ENGINEER- Vol. XXXXI, No. 05, pp. 116-125, 2008

A GIS Approach to Identify Road Network Improvement Needs

- Case Study of Kaduwela, Sri Lanka

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Abstract: Moving from one place to another has become a major concern in today's context. On one hand there is an increasing financial requirement due to cost of vehicles and escalating fuel price, and on the other hand there is traffic congestion thereby increasing the time spent on the road which is considered as unproductive. One of the most important problems that should be looked at by today's leaders, managers, planners, etc., is the improvements that need to be made to the road network in order to reduce wastage of time, fuel and other valuable resources. In this context it is of great importance for the decision-makers to identify the problem causing area to provide attention by means of prioritizing suitable actions, such as road surface improvements, expanding the carriageway or by providing alternative paths. GIS is a tool which provides opportunities for the rational identification of planning and management alternative utilizing Geographic data and managerial experiences. In this work spatial accessibility of Kaduwela area in the outskirts of Colombo is identified using a simple GIS model which incorporates spatial variation of roads, road condition and population in the context of road network accessibility and road service accessibility. Model results indicates the options for improvements to particular pathways in a priority sequence so that, a manager could identify a temporal sequence to provide attention to relevant spatial extents and identify the improvements to the entire geographic area. An Affected Road Index (ARI) is computed for each of the GN divisions. The present work used ArcGIS software with spatial data of 1:50,000 scale to carryout a multilayer GIS analysis to demonstrate the strength of GIS applications in carrying out spatial resource management for the reduction of road congestion.

Key words: GIS, Road Network

1.0 Introduction

Moving from one place to another has become a major concern in today's context. On one hand there is an increasing financial requirement due to increasing cost of vehicles, escalating price and high driver wages. On the other hand a person has to overcome the resistance from traffic congestion to ensure that the loss of time between the moving points is a minimum because most of the time spent on traveling or travel delays is usually unproductive. The traffic congestion also creates another concern with regard to the threat to lives from terrorist activities. Vehicle using general public feel that there is a greater threat of an explosion or suicide killing in areas of high traffic congestion since the crowd in the vehicles are packed together and helpless. In this backdrop, one of the most important requirements which should be attended to by today's leaders, managers, planners etc., is the improvements that should be made to the road network in order to reduce wastage of time, fuel, and other valuable resources. Therefore, it is of great importance for the decision makers to identify the options to minimize the unproductive efforts when moving between points of concern, through suitable traffic management, carriageway expansion, provision of alternative paths, road surface improvements etc. Geographic Information System (GIS) is a tool which facilitates the planning and management of spatially distributed resources through its capability enabling a decision maker to compare several alternatives with relative ease [10]. A GIS can be used to enable a manager to identify spatial extents that require accessibility

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improvements by utilizing the knowledge on spatial variations of important information combined with available managerial experiences. Therefore GIS as a tool has a great potential to support road and associated infrastructure managers in their efforts to develop a better transport network for the general public.

In mobility improvements efforts, there are many factors that need to be considered. The mission profile has a very important role to play in mobility [2], speed of travel is a key factor on fuel consumption [3] conditional vulnerability of links, link nodes, groups of links is important for accessibility [4], and GIS can play a major role in these activities ranging from simple models to web based applications [5, 9]. The use of GIS and its capability to indicate potential improvements to population accessibility through motorway construction programmers have been highlighted in [6]. This paper presents the potential of GIS for road management through a set of results and methodologies pertaining to a study of carried out to identify road network improvement needs in the Kaduwela area. This work demonstrates the strength of GIS which would contribute to road and associated infrastructure managers in their efforts to develop a better transport network for the general public.

2.0 Study Area

Kaduwela which is located in the western province of Sri Lanka is at close proximity to the National Sate Assembly of the Government of Sri Lanaka which is located in the capital city of Sri Jayawaradanapura Kotte (Figure 1). The

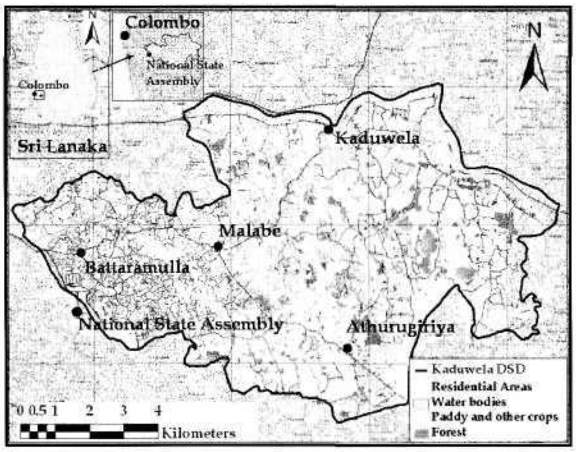

Figure 1 : Study area map

Kotte electorate is located between 60 50' 55" to 60 57' 10" North latitudes and 79° 53' 36" to 80° 2' 44" East longitude. Land use of the area according to the 1:50,000 topographic map [7] is mainly residential (57%) and agriculture (26%) (Table 1). Population in 57 GN divisions totals approximately to 209750. Roads in the area consist of main roads, minor roads and jeep or cart tracks totalling approximately to 280 km. Total area covered by the Kaduwela DSD is 8508 Ha. Data used for the study are indicated in the Table 2.

Table 1 : Study Area Statistics

Table l(a): Land use

Land use Type	HA	%
Commercial	110	1
Forest	62	1
Industrial	167	2
Paddy	1368	17
Public & Semi Public	152	2
Religious	66	1
Residential	4686	58
Vacant Land	182	2
Services & Utilities	48	1
Water Bodies	407	5
Quarry	95	1
Other Crops	744	9
Total	8092	100

Table l(b): Roads

Item	Road Type	Length (km)
01	ASP	1
02	B1	11
03	Minor Road	166
04	Jeep or Cart Tracks	101

Table l(c): Population in GN Divisions

	Total Population	House Units	Non-House Units
Max	**8583**	**2022**	**503**
Min	**1192**	**350**	**9**
Avg	**3680**	**935**	**119**

3.0 Objective

The Objective of the study is to demonstrate a GIS approach to assess the spatial distribution of accessibility within the Kaduwela DSD through an identifying accessibility to Battamulla city centre and then to provide options to facilitate road network improvements.

Table 2: Spatial Data layers used for the study

Item	Data Layer	Description	Layer type	Spatial Zoning
01	Road network layer.	Classifications of roads are available in 1:50000 scale.	Polyline	Roads Distance Buffering, Feeder cluster road density, Road condition density
02	Grama Niladari Boundary Layer	Population boundaries and Grama Niladari Boundaries are available in 1:50000 scale.	Polygon	Population density.
03	Main Cities Layer	Contains main cities in project area. Prepared using Land Use Layer by digitizing at 1:50000 zooming scale.	Point	None
04	Land use Layer	Contains land use classification for project area at 1:50000 scale.	Polygon	Land use Identification Demarcation of water body

4.0 Methodology

The overall process flowchart for the study methodology is shown in Figure 2. Accessibility is the extent to which spatial separation can be overcome. Improvements to transport infrastructure in respective areas has been identified as a key element to overcome spatial imbalances. In case of planning and management of infrastructure, indicators are used quite frequently. There are various examples of indicators ranging from condition assessments to exposure assessments [8, 4] and they are helpful in carrying out comparisons of one spatial location with another. In literature, there is a lack of a single definition for accessibility and therefore, this has been identified or measured in many ways [6]. In order to assess the spatial distribution of accessibility indicators and then to identify the road network improvement needs for Kaduwela, the study identified accessibility as a function consisting of one component due to the physical location of a land parcel and another component which is directly connected to the quality of transport service for that land parcel. In this study the accessibility indicator of a land parcel was taken as that pertaining to the road network and its service status only. Transportation services such as bus, van or motor car were not considered for assessment. Total Spatial Accessibility Indicator (TSAI) of this study considers a spatial location with respect to the capability to travel from that location and identifies the accessibility to a particular location starting from the same spatial entity but through different paths. The study then identifies the changes to accessibility indicator once the road improvements are affected.

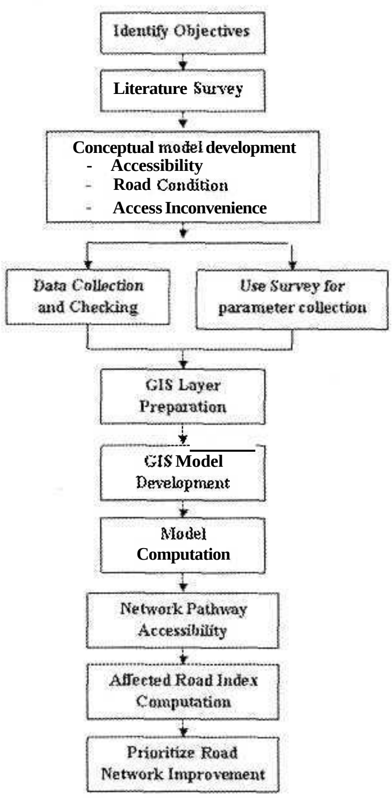

Figure 2: Overall Process Flowchart for the Study

It is assumed that the accessibility indicator of a specific location is a function of the road network accessibility and road service accessibility [8]. Literature survey identified that road network, road type, service status and population in the associated regions directly influence the Total Spatial Accessibility Indicator (TSAI). Road network contribution to accessibility of a spatial location is taken as the

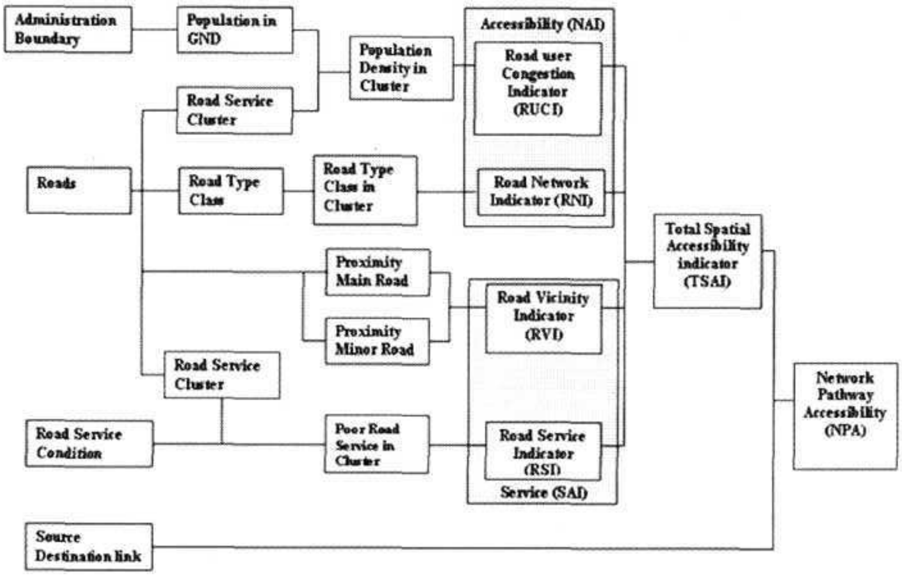

Figure 4: Operation Sequence in GIS Model

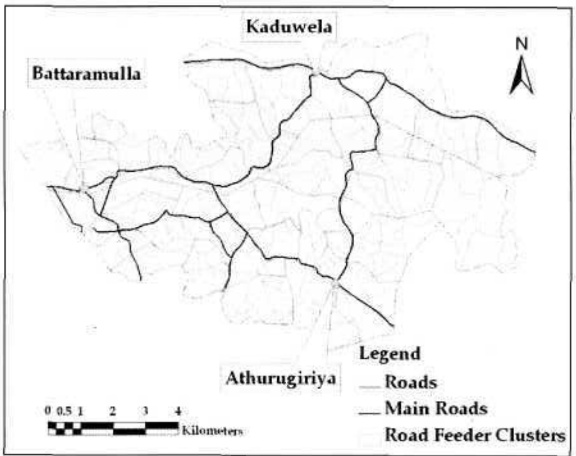

Figure 3: Road Feeder Cluster in the study Area

contribution of the spread of roads within a spatial cluster that serves the selected spatial location. In order to identify the road network accessibility indicator, study area roads were separated into road service clusters. Main and minor roads were studied to assess the spatial areas serviced by each minor road. Reasonable sized spatial extents were demarcated based on the service area and then the direction of flow was established from a particular dwelling to outside. Minor roads contributing to major roads were grouped into these feeder clusters (Figure 3). A conceptual GIS Model (Figure 4) was used to incorporate

Table 3: Description of Indications and Data Layers

	Indicator component	Representation Layer Type	Description
Overall Accessibility Indicator	Road Network Accessibility	Road User/ Population resident	Population creates a competitive environment for travel. Population resident in an area is considered representative of road community.
		Travel distance	Distance to the destination is directly proportionate to the less inconvenience.
		Road Network	network layout and the spatial distribution containing A, B and C class roads.
	Road Service Accessibility	Road capacity	Road capacity is the ability of a road to handle traffic volume.
		Bad Road Segments	Indicated by line features of layer stretchers and bottlenecks
		Bottlenecks	Short road stretches which restrict flow past that location, indicated by point in GIS
		Road Type	Road type indicates different type of roads naming A, B & C. Road types are also indicators of road capacity.

the contribution from the road network and its services (SAI - Service Accessibility Indicater) to the overall accessibility (TSAI). Administrative boundary layer providing details of population according to Grama Niladari Divisions (GND), Roads layer with road type, Road condition layer with poor road sections and the Source-Destination layer with accessibility paths were combined through GIS overlay operation. Network Accessibility Indicator (NAI) was subdivided as Road User Congestion Indicator (RUCI), and Road Network Indicator (RNI). Service Accessibility Indicator (SAI) was considered to consist of contributions from two indicators named Road Vicinity Indicator (RVI) and Road Service Indicator (RSI). Outline of the Indicator and Layer representations are described in Table 3.

The population residing within a feeder cluster was taken as an indicator of the component of road accessibility indicator due to road user congestion (RUCI). Population data were on a Grama Niladari Division basis. Population density value of each GN was used to identify the population pertaining to feeder clusters. GIS overlay of GN layer with feeder clusters enabled the identification of spatial units with uniform population density and these values were used for the computations.

Where Ai and PDGNi are the Area and the Population Density of the ith land parcel, and n is the number of land parcels within the jth

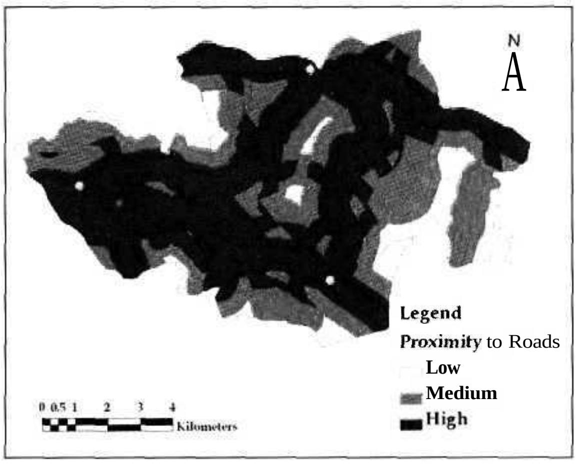

Figure 5- Proximity to Road Layer in the study area

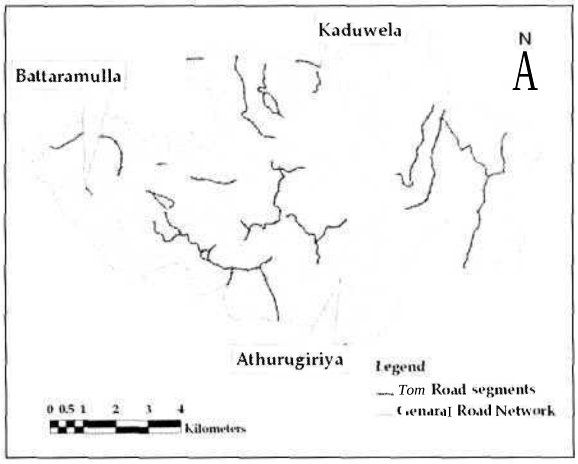

Figure 6- Poor Road segments in Study area

feeder cluster. Road coverage in each feeder cluster was computed as the length of roads per unit area within each cluster. Density of road coverage in each spatial unit was considered as the RNI. Proximity to different road types were identified and spatially zoned to compute the VCI.

Table 4 : User Preference for Road Proximity

Accessibility Rank	Distance Range from Main Road	Preference	Frequency
High	100	0	0%
	300	4	20%
	500	11	55%
	700	4	20%
	900	1	5%
Medium	800	2	10%
	1000	14	70%
	1200	1	5%
	1300	1	5%
	1500	2	10%
Low	500	0	0%
	1000	1	5%
	1500	1	5%
	2000	11	55%
	2500	7	35%

Preferred proximity values were determined through a survey of road users. User survey was carried out on a self selected sample (Tan 2004 [11]) and responses were analyzed for frequency of priorities. Spatial zoning of road vicinity was taken as, up to 500m, 500-1000 m and 1000-2000 m for High, Medium and Low accessibility. Spatial converge of project area beyond 2000 m was also taken to have Low accessibility. An average of approximately 60% user preference value was obtained for the indicated road proximity classification (Table 4). Considering the comparatively high density of road coverage in the project area, the values from sample survey for preference with respect to main roads

Table 5 : Spatial Zoning for the Cumulative GIS overlay model

Accessibility Indicators	Unit	Spatial Zoning of Accessibility		
		Class	Rank	Numeric **Indicator**
RUCI	Person/ha	192.3 - 423.9	L	1
		96.7 - 192.3	M	2
		12.1 - 96.7	H	3
RNI	m/ha	37.8 - 60.3	H	3
		22.1 - 37.8	M	2
		0 - 22.1	L	1
Proximity to Main Road	Meters 500-1000	0-500 M	H 2	3
		1000-2000	L	1
Proximity to Minor Road	Meters	0-250 250-500	H M	3 2
		500-1000	L	1
RSI	m/ha	12.8 - 23.4	L	1
		3.8 - 12.8	M	2
		1 - 3.8	H	3

were reduced by the ratio of the road widths of main roads to minor roads. Major roads were taken to have an average width of 12 meters whereas the minor roads were assumed to have an average width of 6 meters. Road Proximity Layer is shown in Figure 5.

In case of road conditions, a field survey was conducted to identify road segments that were affected by either due to poor surfaces, bottlenecks or due to road width constraints (Figure 6). Road condition layer was attributed to each feeder cluster in order to identify the spatial distribution of RSI. Each layer representing an accessibility indicator component was classified according to a three class qualitative zoning which allocated individual index contributions as High, Medium and Low. This incorporation of a

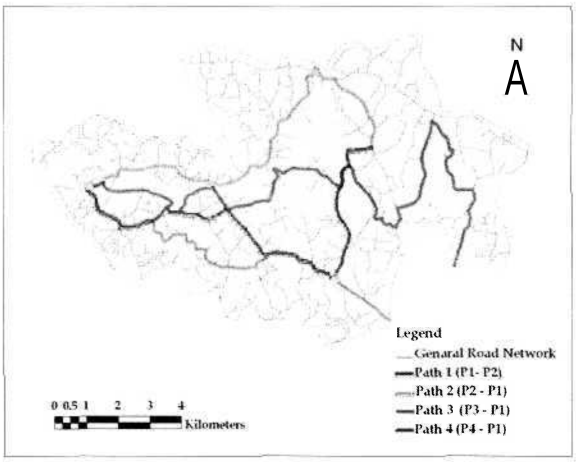

Figure 7- Pathways use for comparative computations

uniform qualitative ranking for spatial zoning identified a non weighted contribution by each functional layer. The Spatial zoning of accessibility qualitative ranks and corresponding numerical representations are shown in Table 5. Since the TSAI is, required to represent the cumulative effect of each functional contribution with respect to a particular spatial unit, ranks of High, Medium and Low respectively were reassigned to the average accessibility rank. Ranking was based on the natural breaks in the frequency curve of indicator values obtained through overlay operation. Population, road length and poor road condition densities for the spatial extents were classified into the qualitative zoning classes according to the natural breaks observed in the spatial distribution datasets of respective parameters. As accessibility depends on source-destination link, a separate line feature dataset was developed to represent several locations that were to access the Battaramulla City Center through different pathways (Figure 7). In the present work the accessibility indicator reflects the ease of access pertaining to a particular location. Therefore, the Network Pathway Accessibility corresponds to the ease of accessing one point from another through a given pathway. The Network Pathway Accessibility was defined as, where n is the number of accessibility layer segments in a given pathway Pj and i denotes the ith segment. Overlay of Source-Destination pathways layer with the spatial accessibility indicator captured cumulative accessibility indicator for a particular pathway which is the Network Pathway Accessibility (NPA).

Road service condition layer enables the identification of poor road condition impact on a particular pathway. An overlay of a revised road condition layer with the other spatial accessibility indicator layers enable the comparison of different pathways resulting from a road network improvement which was reflected in the road condition layer.

Since a resource manager would opt to identify a methodology to prioritize the most needy spatial administration, an Affected Road Index

(ARI) was defined. ARI consist of two sub indices. They are the RUIC which represents the congestion on the roads of a particular area, and the ratio of RSI to RNI which represents the proportion of affected roads in that particular area. Therefore, representing the effects of affected roads and congestion of the spatial extents, the Affected Road Index (ARI) was consist of both sub indices were separately computed in the layer attributetable. In order to ensure uniformity in the representation, the values of both sub-indices were classified to a five class qualitative scale of Very High, High, Medium, Low and Very Low. These qualitative scales were then summed with the use of a numerical representation for the above five classes as 5, 4 3, 2 and 1 respectively. Overlay operation in the GIS model incorporated feeder clusters as uniform spatial extents for computations. Since resource managers would be more accustomed to the regular administrative boundaries, the values obtained for feeder clusters were apportioned to GND

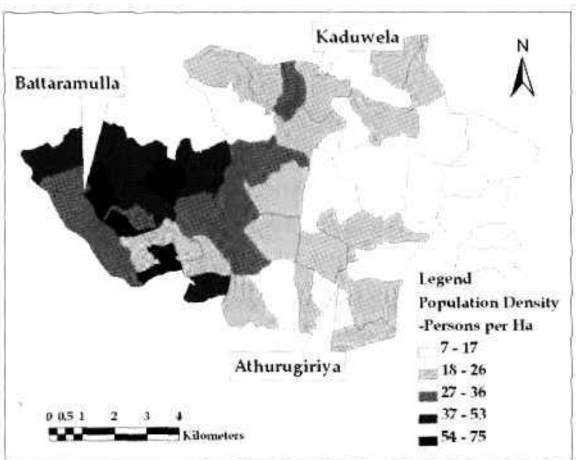

Figure 8- GND Population Density Distribution

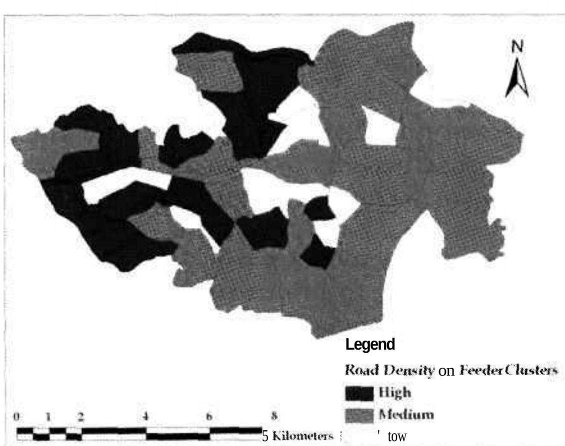

Figure 9 - Road Network Coverage Density

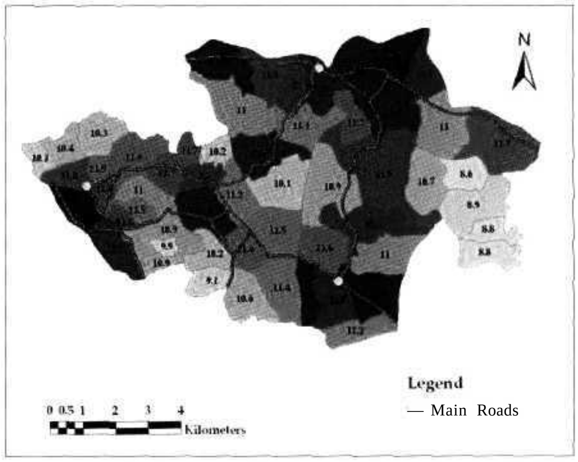

Figure 10 - Total Spatial Accessibility Indicator (TSAI) value for each feeder cluster

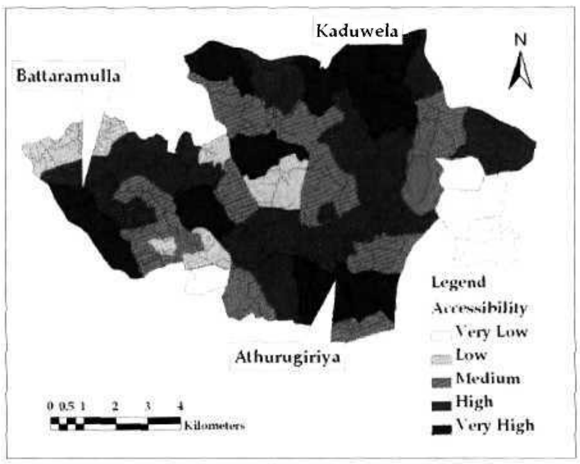

Figure 11 -Five class natural break grouping of the same indicator

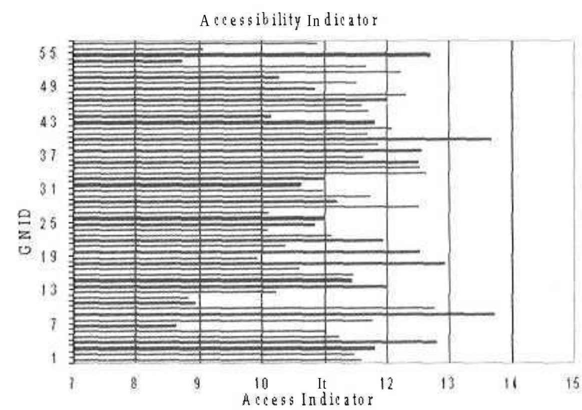

Figure 12 - fiveclass indicator values for GN

Table 6 : GN Identities

GNID	GN NAME	GNID	GN NAME	GNID	GN NAME	GNID	GN NAME
1	Arangala	16	Hokandara North	31	Nawagamuwa	46	Thalangama North A
2	Aruppitiya	17	Hokandara South	32	Nawagamuwa South	47	Thalangama North B
3	Asiri Uyana	18	Ihala Bomiriya	33	Oruwala	48	Thaldiyawala
4	Athurugiriya	19	Jayawadanagama	34	Pahala Bomiriya	49	Thunadahena
5	Athurugiriya South	20	Kaduwela	35	Pahala Bomiriya B	50	Udumulla
6	Batapotha	21	Kalapaluwawa	36	Pahalavvela	51	Walpola
7	Batewela	22	Korathota	37	Pore	52	Wekewatta
8	Battaramulla North	23	Kothalawala	38	Pothuarawa	53	Welihinda
9	Battaramulla South	24	Kotuwegoda	39	Raggahawatta	54	Welipillewa
10	Boralugoda	25	Kumaragewatta	40	Rajamalwatta	55	Welivita
11	Dedigamuwa	26	Mahadeniya	41	Ranala	56	Wellangiriya
12	Embilladeniya	27	Malabe East	42	Shanthalokagama	57	Wickramasinghapura
13	Evarihena	28	Malabe North	43	Subhoothipura		
14	Hewagama	29	Malabe West	44	Thalahena North		
15	Hokandara East	30	Muttettugoda	45	Thalahena South		

Table 7 : Pathway Spatial Accessibility

Pathway	Pathway Spatial Accessibility Indicator
Path 1	**1270**
Path 2	**1110**
Path 3	**1085**
Path 4	**2271**

Table 8 : Spatial Accessibility Indicator for Project Area

Accessibility Indicator	% Area
Very High	5%
High	34%
Medium	21%
Low	20%
Very Low	20%

Table 9: Accessibility Indicators for Project Area

Accessibility Indicators	% Area		
		H M	L
RN1	26%	63%	11%
RSI	11%	41%	48%
RUCI	13%	39%	49%
Proximity to Main Road	24%	48%	28%
Proximity to Minor Road	53%	27%	20%

using an area weighted approach similar to the population apportioning from GND to feeder clusters.

5.0 Results

Population density distribution according to Grama Niladari Divisions is shown in Figure 8. Road network coverage density in the identified feeder cluster is shown in Figure 9.

Total Spatial Accessibility Indicator (TSAI) value for each feeder cluster is shown in Figure 10, while Figure 11 shows the five class natural break grouping of the same indicator. TSAI was aggregated with respect to each GND to enable easy administration of resource allocation and needs assessment.

Figure 12 shows the five class indicator values for GN identities given in the Table 6. Comparative assessment were done on (i) two different path (Path 1 and Path 2) starting from a single spatial location and ending at Battaramulla City Center through different paths, and (ii) two other paths identified as Path 3 and Path 4. Indicator comparison is shown in Table 6. Affected road index values computed for each GN is shown in Figure with the index value of each GN. Summary statistics of the project area for various indicators are shown in Table 7 and Table 8.

6.0 Discussion

The GIS model which assessed the spatial variation of accessibility identified various type of spatial data ranging from lines to polygons. A vector data model was used to overlay geographic data of road layout, road condition and population distribution to identify the Total Spatial Accessibility Indicator using a qualitative conceptual model. The higher the Total Spatial Accessibility Indicator (TSAI) the higher is the easiness to access. Therefore, it can be described that TSAI represents a value

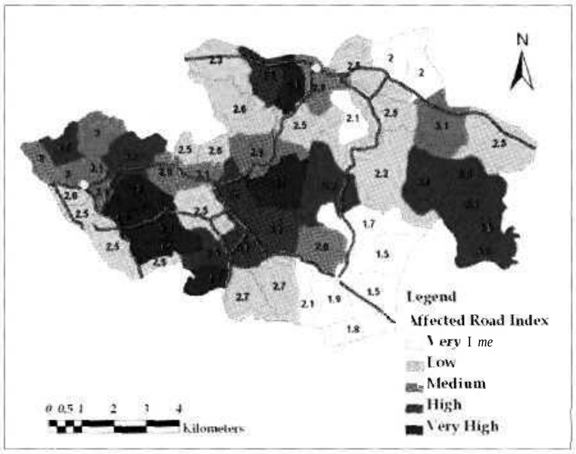

Figure 13- Affected Road Index values computed for each GN

similar to speed of travel. Vector GIS Model incorporated a methodology to capture the accessibility of a network pathway (NPA) by incorporating a line theme along with an overlay aggregation arrangement. This enables the capturing of a relative measure which would be proportionate to the time taken to travel along with particular pathway. Therefore higher the NPA the higher would be the time taken to access a location through that a pathway. The Affected Road Index (ARI) enables a manager to prioritize the GND according to human - physical parameters which affect the accessibility. The higher the ARI the higher is the need to provide assistance to develop the roads in a particular land extent. Therefore, these three indicators developed for the rational management of road infrastructure attempts to reflect three scenarios. TSAI enables a person a to identify land extents or zone with suitable accessibility, while NPA enables a person to select a pathway. ARI provides information to select the spatial extents white requesting early attention. GIS model shows the potential of working with various data types and the strength in the use of models combining both literature cited approaches and conceptual frameworks. A manager or a decision marker may easily use this model by incorporating a line feature dataset indicating a desired pathway and the model could capture an assessment of accessibility. At the same time having noted the data layers, a manager may change the model structure to incorporate one or more data layers to perform suitable GIS computations to arrive at appropriate indicators.

7.0 Conclusions

1.0 A simple model developed for Kaduwela area presented the potential of GIS in the assessment of accessibility, thereby identifying the zones with various degrees of accessibility.

2.0 Incorporation of a user identified pathway dataset together with the Total Spatial Accessibility Indicator would enable a manager to assess the pathway accessibility in a comparative manner by using the Network Pathway Accessibility indicator computations.

3.0 The various sub indices used in the model clearly demonstrate the that such indicators captured on a GIS enable the resource manager to engage resource mobilization.

4.0 The Affected Road Index is an index that could be easily computed on a GIS and which would enable a resource manager to assess priority area for resource mobilization.

8.0 Acknowledgement

The authors wish to extend sincere appreciation of the encouragement given by the management and the staff of Ministry of Defense, and the Centre for Research and Development to publish this work. Support of the ICGAT of University of Moratuwa and its staff is gratefully acknowledged.

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