gini coefficient, the Theil index also ranges from 0 to 1, where 0 stands for perfect equality and 1 denotes perfect inequality.

The decomposition of the inequality indicator assesses the contribution of within-inequality, between-inequality, and a residual term to total inequality (Bellu and Liberati 2006), as shown in Equation (4). Within-inequality captures disparity due to the variability of the RAI within each regional group. Between-inequality shows disparity due to the variability of the RAI across different regional groups. The coefficient of variance and the Gini index are not perfectly decomposable (Bellu and Liberati 2006; Cowell 2011), hence only the Theil index was decomposed. Let us assume that there are m regional groups. The Theil index can be decomposed as follows:

$$T_t = \sum_{k=1}^{m} \frac{n_k}{n} \frac{\overline{RAI}_{kt}}{\overline{RAI}_t} T(RAI_{kt}) + T\left(\overline{RAI}_t\right) \tag{4}$$

n_k is the number of smaller regions in the regional group k. $T(RAI_{kt})$ is the Theil index of regional group k in year t. $T\left(\overline{RAI}_t\right)$ is calculated by replacing each actual RAI of the regional group with the corresponding means, then computing the Theil index of this fictitious RAI distribution (Bellu and Liberati 2006).

We also checked whether the convergence of the RAI occurred. Convergence measurements can use σ convergence (Equation (5)) and β convergence (Equation (6)). Because σ convergence cannot indicate the significance of convergence itself, this study also used β convergence. σ convergence refers to the decline in the cross-sectional dispersion (disparity) of a rural road access indicator across regions, that is, whether $\sigma\ convergence_{t+T} < \sigma\ convergence_t$.

The concepts of σ and β convergences are related. Intuitively, we can see that if the RAI levels of 2 regions become more similar over time, it must be the case that the poor region is growing faster. As an illustration, the RAI in region A starts out being higher than the RAI in region B. There is an initial distance or dispersion between the 2 levels of the RAI. If the growth rate of the RAI in region A is smaller than the growth rate of the RAI in region B between times t and $t + T$, we say that there is β convergence. Because dispersion at $t + T$ is smaller than at time t, we also say that there is σ convergence. In other words, β convergence is a necessary condition for σ convergence (Sala-i-Martin 1996).

$$\sigma\ convergence_t = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left(ln\ RAI_{it} - ln\ \overline{RAI}_t\right)^2} \tag{5}$$

Suppose that β convergence holds for a group of regions i, where $i = 1, 2, \ldots, n$, the RAI in region i at time t, corresponding perhaps to annual data, can be approximated by:

$$\frac{1}{T} ln\left(\frac{RAI_{i,t+T}}{RAI_{it}}\right) = \alpha - \beta \, ln \, RAI_{it} + u_{it} \quad (6)$$

where α is an intercept and u_{it} is a disturbance term. The annual growth rate of RAI between t and $t + T$ $\left(\frac{1}{T} ln\left(\frac{RAI_{i,t+T}}{RAI_{it}}\right)\right)$ is inversely related to *ln RAI* at time t $(ln \, RAI_{it})$. The negative sign of the coefficient on *ln RAI* exhibits convergence (Sala-i-Martin 1996). On the contrary, the positive sign of this coefficient indicates divergence. Equation (6) assumes that all regions are structurally similar. They have the same steady state and differ only in terms of their initial conditions. It depicts unconditional β convergence (Tselios 2009).

3. Results and Discussion

3.1. Best Approach for Calculating the RAI

We calculated the RAI for a selection of districts in 2018 using various population distribution data, such as WorldPop and LandScan population distribution data. Because of the absence of regional road quality data, this study utilised the national road network map from the Directorate General of Highways and the accessibility data from the Directorate General of Highways and BPS-Statistics Indonesia. The results, displayed in Table 2, show similar values. The Indonesian RAI ranged from 18.94 per cent to 25 per cent. According to WorldPop data, the proportion of the Indonesian rural population in 2018 was 60.61 per cent. In the same year, LandScan data showed that the percentage of the Indonesian rural population was 64.75 per cent. The RAI using LandScan is higher than the RAI using WorldPop data, whichever RAI methods are used, because the WorldPop dataset has the lowest concentration of population in rural areas. This result is in line with Mikou et al. (2019). In general, with the same method, RAIs using different population distribution datasets have the same pattern, as shown in Figures A2 and A3. Table 2 also displays the Pearson correlations of the RAI between different population distribution datasets for each method over 0.8.

Table 2. 2018 Indonesian RAI by road network condition data and population distribution data.

Method	Road Network Condition Data	Indonesian RAI (per cent)		Pearson Correlation
		WorldPop	LandScan	
1	IRI	18.94	21.67	0.8732
2	Road condition	21.21	24.17	0.8790
3	Podes	21.59	25.00	0.8747

Source: Author's calculation.

WorldPop data were chosen for the population layer because the computational process underlying the WorldPop data is fully transparent (Stevens et al. 2015), and the model is considered to be the most accurate and robust among the currently available datasets (World Bank 2016). From three methods using WorldPop data, the descriptive statistics of RAI at the district level were similar. The RAI using IRI, road condition, and Podes data had means of 23.41 per cent, 25.21 per cent, and 25.71 per cent, respectively. These data are also in line with the scatter plots in Figure 2. The Pearson correlation between RAI using Podes data and RAI using IRI data was 0.9475. Furthermore, the correlation between RAI using Podes data and RAI using road condition data was also positive, with a Pearson correlation coefficient value of 0.9833. A one-way analysis of variance (ANOVA) was also used to assess whether there were differences between the three methods. The results concluded that there were no differences between the group means (F (2,1322) = 2.01, p = 0.135)[1].

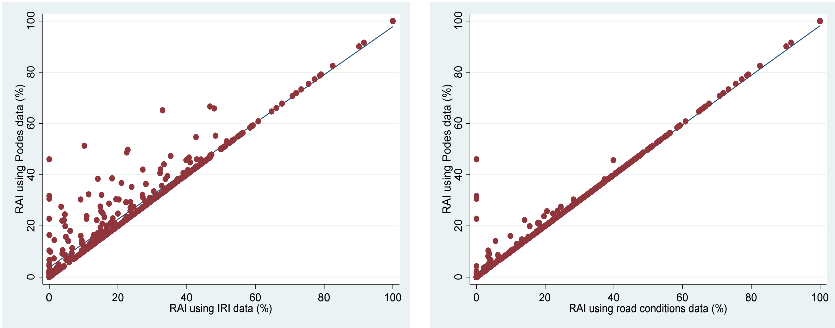


Figure 2. Scatter plots between RAI using Podes-WorldPop data and RAI using other methods-WorldPop data in 2018. Source: Author's calculation.

Provincial road quality data from the Directorate General of Highways was unavailable. Based on previous results, this study used population distribution maps from WorldPop, the national and provincial road maps from the Directorate General of Highways, and road network condition data from BPS-Statistics Indonesia to calculate the RAI in 2014, 2018, 2019, and 2020. Table A1 shows the results.

3.2. Road Infrastructure Access across Districts in Rural Indonesia

For analysis, this study divided Indonesia into seven regional groups[2]. Figure A4 shows the district locations in each regional group. The results in Figure 3 show that in 2020, rural residents in 3.31 per cent of districts did not live within a two-kilometre radius of all-season national and provincial roads. This data was lower than the 8.56 per cent recorded in 2014. The RAI median also increased from 29.43 per cent in 2014 to 33.68 per cent in 2020. The paired t-test results reached the same conclusion. The 2020 RAI was significantly higher than the 2014 RAI, with a p-value of less than 0.001.

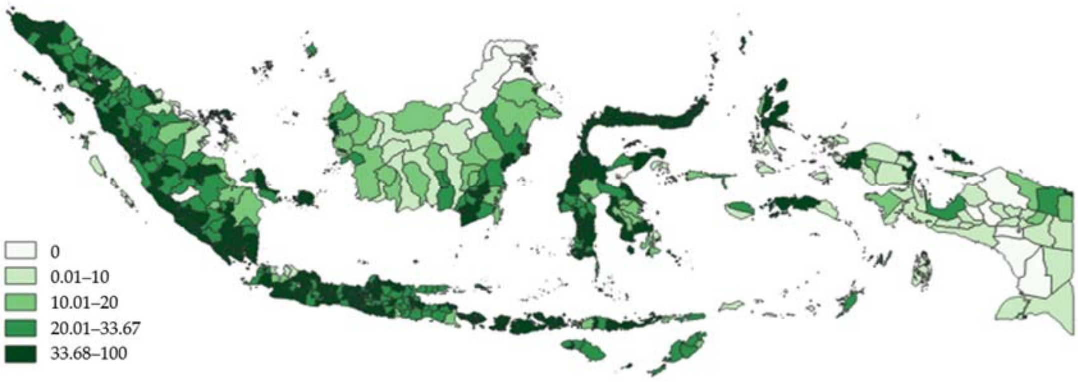


Figure 3. 2020 Indonesian RAI by district (per cent). Source: Author's calculation.

The majority of districts with a high RAI are located in four regional groups: Sumatra, Java, Bali and Nusa Tenggara, and Sulawesi. RAI was low in most districts in Borneo, Moluccas, North Moluccas, Papua, and West Papua. During the same time period, 77.38 per cent of districts had a higher RAI. The positive change in RAI occurred in districts with a low RAI, namely in eastern Indonesia, which is the priority of the Nawacita programme (see Figure 4). This shows that the Nawacita programme implementation was relatively successful.

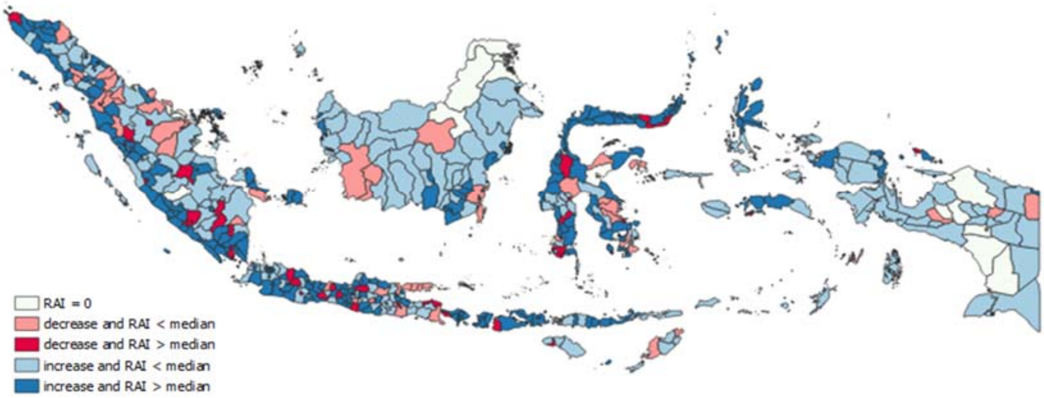


Figure 4. Change in the RAI during 2014–2020 by district. Source: Author's calculation.

3.3. Road Infrastructure Access Inequality in Rural Indonesia

This study uses the following indicators of inequality to establish the evolution of road infrastructure access inequality in rural Indonesia for 2014–2020: the coefficient of variance, the Gini coefficient, and the Theil index. We decomposed the inequality indicator by region subgroups, using the decomposition technique of Bellu and Liberati (2006); Cowell (2011) and Haughton and Khandker (2009) to analyse the contributions of each region's disparity to total inequality.

The RAI in all regional groups increased significantly after the Nawacita programme's implementation. Bali and Nusa Tenggara had the highest RAI, which increased from 37.62 per cent in 2014 to 44.99 per cent in 2020. Papua and West Papua had the lowest RAI, which reached 9.23 per cent in 2014 and increased to 10.23 per cent in 2020. The policy had a positive impact, reducing Indonesia's inequality between 2014 and 2020. As described in Table 3, the coefficient of variance decreased from 0.665 to 0.587, the Gini coefficient decreased from 0.37 to 0.325, and the Theil index went down from 0.164 to 0.16. Indonesia's Gini coefficient was categorised as "medium inequality". Figure 5 represents the shifts in the Lorenz curve from 2014 to 2020. The results also indicate that inequality fell between 2014 and 2020.

Since 2014, as shown in Table 3, all indicators have demonstrated a consistent declining trend across all Indonesian regions. Java had the lowest level of inequality, while Papua and West Papua had the greatest. Even though Papua and West Papua's rural regions had the lowest RAI and the greatest inequality, this value had decreased. This trend is stronger in this region than in the others.

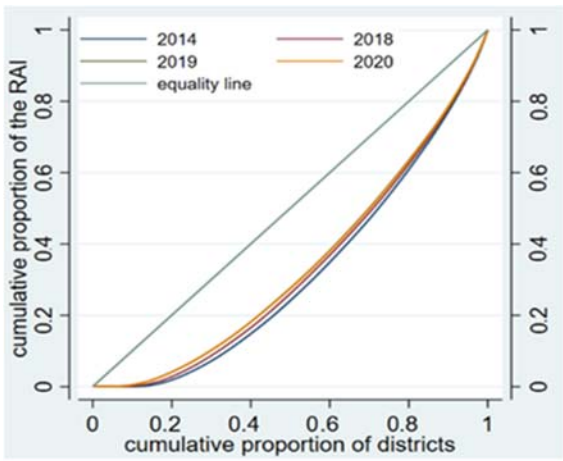


Figure 5. Lorenz curve of the RAI. Source: Author's calculation.

Table 3. Inequality indicators in 2014–2020 by regional group.

Inequality Indicators	2014	2018	2019	2020
Coefficient of variance				
Indonesia	0.665	0.623	0.584	0.587
Sumatra	0.529	0.510	0.471	0.477
Java	0.480	0.450	0.418	0.418
Bali and Nusa Tenggara	0.531	0.452	0.447	0.450
Borneo	0.911	0.862	0.816	0.823
Sulawesi	0.569	0.543	0.502	0.503
Moluccas and North Moluccas	0.908	0.711	0.584	0.586
Papua and West Papua	1.818	1.597	1.345	1.346
Gini coefficient				
Indonesia	0.370	0.345	0.324	0.325
Sumatra	0.285	0.273	0.254	0.256
Java	0.250	0.235	0.219	0.218
Bali and Nusa Tenggara	0.295	0.247	0.247	0.249
Borneo	0.473	0.458	0.438	0.439
Sulawesi	0.317	0.299	0.277	0.277
Moluccas and North Moluccas	0.484	0.393	0.324	0.326
Papua and West Papua	0.769	0.714	0.657	0.656
Theil index				
Indonesia	0.164	0.165	0.159	0.160
Sumatra	0.104	0.112	0.101	0.103
Java	0.101	0.089	0.089	0.089
Bali and Nusa Tenggara	0.121	0.082	0.096	0.097
Borneo	0.281	0.257	0.228	0.230
Sulawesi	0.105	0.098	0.104	0.104
Moluccas and North Moluccas	0.276	0.235	0.190	0.191
Papua and West Papua	0.653	0.716	0.624	0.621
Theil index decomposition				
Within-region inequality	84.98	82.94	80.9	80.77
Between-region inequality	15.02	17.06	19.1	19.23

Source: Author's calculation.

The Theil index can be broken down into within-regional and between-region RAI inequalities. In 2020, for instance, we can deduce that Indonesia's inequality was primarily driven (80.77 per cent) by within-regional inequality. In contrast, between-region inequality made a lower contribution to overall inequality at 19.23 per cent. The contribution of within-region inequality has decreased consistently. This trend indicates that the inequality reduction in Indonesia since 2014 has been uniform across geographical locations, whereas the gap between regional groups has risen slightly in recent years.

3.4. Convergence of Road Infrastructure Access across Indonesian Districts

Our district analysis captured a strong pattern of regional convergence. As shown in Figure 6, the σ convergence of the RAI decreased over time. In 2014, this value was 1.054, and it reached 0.975 in 2020. Table 4 describes the equation of β convergence. The regression of the change in the RAI as a function of its initial level confirms the β convergence in which the coefficient of the initial value is negative and statistically significant at the 1 per cent level. This means that the rate of increase in the RAI was faster in the district with an initially low RAI and vice versa. The negative trend of σ convergence and the negative coefficient of the initial value in the equation of β convergence reinforce the previous statement that the Nawacita programme implementation reduced regional inequality during 2014–2020.

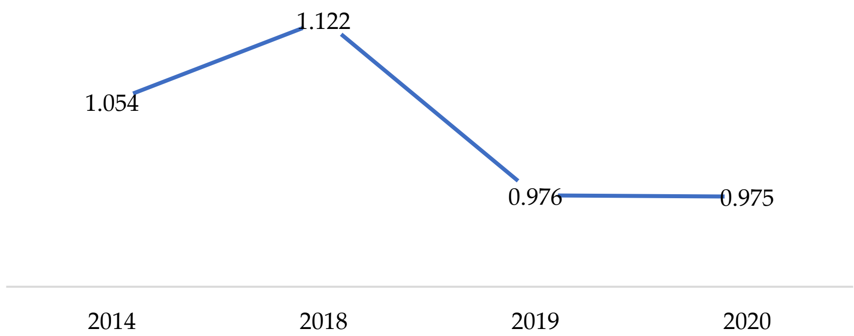


Figure 6. The σ convergence of RAI across Indonesian districts in 2014–2020. Source: Author's calculation.

Table 4. β convergence of RAI across Indonesian districts in 2014–2020.

Dependent Variable: $\frac{1}{6} ln\left(\widehat{\frac{RAI_{i,2020}}{RAI_{i,2014}}}\right)$	Coefficient	Std. Error	t Statistic	Prob.
$ln\ RAI_{i,2014}$	−0.0599 ***	0.003	−17.36	0.000
Constant	0.2255 ***	0.012	19.41	0.000
N	429			
R-squared	0.4138			
F-statistic	301.48 ***			

Note: *** significant at 1 per cent. Source: Author's calculation.

3.5. Discussion

From the RAI formula, the change in total rural populations and the change in total rural populations who live within 2 km of all-season roads may drive the inequality reduction and convergence phenomenon of the RAI between districts. Table 5 shows that the median annual growth rate in total rural populations who lived within 2 km of all-season roads between 2014 and 2018 was faster than the median annual growth rate in total rural populations, especially in Papua and West Papua. Based on data from BPS-Statistics Indonesia, the government built 24,557 km of roads between 2014 and 2018, including the Trans-Sumatra, Trans-Borneo, Trans-Sulawesi, Trans-Moluccas, and Trans-Papua roads. This road construction facilitated rural populations' access to all-season roads so that the proportion living within 2 km of all-season roads increased, and improved RAI scores. This argument fits with the values in Table 6 for the Pearson correlations between the RAI and its individual parts. The RAI is strongly linked to rural populations who live within 2 km of all-season roads.

Table 5. Median annual growth rate in rural populations and rural populations within 2 km of all-season roads at the district level by regional group (per cent).

Regional Group	Rural Population			Rural Population within 2 km from All-Season Roads		
	2014–2018	2019	2020	2014–2018	2019	2020
Sumatra	1.27	1.36	1.42	2.55	3.32	0.35
Java	0.79	0.74	0.32	1.68	0.25	−0.04
Bali and Nusa Tenggara	2.04	1.88	1.94	3.45	0.77	1.43
Borneo	2.47	2.55	2.68	4.90	6.18	0.99
Sulawesi	2.38	2.02	1.98	4.06	2.33	1.90
Moluccas and North Moluccas	3.90	3.56	3.38	15.22	9.97	1.52
Papua and West Papua	9.57	7.87	7.46	14.53	6.30	7.30
Indonesia	2.02	1.66	1.75	3.29	2.53	0.85

Source: Author's calculation.

Table 6. Pearson correlation between the RAI and constituent variables.

Constituent Variable	2014	2018	2019	2020
Rural populations who live within 2 km of all-season roads	0.357 ***	0.3181 ***	0.2957 ***	0.2954 ***
Rural populations	0.0464	−0.0027	−0.0372	−0.0458

Note: *** significant at 1 per cent. Source: Author's calculation.

Besides road construction, the government can boost the RAI by improving the quality of rural roads. We can use the step-by-step procedures in Figure 1 to calculate the RAI by assuming that the government repairs all existing rural roads so that all rural roads are equal to all-season roads. As shown in Figure 7, the results demonstrate that the increase in all rural road quality did not significantly increase the RAI. The median RAI in Papua and West Papua was still the lowest. Table 7 shows that indicators of inequality decreased slowly. For example, in 2020, the coefficient of variance, Gini coefficient, and Theil index only decreased by 0.051, 0.028 and 0.019, respectively.

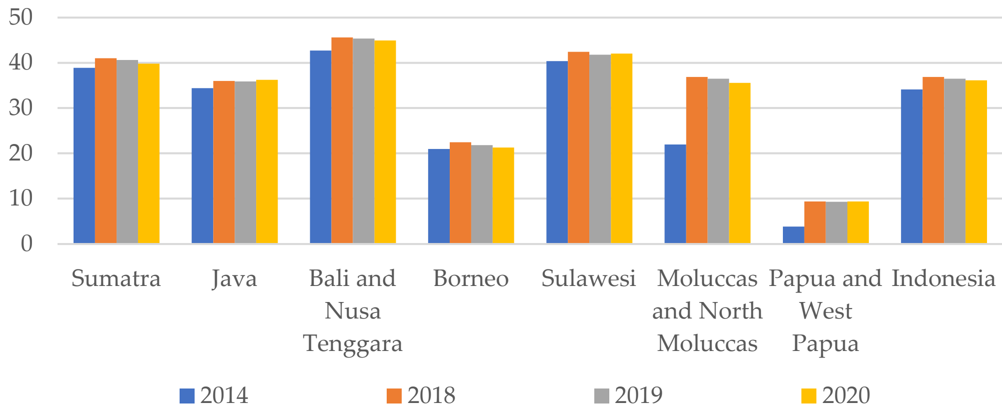


Figure 7. The median of the RAI when all rural roads are all-season roads. Source: Author's calculation.

Table 7. Real condition and simulation of inequality indicators in 2014–2020.

Inequality Indicators	2014	2018	2019	2020
Coefficient of variance				
Before	0.665	0.623	0.584	0.587
After	0.580	0.528	0.533	0.536
Gini coefficient				
Before	0.370	0.345	0.324	0.325
After	0.324	0.294	0.295	0.297
Theil index				
Before	0.164	0.165	0.159	0.160
After	0.153	0.137	0.139	0.141

Notes: "Before" shows the real condition. "After" shows the simulation when all rural roads are all-season roads. Source: Author's calculation.

Analysing the link between the RAI and the District Fiscal Capacity Index (DFCI)[3] can help the government decide on the policy priority: new road construction or old road maintenance. For example, as shown in Figure 8, in 2020, the number of districts with low RAI and low DFCI in Moluccas, North Moluccas, Papua, and West Papua was higher than the number of districts in other regional groups. This indicates that the government needs to prioritise the construction of new national and provincial roads in these areas because the district's ability to fund local road development is low. In general, the construction of national and provincial roads is right on target because it is carried out in districts with a low DFCI. However, the construction of national and provincial roads in Bali, Nusa Tenggara, and Borneo requires collaboration between the central, provincial, and district governments because, financially, the fiscal capacity of districts in these regional groups is relatively good. Coordination can prevent road construction from being concentrated in certain areas and guarantee connectivity between national and regional roads.

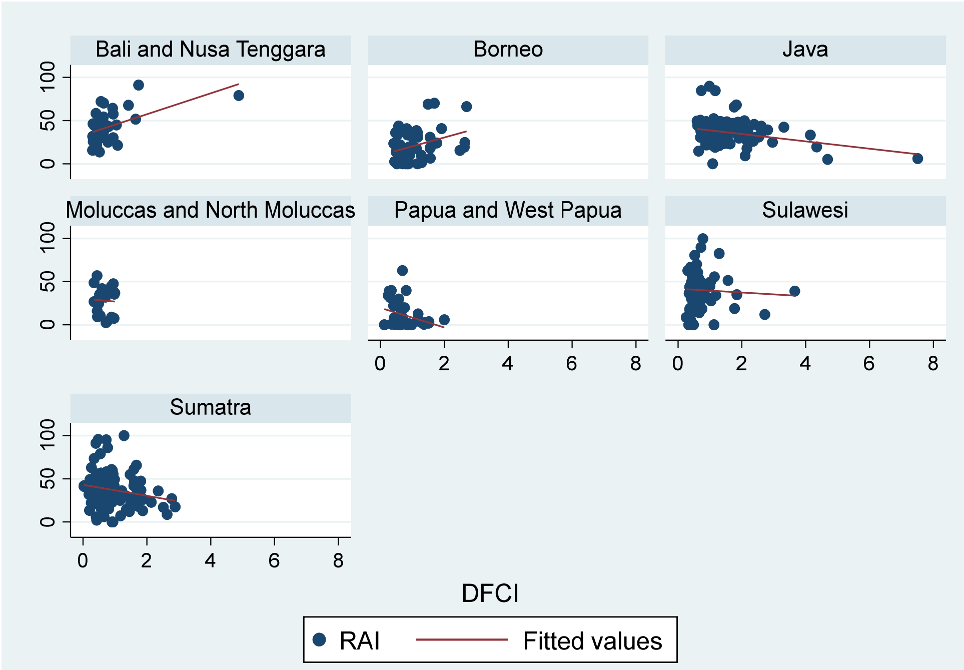


Figure 8. Scatter plots between the RAI and DFCI by regional group. Source: Author's calculation.

4. Conclusions

The RAI, as SDG indicator 9.1.1, is a relatively good predictor of rural road quality. Due to data limitations, it is challenging to calculate this predictor at the regional level. This study attempted to determine the RAI for each district in Indonesia during 2014–2020. The results show that since the implementation of the Nawacita programme, the RAI has increased, inequality has declined, and there has been a strong pattern of regional convergence. To ensure the future success of this implementation, the government can create regulations to designate several road infrastructure projects as a national strategy. This regulation can specify the types of permits and non-permits that can be expedited by a minister, head of a national agency, or mayor of a region, as well as spatial planning compliance, land availability, and procurement methods. Since most road infrastructure spending comes from the government budget, there needs to be more long-term work to increase tax collection, such as the tax amnesty programme. To encourage more public–private partnerships, the government can also use fiscal policies, such as government guarantees for direct loans.

Author Contributions: Conceptualization, R.N.T.W., M.I., A.D. and K.K.; methodology, R.N.T.W.; software, R.N.T.W.; validation, M.I., A.D. and K.K.; formal analysis, R.N.T.W.; investigation, M.I., A.D. and K.K.; resources, R.N.T.W.; data curation, R.N.T.W.; writing—original draft preparation, R.N.T.W.; writing—review and editing, R.N.T.W., M.I., A.D. and K.K.; visualization, R.N.T.W.; supervision, M.I., A.D. and K.K.; project administration, R.N.T.W.; funding acquisition, R.N.T.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. Indonesian RAI using the national road network map, WorldPop, and Podes by district (per cent).

Code	District	2014	2018	2019	2020	Code	District	2014	2018	2019	2020
1101	Simeulue	32.3	37.8	45.5	45.0	3672	Cilegon	0.0	0.0	0.0	0.0
1102	Aceh Singkil	13.2	12.9	16.0	15.8	3673	Serang	35.6	36.5	37.2	37.5
1103	Aceh Selatan	36.1	37.9	42.4	41.6	5101	Jembrana	57.9	58.5	57.7	57.6
1104	Aceh Tenggara	28.0	29.0	29.0	28.5	5102	Tabanan	69.5	70.0	70.0	70.2
1105	Aceh Timur	33.9	35.5	33.0	32.0	5103	Badung	78.7	78.9	78.9	79.0
1106	Aceh Tengah	39.8	46.2	47.0	46.2	5104	Gianyar	86.5	91.4	91.4	91.2
1107	Aceh Barat	27.4	28.2	30.5	29.8	5105	Klungkung	24.6	24.5	24.1	25.0
1108	Aceh Besar	64.6	65.6	61.6	61.1	5106	Bangli	65.3	66.6	72.3	72.1
1109	Pidie	42.4	43.9	44.2	43.1	5107	Karang Asem	67.3	67.3	66.7	67.3
1110	Bireuen	42.3	44.7	55.0	55.0	5108	Buleleng	67.5	68.0	67.7	67.8
1111	Aceh Utara	33.7	34.8	37.5	36.8	5201	Lombok Barat	39.7	40.5	64.2	64.3
1112	Aceh Barat Daya	46.2	47.9	55.7	55.5	5202	Lombok Tengah	28.4	39.2	44.8	44.9
1113	Gayo Lues	30.6	32.3	32.0	31.0	5203	Lombok Timur	30.4	30.0	51.6	51.6
1114	Aceh Tamiang	13.3	14.1	14.3	13.5	5204	Sumbawa	40.1	43.0	43.3	43.2
1115	Nagan Raya	34.9	43.7	46.2	45.4	5205	Dompu	52.7	54.6	54.3	54.2
1116	Aceh Jaya	33.1	30.6	35.2	34.3	5206	Bima	46.3	48.5	49.5	49.3
1117	Bener Meriah	24.3	34.8	41.6	41.2	5207	Sumbawa Barat	37.9	37.8	37.3	37.3
1118	Pidie Jaya	55.2	57.7	56.2	55.5	5208	Lombok Utara	44.6	48.5	50.7	50.3
1172	Sabang	59.4	91.2	91.2	91.1	5272	Bima	57.3	58.7	57.8	58.3
1173	Langsa	41.1	39.8	72.7	73.5	5301	Sumba Barat	52.0	55.1	47.8	46.3
1174	Lhokseumawe	57.5	53.9	52.5	52.6	5302	Sumba Timur	30.5	31.2	32.2	32.6
1175	Subulussalam	43.8	45.3	45.6	45.0	5303	Kupang	30.3	31.7	30.5	29.6
1201	Nias	25.2	31.0	39.5	38.9	5304	Timor Tengah Selatan	18.3	18.5	21.6	21.4
1202	Mandailing Natal	36.8	38.5	39.7	39.0	5305	Timor Tengah Utara	29.1	31.7	31.3	31.1
1203	Tapanuli Selatan	34.3	34.5	33.6	33.5	5306	Belu	31.3	32.3	30.4	30.1
1204	Tapanuli Tengah	49.4	51.3	50.3	50.1	5307	Alor	17.1	19.7	22.5	21.9
1205	Tapanuli Utara	40.2	42.9	43.5	43.3	5308	Lembata	11.5	21.4	15.9	15.7
1206	Toba Samosir	44.6	44.6	47.0	45.8	5309	Flores Timur	34.2	40.3	42.9	43.2
1207	Labuhan Batu	24.7	25.5	28.6	28.1	5310	Sikka	38.6	39.9	40.5	40.1
1208	Asahan	26.7	28.1	27.0	26.0	5311	Ende	43.5	44.6	43.8	44.4
1209	Simalungun	30.6	31.7	32.8	32.0	5312	Ngada	38.8	39.9	39.3	39.2
1210	Dairi	29.5	31.0	28.8	28.4	5313	Manggarai	37.5	40.2	38.6	38.0
1211	Karo	41.8	42.7	43.9	43.2	5314	Rote Ndao	22.2	33.4	31.8	31.7
1212	Deli Serdang	25.4	26.5	29.2	29.3	5315	Manggarai Barat	12.9	15.0	14.6	13.7
1213	Langkat	20.8	25.1	25.7	25.0	5316	Sumba Tengah	22.2	22.9	25.0	24.4
1214	Nias Selatan	16.6	17.8	19.5	19.2	5317	Sumba Barat Daya	22.4	23.0	26.0	25.7
1215	Humbang Hasundutan	26.6	26.5	26.6	26.6	5318	Nagekeo	45.5	45.6	45.5	46.1
1216	Pakpak Bharat	30.3	29.9	30.3	30.0	5319	Manggarai Timur	23.9	25.8	28.5	28.2
1217	Samosir	30.7	33.3	46.3	45.8	5320	Sabu Raijua	14.6	47.2	39.8	40.4
1218	Serdang Bedagai	36.9	36.9	38.7	37.7	5321	Malaka	0.0	0.0	15.9	15.9
1219	Batu Bara	32.1	32.1	34.2	34.4	5371	Kota Kupang	8.5	40.1	92.9	92.9
1220	Padang Lawas Utara	32.4	33.4	31.6	30.7	6101	Sambas	11.2	18.7	20.2	19.5
1221	Padang Lawas	34.5	35.5	39.9	39.8	6102	Bengkayang	10.6	25.0	23.9	23.5
1222	Labuhan Batu Selatan	22.8	23.9	22.4	22.0	6103	Landak	14.9	16.0	16.4	15.8
1223	Labuhan Batu Utara	17.8	17.8	16.9	17.0	6104	Pontianak	41.8	44.2	48.6	47.8
1224	Nias Utara	33.0	33.5	38.9	38.3	6105	Sanggau	16.7	18.7	18.3	17.8
1225	Nias Barat	28.3	29.1	20.6	20.3	6106	Ketapang	11.3	11.7	10.5	10.5
1276	Binjai	19.9	20.3	19.8	20.2	6107	Sintang	6.0	6.3	6.6	6.5
1277	Padangsidimpuan	72.5	72.3	72.4	72.4	6108	Kapuas Hulu	13.4	13.8	14.5	14.5
1278	Gunungsitoli	64.4	66.0	64.8	64.3	6109	Sekadau	8.9	10.8	10.3	9.9
1301	Kepulauan Mentawai	0.0	7.6	6.0	5.8	6110	Melawi	2.5	2.6	4.4	4.4
1302	Pesisir Selatan	16.5	18.7	30.6	29.2	6111	Kayong Utara	19.3	21.3	22.2	21.9
1303	Solok	39.9	44.0	43.4	41.9	6112	Kubu Raya	11.3	11.9	19.9	19.6
1304	Sijunjung	36.2	38.7	40.6	38.6	6172	Singkawang	36.0	38.0	37.1	36.0
1305	Tanah Datar	58.1	59.9	59.3	58.2	6201	Kotawaringin Barat	19.0	19.8	19.8	19.7
1306	Padang Pariaman	49.4	50.4	57.0	56.1	6202	Kotawaringin Timur	14.2	14.5	19.4	19.4
1307	Agam	38.2	38.6	40.1	39.3	6203	Kapuas	5.0	6.5	10.2	9.9

Table A1. *Cont.*

Code	District	2014	2018	2019	2020	Code	District	2014	2018	2019	2020
1308	Lima Puluh Kota	34.7	36.6	34.8	34.0	6204	Barito Selatan	9.1	12.0	12.5	12.4
1309	Pasaman	31.4	34.5	32.4	30.6	6205	Barito Utara	3.2	5.7	16.8	16.7
1310	Solok Selatan	28.1	30.8	31.3	29.5	6206	Sukamara	2.7	2.7	2.6	2.5
1311	Dharmasraya	24.4	25.6	25.8	25.6	6207	Lamandau	14.5	13.4	13.5	13.7
1312	Pasaman Barat	36.1	37.8	40.3	39.3	6208	Seruyan	1.6	1.6	6.2	6.5
1371	Padang	46.0	46.6	46.7	47.3	6209	Katingan	2.4	3.9	4.6	4.5
1372	Solok	40.3	41.0	40.1	39.8	6210	Pulang Pisau	28.6	33.1	34.0	33.7
1373	Sawah Lunto	44.6	46.3	46.7	46.7	6211	Gunung Mas	7.7	9.4	17.8	17.8
1374	Padang Panjang	100.0	95.4	95.3	95.6	6212	Barito Timur	9.3	10.2	18.3	18.2
1376	Payakumbuh	58.4	62.4	31.4	31.5	6213	Murung Raya	3.4	2.6	2.9	2.6
1377	Pariaman	67.3	78.3	78.2	79.0	6271	Palangka Raya	16.7	16.5	30.9	30.6
1401	Kuantan Singingi	23.0	25.2	26.4	25.9	6301	Tanah Laut	34.9	42.0	41.6	40.7
1402	Indragiri Hulu	28.2	24.8	26.0	26.1	6302	Kota Baru	20.4	22.3	19.8	19.2
1403	Indragiri Hilir	5.9	4.4	7.1	7.2	6303	Banjar	32.9	36.4	39.5	38.4
1404	Pelalawan	15.3	15.2	14.7	14.7	6304	Barito Kuala	27.6	29.3	33.3	32.9
1405	Siak	24.5	26.7	30.3	30.1	6305	Tapin	25.3	29.6	31.5	30.9
1406	Kampar	24.6	32.4	32.5	31.6	6306	Hulu Sungai Selatan	43.7	45.9	44.7	43.7
1407	Rokan Hulu	20.3	21.6	22.4	22.7	6307	Hulu Sungai Tengah	34.3	37.3	37.7	36.7
1408	Bengkalis	18.0	17.9	8.9	8.7	6308	Hulu Sungai Utara	26.8	29.6	30.8	30.0
1409	Rokan Hilir	25.2	27.0	26.5	26.3	6309	Tabalong	29.3	34.7	34.7	33.5
1410	Kepulauan Meranti	0.0	0.0	0.0	0.0	6310	Tanah Bumbu	25.8	29.5	32.0	30.7
1471	Pekanbaru	36.4	36.2	35.2	35.9	6311	Balangan	33.8	37.3	38.0	36.4
1473	Dumai	23.0	23.2	61.0	60.7	6371	Banjarmasin	15.4	15.9	70.1	70.1
1501	Kerinci	33.1	34.1	36.5	35.3	6372	Banjar Baru	77.5	78.6	78.4	78.3
1502	Merangin	26.3	25.9	27.8	28.0	6401	Paser	22.2	24.2	24.1	24.1
1503	Sarolangun	31.0	31.3	32.9	32.8	6402	Kutai Barat	16.8	17.1	19.3	19.3
1504	Batang Hari	35.6	36.0	35.0	35.0	6403	Kutai Kartanegara	23.2	24.5	24.9	24.7
1505	Muaro Jambi	25.1	38.0	42.5	42.0	6404	Kutai Timur	14.6	15.7	15.7	15.5
1506	Tanjung Jabung Timur	13.6	13.2	14.4	14.5	6405	Berau	12.9	16.8	18.3	18.0
1507	Tanjung Jabung Barat	15.2	16.9	29.5	29.6	6409	Penajam Paser Utara	34.4	35.6	40.5	40.7
1508	Tebo	24.3	25.7	29.1	29.4	6411	Mahakam Ulu	0.0	0.0	0.0	0.0
1509	Bungo	34.4	36.2	35.8	35.2	6471	Balikpapan	66.1	66.5	65.8	66.2
1571	Jambi	86.9	100.0	100.0	100.0	6472	Samarinda	9.1	9.2	68.6	69.0
1572	Sungai Penuh	56.0	56.8	55.6	55.6	6474	Bontang	1.3	1.3	1.3	1.4
1601	Ogan Komering Ulu	24.8	26.4	26.6	25.2	6501	Malinau	0.0	0.0	0.0	0.0
1602	Ogan Komering Ilir	17.1	18.5	18.2	18.1	6502	Bulungan	0.0	0.0	0.0	0.0
1603	Muara Enim	25.9	27.3	26.5	26.3	6503	Tana Tidung	0.0	0.0	0.0	0.0
1604	Lahat	34.5	34.9	33.9	33.7	6504	Nunukan	0.0	0.0	0.0	0.0
1605	Musi Rawas	21.4	22.5	22.7	22.1	6571	Tarakan	0.0	0.0	0.0	0.0
1606	Musi Banyuasin	17.1	17.7	23.4	22.9	7101	Bolaang Mongondow	39.2	44.9	49.9	49.2
1607	Banyuasin	11.0	11.2	13.6	13.1	7102	Minahasa	45.8	46.4	70.0	70.1
1608	Ogan Komering Ulu Selatan	30.7	32.4	33.2	33.2	7103	Kepulauan Sangihe	59.8	62.4	61.9	62.2
1609	Ogan Komering Ulu Timur	41.0	41.6	40.2	39.8	7104	Kepulauan Talaud	53.7	56.0	65.4	66.7
1610	Ogan Ilir	36.2	36.6	36.5	36.1	7105	Minahasa Selatan	53.9	56.2	62.4	61.7
1611	Empat Lawang	26.9	28.9	39.9	38.9	7106	Minahasa Utara	59.8	61.7	61.1	60.7
1612	Penukal Abab Lematang Ilir	0.0	0.0	12.0	12.1	7107	Bolaang Mongondow Utara	57.3	56.2	56.2	55.9
1613	Musi Rawas Utara	0.0	0.0	0.0	0.0	7108	Siau Tagulandang Biaro	9.6	9.5	9.2	8.9
1671	Palembang	15.9	16.1	18.0	17.5	7109	Minahasa Tenggara	61.5	63.5	63.0	62.8
1672	Prabumulih	52.9	55.6	55.6	56.7	7110	Bolaang Mongondow Selatan	46.7	52.5	44.0	43.9
1673	Pagar Alam	51.4	52.4	51.8	51.0	7111	Bolaang Mongondow Timur	59.9	60.6	50.6	49.9
1674	Lubuklinggau	51.4	60.8	61.1	61.2	7171	Manado	21.0	24.3	82.3	82.5
1701	Bengkulu Selatan	58.0	65.7	65.8	65.7	7172	Bitung	38.2	38.3	38.4	39.0
1702	Rejang Lebong	49.2	49.9	49.4	49.4	7173	Tomohon	80.4	80.3	80.3	80.4
1703	Bengkulu Utara	31.8	33.9	39.2	38.7	7174	Kotamobagu	59.3	89.4	89.6	89.6
1704	Kaur	49.7	47.0	51.4	53.0	7201	Banggai Kepulauan	8.8	9.0	8.8	8.5

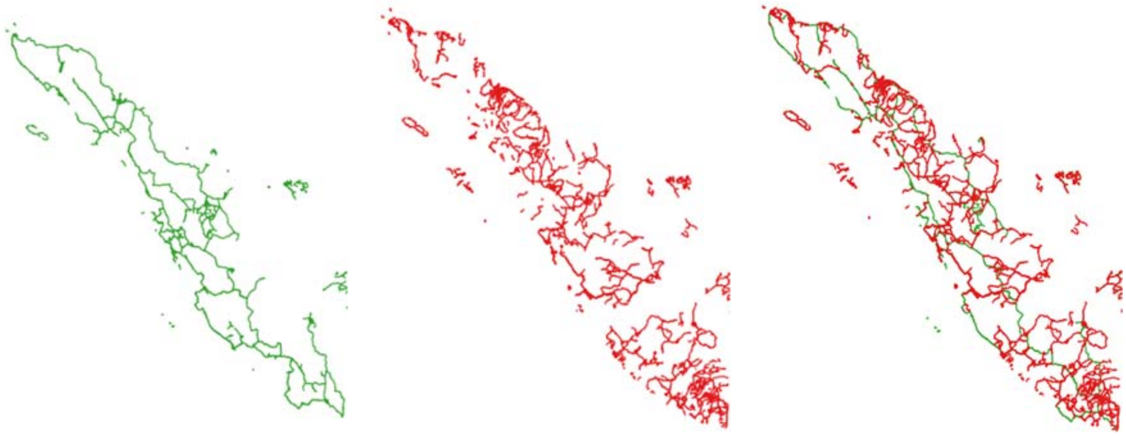
Table A1. *Cont.*

Code	District	2014	2018	2019	2020	Code	District	2014	2018	2019	2020
1705	Seluma	45.5	46.7	48.6	48.1	7202	Banggai	35.5	38.8	48.9	48.9
1706	Mukomuko	37.8	37.7	39.8	40.0	7203	Morowali	30.6	30.4	39.1	40.9
1707	Lebong	41.7	42.2	42.2	41.7	7204	Poso	42.8	41.7	46.5	46.7
1708	Kepahiang	62.3	64.6	64.0	62.9	7205	Donggala	41.3	42.4	41.3	41.6
1709	Bengkulu Tengah	45.9	54.0	49.2	49.1	7206	Toli-Toli	35.8	37.0	46.5	46.5
1771	Bengkulu	34.1	36.9	36.8	36.1	7207	Buol	41.6	44.0	46.3	46.4
1801	Lampung Barat	24.4	25.0	43.0	43.5	7208	Parigi Moutong	34.8	35.2	43.7	44.2
1802	Tanggamus	34.8	38.8	47.9	47.9	7209	Tojo Una-Una	25.6	26.6	25.1	25.1
1803	Lampung Selatan	45.3	46.3	49.4	49.4	7210	Sigi	50.1	50.9	49.8	49.4
1804	Lampung Timur	44.0	44.7	47.8	47.3	7211	Banggai Laut	0.0	0.0	0.0	0.0
1805	Lampung Tengah	42.3	42.2	44.1	43.7	7212	Morowali Utara	0.0	0.0	0.0	0.0
1806	Lampung Utara	46.5	48.4	47.5	47.0	7271	Palu	6.9	8.0	11.7	11.9
1807	Way Kanan	39.2	39.5	42.4	41.9	7301	Kepulauan Selayar	29.3	34.4	33.3	32.0
1808	Tulangbawang	28.7	28.6	33.2	33.7	7302	Bulukumba	41.0	42.7	50.0	49.5
1809	Pesawaran	52.2	53.2	45.4	44.9	7303	Bantaeng	36.0	41.0	39.3	38.3
1810	Pringsewu	48.5	49.9	59.8	59.7	7304	Jeneponto	51.8	53.0	51.5	51.2
1811	Mesuji	27.9	26.1	24.7	24.8	7305	Takalar	28.8	29.2	29.7	29.0
1812	Tulang Bawang Barat	44.2	45.2	44.5	44.1	7306	Gowa	45.0	45.3	44.6	44.6
1813	Pesisir Barat	0.0	0.0	42.2	42.3	7307	Sinjai	29.4	32.9	32.3	31.4
1871	Bandar Lampung	16.5	17.0	17.6	17.0	7308	Maros	31.9	32.4	32.4	32.0
1872	Metro	93.9	94.8	94.8	95.1	7309	Pangkajene Dan Kepulauan	33.5	35.2	33.7	33.0
1901	Bangka	35.4	36.1	35.9	35.7	7310	Barru	43.0	44.4	44.5	43.8
1902	Belitung	29.2	37.3	47.3	46.1	7311	Bone	30.9	35.5	34.5	34.1
1903	Bangka Barat	20.9	20.0	21.4	22.3	7312	Soppeng	41.2	43.5	47.4	46.4
1904	Bangka Tengah	34.3	36.0	38.2	37.3	7313	Wajo	38.6	39.1	39.1	39.0
1905	Bangka Selatan	29.1	29.4	28.9	28.7	7314	Sidenreng Rappang	48.0	50.3	48.1	46.6
1906	Belitung Timur	39.8	39.5	41.7	42.1	7315	Pinrang	32.6	33.0	34.8	34.8
1971	Pangkal Pinang	0.2	0.2	85.4	86.0	7316	Enrekang	31.8	34.9	32.7	31.8
2101	Karimun	1.8	2.3	2.2	2.1	7317	Luwu	24.3	27.7	28.0	27.8
2102	Bintan	43.7	55.7	55.5	55.0	7318	Tana Toraja	24.3	23.4	28.5	28.0
2103	Natuna	23.0	24.0	24.2	24.2	7322	Luwu Utara	14.9	15.4	14.3	14.0
2104	Lingga	0.0	6.6	6.4	6.3	7325	Luwu Timur	22.6	22.8	24.2	25.4
2105	Kepulauan Anambas	0.0	8.3	15.7	15.2	7326	Toraja Utara	15.2	17.8	19.6	18.6
2171	Batam	0.0	27.4	27.4	27.0	7371	Makassar	0.0	0.0	0.0	0.0
2172	Tanjung Pinang	5.1	51.3	48.4	47.6	7372	Parepare	6.9	73.3	72.6	72.4
3201	Bogor	17.7	18.0	19.5	19.6	7373	Palopo	53.1	54.7	53.9	53.0
3202	Sukabumi	30.8	39.0	42.0	41.2	7401	Buton	19.8	21.1	16.4	17.2
3203	Cianjur	30.2	38.2	39.8	39.2	7402	Muna	22.6	31.2	18.9	19.3
3204	Bandung	35.8	37.8	37.3	37.2	7403	Konawe	19.7	19.5	18.4	18.8
3205	Garut	37.2	45.6	46.1	45.7	7404	Kolaka	36.4	38.5	40.9	41.4
3206	Tasikmalaya	20.4	25.8	23.6	23.3	7405	Konawe Selatan	39.8	41.1	39.6	40.1
3207	Ciamis	23.2	25.0	24.4	24.4	7406	Bombana	29.2	33.1	33.9	33.9
3208	Kuningan	33.2	35.0	36.5	36.3	7407	Wakatobi	0.0	21.3	20.8	20.6
3209	Cirebon	44.6	46.1	47.9	48.2	7408	Kolaka Utara	40.8	39.8	42.9	43.8
3210	Majalengka	26.3	25.6	25.9	26.5	7409	Buton Utara	4.9	5.1	5.2	5.6
3211	Sumedang	44.7	45.1	44.2	44.6	7410	Konawe Utara	16.8	16.9	14.7	15.1
3212	Indramayu	34.5	35.4	38.3	38.5	7411	Kolaka Timur	0.0	0.0	17.4	18.2
3213	Subang	34.9	34.5	34.4	34.5	7471	Kendari	85.6	85.7	55.9	55.5
3214	Purwakarta	35.3	34.9	36.0	36.6	7472	Baubau	49.3	51.0	64.0	64.1
3215	Karawang	6.6	8.4	8.9	9.3	7501	Boalemo	34.3	35.2	35.5	36.4
3216	Bekasi	4.7	4.9	5.1	5.1	7502	Gorontalo	46.9	47.8	51.4	51.3
3217	Bandung Barat	24.7	25.4	29.8	29.8	7503	Pohuwato	38.9	43.6	45.8	46.3
3218	Pangandaran	0.0	0.0	50.1	49.5	7504	Bone Bolango	44.0	44.1	49.0	49.5
3278	Tasikmalaya	49.5	50.4	49.5	48.9	7505	Gorontalo Utara	25.0	33.8	62.4	62.6
3279	Banjar	49.5	50.1	50.2	50.4	7571	Gorontalo	0.0	0.0	99.6	99.6
3301	Cilacap	42.8	47.9	47.1	46.7	7601	Majene	17.8	18.8	48.5	49.1
3302	Banyumas	51.9	50.7	49.9	49.8	7602	Polewali Mandar	29.8	34.2	31.4	30.1
3303	Purbalingga	24.8	25.7	25.2	25.5	7603	Mamasa	15.6	21.6	29.3	30.1
3304	Banjarnegara	48.2	49.4	49.0	48.6	7604	Mamuju	30.4	33.4	34.3	34.4
3305	Kebumen	20.9	21.2	20.9	21.1	7605	Mamuju Utara	33.6	35.4	36.0	35.3
3306	Purworejo	38.0	37.4	38.5	38.7	7606	Mamuju Tengah	0.0	0.0	38.4	37.8
3307	Wonosobo	51.1	52.1	51.4	50.9	8101	Maluku Tenggara Barat	11.2	19.8	23.6	23.6
3308	Magelang	50.5	53.1	52.4	52.2	8102	Maluku Tenggara	37.2	46.2	33.2	32.1
3309	Boyolali	29.9	34.5	32.9	32.8	8103	Maluku Tengah	25.6	31.1	47.4	47.4
3310	Klaten	27.0	27.3	27.0	27.0	8104	Buru	19.4	21.7	24.1	24.5

Table A1. *Cont.*

Code	District	2014	2018	2019	2020	Code	District	2014	2018	2019	2020
3311	Sukoharjo	29.0	30.2	29.1	29.1	8105	Kepulauan Aru	0.0	1.1	2.6	2.5
3312	Wonogiri	45.2	46.7	46.5	45.8	8106	Seram Bagian Barat	18.0	29.1	42.5	41.7
3313	Karanganyar	31.6	31.9	33.4	33.2	8107	Seram Bagian Timur	0.7	3.1	7.7	7.5
3314	Sragen	32.5	34.5	34.0	34.2	8108	Maluku Barat Daya	0.0	5.2	3.6	3.5
3315	Grobogan	44.6	45.5	44.7	43.9	8109	Buru Selatan	2.9	7.0	9.3	9.3
3316	Blora	29.9	31.6	33.2	32.9	8171	Ambon	39.9	35.2	36.5	36.9
3317	Rembang	45.0	46.7	45.9	45.1	8172	Tual	24.5	35.9	35.6	35.1
3318	Pati	35.8	36.9	37.4	37.5	8201	Halmahera Barat	15.2	17.1	16.8	16.0
3319	Kudus	40.9	44.4	44.1	44.4	8202	Halmahera Tengah	29.0	48.8	45.7	44.8
3320	Jepara	16.7	19.7	20.6	20.4	8203	Kepulauan Sula	12.4	25.0	27.9	26.8
3321	Demak	35.5	36.9	36.7	36.6	8204	Halmahera Selatan	1.3	7.0	9.1	8.8
3322	Semarang	41.8	43.2	42.4	42.4	8205	Halmahera Utara	34.7	37.1	36.4	35.5
3323	Temanggung	46.1	47.5	46.4	46.1	8206	Halmahera Timur	14.4	38.5	38.1	37.1
3324	Kendal	35.0	36.1	35.7	36.1	8207	Pulau Morotai	19.8	41.4	49.6	48.7
3325	Batang	48.1	48.1	48.9	49.0	8208	Pulau Taliabu	0.0	0.0	10.5	10.4
3326	Pekalongan	42.7	42.5	41.5	41.3	8271	Ternate	67.4	69.4	35.5	34.3
3327	Pemalang	33.7	34.0	33.7	33.5	8272	Tidore Kepulauan	53.8	58.6	57.2	56.8
3328	Tegal	36.9	38.4	38.0	37.7	9101	Fakfak	11.1	22.7	13.7	13.9
3329	Brebes	44.0	43.4	46.4	46.1	9102	Kaimana	0.0	0.6	0.6	0.6
3374	Semarang	31.9	34.8	33.5	33.3	9103	Teluk Wondama	0.0	0.0	0.9	0.9
3375	Pekalongan	0.0	0.0	14.7	14.7	9104	Teluk Bintuni	1.4	1.7	1.7	1.9
3401	Kulon Progo	83.7	83.9	84.8	84.7	9105	Manokwari	54.6	54.8	55.8	56.1
3402	Bantul	84.4	85.0	84.6	84.7	9106	Sorong Selatan	0.7	2.4	0.8	0.7
3403	Gunung Kidul	66.5	66.9	65.9	65.8	9107	Sorong	18.6	29.9	34.5	34.0
3404	Sleman	67.0	68.5	67.8	68.1	9108	Raja Ampat	0.0	0.0	1.8	1.9
3501	Pacitan	31.1	55.8	50.6	49.4	9109	Tambrauw	0.0	0.0	0.2	0.2
3502	Ponorogo	31.4	33.0	32.5	31.5	9110	Maybrat	0.0	13.3	20.0	19.8
3503	Trenggalek	38.7	41.9	41.5	40.8	9111	Manokwari Selatan	0.0	0.0	40.2	39.0
3504	Tulungagung	9.7	19.3	19.3	19.1	9112	Manokwari	0.0	0.0	0.1	0.1
3505	Blitar	13.8	24.1	23.8	23.8	9171	Sorong	77.3	88.2	31.8	31.6
3506	Kediri	23.5	23.8	23.4	23.6	9401	Merauke	1.3	2.8	3.5	3.5
3507	Malang	23.2	23.7	23.3	23.0	9402	Jayawijaya	7.0	8.8	7.5	7.8
3508	Lumajang	22.0	32.4	32.9	32.5	9403	Jayapura	26.0	30.3	29.7	29.8
3509	Jember	26.4	27.2	27.2	27.1	9404	Nabire	19.1	24.6	23.4	22.1
3510	Banyuwangi	21.9	18.3	18.0	17.8	9408	Kepulauan Yapen	11.3	12.0	13.0	12.6
3511	Bondowoso	21.4	22.2	22.0	22.0	9409	Biak Numfor	32.3	40.4	40.6	39.7
3512	Situbondo	41.4	41.6	41.1	40.8	9410	Paniai	7.3	7.9	6.8	6.5
3513	Probolinggo	29.0	33.3	33.3	33.2	9411	Puncak Jaya	0.0	1.0	2.9	3.0
3514	Pasuruan	40.1	43.0	43.5	43.5	9412	Mimika	1.5	5.3	5.6	5.8
3515	Sidoarjo	19.2	24.5	24.9	24.9	9413	Boven Digoel	4.1	3.6	4.6	4.9
3516	Mojokerto	33.6	34.7	34.7	35.0	9414	Mappi	0.0	0.0	0.0	0.0
3517	Jombang	27.5	31.3	31.2	31.5	9415	Asmat	0.0	0.0	0.0	0.0
3518	Nganjuk	28.6	31.7	31.0	30.6	9416	Yahukimo	0.0	0.6	0.5	0.5
3519	Madiun	34.0	36.5	38.7	38.3	9417	Pegunungan Bintang	0.0	0.6	1.7	1.7
3520	Magetan	22.2	22.7	22.3	21.9	9418	Tolikara	0.0	0.5	2.4	2.4
3521	Ngawi	30.3	32.1	32.4	32.1	9419	Sarmi	3.4	14.1	15.8	16.0
3522	Bojonegoro	32.9	33.1	31.7	31.0	9420	Keerom	14.9	15.8	11.0	11.0
3523	Tuban	40.3	41.3	41.2	40.8	9426	Waropen	0.7	0.7	1.5	1.6
3524	Lamongan	30.4	30.7	31.0	31.3	9427	Supiori	40.1	40.3	40.4	39.7
3525	Gresik	26.3	26.1	26.2	26.1	9428	Mamberamo Raya	0.0	0.0	0.0	0.0
3526	Bangkalan	33.4	33.7	33.4	33.1	9429	Nduga	0.0	0.0	0.0	0.0
3527	Sampang	24.4	24.3	23.9	24.3	9430	Lanny Jaya	0.0	1.8	0.9	0.9
3528	Pamekasan	23.4	24.1	23.7	23.4	9431	Mamberamo Tengah	2.9	3.1	1.4	1.5
3529	Sumenep	24.1	24.4	23.8	23.5	9432	Yalimo	16.4	16.8	18.9	19.0
3574	Probolinggo	91.4	90.0	89.2	89.7	9433	Puncak	0.0	0.0	0.0	0.0
3579	Batu	45.0	47.1	45.8	44.8	9434	Dogiyai	4.3	5.6	8.2	7.9
3601	Pandeglang	30.5	32.6	33.0	32.6	9435	Intan Jaya	0.0	0.0	0.0	0.0
3602	Lebak	34.7	37.5	38.1	37.4	9436	Deiyai	0.1	3.9	8.3	8.3
3603	Tangerang	5.7	5.7	5.9	6.1	9471	Jayapura	59.0	62.0	62.1	62.8
3604	Serang	23.1	28.3	30.0	30.6						

Source: Author's calculation.



(**a**) (**b**) (**c**)

Figure A1. OSM data inconsistency (**a**) 2014 (**b**) 2020 (**c**) map merger. Note: Authors only use primary, primary link, secondary, and secondary link road classifications. Source: www.geofabrik.de (accessed on 15 November 2021).

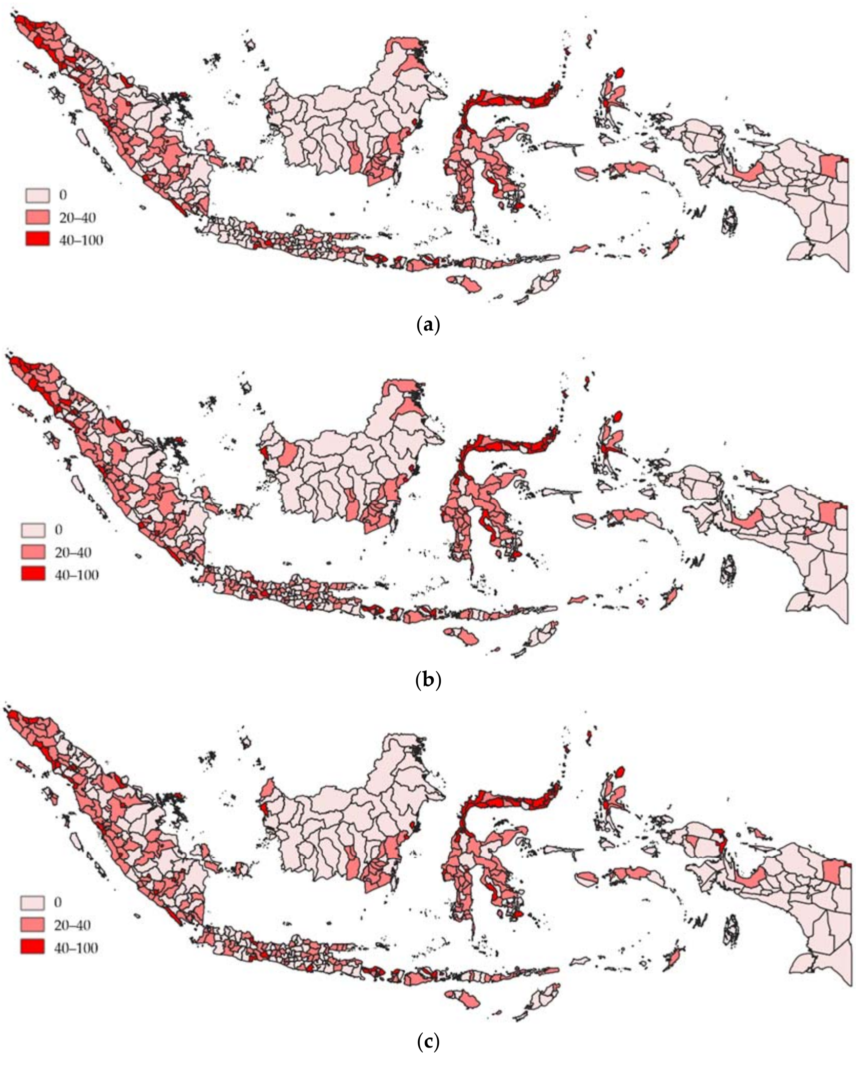
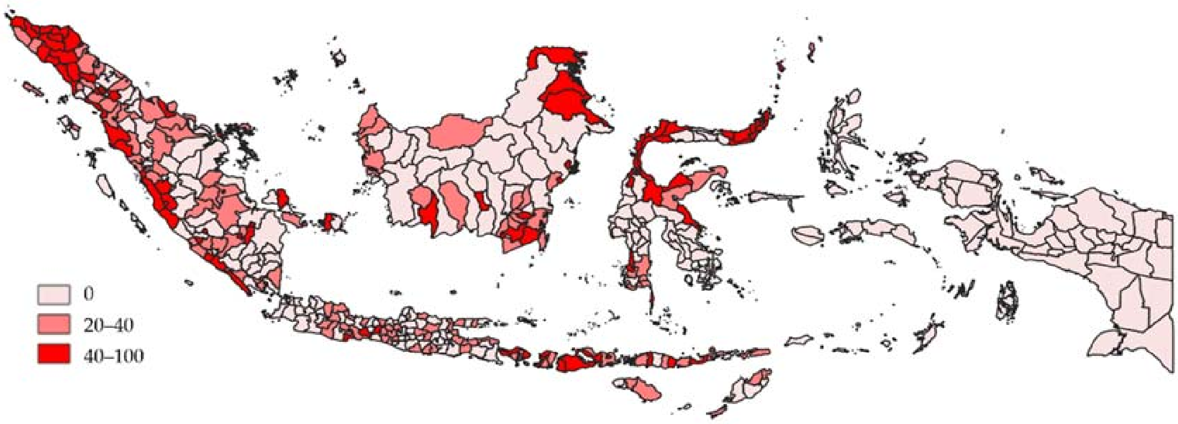
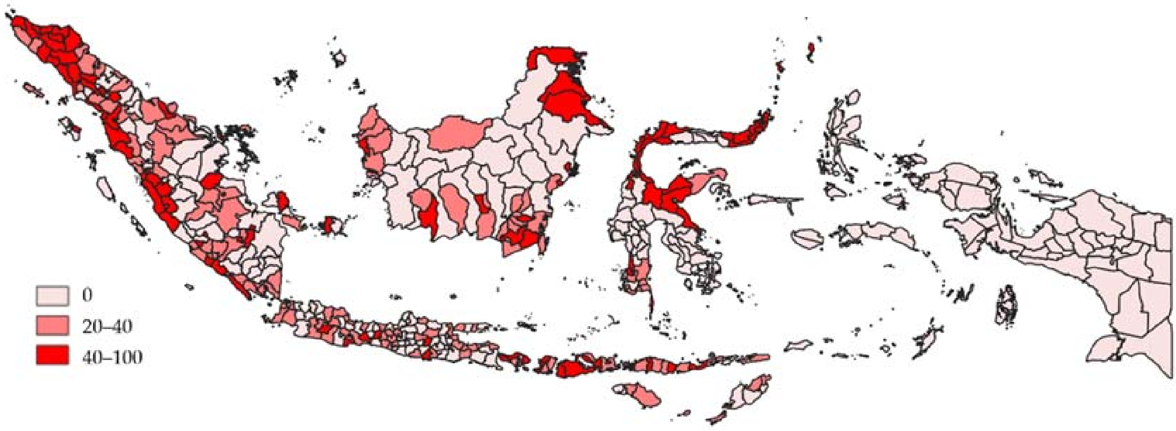


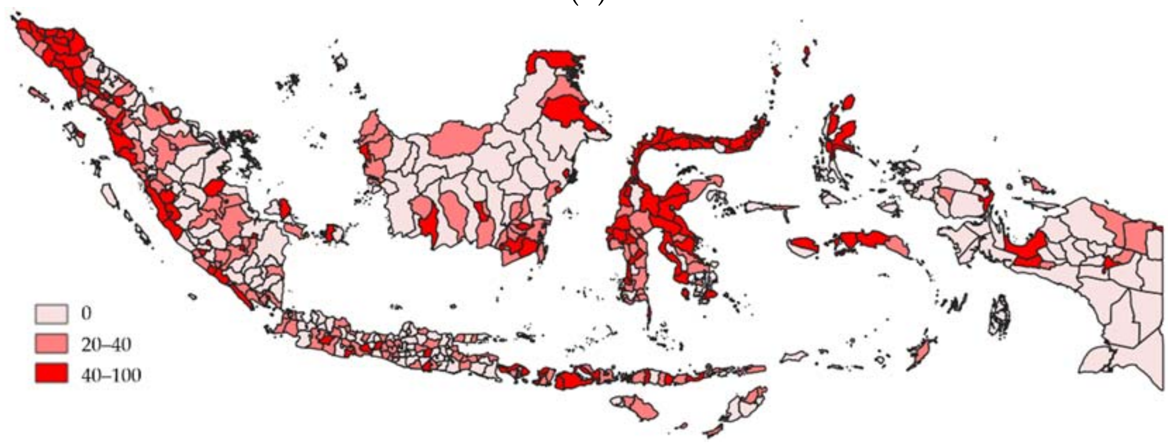
Figure A2. 2018 Indonesian RAI using the national road network map, WorldPop, and different road network condition data (per cent): (**a**) IRI (**b**) Road condition (**c**) Podes. Source: Author's calculation.



(**a**)



(**b**)



(**c**)

Figure A3. 2018 Indonesian RAI using the national road network map, LandScan, and different road network condition data (per cent): (**a**) IRI (**b**) Road condition (**c**) Podes. Source: Author's calculation.

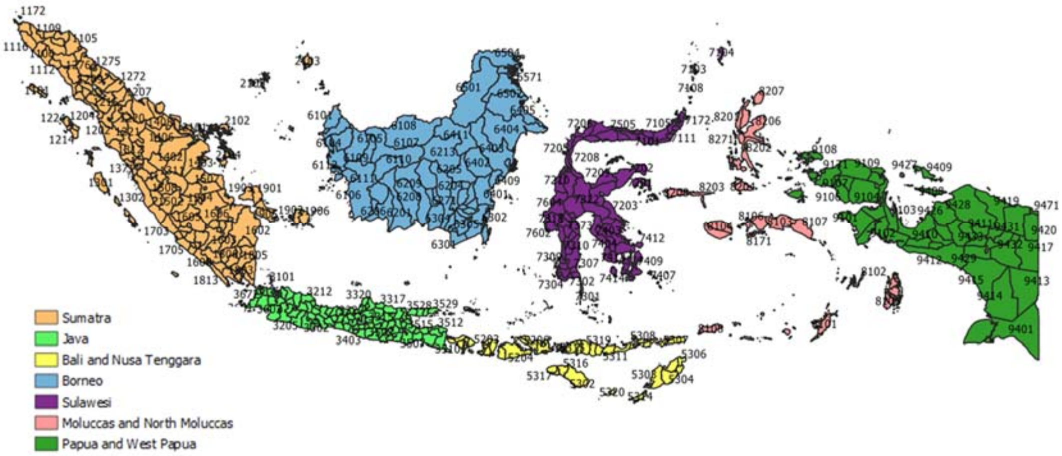


Figure A4. Indonesia by regional group and district's code.

Notes

1. Bartlett's equal-variances test had $\chi^2(2)$ = 0.1065 and p-value = 0.948.
2. Sumatra has district codes 1101–2172, Java has district codes 3201–3673, Bali and Nusa Tenggara have district codes 5101–5371, Borneo has district codes 6101–6571, Sulawesi has district codes 7101–7606, Moluccas and North Moluccas have district codes 8101–8272, and Papua and West Papua have district codes 9101–9471.
3. According to Ministry of Finance Regulation Number 120/PMK.07/2020 about Regional Fiscal Capacity Maps, $DFCI_i = \frac{DFC_i}{\sum_{i=1}^{n} DFC_i/n}$ where DFC_i is government revenue—(government revenue that its alocation is determined + specific expenditure) and n is the number of districts in Indonesia. DFC_i shows the fiscal capacity of district *i.*

References

Asher, Sam, and Paul Novosad. 2020. Rural Roads and Local Economic Development. *American Economic Review* 110: 797–823. [CrossRef]

Bappenas. 2014. *Rencana Pembangunan Jangka Menengah Nasional (RPJMN) 2015–2019*. Jakarta: Bappenas. Available online: http://djsn.go.id/storage/app/media/RPJM/BUKU%20I%20RPJMN%202015-2019.pdf (accessed on 9 September 2022).

Bappenas. 2017. *Ringkasan Metadata Indikator Tujuan Pembangunan Berkelanjutan (TPB)/Sustainable Development Goals (SDGs) Indonesia*. Jakarta: Bappenas. Available online: http://sdgs.bappenas.go.id/wp-content/uploads/2017/09/Buku_Ringkasan_Metadata_Indikator_TPB.pdf (accessed on 18 October 2021).

Bappenas. 2020. *Pedoman Teknis Penyusunan Rencana Aksi Tujuan Pembangunan Berkelanjutan (TPB)/Sustainable Development Goals (SDGs)*. Jakarta: Bappenas. Available online: http://sdgs.bappenas.go.id/buku-pedoman-rencana-aksi-sdgs/ (accessed on 11 June 2021).

Bell, Clive, and Susanne van Dillen. 2014. How Does India's Rural Roads Program Affect the Grassroots? Findings from A Survey in Upland Orissa. *Land Economics* 90: 372–94. [CrossRef]

Bellu, Lorenzo Giovanni, and Paolo Liberati. 2006. *Policy Impacts on Inequality: Decomposition of Income Inequality by Subgroups*. Rome: FAO. Available online: https://www.fao.org/3/a-am342e.pdf (accessed on 1 November 2021).

Cowell, Frank A. 2011. *Measuring Inequality*, 3rd ed. New York: Oxford University Press. [CrossRef]

Dercon, Stefan, John Hoddinott, and Tassew Woldehanna. 2012. Growth and Chronic Poverty: Evidence from Rural Communities in Ethiopia. *Journal of Development Studies* 48: 238–53. [CrossRef]

Haughton, Jonathan, and Shahidur R. Khandker. 2009. *Handbook on Poverty and Inequality*. Washington, DC: The World Bank.

Iimi, Atsushi, Farhad Ahmed, Edward Charles Anderson, Adam Stone Diehl, Laban Maiyo, Tatiana Peralta-Quirós, and Kulwinder Rao. 2016. *New Rural Access Index: Main Determinants and Correlation to Poverty*. Policy Research Working Paper. Washington, DC: World Bank Group. [CrossRef]

Jang, Seongman, Youngsoo An, Changhyo Yi, and Seungil Lee. 2017. Assessing the Spatial Equity of Seoul's Public Transportation Using the Gini Coefficient Based on Its Accessibility. *International Journal of Urban Sciences* 21: 91–107. [CrossRef]

Khandker, Shahidur R., and Gayatri B. Koolwal. 2011. Estimating the Long-term Impacts of Rural Roads: A Dynamic Panel Approach. *Policy Research Working Paper* 5867: 1–37. [CrossRef]

Li, Wanjing, Qi Zhou, Yuheng Zhang, and Yijun Chen. 2022. Visualising Rural Access Index and Not Served Rural Population in Africa. *Environment and Planning A: Economy and Space* 54: 215–18. [CrossRef]

Mestre, Francesc Xavier Salleras. 2021. Accessibility and Equity Assessment in Public Transport Services: A Case Study in Palma de Mallorca. Ph.D. thesis, KTH Royal Institute of Technology, Stockholm, Sweden. Available online: http://kth.diva-portal.org/smash/record.jsf?pid=diva2%3A1617053&dswid=-6534 (accessed on 3 January 2022).

Mikou, Mehdi, Julie Rozenberg, Elco Eduard Koks, Charles James Edward Fox, and Tatiana Peralta Quiros. 2019. *Assessing Rural Accessibility and Rural Roads Investment Needs Using Open Source Data*. Policy Research Working Paper 8746. Washington, DC: World Bank. [CrossRef]

Mu, Ren, and Dominique Van de Walle. 2011. Rural Roads and Local Market Development in Vietnam. *Journal of Development Studies* 47: 709–34. [CrossRef]

Roberts, Peter, Shyam Kc, and Cordula Rastogi. 2006. Rural Access Index: A Key Development Indicator. Transport Paper Series TP-10. Available online: https://openknowledge.worldbank.org/handle/10986/17414 (accessed on 16 January 2022).

Sala-i-Martin, Xavier X. 1996. Regional Cohesion: Evidence and Theories of Regional Growth and Convergence. *European Economic Review* 40: 1325–52. [CrossRef]

Salim, Wilmar, and Siwage Dharma Negara. 2018. Infrastructure Development under the Jokowi Administration: Progress, Challenges and Policies. *Journal of Southeast Asian Economies* 35: 386–401. Available online: https://www.jstor.org/stable/10.2307/26545320 (accessed on 21 February 2022). [CrossRef]

Simon, Nisha S., and Packirisamy Natarajan. 2017. Nonlinearity between Infrastructure Inequality and Growth. *Review of Market Integration* 9: 66–82. [CrossRef]

Stevens, Forrest R., Andrea E. Gaughan, Catherine Linard, and Andrew J. Tatem. 2015. Disaggregating Census Data for Population Mapping Using Random Forests with Remotely-Sensed and Ancillary Data. *PLoS ONE* 10: e0107042. [CrossRef] [PubMed]

Tselios, Vassilis. 2009. Growth and Convergence in Income Per Capita and Income Inequality in the Regions of the EU. *Spatial Economic Analysis* 4: 343–370. [CrossRef]

Workman, Robin, Kevin McPherson, and TRL. 2019. *Rural Access Index (RAI) Supplemental Guidelines: Measuring Rural Access Using New Technologies*. ReCAP GEN2. London: ReCAP for DFID. Available online: https://www.research4cap.org/ral/Workmanetal-TRL-2019-RuralAccessIndexSupplementalGuidelines-ReCAP-GEN2033D-191219-compressed.pdf (accessed on 30 December 2021).

World Bank. 2016. *Measuring Rural Access Using New Technologies*. Washington, DC: The World Bank. Available online: https://openknowledge.worldbank.org/handle/10986/25187 (accessed on 15 November 2021).

Zimm, Caroline. 2019. Methodological Issues in Measuring International Inequality in Technology Ownership and Infrastructure Service Use. *Development Studies Research* 6: 92–105. [CrossRef]