Estimation of Spatial Bus Capacity Bottlenecks for Mandalay City

SU PE THU [a], KAY THWE TUN [b]

[a] *Ph.D. Student, Mandalay Technological University, Mandalay, Myanmar*
[b] *Professor, Mandalay Technological University, Mandalay, Myanmar*
[a] *E-mail: supethu@gmail.com*
[b] *E-mail: kaythwetun.pm@gmail.com*

Abstract: The purpose of the paper is to develop a technique to calculate the bus service area and measure the accessibility levels to the bus routes using GIS. The first part of the study focuses in developing the radial distances in order to analyze the bus service area. The second part of the study is related to identifying the levels of accessibility to the bus routes. In the zone (ward) based accessibility measurement, the bus service area covers 26.5 km^2 which represents 30.9% of the total area with approximately 24% (218978) of the total population (899486). The third part of the study is the calculation of bus service area accessibility index for Mandalay City. The approach, defined the bus service area, determined the levels of accessibility using spatial analysis and spatial selection method. Thus, it can be concluded that the service area analysis in this study supports the decision-makers.

Keywords: Transportation system, Geographic Information System (GIS), Bus service area, Zone (ward) based accessibility measurement, Accessibility index

1. INTRODUCTION

In Mandalay City, there are 52 bus teams under the management of bus control committee (Mandalay Region). People favor motorcycle and private cars and regard conventional public transport as a last solution. One objective of public transportation is to provide an alternative to the use of the private automobile in order to alleviate negative externalities created by automobile dependency. These negative effects include environmental degradation, equity issues (for example, the difficulty experienced by people who are unable to drive due to some physical and mental disability), and economic impacts (such as time lost due to driving congestion and lack of parking space). As one of many available alternative transportation modes, bus service must attract ridership to be competitive. The spatial selection methods helped identify the overall bus service coverage within a geographical area.

2. METHODOLOGY

2.1 Geo-database of the Study

The software ArcGIS10.1 has been used as a GIS platform of this study. The current bus teams, number of bus frequency per day, the average number of buses per day and the daily transportable number of passengers are obtained from Bus Line Control Committee, Mandalay Division. Various data types are needed to collect from different sources. Most of data involved two-pronged spatial and attribute data, which included maps of the study area, and locations of bus routes as spatial data. On the other hand, the attribute data included population; bus routes in terms of statistics and geographic information. After collecting data, the next step is building the geo-database of the study.

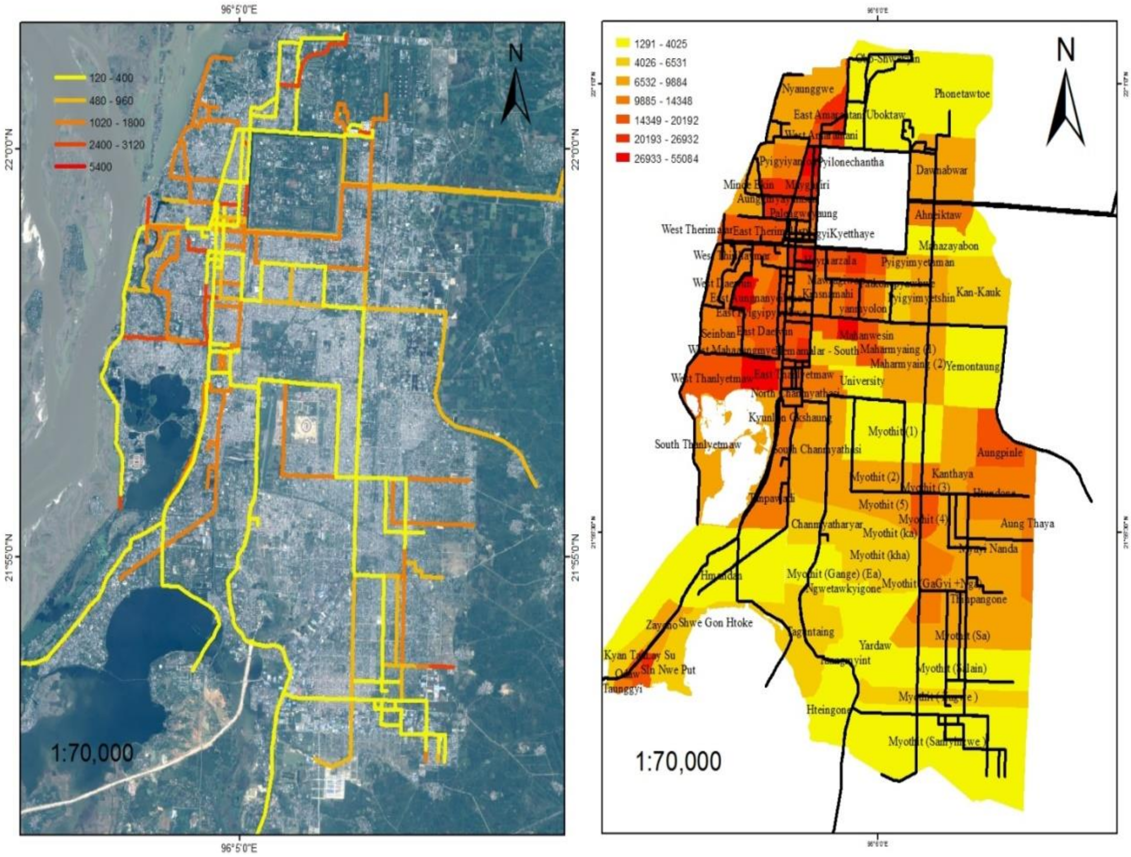

Figure 1. Bus route map with daily supply capacity and population density map in Mandalay

2.2 Calculation of population density along the bus route

Population density (d_n) is calculated based on the population by built up area (zone).

$$d_n = \frac{P_n}{A_n} \quad (1)$$

where,

P_n : population in zone n,

A_n : Area of zone n.

In ArcGIS software, the intersect tool is used to compute the geometric intersection of the input features such as bus route layer and population density layer based on the population by built up area (zone). And then, population density for each route is calculated as follow as:

$$d_{ni} = \frac{P_{ni}}{A_{ni}} \quad (2)$$

where,

d_{ni} : population density in zone n for route i,

P_{ni} : population in zone n for route i,

A_{ni} : Area of zone n for route i.

$$D_{t=S_{ik}} = \frac{\sum_{t=S_{ik}} P_t}{\sum_{t=S_{ik}} A_t} \quad (3)$$

where,

S_{ik} : a set of zones passed by bus k in route i ,

D_t : total population density in zones passed through by bus network,

P_t : total population in zones passed through by bus network,

A_t : total area passed through by bus network.

2.3 Calculation of bus service area and radial distance

The service area is calculated by served people divided by population density.

$$B_n = \frac{C_n}{D_t} \quad (4)$$

where,

B_n : average bus service area for bus network,

C_n : daily supply capacity served by bus network,

$$b_i = \frac{C_i}{d_{ni}} \quad (5)$$

where,

b_i : specific bus service area for bus route i,

C_i : daily supply capacity served by bus route i,

The area of circle is πr^2. The radial distance is calculated by the square root of the result of service area divided by Pi (π) Where Pi (π) represents 3.14.

$$R_n = \sqrt{\frac{B_n}{\pi}} \quad (6)$$

where,

R_n : average radial distance for bus network.

$$r_i = \sqrt{\frac{b_i}{\pi}} \quad (7)$$

where,

r_i : specific radial distance for bus route i.

The daily supply capacity is obtained from the data of Bus Line Control Committee such as: number of bus, frequency and seat capacity. The total population density is 1207435 per kilometer square. The daily served people (50410) are estimated by Bus Line Control Committee. The service area and radial distance are calculated by using field calculator in ArcGIS Software. The average radial distance based on the total supply capacity is 115m. The values of specific radial distance (r_i) are described in Table 1.

Table 1. Values of specific radial distance

No	Bus Team Name	Radial Distance (m)	No	Bus Team Name	Radial Distance (m)
1	No 8*	377. 5	27	No 28	188.5
2	No 25	319.5	28	No 16 *	158.9
3	No 7	243.2	29	No 23	157.3
4	No 11*	260.6	30	No 19 *	113.7
5	No 17	320.1	31	No 19 **	113.7
6	No 10 *	315.0	32	No 1-2-3 **	155.7
7	No 4 *	229. 6	33	No 11 **	125.9
8	No 4 **	232.6	34	No 8 ***	112.0
9	No 5 *	181.9	35	No 21	134.1
10	No 5 **	184.0	36	No 15 *	102.3
11	N0 23	259.9	37	No 19 ***	76.1
12	No 6 *	166.8	38	No 18	88.4
13	No 6 **	204.2	39	No 24	77.4
14	No 6 ***	195.3	40	No 36	105.0
15	No 30	189.1	41	No 37	97.1
16	No 7	183.2	42	No 15 **	111.0
17	No 29	189.4	43	No 20	68.8
18	N0 39	185.4	44	No 33	63.4
19	No 22	191.2	45	N0 26 *	52. 9
20	No 10 **	227.4	46	No 26 **	68.2
21	No 8 **	177.9	47	No 31	63.5
22	No 35	177.8	48	No 12	67.1
23	No 1-2-3 *	172.1	49	No 15 ***	69.1
24	No 22	191.2	50	No 32	56.9
25	No 24	200.5	51	No 34	56.3
26	No 35	197.6	52	No 38	62.6

- * Different routes under same bus team

2.4 Area detection that fall within the service zone or not

Buffer analysis is used to detect the areas that fall within the radial service areas of bus route. In this study, buffers are zones of specified distance given by the radius of bus route service area. After generating the radius values, the buffer analysis is undertaken for each bus route separately.

The results of the buffer analysis for each route are merged into one layer which represents the radial service areas for all bus routes. The second buffer is carried out once due to the value of the average radius and is the same for all bus routes. The accessibility is estimated by detecting the area whether it exists within average radial service area buffer or specific radial service area buffer.

(a) Average radial distance buffer (b) Specific radial distance buffer

Figure 2. Bus service area buffer map for Mandalay City

2.5 Measurement of bus accessibility levels

Selection by location function is used for the outline boundary intersection and centroid containment in order to determine the level of accessibility. Selection by location function is based on choice function. A choice function (selector, selection) is a **mathematical function** *f* that is defined on some collection *X* of nonempty **sets** and assigns to each set *S* in that collection some element *f*(*S*) of *S*. In other words, *f* is a choice function for *X* if and only if it belongs to the **direct product** of *X*.

The spatial selection methods that have been used to select the neighbourhoods include (a) having their centroid in the source layer feature (b) are within the source layer feature, and (c) are crossed by the outlines of the source layer. The spatial selection method of having their centroid in the source layer; the neighbourhoods in the input layer are selected if their centre falls within a service area zone. This method is applied for both layers of the radial distance buffer zone to determine that the neighbourhoods are completely within these areas.

The spatial selection method of being crossed by the outline of the source layer feature and the neighborhoods in the input layer is selected if they are crossed by the outline of the specific radial distance buffer zone. The purpose of this method is to determine neighborhoods that touch small parts of their areas within the outline of the buffer zone.After processing selected neighbourhood features the next step is to combine the layers and remove the features that exist in the other layers. For example, the first step is selecting features in the specific radial distance buffer zone and the second step selecting features in the average radial distance buffer zone. The average zones already contain the features in the specific zones so that the features which exist in the first step must not be within the second step. The process of removing features is in the same function but using a different method.

In third step to remove the features in two layers, the function of selection by location and the spatial selection method are within the source of layers which have been used. The target layer is the first step and the source layer is the second step. After applying the features which exist in the first step and already within the second step, the remaining features are selected. The selected features are removed by deleting the records in the attributes. This step has been used to check all layers to ensure that there are no features overlapping in all levels. The next field is added for each layer showing the levels of access to bus routes. Then all layers are merged in one layer that includes all levels of accessibility.

In the study, two types of accessibility measurement are done namely; zone (ward) based accessibility measurement and route based accessibility measurement. In route based accessibility measurement, there are six steps in order to develop map. Using different methods and more steps in route based accessibility; the analysis is the same as the zone based one.

Table 2. Zone based accessibility measurement

Step	Target Layer	Source Layer	Spatial Selection Method
1st step	Population density layer	Specific radial distance buffer layer	Have their centroid in the source layer
2nd step	Population density layer	Average radial distance buffer layer	Have their centroid in the source layer
3rd step	1st step layer	2nd step layer	Are within the source layer

Table 3. Route based accessibility measurement

Step	Target Layer	Source Layer	Spatial Selection Method
1st step	Road network layer	Specific radial distance buffer layer	Are within the source layer
2nd step	Road network layer	Specific radial distance buffer layer	Are crossed by the outlines of the source layer
3rd step	2nd step layer	1st step layer	Are within the source layer
4th step	Road network layer	Average radial distance buffer layer	Are within the source layer
5th step	Road network layer	Average radial distance buffer layer	Are crossed by the outlines of the source layer
6th step	5th step layer	4th step layer	Are within the source layer

Table 4. Clarification of Accessibility levels

No	Spatial Selection Method	Accessibility levels
1	Falls within the average radial distance buffer layer	Good
2	Falls within the specific radial distance buffer layer	Fair
3	Area have incomplete coverage and completely out of radial distance buffer layers	Repair and no service area

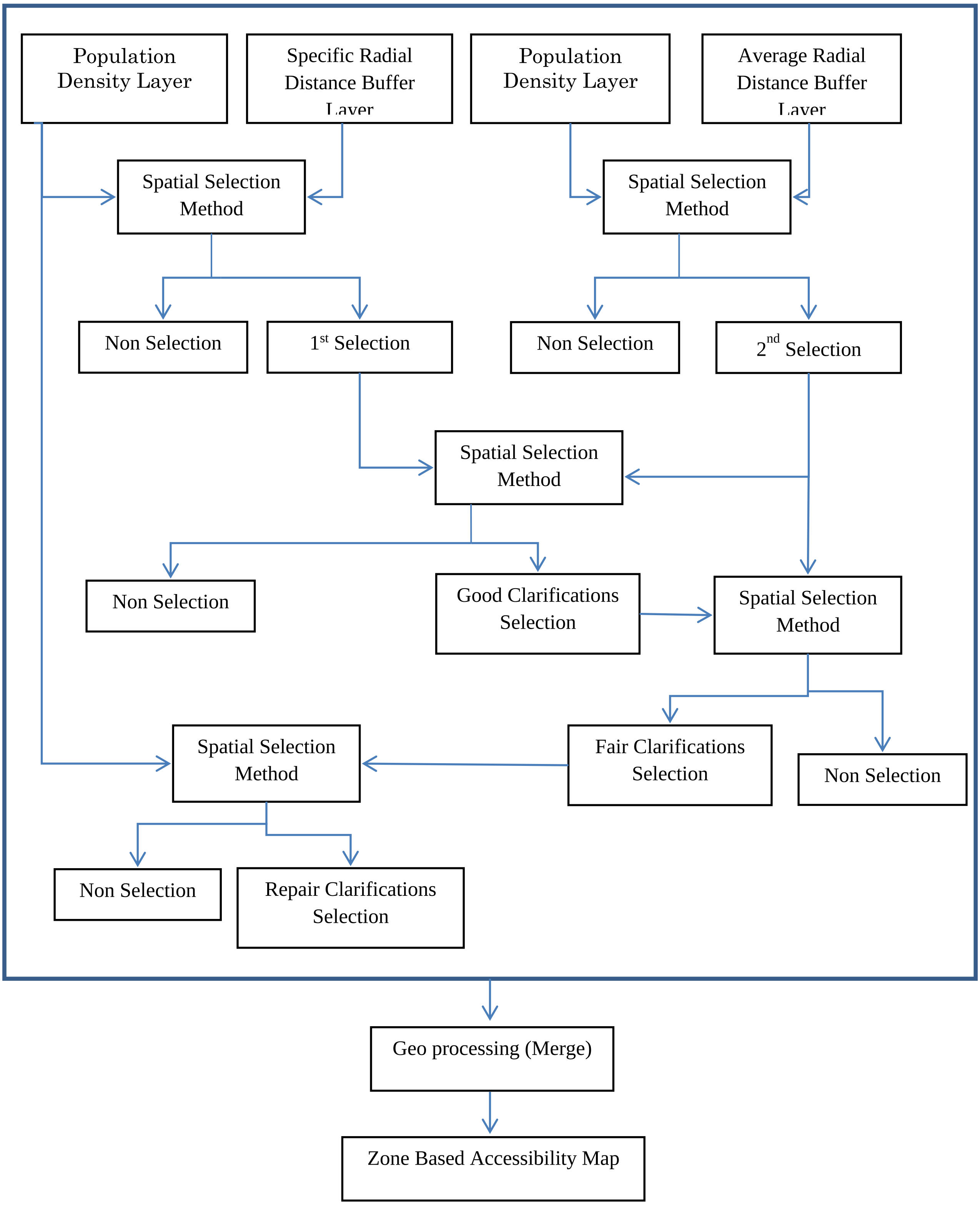

Figure 3. Flow chart for zone based accessibility map

In Table 5, there are six townships in the study: -Town 1= Aungmyaythazan, Town 2 = Chanayethazan, Town 3 = Maharaungmyay, Town 4= Chanmyathazi, Town 5 = Pyinkyithakhun and Town 6 = Amarapura .

Table 5. Clarification of Accessibility levels

Town	Zone	Bus Service Area	Total Area	Area (%)	Population in Bus Area	Total Population	Population (%)	Access
Town 1	7	7.45	20.58	36.19	69001	177761	38.82	Good
Town 2	4	1.60	11.70	13.67	24558	146138	16.80	Good
Town 3	3	0.76	14.37	5.27	21528	172841	12.46	Good
Town 4	3	7.17	22.60	31.72	46330	205113	22.59	Good
Town 5	2	2.15	32.71	6.56	18119	145929	12.41	Good
Town 6	5	7.37	9.36	78.77	39442	51704	76.28	Good
Total	24	26.50	111.33	23.80	218978	899486	24.34	
Town 1	6	2.66	20.58	12.95	66376	177761	37.34	Fair
Town 2	8	4.47	11.70	38.21	61347	146138	41.98	Fair
Town 3	5	2.71	14.37	18.86	31883	172841	18.45	Fair
Town 4	3	2.90	22.60	12.82	38846	205113	18.94	Fair
Town 5	5	12.30	32.71	37.59	59980	145929	41.10	Fair
Town 6	1	0.65	9.39	6.90	6226	51704	12.04	Fair
Total	28	25.69	111.33	23.07	264658	899486	29.42	
Town 1	5	10.47	20.58	50.86	42384	177761	23.84	Repair
Town 2	8	5.63	11.70	48.12	60233	146138	41.22	Repair
Town 3	10	10.91	14.37	75.88	119430	172841	69. 10	Repair
Town 4	8	12.54	22.60	55.46	119937	205113	58.47	Repair
Town 5	8	18.27	32.71	55.85	67830	145929	46.48	Repair
Town 6	2	1.34	9.36	14.33	6036	51704	11.67	Repair
Total	41	59.15	111.34	53.13	415850	899486	46.23	
Total Sum	93			100			100	

3. CALCULATION OF BUS ACCESSIBILITY INDEX

The PTAL is used as a development planning tool in London, to determine both permitted parking standards and development densities. Public Transport Accessibility Levels (PTALS) are a detailed and accurate measure of the accessibility of a point to the public transport network, taking into account walk access time and service availability. The method is essentially a way of measuring the density of the public transport network at any location within the study area.

3.1 Point of interest

Bus service areas are defined as points of interest.

Figure 4. Bus service area along one bus route in bus network

3.2 Walk access times

The specific radial distances to estimate bus service area are assumed as walking distances for bus routes. The distances are converted to a measure of time using an assumed a walk speed of 4.8 kph (3 mph), which has been fractionally adjusted for crow flies optimism. Radial distances are converted to a measure of time using an assumed average walk speed of 4.8 kph.

3.3 Average waiting time (AWT)

Headway data (peak period = 6am-9am) is collected from bus employee interview survey and Bus Line Control Committee.For each selected route the scheduled waiting time (SWT) is calculated. This is estimated as half the headway(H/2) (i.e. the interval between services,).To derive the average waiting time, reliability factors (RF) are applied to the SWT according to the mode of transport used. To allow for reliability additional wait times assumed are 2 minutes for buses. For example, a 10-minute service frequency (6 buses per hour) would give an SWT of 5 minutes. In addition, to make the calculations more realistic, a "reliability factor" (K) is added to the SWT depending on the transport mode, which is assumed to be 2 minutes for buses and 0.75 minutes for rail services.

$$AWT = \frac{H}{2} + RF \tag{8}$$

3.4 Total access time

Total access time is made up of a combination of factors: combining the walk time from the POI to the SAP and the time spent waiting at the SAP for the desired service to arrive.

$$TotalAccessTime = WalkTime + AWT \tag{9}$$

3.5 Equivalent doorstep frequency

The access time is converted to an Equivalent Doorstep Frequency where:

$$EDF = \frac{30}{TotalAccessTime} \tag{10}$$

3.6 Accessibility Index

For bus service area zones, the AI (at a single POI) can be calculated using the following formula:

$$AI_{zone} = EDF_{zone} + (0.5 \times AllOtherEDFs) \tag{11}$$

The above calculation is done in ArcGIS software and then the accessibility indices for each bus service area zone are calculated.

Table 6. Value of accessibility index for Aungmyaythazan Township

Zone name	PD	AI	PD(%)	AI (%)
Pyilonechantha	55084	9.94	22.11	5.41
Aunggmyaythasan	24350	11.89	9.77	6.47
East Amarahtani	24184	10.52	9.71	5.73
Maygagiri	23696	8.03	9.51	4.37
Palengweyaung	20192	9.18	8.10	4.99
East Therimalar	19076	23.45	7.66	12.77
West Amarahtani	18751	10.42	7.53	5.67
PyigyiKyetthaye	14348	39.44	5.76	21.48
Ahneiktaw	10449	9.13	4.19	4.97
Minde Ekin	9691	5.91	3.89	3.22
Dawnabwar	7116	12.75	2.86	6.94
Obo-Shwekyin	3750	5.15	1.51	2.80
Nyaunggwe	6997	6.08	2.81	3.31
Obo-Shwekyin	3750	5.15	1.51	2.80
Uboktaw	3408	8.39	1.37	4.57
Mahazayabon	2938	5.39	1.18	2.94
Phonetawtoe	1371	2.83	0.55	1.54
	249151	183.64	100	100
	14655.94118	10.80		

Table 7. Value of accessibility index for Chanmyathazi Township

Zone name	PD	AI	PD(%)	AI (%)
Myothit (4)	19364	9.92	13.70	5.65
Aungpinle	17766	3.67	12.57	2.09
Myothit (3)	14172	16.98	10.02	9.67
Kyunlon Okshaung	13418	35.72	9.49	20.34
Aung Thaya	12132	4.24	8.58	2.41
Htundone	11004	7.20	7.79	4.09
Tanpawadi	10414	10.89	7.37	6.20
South Chanmyathasi	9165	34.49	6.48	19.64
Kanthaya	8308	8.70	5.89	4.96
South Thanlyetmaw	8063	8.01	5.71	4.56
Myayi Nanda	7762	7.95	5.49	4.53
Myothit (2)	7548	12.92	5.34	7.36
Myothit (1)	2203	14.92	1.56	8.49
	141319	175.60	100	100
	10870.69	13.51		

Table 8. Value of accessibility index for Maharaungmyay Township

Zone name	PD	AI	PD(%)	AI (%)
Setkyanwesin	39993	3.84	14.41	1.70
East Thanlyetmaw	35640	3.24	12.84	1.43
East Maharaungmye	26488	6.50	9.54	2.87
Hemamalar - North	19681	9.04	7.09	3.99
West Yadanabonmi	19203	35.25	6.92	15.59
Shweboneshein	18343	37.85	6.61	16.74
East Yadanabonmi	17197	8.14	6.19	3.59
West Thanlyetmaw	16260	2.56	5.86	1.130
East Daewun	16044	5.50	5.78	2.43
West Mahaaungmye	15335	34.61	5.52	15.31
North Chanmyathasi	13427	33.63	4.84	14.87
Seinban	11304	6.49	4.07	2.87
Maharmyaing (1)	9371	12.94	3.38	5.73
Maharmyaing (2)	6933	6.87	2.50	3.04
Hemamalar - South	6435	5.18	2.31	2.29
University	3366	11.48	1.21	5.08
Yemontaung	2584	3.00	0.93	1.33
	277604	226.10	100	100
	16329.65	13.30		

Table 9. Value of accessibility index for Pyinkyithakhun Township

Zone name	PD	AI	PD(%)	AI (%)
Myothit(GaGyi +Nga)	11406	9.65	14.44	5.46
Thinpangone	9884	13.48	12.51	7.62
Myothit (Sa)	7909	10.99	10.01	6.21
Myothit (ka)	5909	9.24	7.48	5.23
Myothit (kha)	5605	9.20	7.09	5.21
Myothit (Gange) (Ea)	5100	9.14	6.45	5.17
Taguntaing	4781	13.06	6.05	7.39
Chanmyatharyar	4353	15.18	5.51	8.58
Myothit (Zagwe)	4313	16.25	5.46	9.19
Taungmyint	4025	11.54	5.09	6.53
Yardaw	3935	11.52	4.98	6.51
Myothit (Salain)	3880	10.42	4.91	5.89
Ngwetawkyigone	3877	12.96	4.91	7.33
Hteingone	2745	11.17	3.47	6.32
Myothit (Samyinzwe)	1291	13.01	1.63	7.36
Total	79013	176.80	100	100
Average	5267.53	11.77		

Table 10. Value of accessibility index for Chanayethazan Township

Zone name	PD	AI	PD(%)	AI (%)
East Chan Aye Thar Zan	38901	18.17	7.891	4.32
West Pyigyipyawbwe	38257	4.06	7.76	0.97
Middle Chan Aye Thar Zan	26932	39.31	5.46	9.36
Seiktramahi	24383	5.68	4.94	1.35
Mawragiwa	18421	11.78	3.74	2.80
Haymarzala	17276	16.17	3.50	3.85
Patkonwunkyin	15832	5.58	3.21	1.33
West Aungnanyeiktha	15825	17.96	3.21	4.28
East Thirihaymar	15317	6.86	3.11	1.63
West Thirihaymar	14125	12.13	2.87	2.89
East Aungnanyeiktha	13691	39.92	2.78	9.51
West Daewun	12999	8.79	2.64	2.09
yanmyolon	12348	11.51	2.50	2.74
Kinsnamahi	11413	15.84	2.32	3.77
West Chan Aye Thar Zan	11334	11.65	2.30	2.77
East Pyigyipyawbwe	10898	2.94	2.21	0.69
Pyigyimyethman	8591	9.76	1.74	2.32
Pyigyimyetshin	7573	9.16	1.54	2.18
Patkonepyawbwe	6112	10.95	1.24	2.61
Total	492988	419.93	100	100
Average	16999.59	14.48		

Table 11. Value of accessibility index for Amarapura Township

Zone name	PD	AI	PD(%)	AI (%)
Lay Su	25241	6.30	31.57	14.91
Odaw	18204	6.15	22.77	14.56
Taunggyi	11543	5.92	14.44	14.00
Zaycho	9647	5.82	12.07	13.77
Kyan Tan	6531	5.59	8.17	13.22
ShweGon Htoke	4795	3.90	5.99	9.23
Hmandan	3982	8.59	4.98	20.32
Total	79943	42.27	100	100
Average	11420.429	6.04		

4. RESULT AND DISCUSSION

The purpose of studying accessibility is to evaluate the access of the affected areas to the bus routes. The results and discussion in this regard include maps, tables, and charts.

As shown in Figure 5, the comparison of the percentage of population, population density and bus service area is analysed. In Pyin kyi Tha Khun, the largest bus service area (32%) exists but the lowest percentage of population density (7%) is found. 15% of the total bus service area is supplied in Ma ha Aung Myay and Chan Aye Thazan with the largest percentage of population density (22%). The ratio between bus service area and population density is not proportional. It can be seen that the largest gap between bus service area and population is found in Chan Mya Thazi (the highest population percentage, 23%).

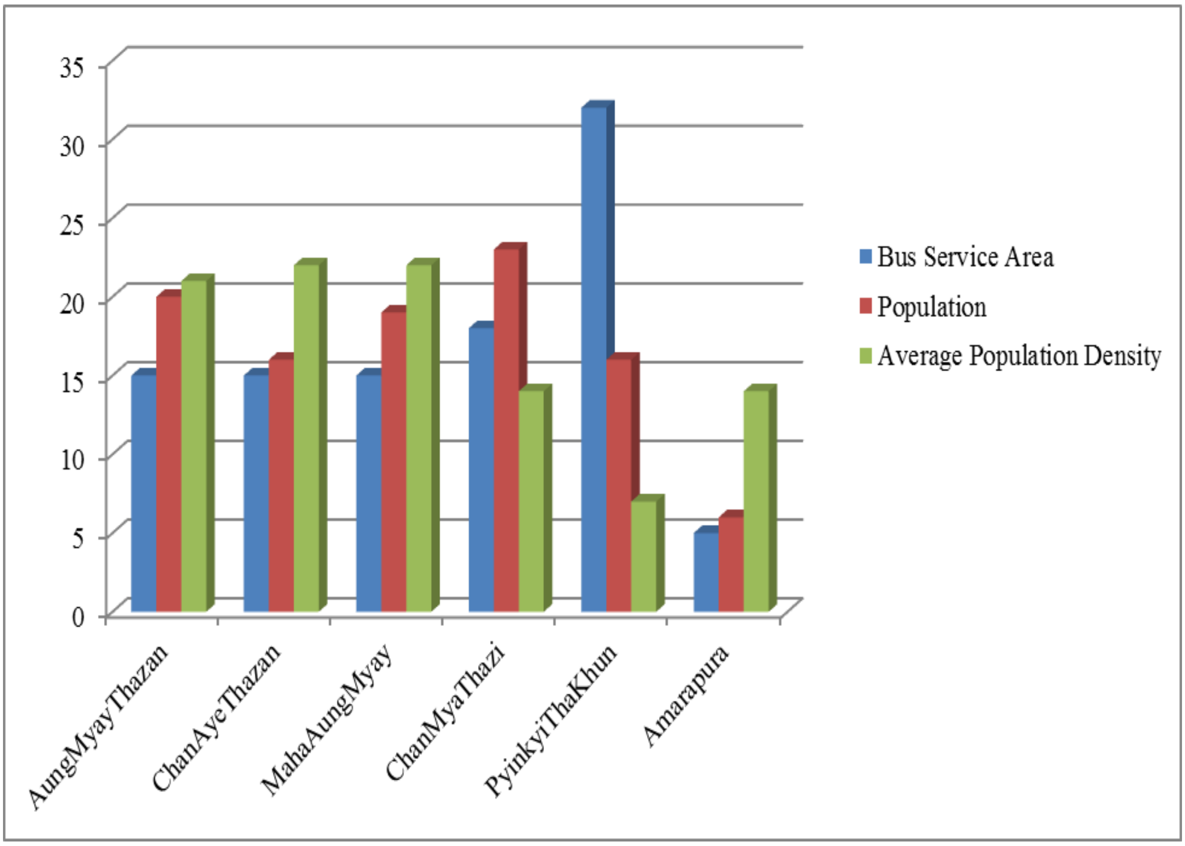

Figure 5. Percentage comparisons of population, population density and bus service area

The current bus system is targeting to the industrial zones and new towns and the total travel time takes longer and longer by gathering passengers and so the demand is decreasing. Similarly, the advantage of the current bus system is to carry the various things bought by the passengers. Therefore, new bus planning for urban area such as, developing time based bus service area with efficient and enough service is required.

In the zone (ward) based accessibility measurement, Pyin kyi Tha Khun with the largest bus service area is discussed firstly. There are 12% good access, 42% fair access and 46% repair and no access area in the township population percentage. According to the population percentage, the least accessibility level in population is found in Pyin kyi Tha Khun. Compared to the service area percentage, there is 6.6% good access, 37.6% fair access and 55.8% repair and no access area in the total township area percentage. It is the second least accessibility in the total area. In Amarapura, there are 51704 of population and total area 9.4 km^2 with bus service area, 7.4 km^2. Therefore, it is found that the best bus accessibility level of Mandalay City exists in Amarapura with 76% good access, 12% fair access and 12% repair and no access area. Equally, there are reasonable proportions in area percentage with 79% good access, 7% fair access and 14 % repair and no access area. Moreover, the maximum supply route is originated in Amarapura. So, it is interpreted that passenger demand in urban township is decreasing because there is no efficient and enough supply.

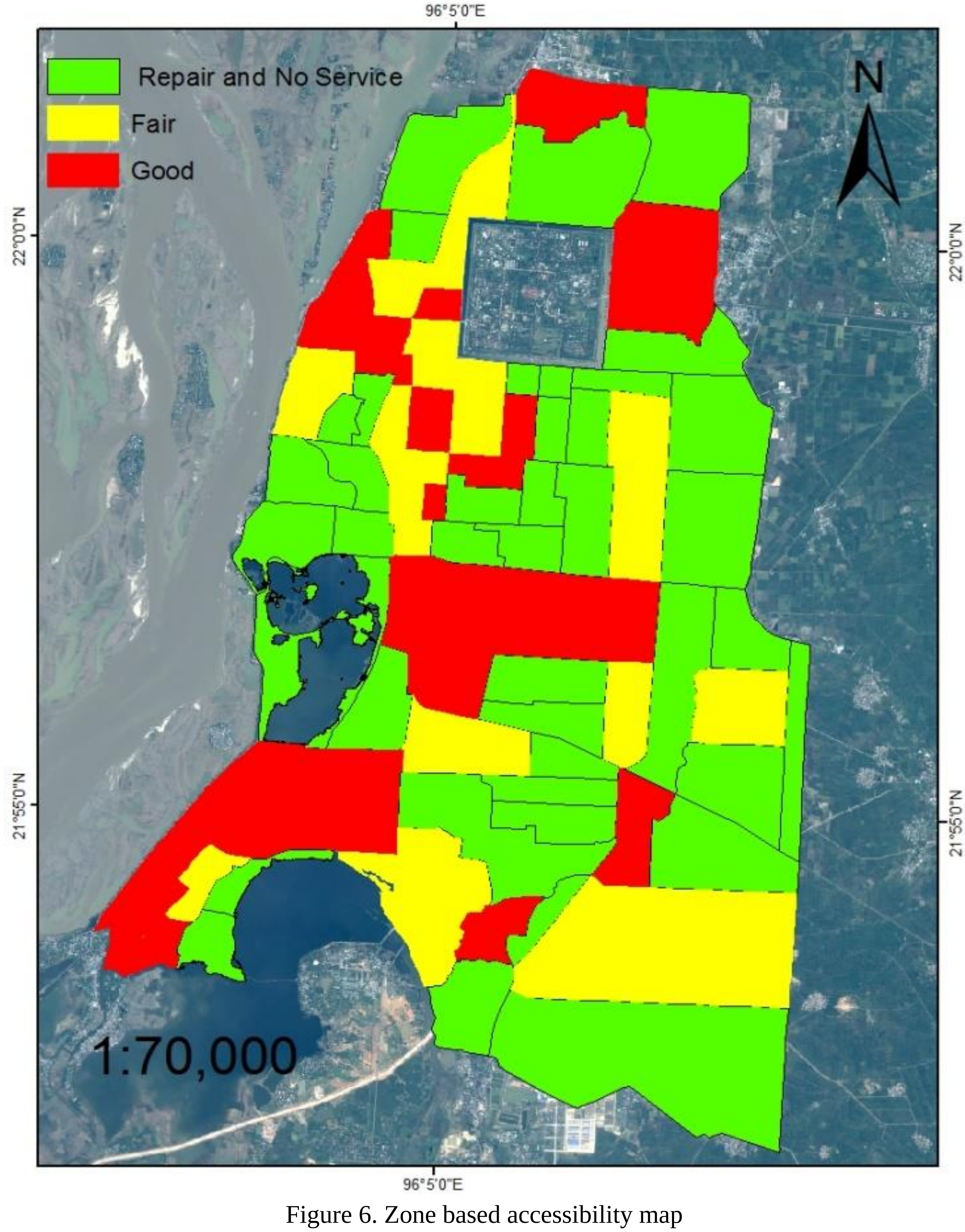

Figure 6. Zone based accessibility map

In route based bus service area measurement, the results of the accessibility levels are found that good level covers only 63.1 km which represents 4.7% of the road network, fair level covers 155.6 km which represents 11.5% of the road network and inaccessible level covers 1131.6 km which represents 83.8% of the road network of Mandalay City.

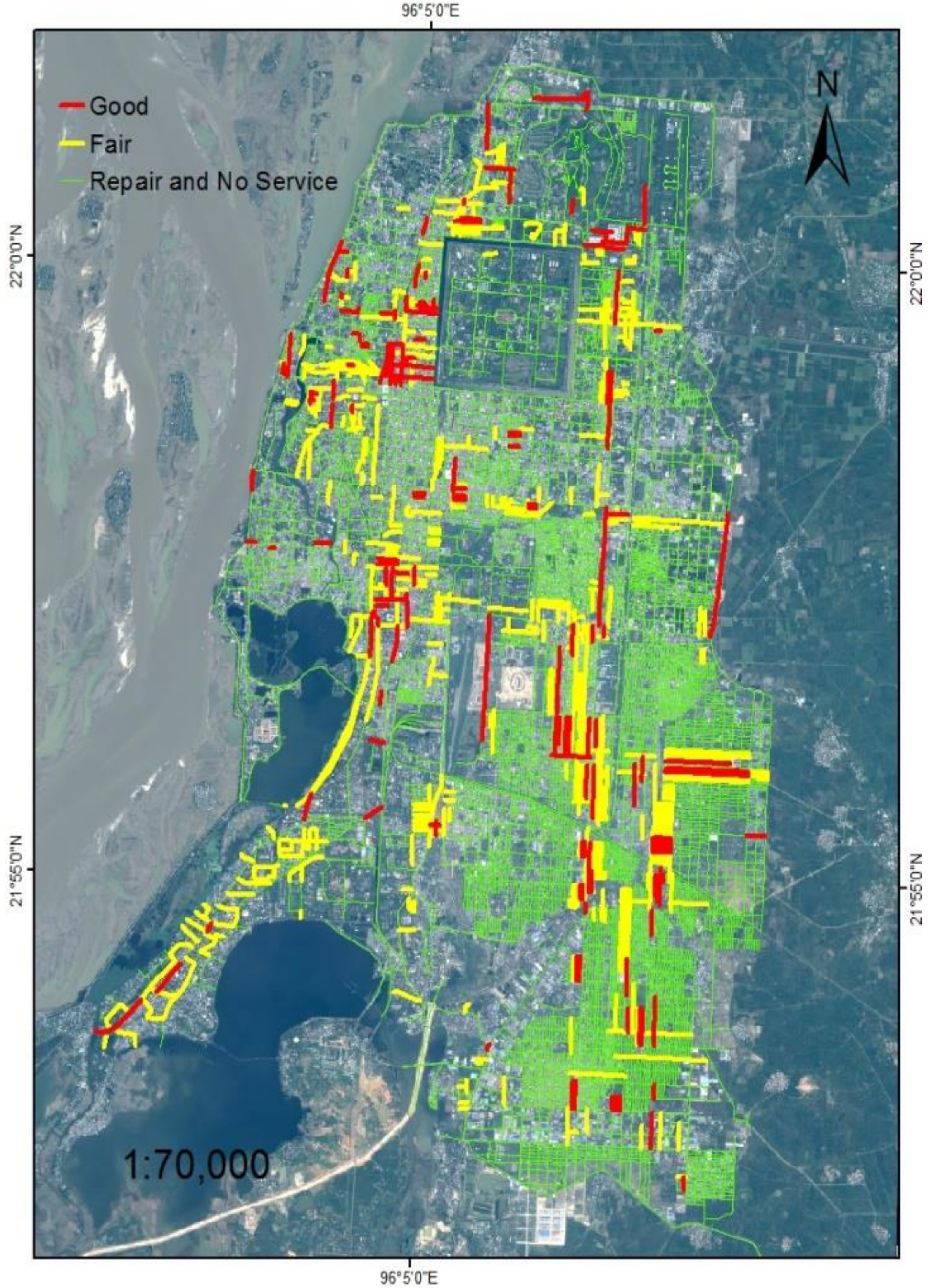

Figure 7. Route based accessibility map

In the calculation of accessibility index, the spatial bus capacity bottlenecks for Mandalay City are estimated by using PTAL methodology.

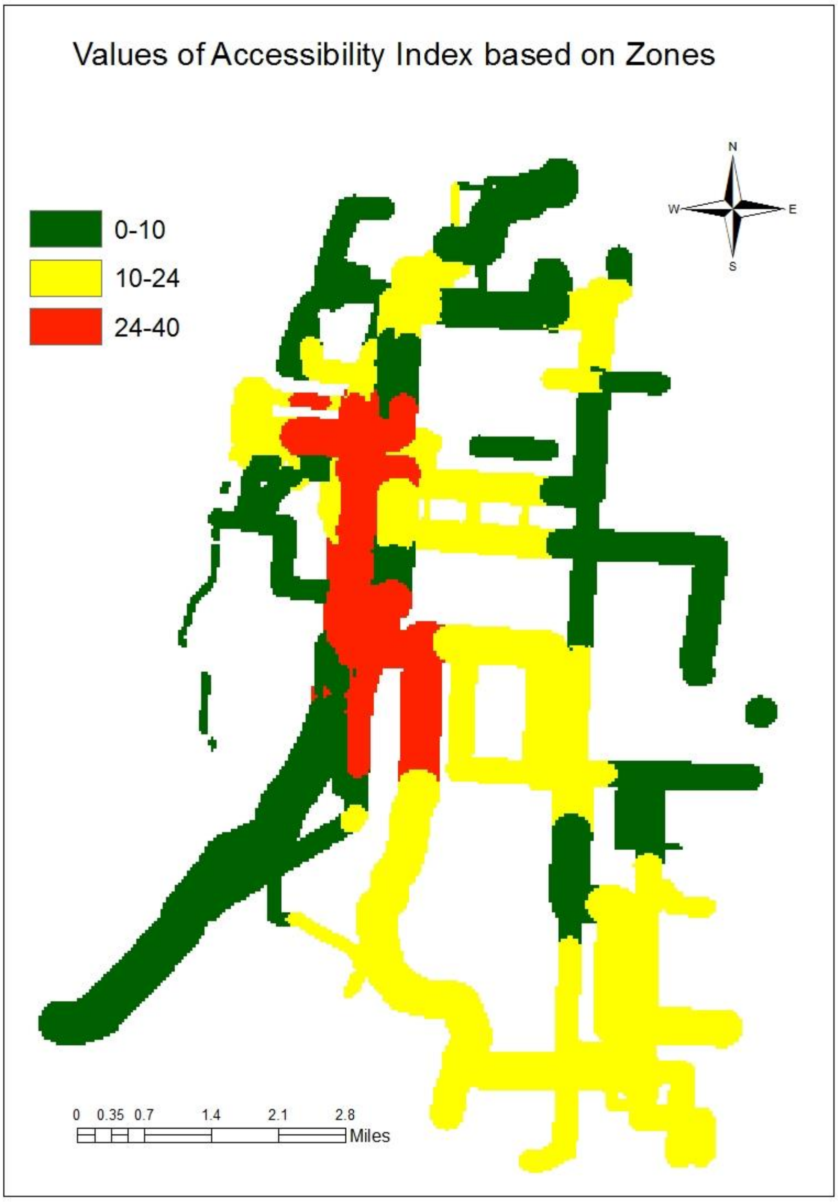

Figure 8. Bus route accessibility index map

5. CONCLUSION

This paper describes the calculation of radial distance (R) based on the service area, population density and served people. The purpose of the study is to estimate the bus service area for Mandalay City. The methods that are used in this study are selected carefully to fit the study area situation.

The process of selecting data is the first step in the phase of collecting data. The data included in the study are collected from government offices and by analysing the raster features in the ArcGIS software. The data involved is route network layer (spatial data) of Mandalay City and daily supply bus system operation data (attribute data) represented the study area and the bus routes. The analysis of buffer is used to create the bus service area according to the results of the calculation. Selection by location function is used to select neighbourhoods in order to determine the levels of accessibility of the affected areas. In the zone (ward) based accessibility measurement, the bus service area covers 26.5 km^2 which represents 30.9% of the total area with approximately 24% (218978) of the total population (899486). In the route based accessibility measurement, there is 67 km good cover length in the total service length of 1350km. The bordering neighbourhoods of the bus service area have a low score of accessibility to the bus routes. The levels of accessibility are determined in this study by three levels; good, fair and inaccessible.

And then, the accessibility index based on walking distances and bus service zones are calculated by using PTAL methodology. The study has been used the basic spatial analysis required for the case study. Finally, these methods have achieved the aim and the purpose of the study.

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