RESEARCH ARTICLE

# ANALYSIS OF GARBAGE COLLECTION NETWORK OF COLOMBO DISTRICT USING CENTRALITY MEASURES

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## ABSTRACT

Waste management is a common problem faced by all developing countries. Colombo city faces the biggest garbage problem than other cities in Sri Lanka. Even through many studies were carried out for waste management problem using different approaches, there were very few research findings were available using graph theoretical approach. In this research, applications of graph theory in garbage collection procedure are depicted. The study mainly focuses on analyzing the garbage collection procedure of Colombo municipal council area in western province through constructing garbage collection network and using centrality measures. Centrality measures are used to compute the importance of any node in a network. Colombo municipal area divides into 6 main administrative districts, and each of these is divided into municipal wards with several junctions and streets. Garbage collection network was initially constructed by assigning a node by a location in google map, and an edge by a street or a path between two locations. Constructed network is an undirected unweighted graph and betweenness, closeness, degree, and eigenvector centrality measures are used to find central locations of the network. By identifying central locations, some machines or recycling trucks can be placed in that central places to deposit the waste. Next, a weighted graph was constructed by taking the weights of an edge as a fraction of weight of collected garbage between two locations. Collected garbage weights and betweenness and degree centrality values for weighted graph are used to identify the shortest paths between central nodes in each municipal ward. Garbage collection trucks can be followed this shortest path in order to reduce their fuel cost and collection time.

**Keywords**: *Centrality measures, Between centrality, Network, Degree centrality, Shortest path*

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## 1. INTRODUCTION

Waste management is one of the biggest environmental problems in the world. There are so many environmental impacts in the world such as ground and surface water pollution, soil pollution, air pollution and so on. When the population and urbanization increase, the garbage crisis becomes the major problem in the developing world. In developing countries dumping of waste and collection of waste are the most common troubles. Sri Lanka also faces the global waste challenge. These challenges required local appropriate solutions. To solve this type of problems, garbage authorities in Sri Lanka needs to take some actions under the town council, municipal councils, and provincial councils in order to collect garbage by household level and want to introduce and implement garbage recycling programs, materials recovery programs, composting, waste avoidance, reduction, reuse and so on.

Municipal waste divided into many parts. Domestic waste (exclusive of sewage and hazardous waste), commercial waste (market waste), institutional wastes (schools, hospitals (non-clinical), public offices, etc.), street sweeping and beach cleansing waste, garden waste (tree cuttings and grass cutting wastes). Sri Lanka has the highest amount of waste in the kitchen at 74.6 %, followed by paper and cardboard at 7.8 % and garden waste at 4.8 % [1]. In the waste collection method, municipal council collect these waste and transport to a disposal sites. Waste collection is one of the basic tools of any waste management system. Garbage collection includes collecting garbage from residential, business, institutional, commercial, and industrial factories and other places, load them into a collection vehicle and tow them or transfer to a disposal site. The collection of unsorted and segregated solid waste in an urban area is difficult and complicated.

In this study, we consider the household garbage collection procedure of Colombo city due to its high population. Garbage authorities collect garbage by household level using garbage trucks. According to the literature there were no information about use of graph theoretical approach to analyze garbage networks. This study focuses on use of mathematical techniques to address the challenges in waste collection procedure. In the current situation, municipal council of Colombo is collecting garbage at household level in once or twice a week. In this study, we introduce centralized places of municipal area by using centrality measures and create shortest path including those nodes. Municipal council can collect waste from this central nodes and people can bring their garbage to this point according to the scheduled days. Centrality measures are the basic tools used to identify the central nodes in a network [3]. Centrality measures have been used to analyze several networks including road network, water distribution networks and social networks. Das et al. [4] presented some applications of centrality measures in biology, research, security, traffic, transportation, drug, and classroom. Objective of this study is to find the degree, betweenness, eigenvector and closeness centrality measures of the network in order to find the central locations. Shortest routing can be followed these centrality measures.

## 2. MATERIAL AND METHODS

This research is focused on Colombo municipal council area situated in western province, Sri Lanka. Colombo is a highly environmental polluted city in Sri Lanka. By municipal council website, we obtained the map of garbage collection places around Colombo district as given in the Figure 1. It was divided into 6 administrative districts and each administrative district is divided into at least 6 municipal wards as given in the Table 1. One municipal ward consists of several places and streets, which we considered as garbage collection points.

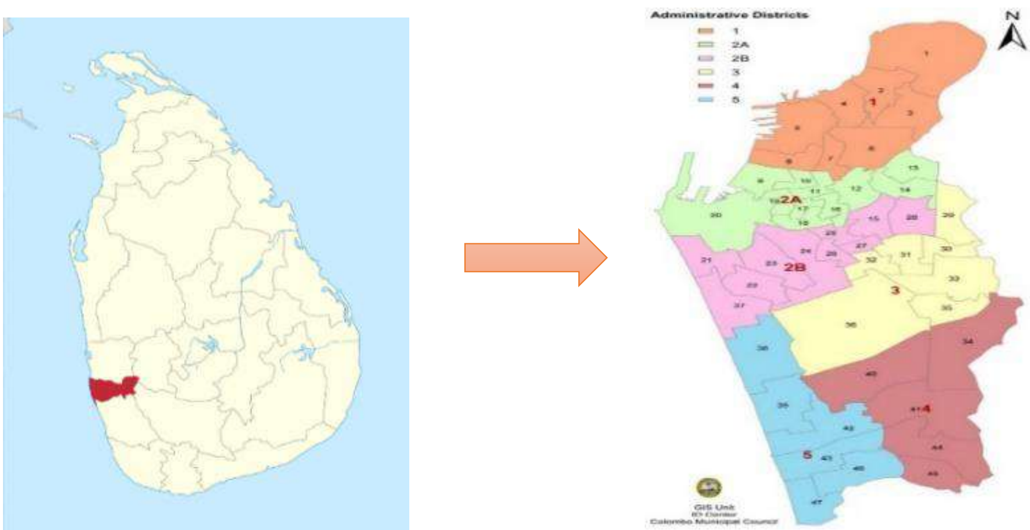


**Figure 1:** City Map of Colombo District

We construct a garbage collection network covering these streets and places, where each node represents a one garbage collecting point (i.e., main street or place) and each edge represents a path between two points. Distances between points are calculated using google map and nodes are taken from municipal council web site. We assume that each street is two ways and therefore we consider undirected network. First, we constructed an unweighted graph and using that, we can find central location of network by calculating centrality measures. Python software is used to develop the garbage networks for each municipal ward and to calculate the centrality measures of that networks. Central nodes can be identified by choosing the highest closeness centrality values of the network.

| Administrative District | Municipal Wards |
|---|---|
| District 1 | Mattakkuliya, Modara, Mahawaththe, Aluthmawatha, Lunupokuna, Bloemendhal, Kotahena East. |
| District 2A | Keselwaththa, Aluthkade East & West, Masangas Weediya, Ginthupitiya, Kochchikade North, Grandpass North, Kochchikade South, New Bazzar. |
| District 2B | Slave Island, Wekande, Hunupitiya, Suduwella, Panchikawatte, Maradana, Maligakanda, Kollupitiya, Maligawatte West, Maligawate East. |
| District 3 | Dematagoda, Wanathamulla, Kuppiyawatte East, Kuppiyawatte West, Borella North, Borella South, Cinnamon Gardens. |
| District 4 | Narahenpita, Kirula, Kirulapana, Pamankada East, Torrington. |
| District 5 | Bambalapitiya, Milagiriya, Havelock Town, Wellawatte North, Wellawatte South, Pamankada West. |

**Table 1:** Administrative district and municipal Wards

## 2.1 Preliminaries

Some of the key terms used to calculate the centrality measures of the garbage collection network is introduced here.

## 2.2 Betweenness Centrality

This measure identifies all shortest paths and how many times each node falling into one in the graphs. Betweenness centrality is important for analyzing communication dynamics. Betweenness centrality is a measure of centrality in a graph based on shortest path.

$$C_B(i) = \left[ \sum_{j<k}^{N} \frac{g_{jk}(i)}{g_{jk}} \right] \frac{2}{(n-2)(n-1)}, \quad (1)$$

where $g_{jk}$, $g_{jk}(i)$, and $n$ are respectively the number of shortest paths connecting $jk$, the number that actor $i$ is on and number of nodes.

### 2.3 Closeness Centrality

Closeness centrality scores each node based on the length of average shortest path between a node and all other nodes in the networks. This measure indicates how close a node is to all other nodes in the network.

$$C_c(i) = \frac{[\sum_{j=1}^{N} \mathrm{d(i,j)}]^{-1}}{(n-1)}, \tag{2}$$

where $d(i,j)$ is the shortest distance between node $i$ to node $j$.

### 2.4 Eigenvector Centrality

Eigenvector centrality is a measure of the influence of a node in a network. Similar to the degree centrality, eigenvector centrality measures a node impact based on the number of degree it has to other nodes in the network.

$$C_i(\beta) = \left[\sum_{j=1}^{N}(\alpha + \beta c_j)\right]A_{ij}, \tag{3}$$

where $\alpha$ is a normalization constant, $\beta$ $d$etermines how important the centrality of the neighbors is, and $A_{ij}$ is the adjacency matrix.

### 2.5 Degree Centrality

This measure is used to find every connected individual, important individuals, who can connect quickly in wider networks. The degree centrality of a node is simply it's degree, the number of edges connect to it.

$$C_d(j) = \frac{\left[\sum_{j=1}^{N} A_{ij}\right]}{(n-1)}, \tag{4}$$

where $A_{ij}$ is the number of edges between node $i$ and $j$.

After calculating centrality measures and finding central nodes of garbage network we can identify the shortest path of the network using garbage weights to reduce garbage collection cost and collecting time. Weighted garbage collection network was constructed using the weight of collected garbage between two locations. A fraction of the weight of collected garbage between two locations is assigned as a weight of an edge. Weight ($W$) of an edge is defined as

$$W_i = \frac{\text{Collected garbage weight at i}^{\text{th}}\text{ edge (MT)}}{775(\text{MT})} \qquad (5)$$

The total amount of garbage collected in Colombo area is 775MT per day in 2016 [2]. By computing betweenness and degree centrality measures of the weighted network, central nodes were selected. Then the shortest path can be identified by including the central nodes.

## 3. RESULTS AND DISCUSSION

A network for each of the municipal council was constructed. Figure 2 shows the network for Mattakkuliya municipal ward in administrative District 1. Degree centrality, betweenness centrality, closeness centrality and eigenvector centrality values for each garbage collection-points were calculated and tabulated in Table 2.

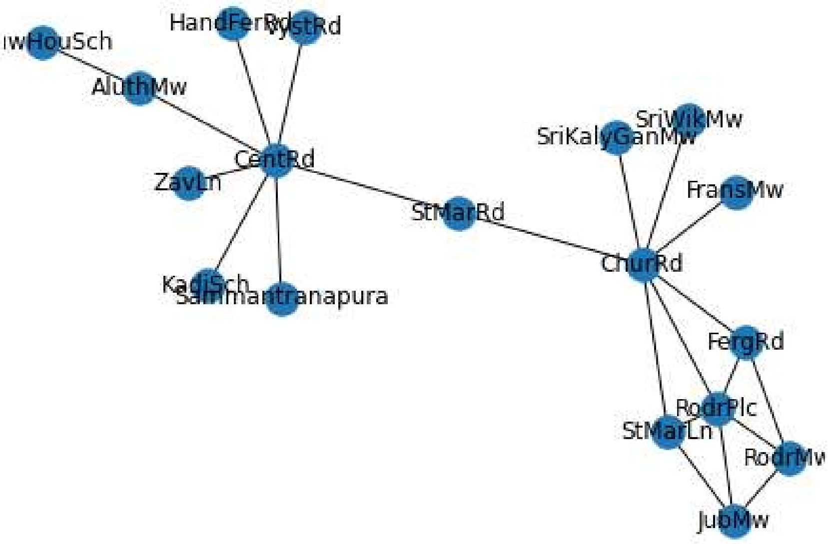


**Figure 2:** Garbage Network of Mattakkuliya Municipal Ward

According to the Table 2, the highest closeness centrality values were obtained for Church Road and the value is 0.48571428571. Closeness centrality value for St Marry's road is also 0.48571428571. Therefore, the Church Road and St. Marry's road can be taken as the central places of Mattakkuliya municipal ward. Garbage network for Mahawaththa and Lunupokuna municipal areas are given in the Figure 3 and Figure 4 respectively. A summary of the results for all municipal areas are tabulated in Table 2.

**Table 2:** Calculations of central nods in Mattakkuliya Municipal Ward

| Garbage Collection Route Names | Degree Centrality values | Betweenness Centrality values | Closeness Centrality values | Eigenvector Centrality values |
|---|---|---|---|---|
| Aluthmawatha Road | 0.1176470588 | 0.1176470588 | 0.3333333333 | 0.022099974 |
| Centre Road | 0.4117647058 | 0.6617647058 | 0.4594594594 | 0.074893807 |
| Zavia Lane | 0.0588235294 | 0.0 | 0.3207547169 | 0.020451797 |
| Vystwyke Road | 0.0588235294 | 0.0 | 0.3207547169 | 0.020451797 |
| Cruw Island Housing Scheme | 0.0588235294 | 0.0 | 0.2537313432 | 0.006035181 |
| Handala Ferry Road | 0.0588235294 | 0.0 | 0.3207547169 | 0.020451797 |
| Kadirana watta Scheme | 0.0588235294 | 0.0 | 0.3207547169 | 0.020451797 |
| Church Road | 0.4117647058 | 0.6654411764 | 0.4857142857 | 0.474081352 |
| Sri Kalyani Gangarama Mawatha | 0.0588235294 | 0.0 | 0.3333333333 | 0.129452589 |
| St Marry's Road | 0.1176470588 | 0.52941176470 | 0.4857142857 | 0.149904387 |
| St Marry's Lane | 0.1764705882 | 0.04779411764 | 0.3617021276 | 0.351445997 |
| Jubili Mawatha | 0.1764705882 | 0.00367647058 | 0.2881355932 | 0.317959042 |
| Rodrigo Mawatha | 0.1764705882 | 0.00367647058 | 0.2881355932 | 0.317959042 |
| Rodrigo Place | 0.2941176470 | 0.10661764705 | 0.3777777777 | 0.495027119 |
| Fergusion Road | 0.1764705882 | 0.04779411764 | 0.3617021276 | 0.351445997 |
| Sri Wikrama Mawatha | 0.0588235294 | 0.0 | 0.3333333333 | 0.129452589 |
| Fransawatta Mawatha | 0.0588235294 | 0.0 | 0.3333333333 | 0.129452589 |
| Sammantranapura | 0.0588235294 | 0.0 | 0.3207547169 | 0.020451797 |

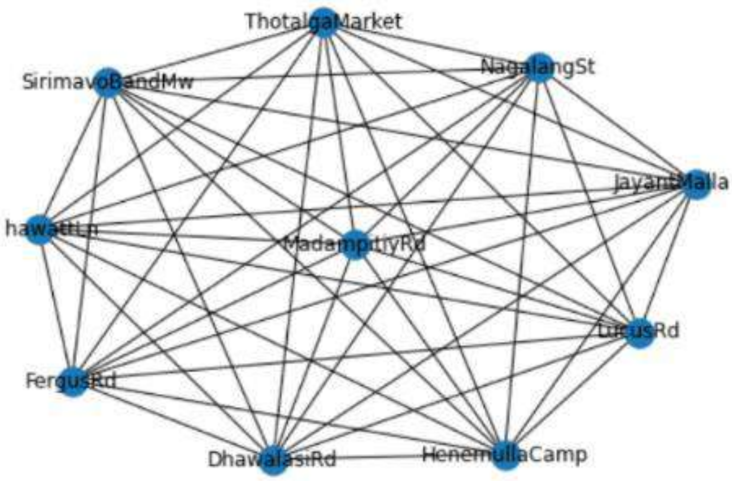


**Figure 3:** Garbage network of Mahawattha municipal ward.

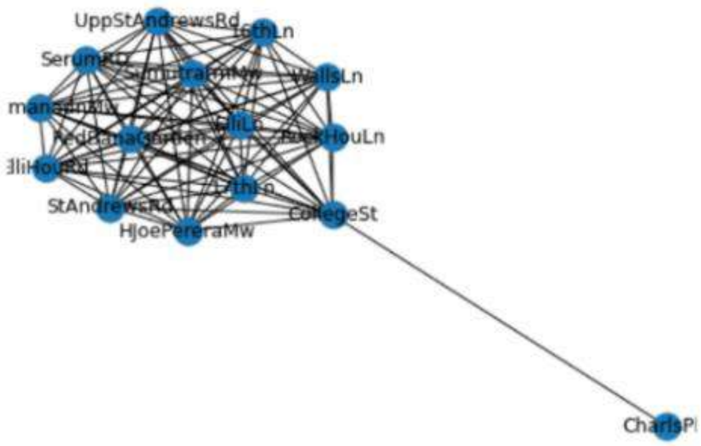


**Figure 4:** Garbage network of Lunupokuna municipal ward

**Table 3:** Summary of the central nodes of all municipal areas

| Areas of municipal wards | Central places |
|---|---|
| Kuppiyawaththa East | Sri Dhamma Mawatha, Ananda Rajakaruna Mawatha, J. D. Fernando Mawatha, Aliyas Place, Karunarathna Abeysinghe Mawatha. |
| Kuppiyawaththa West | Maradana Road, Tichbone Avenue, Ananda Mawatha. |
| Dematagoda | Kolonnawa Road, Sri Mahindadhamma Mawatha. |
| Wanathamulla | Seevali Lane, Mart Terrence, Veluwana Road. |
| Borella North | Seevali Lane. |
| Borella South | Turner Road, Grenier Road. |
| Hospital Squre | D. E. Seram Place, Kincy Road, Kincy Place, Regent street, Hedges Court |
| Green Path | Green Path Road, Flower Road. |
| Townhall Squre | Green Path Road, Red Cross. |
| Gregory’s Road | D. S. Senanayake College, Maitland Crescent. |
| Mattakkuliya | Church Road, St Marry’s Road. |
| Modara | Rajamalwaththa Road, St John Way. |
| Mahawaththa | Madampitiya Road, Dhawalasingherama Road, Jayatha Mallamarachchi Road, Mahawatta road, Nagalangama Street, Fergusion Road, Lucus Road, Sirimavo Bandaranayake Mawatha, Henamulla Camp, Thotalanga Market. |
| Aluthmawatha | Walls Lane, Joseph Dias Lane. |
| Lunupokuna | College Street. |
| Bloemandhal | Mahakumarage Mawatha, Sirimavo Bandaranayake Mawatha, Stadium Gama, Bloemandhal Road, Bloemandhal Flats, 6th Lane, Bloemandhal Lane, Sugathadasa Stadium, Arthur De Silva Mawatha. |
| Kotahena East | Kotahena Street, St Benadic Mawatha. |
| Kotahena West | Pickrings Road. |

| | |
|---|---|
| Narahenpita | Castle Street. |
| Kirula | Elvitigala Road, Abayarama Lane. |
| Kirulapone | Kirulapone Mawatha, High level Road, Polhengoda Road. |
| Pamankada East | Nihal Silva Place. |
| Torrington | Jawaththa Road. |
| Bambalapitiya | Tea Board Lane. |
| Milagirya | Vajira Road, R.A. De Mel Mawatha, Dichmens Road, Gower Street. |
| Havlock Town | Mac Leod Road, Kensingston Garden, Devidson Road. |
| Wellawaththa North | W. A. Silva Mawatha, Fedrica Lane, Manning Place. |
| Wellawaththa South | E. S. Fernando Mawatha, Vihara Lane, Ramakrishna Road, 47th Lane, Moor Road, Boswell Place, Nelson Place, 36th Lane, International Budhdhist Center Road, Vaverset Place, Fernando Road, Rajasinghe Road, E. A. Cooray Mawatha, 42nd Lane. |
| Pamankada West | W. A. Silva Mawatha, Hamdon Lane. |
| Keselwaththa | Mihindu Mawatha, M.D. Gunasena Road. |
| Aluthkade East & West | Meeraniya Street, Hulfdrof Street, Peersaibo Lane. |
| Masangas Weediya | Massenger Street. |
| Ginthupitiya | Wolfendhal Street, New Chetty Street, Ginthupitiya Street. |
| Kochchikade North | Sea Street, Ratnam Road. |
| Grandpass North | Grandpass Junction, St joseph Street. |
| Kochchikade South | Sauder’s Place, Dias Place. |
| New Bazzar | Sumanatissa Mawatha,, Jethawanarama Road. |

**Cost effective routing:** Fuel cost of trucks and the garbage collection time can be minimized by identifying the shortest path. To optimize this path, betweenness centrality measure with weighted edges can be included to the garbage network. Weights of the edges are assigned as the collected garbage between two places. According to the literature, total amount of garbage collected in Colombo area is 775MT per day in 2016 [2]. Since there are no data available for weight of collected garbage at each location, we use random values for the simulation purpose. We weight the edges of network using the proportion of weight of garbage collected in Colombo area. Define,

$$W_i = \frac{\text{Collected garbage weight at i}^{\text{th}}\text{ edge (MT)}}{775(\text{MT})}$$

Due to the unavailability of the data, collected garbage weight at $i^{th}$ edge is assigned by a random number. For an example, for the Mattakkuliya municipal ward in D1, a weighted network was constructed using weighted edges $W_1$, $W_2$, $W_3$, $W_4$, $W_5$, $W_6$, $W_7$, $W_8$, $W_9$, $W_{10}$, $W_{11}$, $W_{12}$, $W_{13}$, $W_{14}$, $W_{15}$, $W_{16}$, $W_{17}$, $W_{18}$. $W_{19}$, $W_{20}$, $W_{21}$, and $W_{22}$.

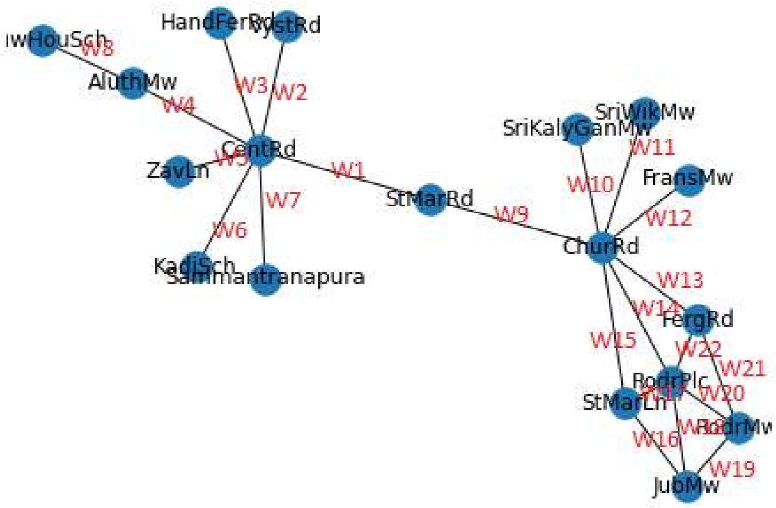


**Figure 5:** Garbage Network of Mattakkuliya Municipal Ward with Weights

Next, the degree centrality values and betwenness centrality values of weighted network of Mattakkaliya municipal ward were calculated. Define the Degree Centrality for weighted graph as,

$$C_d(j) = \frac{\left[\sum_{j=1}^{N} w_{ij}\right]}{(n-1)}, \tag{6}$$

where $W_{ij}$ and $n$ respectively denote weight of edges between node $i$ and $j$, and number of nodes. Then, the degree centrality measures are:

$C_d$ (Aluthmawatha Road) = $[W_8+W_4]/(n - 1)$

$C_d$ (Centre Road) = $[W_1+W_2+W_3+W_4+W_5+W_6+W_7]/(n - 1)$

$C_d$ (Zavia Lane) = $[W_5]/(n - 1)$

Similarly, Betweenness centrality for weighted graph was defined as,

$$C_B(i) = \left[\sum_{j<k}^{N} \frac{g_{jk}(i)}{g_{jk}}\right] \frac{2}{(n-2)(n-1)}, \tag{7}$$

where $g_{jk}$ is the number of shortest paths connecting $jk$, and $g_{jk}(i)$ is the number that actor $i$ is on.

$C_B$ (Aluthmawatha Road) = $[9W_1 + W_2 + W_3 + 14W_4 + 2W_5 + W_6 + W_7 +15W_8 + 8W_9 + W_{10} + W_{11} + W_{12} + 1.5W_{13} + W_{14} + 1.5W_{15} + 1.5W_{16} +0.5W_{21}]\ 2/(n-1)\ (n-2)$;

$C_B$ (Centre Road) = [64$W_1$ + 15$W_2$ + 16$W_3$ + 26$W_4$ + 29$W_5$ + 16$W_6$ + 16$W_7$ + 13$W_8$ + 57$W_9$ + 6$W_{10}$ + 8$W_{11}$ +7 $W_{12}$ + 11$W_{13}$ + 7$W_{14}$ + 11$W_{15}$ + 4$W_{16}$ + 4$W_{21}$] 2/(n-1) (n-2);

$C_B$ (Zavia Lane) = 0.

By using the above degree centrality and betweenness centrality, it is possible to identify the priority nodes. The following example calculate the priority nodes of Mattakkuliya municipal ward in D1, assigning the randomly generated values to the weight of garbage.

**Example:** Suppose $W_1 = 40$, $W_2 = 15$, $W_3 = 20$, $W_4 = 35$, $W_5 = 7$, $W_6 = 12$, $W_7 = 25$, $W_8 = 50$, $W_9 = 45$, $W_{10} = 10$, $W_{11} = 13$, $W_{12} = 23$, $W_{13} = 11$, $W_{14} = 15$, $W_{15} = 18$, $W_{16} = 6$, $W_{17} = 8$, $W_{18} = 14$, $W_{19} = 9$, $W_{20} = 10$, $W_{21} = 12$, $W_{22} = 8$.

Then the betweenness centrality and degree centrality values were calculated for the weighted graph of Mattakkuliya municipal ward.

By comparing weighted degree centrality values and weighted betweenness centrality values we can find optimum nodes and the path. Accordingly, Aluthmawatha Road, Centre Road, Church Road, St Marry's Road and Rodrigo Place are the priority nodes. Therefore, we can conclude that this path is the shortest path of Mattakkuliya municipal ward in D1. By proceeding this method with the actual data, it is possible to find the cost effective garbage collection routing. Then the garbage trucks can follow this route to collect garbage, or they can install garbage bins there.

**Table 4:** Calculated centrality values of Mattakkuliya municipal ward

| Betwenness Centrality Values | Degree Centrality Values |
|---|---|
| $C_B$ (Aluthmawatha Road) =15.92279 | $C_d$ (Aluthmawatha Road) = 5 |
| $C_B$ (Centre Road) = 109.72058 | $C_d$ (Centre Road) = 9.0588 |
| $C_B$ (Zavia Lane) = 0 | $C_d$ (Zavia Lane) = 0.41176 |
| $C_B$ (Vystake Road) = 0 | $C_d$ (Vystake Road) = 0.88235 |
| $C_B$ (CruwIsl and Housing Scheme) = 0 | $C_d$ (CruwIsl and Housing Scheme) = 2.94117 |
| $C_B$ (Handala Ferry Road) = 0 | $C_d$ (Handala Ferry Road) = 1.17647 |
| $C_B$ (Kadirana Watta Scheme) = 0 | $C_d$ (Kadirana Watta Scheme) = 0.70588 |
| $C_B$ (Church Road) = 60.72058 | $C_d$ (Church Road) = 7.941176 |

| | |
|---|---|
| $C_B$ (Sri Kalyani Gangarama Mawatha) = 0 | $C_d$ (Sri Kalyani Gangarama Mawatha) = 0.588235 |
| $C_B$ (St Marry′s Road) = 56.32352 | $C_d$ (St Marry′s Road) = 5 |
| $C_B$ (St Marry′s Lane) = 4.56617 | $C_d$ (St Marry′s Lane) = 1.88235 |
| $C_B$ (Jubili Mawatha) = 0.05514 | $C_d$ (Jubili Mawatha) = 1.70588 |
| $C_B$ (Rodrigo Mawatha) = 0.07721 | $C_d$ (Rodrigo Mawatha) = 1.82352 |
| $C_B$ (Rodrigo P lace) = 9.91911 | $C_d$ (Rodrigo Place) = 3.47058 |
| $C_B$ (Fergussion Road) = 4.65808 | $C_d$ (Fergussion Road) = 1.82352 |
| $C_B$ (Sri Wickrama Mawatha) = 0 | $C_d$ (Sri Wickrama Mawatha) = 0.76470 |
| $C_B$ (Fransawatta Mawatha) = 0 | $C_d$ (Fransawatta Mawatha) = 1.35294 |
| $C_B$ (Sammantranapura) = 0 | $C_d$ (Sammantranaoura) = 1.470588 |

## CONCLUSION

Colombo city faces biggest garbage problem compared to other cities in Sri Lanka. This study primarily focuses on identifying the central places within each municipal area of Colombo city using centrality measures. A garbage collection network is constructed for each municipal ward with main street or garbage collection routes serving as nodes. Degree centrality, betweenness centrality, closeness centrality and eigenvector centrality measures are employed to identify the central places in the network. Furthermore, the collected garbage weights and centrality measures are utilized to determine the shortest path thereby minimizing transportation cost and collection time. Based on the identification of the central nodes in the network, it is recommended to install additional garbage bins or recycling trucks in order to optimize the collection procedure.

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