A GIS based approach: Objectively measured neighbourhood physical environment and walking among adults in Colombo, Sri Lanka

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Abstract

Background: Physical Activity (PA) plays an important role for health. Walking is the easiest way to incorporate activity into everyday life. However, few adults achieve the recommended levels of activity. This study examined the association of the objectively measured neighbourhood physical environment with walking among the adults in Colombo, Sri Lanka through a cross sectional design.

Methods : Primary data collection was carried out to assess the minutes walked, socio-demographic characteristics and geo location of residence. Secondary data was obtained to assess neighbourhood environment from existing spatially referenced data. Geographic Information Systems (GIS) was used to calculate density measures (residential density, land use, connectivity and access) and distance measures.

Results: A sample consisted of 284 adults aged 29-59 years (mean age 40.6 (SD-10.9) years, Female: 56%). Adults reported a mean of 175.8 (SD214.0) minutes/week of total walking out of which, 158.4 (SD-196.6) minutes/week of walking was for transportation and 17.5 (SD-70.1) minutes/week of walking was for leisure. All residential density measures, building foot print area, length of major roads, number of intersections, number of bus stops, and distance to nearest major roads showed significant moderate degree of correlations with total walking, ($p < 0.001$). These results were similar with walking for transportation.

Conclusion: There is indication that neighbourhood features could be associated with walking in Sri Lankan adults. Understanding the relationship between objectively measured neighbourhood physical environment attributes for walking gives insight for designing effective interventions to promote walking. Therefore, future studies in Sri Lanka, should consider a more comprehensive framework including objective and perceived measures of the built environment to evaluate the neighbourhood physical environment to promote walking.

Background

The burden of non-communicable diseases (NCD) s are on the rise in the developing countries and the mortality is reported to be 20–50% higher in Sri Lanka, than in many developed countries [1]. Therefore, the prevention and control of NCD is now considered as a national agenda [2]. Physical inactivity is the fourth leading risk factor for death in the world [3] and its national prevalence stands at 7.3% for males and 13.8% for females from the world health survey 2002–2003 [4]. In the District of Colombo in 2011, 18% of adult males and 20.3% of adult females were reported to be inactive [5]. It also showed that 79.4% walked for transport and only 14.5% walked for leisure.

Many factors are known to be associated with walking and exploration into these are necessary to promote and facilitate walking. Apart from the personal factors affecting walking, positive attributes in the environment have shown to be supportive for walking over the years and in many settings [6, 7, 8, 9, 10, 11]. Environment is usually assessed by assessing perception of the environment or by observations

and many have highlighted the importance of using objective measures to assess the environment to understand better, the relationship between physical environmental attributes and PA [12, 13, 14]. GIS has been used to objectively measure the physical environment over large study areas using publicly available geospatial data and have been used in correlation analysis evaluating the relationship between physical environmental characteristics and the environment variable of interest [15]. The use of GIS assesses spatial relationships and is important to solve public health issues [16]. Although the initial costs for establishing GIS are high, once developed, it would be very useful and convenient for studies where spatial patterns are considered.

Measures of physical environmental attributes such as residential density, land use, intersection density, street connectivity and access and distance to facility are important measures considered in describing the factors in the built environment for PA and walking [17]. Three concepts “proximity”, “connectivity” and “urban design” are identified in the literature to discuss the environment in relation to PA [18]. Proximity refers to how close different travel destinations are to one another in space, and is operationalized in terms of “density” and “land use mix”. Density normally means the concentration of people, dwelling units or households. Land use mix refers to the spatial placement of different types of land uses (industrial, residential, commercial). When land uses are mixed there is greater number of destinations that are close to a person’s home or office. “Connectivity” refers to the number and directness of transportation linkages between destinations [19]. A highly connected neighbourhood has many linkages between destinations and is usually defined in terms of number of road intersections in an area. A highly connected neighbourhood provides more route options for travellers and shortens trip distance, thereby influencing people to use non-motorized forms of transportation. A GIS Based assessment of physical environment across 12 countries used similar built environment features such as residential density, street connectivity, mix of land uses, and access to public transit, parks, and private recreation facilities [20].

There is inadequate information on the contribution of the built environment towards the walking habit of adults in Sri Lanka.

Methods

Study aim, design and setting

We conducted a cross-sectional study in CMC in Colombo District, Sri Lanka. The aim of this study was to assess the objectively measured physical environmental factors associated with walking using GIS in the Colombo Municipal Council (CMC) area Sri Lanka. Colombo is the island's capital, by far the country’s biggest city, as well as the most developed. The main reason for selecting this area was the availability of digital data such as the road structure, land use and other services making it possible to carry out environmental data analysis using GIS. Data collection was carried out from September 2010- February 2011.

Selection of neighbourhoods

Study participants were recruited across 10 *Grama Niladhari* Divisions (GNDs) in CMC, from the 55 existing GNDs using probability proportional to size method A GND was the primary sampling unit, the smallest administrative entity for which information on socio demographics are produced by Department of Census and Statistics in Sri Lanka. The GNDs selected are shown in Fig. 1.

Selection of households and study participant

Within a neighbourhood, 40 households were selected in a systematic manner selecting 400 households. Within a household we selected an adult (20–59 years) who had been residing in the area for a continued period of not less than six months, one each from a household using a random procedure, where recruitment was done irrespective of the availability of the study participants in the house at the time of the first visit.

Primary data collection

Survey measures

The study instrument was a reliable and pre-tested interviewer administered questionnaire. Socio-demographics measures were the age, sex, ethnicity, civil status, educational level, average monthly household income and self-rated health status. Walking was assessed using the International Physical Activity Questionnaire, Long Form (IPAQ). It is a standardized instrument to measure the habitual practice of PA of populations over the last 7 days [21, 22]. This questionnaire is validated for Sri Lanka [23]. Participants reported the frequency and usual duration of each type of activity. They reported the number of days and duration (minutes/hours) of vigorous or moderate intensity activity and walking undertaken during the previous week in the different domains of job, transport, domestic/garden chores and leisure. Thereafter, minutes of walking carried out during transportation and leisure was calculated.

Location measures

The data collectors with a medical background were trained on measuring the coordinates of the housing location. After completing the questionnaire, the coordinates of the locations were recorded using Megallon eXplorist 510 GPS units.

Secondary data collection

We used the population estimates from the most recent available census data in Sri Lanka- 2010 to determine population density [24]. Neighborhood environment characteristics were gathered from the Colombo land use maps (1:50,000) which were the most recent data collected, geocoded and verified by the Survey Department, Sri Lanka. The details of the digital data layers including the scale and format are shown in Fig. 2. No parcel data were available. The variables types were density measures, and distance measures.

Density measures

Density measures were carried out within the 200 m, 400 m and 600 m buffer limit of the participant's residence. All buffers were straight-line buffers as the network structure was incomplete for Colombo. The neighbourhoods were defined by creating a 600 m radius "straight line" around each geo-coded participant's address. Small radii of 200 m and 400 m were also evaluated as it was hypothesised that a smaller area around one's home might be more influential in individual's choice to walk [15]. Residential density was assessed by calculating the population, housing and employment densities within the buffers. Land use measure is a measure of ground covered with buildings, which cannot be used for walking. The number of buildings and the building foot area were then calculated within the buffer zones. Road lengths (both main and other roads) per unit area, intersections per unit area, and number of bus stops per unit area were used to assess access and connectivity.

Layer	Scale	Format
10 m Interval Contours	10 m	DGN and geo database
Spot Heights	11111 m	DGN and geo database
Streams and Rivers	1: 10,000	Coverage
Land Use	1: 50,000	Coverage
Roads	1: 50,000	Coverage
District, DSD, and GND	1: 250,000 and 1: 50,000	Shape files and Coverage
Buildings	1: 10,000	DGN format

Distance measures

Distance to the nearest major roads, nearest beach and the nearest ground/ park was calculated as a measure of distance to facility (Fig. 3) which were all were straight-line distances.

Indices	Concept	Formulae
Density measures for the total buffer area	Population density	No of persons within the buffer / Total buffer area
	Housing density	No of housing units within the buffer / Total buffer area
	Employment density	No of employees within the buffer area / Total buffer
Density measures for the residential area	Population density	No of persons within the buffer / Total residential buffer area
	Housing density	No of housing units within the buffer / Total residential buffer area
	Employment density	No of employees within the buffer area / Total residential buffer area
Built area measures	Number of buildings per total buffer area	Total number of buildings per buffer area
	Building foot print area within the total buffer area	Building footprint area in the buffer excluding vacant or agricultural land uses.
Access and connectivity	Length of major roads within the total buffer area	Length of major road with both interstates and ramps removed per total buffer area
	Length of other roads within the total buffer area	Length of other road with both interstates and ramps removed per total buffer area
	Number of intersections within the total buffer area	No of intersections within the buffer area
	Number of bus stops within the total buffer area	No of bus stops within the buffer area
Distance to facility	To nearest major roads	Straight line distance to nearest major roads
	To nearest beach	Straight line distance to nearest beach
	To nearest park	Straight line distance to nearest park

Analysis

GIS spatial analysis

Quality of data was verified before GIS spatial analysis. The primary data collected, were rechecked for its accuracy 10 housing locations by the experts in GPS. The coordinates of the household were downloaded from the GPS units using the vantage point software and was further visualised using the OZI explorer software. Thereafter, it was converted to shape file format as a point layer by the OZI

explorer software. These were converted from their original spatial reference parameters of WGS84 to Kandawala system to be appropriate for Sri Lanka.

Initially, all the spatial data were converted in to ArcGIS geodatabase data model. Thereafter, a feature dataset was created. ArcGIS 9.3 software and its extensions such as 3D Analyst, Network Analyst, and Data interoperability were used in the study. Further, free extensions available such as Hawth's tools, X tools etc were also used for the various spatial analysis in the study. The physical environmental variables were created and were based on the literature available, especially the GIS protocol developed for the Twin City study [25]. The Concept and formulae in conducting GIS spatial analysis, for the indices are outline in Fig. 3.

Statistical analysis

Statistical analysis was performed using SPSS version 17. Thereafter, the values for the physical environmental variables thus calculated at each neighbourhood level were correlated with minutes walked a week. Statistical significance was set at $p < 0.05$ for assessing associations.

Results

Sample characteristics

Table 1 describes the socio-demographic characteristics study sample. In total, 284 (71%) participants with mean age of 40.6 years (SD = 10.9) provided complete data after exuding participants with missing data. The sex ratio of male to females was 1: 1.2. The major ethnic group was Sinhalese (61%) followed by Moors/Malay (27.8%). Majority (82%) were married. More than half the sample had an education of secondary level or more, with less than 1% having no formal education.

Table 1
Socio-demographic characteristics of the stud sample (n = 284)

Socio- Demographic characteristic	No.	%
Age (years)		
20–29	49	17.3
30–39	84	29.6
40–49	77	27.1
50–59	74	26.0
Sex		
Male	126	44
Female	158	56
Ethnicity		
Sinhalese	174	61.3
Tamil	28	9.9
Moor/Malay	79	27.7
Other	3	1.1
Religion		
Buddhism	152	53.5
Hinduism	23	8.1
Christianity	31	10.9
Islam	78	27.5
Civil status		
Never Married	44	15.5
Currently Married	233	82.0
Separated /Divorced	3	1.1
Widowed	4	1.4
Education(highest achievement)		
No formal education	1	0.4
Grade 5	30	10.6
Grade 6-grade10	105	37.0

Socio- Demographic characteristic	No.	%
G.C.E.O/L	100	35.2
G.C.E.A/L	33	11.6
Higher education (University/diploma/technical)	15	5.2
Average monthly household income (in Rupees)		
30,000 or less	233	82.0
More than 30,000	51	18.0
Self-rated health status		
Excellent	7	2.5
Very good	44	15.5
Good	111	39.1
Fair	116	40.8
Poor	6	2.1

Pattern of walking

The distribution of the pattern of walking among the study sample is shown in Table 2. The mean minutes of walking for transport were 158 minutes a week (SD- 196.6). The minutes walked, a week for leisure was 17.5 (SD-70.1) and the IQR was zero as only 30 persons (10.5%) walked for leisure. Males walked more than females in total. Walking for leisure was observed more among the higher income group and among males. Walking for transport was observed more in the lower income category.

Table 2
Distributions of the pattern of walking by selected socio demographic factors

Characteristics		Walking for Leisure -Mean Min/Week (SD)	Walking for Transport- Mean Min/Week (SD)	Total walking- Mean Min/Week (SD)
Sex	Male (n = 126)	23.2 (74.8)	158.9 (189.6)	182.1 (210.6)
	Female (n = 158)	13.0 (66.2)	157.9 (202.6)	170.9 (217.2)
Age Group	18–29 (n = 49)	12.8 (66.5)	161.7 (179.1)	174.6 (184.6)
	30–39 (n = 84)	9.0 (46.3)	122.8 (178.2)	131.9 (185.9)
	40–49 (n = 77)	24.9 (80.9)	171.7 (215.5)	196.6 (236.8)
	50–59 (n = 74)	22.5 (81.9)	182.6 (205.2)	205.1 (232.1)
Income	Rs 30,000 or less (N = 233)	10.9 (60.8)	161.1 (201.5)	172.0 (221.1)
	More than 30,000 (n = 51)	47.6 (97.7)	145.9 (173.6)	193.5 (178.8)
Total		17.5(70.1)	158.4 (196.6)	175.8 (214.0)

Distribution Of The Neighbourhood Environment Attributes

The physical environment attributes that were assessed around 200 m, 400 m and 600 m buffers showed a non- normal distribution. The values for the 200 m buffer are shown in Table 3.

Table 3
Descriptive statistics of physical environment attributes within 200 m buffer area (n = 284)

Physical environment attributes	Unit	Mean	Standard error of mean	Standard Deviation	Skewness	Kurtosis
Residential density measures within a 200 m buffer area						
Housing density	Houses/km^2	3647.8	119.9	2021.2	0.5	-0.8
Population density	Persons/km^2	20286.2	728.0	12269.08	0.5	-0.9
Employment density	Persons/km^2	7436.3	222.1	3742.58	1.2	1.1
Residential density measures per residential area within a 200 m buffer area						
Housing density	Houses/km^2	203563.8	175692.3	2955602.3	16.8	282.2
Population density	Persons/km^2	989235.0	844940.0	14214091.7	16.8	282.2
Employment density	Persons/km^2	345987.1	296244.3	4983600.9	16.8	282.2
Land use measures						
Number of buildings within the total buffer area	Units	141.6	4.6	78.1	1.8	2.1
Building foot print area within the total buffer area	Units	0.1	0.0	0.0	1.3	2.1
Access and connectivity						
Length of major roads within the total buffer area	m	544.9	26.0	439.6	0.2	-1.1
Length of other roads within the total buffer area	m	2607.2	36.1	608.6	-0.1	-1.3

Physical environment attributes	Unit	Mean	Standard error of mean	Standard Deviation	Skewness	Kurtosis
Number of intersections within the total buffer area	Units	12.3	0.5	7.9	0.7	-0.3
Number of bus stops within the total buffer area	Units	18.5	0.6	10.4	0.9	0.11

Association between neighbourhood physical environment and walking Table 4 shows that all residential density measures, building foot print area, length of major roads, number of intersections, number of bus stops, and distance to nearest major roads showed significant moderate degree of correlations with total walking, in the 200 m buffer zone. The results were similar with walking for transportation with a slightly higher degree of correlation. However, most environment features did not show moderate significant correlations with walking for leisure. A negative significant correlation was observed with the building foot print area, length of major roads for the total walking. Similar correlations were observed in the 400 m and 600 m buffers.

Table 4
Association between neighbourhood physical environment and walking

	Physical environmental attributes	Transportation walking minutes a week		Leisure time walking minutes a week		Total walking minutes a week	
		r	p value	r	P value	r	p value
	Density measures (at 200 m buffer)						
Residential Density	Housing density per total buffer area	0.33	**0.001****	-0.40	0.499	0.29	**0.001****
	Population density per total buffer area	0.33	**0.001****	-0.03	0.568	0.29	**0.001****
	Employment density per total buffer area	0.35	**0.001****	0.09	0.12	0.33	**0.001****
	Housing density per residential area within buffer	0.40	**0.001****	-0.16	**0.01****	0.34	**0.001****
	Population density per residential area within buffer	0.39	**0.001****	-0.17	**0.003***	0.33	**0.001****
	Employment density per residential area within buffer	0.44	**0.001****	-0.15	**0.02***	0.38	**0.001****
Land use	Number of buildings within the total buffer area	-0.09	0.12	0.17	**0.004***	-0.06	0.35
	Building foot print area within the total buffer area	0.21	**0.001****	-0.14	**0.02***	-0.23	**0.001****
Access / connectivity	Length of major roads within the total buffer area	-0.43	**0.001****	-0.10	− 0.09	-0.43	**0.001****
	Length of other roads within the total buffer area	-0.03	0.58	-0.01	0.98	-0.02	0.75
	Number of intersections within the total buffer area	0.29	**0.001****	-0.15	**0.02***	0.25	**0.001****
	Number of bus stops within the total buffer area	0.26	**0.001****	-0.08	− .16	0.23	**0.001****

	Physical environmental attributes	Transportation walking minutes a week		Leisure time walking minutes a week		Total walking minutes a week	
		r	p value	r	P value	r	p value
	Distance measures – straight line						
	Distance to nearest major road	0.20	**0.001****	0.19	0.03	0.20	**0.001****
	Distance to nearest beach	0.14	**0.02***	0.19	**0.01***	0.18	**0.001****
	Distance to nearest grounds /park	0.02	0.77	-0.15	**0.02***	-0.02	0.74

r: Spearman r

p: probability

**- significant at $p < 0.001$

*- significant at $p < 0.05$

Discussion

Few studies have examined the relationship of the built environment and walking in developing countries through a GIS approach. This study is one of the first to examine this association in Sri Lanka. A cross sectional study methodology was adopted like many others studies looking at walking and its association with objectively measured physical environmental attributes using GIS [15]. This study adopted the GIS concepts and formulae derived from the GIS protocol developed for the Twin City Study [25] and adjusted it according to the availability of secondary data, after discussing with the experts in GIS. Although, these data were not collected for the purpose of studies related to PA, similar approaches have been used in many other studies where the secondary data were gathered for other purposes [26] as collecting environment related spatially referenced data is expensive.

This study showed that socioeconomic status explained much of the difference for activity based on gender, age and income level. A person with a lower income was less likely to engage in walking for leisure compared with a person with a higher income. Both male and female respondents were less likely to engage in walking for leisure than walking for transport. However, males engaged more in walking for leisure than females. Low-income individuals may be more likely to walk for transport purposes than higher income individuals. People in low-income households twice as likely to walk compared to the

higher income households [27]. Similarly, in China it was seen that level of PA was higher among the low socio-economic group [28].

In the present study, only mild to moderate correlations between minutes of walking for transport and total walking with objectively measured indicators of residential density and connectivity at the 200 m buffer. This was similar to that observed in the Twin city study where the correlation coefficients ranged between 0.3–0.5 [25]. However, a study done in Atlanta in 2003 which assessed the net residential density (number of residential units per residential area), street connectivity (number of intersections per unit area) and land use mix (evenness of distribution of square footage of residential and commercial development) through a GIS database, showed that all of the above indicators were positively associated with the number of minutes of moderate PA per day.

The present study has limitations that should be recognized. As this study was a cross-sectional design, this prevents assessment of causality. The GIS based study had only five environmental factors. It did not consider some important environmental variables that often are not available in GIS databases. Further analysis from the available data could not be carried out due to logistic and data handling limitations. Network analysis could not be carried out due to incomplete networks in the secondary data. Collecting primary data and carrying out objective measurement through geo-coding was not feasible due to logistic constraints. Therefore, this GIS study explored the possibility of using GIS based data for future studies related to PA and the physical environment in developing countries with limited resources.

However, the strengths of this study was the valid measurement of PA by using IPAQ, which is validated for Sri Lanka. PA was recalled from the previous 7 days, which reduce the possibility of recall bias. Second, the association between PA and the GIS based physical environment attributes such as residential density, land use, connectivity have been assessed using correlation analysis as in many studies [15, 25]. Third, the use of three network buffers specific to neighbourhood is a key strength of this analysis. Neighbourhoods were defined around a radius of 200 m, 400 m and 600 m from the participants residents, which was also the method adopted in the Twin City study [25].

Conclusions

This was the first Sri Lankan study to examine the walking and objectively measured environment attributes in adults. There is an indication that neighbourhood features are associated with walking in Sri Lankan adults. It can be concluded that GIS based studies could be adopted in Sri Lanka in understanding how neighbourhood physical environment attributes for walking affect the walking pattern. This understanding could help in designing effective interventions to promote walking and thereby make the people more active and healthy.

Declarations

Ethics approval

The Ethics Review Committee of Faculty of Medicine, University of Colombo approved the study protocol (reference number EC-09-084) and data collection was carried out after obtaining informed written consent from each participant.

Consent for publication

Not applicable as no individual personal data in any form is presented here.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

SDW –contributed to the design, planning the study, literature search, acquisition of data, analysis and interpretation of the results, drafting the manuscript and revising it critically and has given final approval of the version to be published.

DF - contributed to the planning of the study, assisted in planning data analysis, drawing conclusions and in revising it critically for important intellectual content the preparation of the research paper and has given final approval of the version to be published.

SW -contributed to data analysis, drawing conclusions and in revising it critically for important intellectual content the preparation of the research paper and has given final approval of the version to be published.

JG – contributed to the planning of the study, planning data analysis, drawing conclusions and in revising it critically for important intellectual content the preparation of the research paper and has given final approval of the version to be published.

All the authors have read and approved the manuscript and have given consent for publication.

Availability of data

Data can be made available if there is a request for data

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Abbreviations

CMC: Colombo Municipal Council

GIS: Geographic Information Systems

GNDs:*Grama Niladhari* Divisions

GPS: Geographic information system

IPAQ: International Physical Activity Questionnaire

IQR: Interquartile Range

NCDs: Non-Communicable Diseases

PA: Physical Activity

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Figures

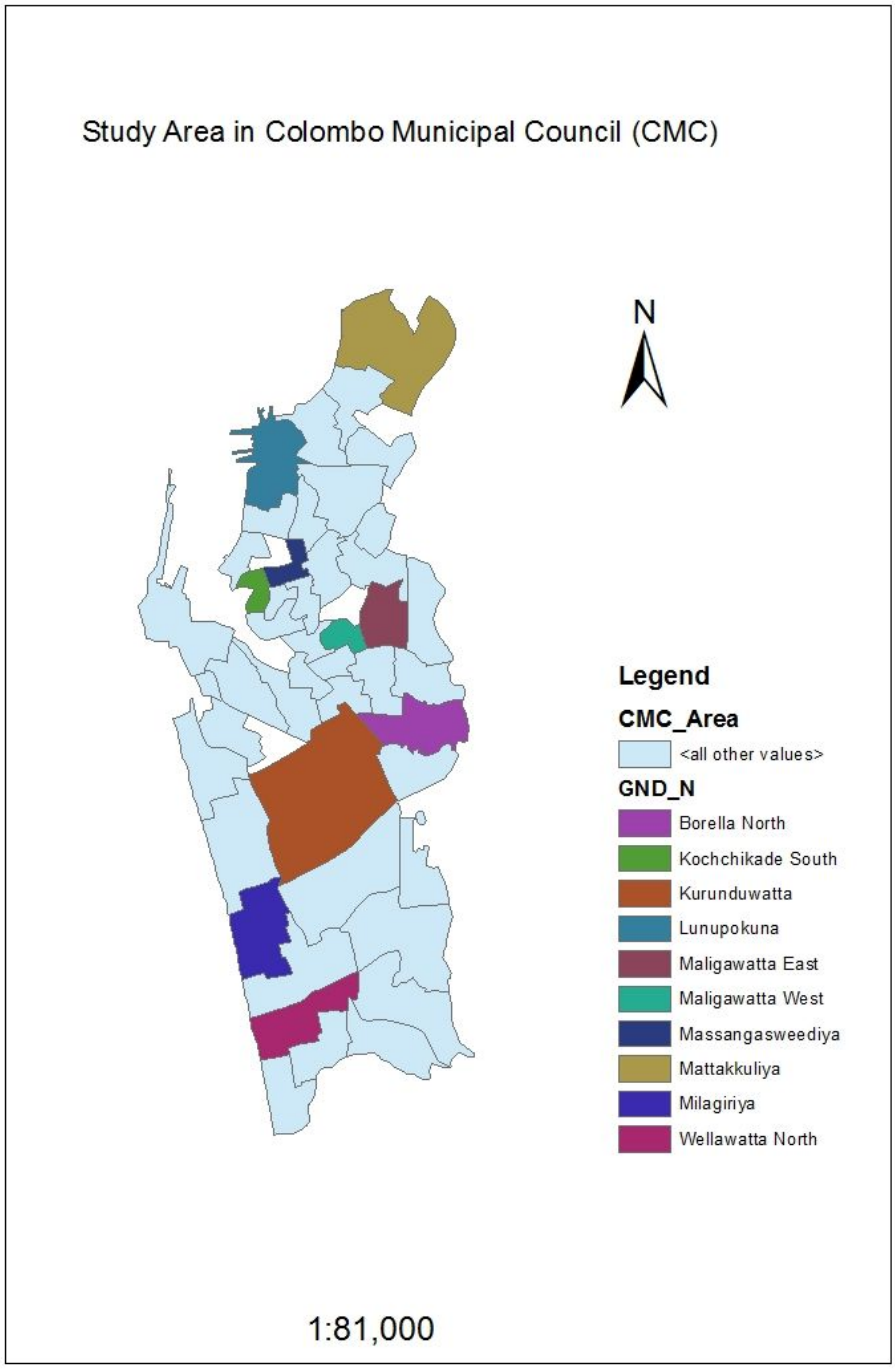

Figure 1

CMC Neighbourhood Study map