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An order fulfilment location planning model for perishable goods supply chains using population density

Chamath Ekanayake [a], Yapa Mahinda Bandara [b], Maxwell Chipulu [b], Prem Chhetri [c]

[a] University of Greenwich, United Kingdom
[b] Edinburgh Napier University, United Kingdom
[c] RMIT University, Australia

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ABSTRACT

The increased frequency of purchases and growing distances between the final distribution points of the perishable products and consumers are contributing to multiple handling, high intermediation, and a greater concentration of outlets selling perishables goods. These in turn have increased logistics costs, and inefficiencies in the supply chain. This study presents a modelling framework for locating perishable goods order fulfilment centers (OFC) near the consumer by using population density as a proxy for demand. The centrality and Borda count measures are used to identify optimal locations in perishable goods supply chain networks. We present a case study to demonstrate the applicability and efficacy of the proposed density-based spatial methodology.

1. Introduction

With increased population and growing income levels, the demand for perishable products has significantly increased in developing countries. The demand for fresh food is also accelerated with increased awareness of healthy lifestyle, choices and labelled nutritional quality [1]. Compared to the Fast-Moving Consumer Goods (FMCGs), the research on perishable goods supply chains has attracted little attention until recent years. The supply chain of perishable products is more complex as they are time-sensitive, costly and required stringent material handling requirements such as storage, monitory and refrigerated transportation. Perishable and semi-perishable goods consist of dairy products, meat, eggs, seafood, vegetables & fruits. The lifetime of agricultural perishables is different from each type and, impacted by various external factors such as preharvest and postharvest factors, and conditions under which goods are stored. The quality and functionality of items, in storage or transit, deteriorate over time. The value of perishables such as fresh vegetables, fish and fruits degrades with time while other perishables such as blood have fixed lifetimes and cannot be used beyond its expiry [2]. Therefore, logistics management of time-sensitive goods need to be integrated in terms of production, distribution, and transportation. In addition, for vegetables and fruits, preharvest factors includes fertilizer application, pruning, cultivation type, and irrigation; while the temperature and relative humidity in storage, physical handling, handling methods, geographical location of storage and distribution are some of the postharvest factors affecting food waste [3,4].

Due to the perishability, appropriate logistics provisions are required to transport agricultural products from the farm gate to the final consumer. However, the existing perishable supply chains have a high lead time due to the involvement of intermediaries, longer distances from production to the final consumer, and inadequate infrastructure for handling goods [5]. When considering the intermediaries in the context of developing countries, the existing perishable supply chain comprises of many intermediaries which are farmers, vegetable collectors, traditional wholesalers, regional vegetable collecting centers, central purchasing centers, vegetable suppliers, supermarkets, and small sized selling outlets [6]. Due to the high number of intermediaries, the final market prices of perishable goods to the consumer are relatively higher. The geographic location of distribution centers is one of the important intermediaries, which serves as the final wholesale point connecting the final customer with the order fulfillment centers (OFC).

In recent years, the frequency and demand volatility of perishable goods have increased in buying behavior [1]. Higher consumption and shorter lifetime of the perishable products may have resulted in frequent purchases and delivery of perishable goods. Therefore, the trips generation for the order fulfilment centers is high as the customers make frequent visits to order fulfilment centers to buy perishable products creating not only a high demand for the perishable goods in order fulfilment centers also a pressure on the regional transport network. This high demand does not depend on the buying location, or the dis-

E-mail address: Y.Bandara@napier.ac.uk (Y.M. Bandara).

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tance to the buying location. Further, the demand decision has a low dependency on the price therefore the demand for such goods is price inelastic.

This paper focuses on the location point of a regional order fulfillment center and develops a model to help distribute and reduce wastage of perishable goods efficiently and effectively. This paper is organized as follows. Section 2 present the literature review followed by the methodology in Section 3. Analysis results and Discussion is presented in Section 4. Section 5 concludes.

2. Literature review

Location decisions involve determining the geographical positioning of a facility by considering its interactions with supply chain participants such as customers, suppliers, retailers, households and other complementary facilities. Literature on location analysis address questions around determining facility location, the number of facilities, and their capacities, and allocating the demand for the facilities' services. In urban logistics networks, the perishable goods order fulfilment centers are generally located in relatively less densely populated areas and often in urban and industrial zones (Fig. 1).

Therefore, perishable goods need to be transported to consumers concentrated in residential areas from the fulfilment centers via urban retail networks. This logistics networks and spatial arrangement of urban spaces do not support the near just-in-time service delivery of perishables in densely population areas; whilst resulting in an excess supply of perishables in less densely population areas. Thus, consumers are required to travel a significant distance to purchase goods which cost additional time and money. The accessibility to perishable goods-based order fulfilment centers can be improved by way of reducing the distance, time, cost, and the lead time. Other distribution models with the aid of ordering IT platforms can also be effectively adopted. The extant literature has provided assortment of distribution models for logistics services, in all most all cases, the location was taken as given. The location was critical in supply chain and inaccurate decisions on location and loopholes in regional distribution planning can be costly to the overall perishable supply chain operations and management. In addition, inventory optimization and route planning are other key decision-making parameters in facility location-allocation models [1].

A large number of research focus on optimizing the delivery/distribution of perishable goods in urban settings. Much of the concentration has been on reducing traffic congestion and pressure on infrastructure [7], the balancing transportation and inventory holding costs and lost sales [6], efficient urban vegetable distribution and lowering transportation and economic costs (monetary and emission) [8–10], transport cost, time, distance and uncertainty in demand [11], satisfying a higher customer base, lower construction cost and the timeliness of the distribution [12], optimizing the capacity and time [13], the total deterioration value (TDV) and minimize distance travelled, and maximizing the delivery frequency [14], and the number and the area coverage, lowering supply chain cost and preserving the freshness of perishables with an efficient distribution channel [1,15], minimizing overall supply chain cost (infrastructure construction costs, transportation costs, inventory costs, and freight losses) [16], and the use of online platforms [17]. Yet only a small number of studies focus on location decision of a distribution/logistics center based on the most important parameter that affect most aforementioned factors, which is demand. The population density can be used as a proxy for demand [18]. Various spatial and non-spatial factors influence location selection decision of a logistics center [19]. However, the demand for goods, proxied by population density and its distribution was explicit. As the key to perishable goods distribution is the demand fulfillment within a short time period to minimize supply side losses, the proximity to the consumer is thus vital [20]. This can be achieved by locating the order fulfilment center near to the consumers considering the population density and its distribution. Locating an order fulfillment center in a highly concentrated demand area can reap number of benefits and also complement most of routing-based solutions for urban supply chains of perishable goods.

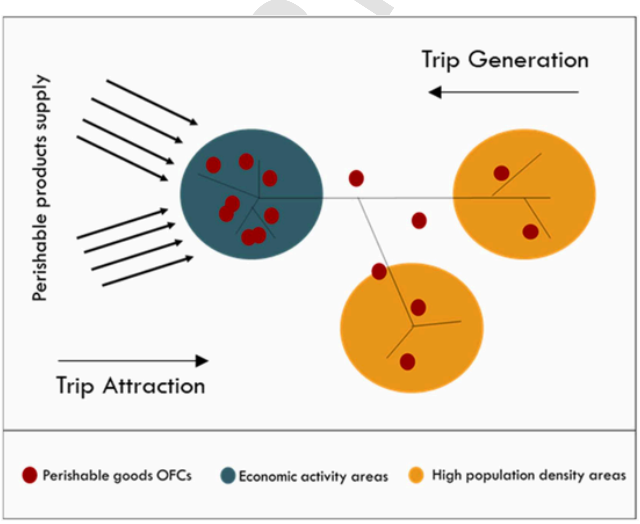


Fig. 1. Existing Perishable goods OFC location arrangement.

In this section, the relevant literature in perishable goods and supply chain planning (2.1), the nature of demand for perishable products (2.2) and location allocation problem for general goods and perishable goods distribution centers (2.3) are reviewed and presented.

2.1. Demand for Perishable goods and supply chain planning

The effect of perishability limits the amount of stocks that can be stored to fulfill the customer demand. The quality of products deteriorates over the time leading to spoilage and waste. Therefore, perishable goods needs to be stocked to align with demand volatility and frequency [6]. Perishables accounts for a larger portion of daily food intake of consumers. The quality of perishable goods decreases gradually even the shelf life increases by improved storage technology [21]. Fatemi, Ghomi and Asgarian [21] proved that as the time on sale of the perishable good increases, the demand for the good decreases resulting in lost sales.

The demand for perishables is influenced by several factors. These factors are beyond the conventional demand determinants (e.g. price and substitutability). Orjuela-Castro et al. [22] identified that the consumption of the agricultural products significantly depends on gender, income levels, education, and knowledge [23]. Weatherspoon et al. [24] analyzed consumers' fresh vegetable purchasing behavior using a data obtained from nonprofit groceries and found that consumers' respond to prices even though their incomes are similar to an average American. Despite the accessibility concerns, the low-income factor limits the purchasing quantity and consumption of vegetable and fresh fruits, demonstrating that there are serious demographic factors affecting the perishable goods demand. In response to this, many city governments are now promoting urban farming to shorten the distance or transport mile of perishable goods to selling points. The main objective of such planning approach is to produce food in areas where the population density is higher and to optimize transportation cost and connect the consumer to the food market systems directly. However, the drawback of this approach is that the space for urban agriculture requires roughly one third of total world urban area to meet the urban agricultural good demand [25]. Because of the space and time constraints, unlike residents in rural areas the urban population do not have the space to grow agricultural foods in their backyards [1].

For perishable goods, a strategic alignment of supply chain and is important for its seamless functions. Fig. 2 illustrates an integrated net-

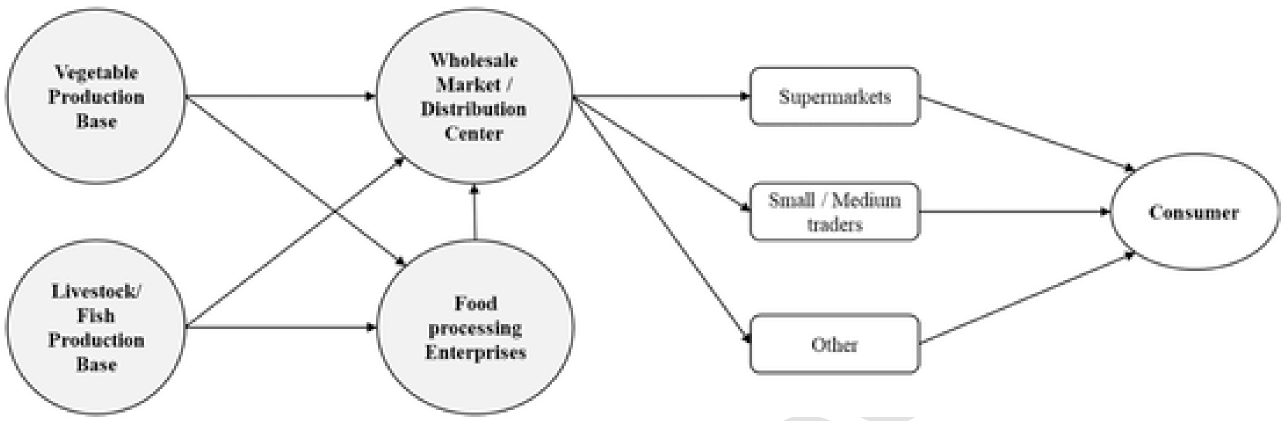


Fig. 2. Integrated network architecture of a perishable product supply chain [26].

work architecture of a perishable goods to enhance supply chain efficiency.

Gong, Li, Liu, Yue, and Fu [26] presented an integrated network architecture comprising of collection and distribution of perishable products performed by the distribution center or the wholesale market. This framework proved to maintain the quality of products in transit, smooth flow of goods, efficient processes and less wastage with a low final price for perishable products. This framework can be further improved by eliminating intermediaries and bringing distribution centers. In this paper we referred the concept of DC as ‘order fulfilment centers’, operating in closer proximity to demand points/locations where the final consumers are spatially concentrated.

Ahumada and Villalobos [27] states that there is a lack of models to manage distribution and inventory control of agricultural perishable goods in the real-world scenarios. However, the emergence of supermarket chains has majorly become the current solution for the idea of eliminating the intermediaries from the perishable good supply chain. In Chinese perishable good markets in the earlier stages the network consisted of several small to medium warehouses and retailers delivering products to customers. With the development of technology, it has transformed into a very few distribution centers integrated with supermarket chains [28]. The supermarket chains used cold chains to store perishables, and distribute within the chain to offer for sales as retails. Neverthless, the evidence from developing contries suggest that the perishable supply chains are complex and comprise of several channels to deliver goods to final consumers [5].

Perishable goods transportation incurs a higher transportation and logistics cost due to high volume, multiple handling, and frequency demand. Sánchez-Díaz [29] studied urban freight generation in Gothenburg, Sweden with a set of models developed using regression analysis and discrete choice models. The results explained that the retailers of perishable goods show the highest freight generation from peripheries to urban areas. This is because consumers in urban areas are highly concentrated and have a higher level of demand for agricultural food products. The reason for higher concentration of people is internal migration to cities and a high population growth in the urban areas. This has created a complex distribution network within urban areas, and increased needs and spontaneous trips to marketplace and/or online ordering through platforms. This in turn has created a dense transport/delivery network with multiple and haphazard development of storage and logistics centers for dispatching goods.

2.2. Location allocation problem for perishable product distribution centers

A distribution center is a major node in the perishable agricultural supply chain. Its location determines the level of efficiency and effectiveness of the supply chain [30]. Most studies on the inventory routing or distribution center selection problems have not considered perishability of the goods or excluded perishable goods. Generally, optimization of facilities has only limited to either up to the central distribution centers (DC was taken as explicitly determined) or to the whole distribution network. The main factors considered are the costs such as transportation, wastage, time [31]. When deciding order fulfilment center locations, population density, space, transportation infrastructure, land cost, accessibility, environmental factors, parking space, geographical distribution of population and also adaptability and adjacency, capability and capacity are found to have significant impact on optimal locations [32].

In urban logistics, last mile delivery problem was widely researched in recent years. The key focus of last mile logistics is on optimizing the delivery route to satisfy multiple objectives [33], to integrate location, transportation, delivery to achieve higher customer satisfaction [34], and more recently to minimize financial and environmental cost focusing on sustainability parameters [35].

However, locating facilities in agricultural perishable supply chain in urban areas considering consumers’ geographical distribution is an area which has not widely addressed in the previous studies [25]. Further there had been many studies on location allocation problem in urban logistics. These location allocation studies are complex and use mathematical programming such as simple linear to non-linear probabilistic models. Further, the area of location allocation for perishable good supply chain has also been addressed by many advanced operational techniques such as p-median method, p-center, hubs, multi-product, multi-services to get the best possible location for distribution centers [20,29,32]. Many of those models have considered only to optimize cost and the distance.

The traditional p-median model developed added with time dimension on distance-based spatial dimension is found to be more suitable in the site selection for vegetable and fruit distribution center and to ensure efficient distribution with reduced the wastage and logistics costs [20]. Drezner and Scott [36] developed a distribution model to minimize the total cost of distribution (transportation costs from a central location DC to sales outlets and the inventory costs of the sales outlets). Jouzdani et al. [7] generated a model for optimal location of facilities and derived the level of production to minimise transport costs considering road traffic congestion level and the demand uncertainty. Demand uncertainty arises when a distribution facility or sales outlets are not located near demand points, essentially households. Perishable goods are high moving products on daily basis. Consumers do not often store them similar to other dry food items. Consumers often prefer to shop within a closer proximity to retail outlets. Therefore, while transport cost is important, it is not a necessary condition for distribution centres or sales centres when they are near to highly dense demand points, and the problem minimizes only to a distribution problem when orders are made. The nature of population density therefore plays a critical role in creating demand uncertainty. Online ordering of goods and their delivery in the last mile are negatively affected by lower level of population density [37].

Hiassat, Diabat and Rahwan [38] developed the location inventory routing model for perishable goods. They determined the number of warehouses, inventory level for retail shops and the route allocation for each vehicle. Etemadnia et al. [39] created an optimal wholesale hub location network for agricultural markets to improve the connectivity with producers, and farmers. By mixed linear integer programming, they developed a model to minimize the total network cost. Tong et al. [40] showed the correlation between food intake, Body Mass Index and supermarket accessibility with the geographic characteristics, transport modes, socio-economic characteristics and provides policy directive to guide spatial access improvement to supermarkets. They conclude that most of the residencies were not within the 1 km of supermarkets. They suggested accessibility improvements policies such as restructuring or building new perishable foods distribution centers based on population trends and densities, and the development of infrastructure to improve access to the perishable goods order fulfillment centers.

A location selection for a distribution center was designed by Wang, Wang & Chen [12] for an efficient urban vegetable distribution and lowing transportation and economic costs. Although the work identified population growth in cities as a key factor, yet they did not incorporate population growth or density as a parameter in the model. However, the model accounts for the transport network that can satisfy a higher customer base, lower construction cost and the timeliness of the distribution. Similarly, the approach presented by Suraraksa & Shin [13] using GIS on location allocation follows the same approach based on the number of predetermined DCs to minimize the number of DCs with maximum demand coverage. Therefore, the approach presented in this paper is complementary to the models as locating a DC in an optimal location further support distribution cost minimization and maximizing order fulfilment rate. The mathematical model developed by Raoui, Oudani, and Alaoui [41] to deal with vehicle routing problem for a selected DC using the capacity and time as constraints for perishable food delivery could also be complemented with the approach we developed to locate a DC from which the distribution can be carried out as the problem of distribution is solved using real road network graph. The model by Chen, Fan & Pan [14] to minimise the total deterioration value (TDV) and distance travelled in perishable goods is also supported by offering the best DC location as proposed by the current study which can reduce the number of trips, and distances.

More importantly the decision on OFC location is critical in addressing major issues which stemmed from suboptimal or unplanned distribution centres, as elaborated by Orjuela-Castro, Orejuela-Cabrera, and Adarme-Jaimes, [22] in their last mile distribution model. The perishable loss is proportional to the volume and the time, which are affected by the distance and the speed of travel, and the time spent at each stop. Regional OFC proposed by this paper significantly reduces the volume, time, and the distances, whereby the economic gains are accrued to the service provider and the customer. An integrated model of location-inventory-routing for perishable products developed by Liu, Zhu, Xu, Lu, & Fan [1] also only considered factors such as carbon emissions due to distribution and product freshness for a given set of locations, which was implicitly determined. The importance of locating a DC in urban logistics operation with the distances to customers being served relatively short and the population density of the area is emphasized in designing an operational model for planning new logisitcs centers [18,42]. Proximity to the city centre, demand and supply nodes is prerequisite for locating a logistics facility [42]. Yet both studies do not account for population density distribution in the logistics center location decision. This paper addresses this highlighted research gap.

This paper focuses on determining the order fulfilment center locations considering population density and its distribution as a proxy for perishable good demand. The paper attempts to provide a solution for location selection for order fulfillment centers of perishable products considering the consumer's demand and the need for an efficient and effective ways distribute them. Therefore, this study limits to the point of the total supply chain where perishable good order fulfilment centers and the consumers interact. This point is also defined as the final point, point of sale in the perishable goods supply chain (Fig. 3).

3. Methodology and model development

The methodology used in this paper consisted of three steps to develop the model. For mapping, ArcGIS was used as the main analysis tool. The steps followed are as follows:

Step 1: Mapping the current structure of the order fulfillment centers in a selected administrative area.

Step 2: Mapping the demand points in the selected administrative area to locate central distribution center and order fulfillment centers considering population density as a main parameter.

Step 3: Comparing the existing structure with the demand points for order fulfillment centers that have been analyzed.

The methodology was developed considering more practical aspects of a real-world issue that was identified with observation surveys in the specific area. When reviewing the factors influencing the perishable goods demanded, there are several factors that can be considered as main demand parameters. Literature review showed that the population density is one of the main factors included among those parameters. The methodology has been built to identify the perishable goods demand considering the population density and, with some adjustments, this model can be converted into a model for identifying the perishable goods demand considering the above mentioned other demand parameters other than the population density.

3.1. Step 1: Mapping current structure of the order fulfillment centers

The current locations of outlets of perishables were georeferenced and mapped using a waypoint marking survey from the selected market area. The process is outlined in Fig. 4.

The order fulfillment centers were mapped separately by categorizing them into the following types.

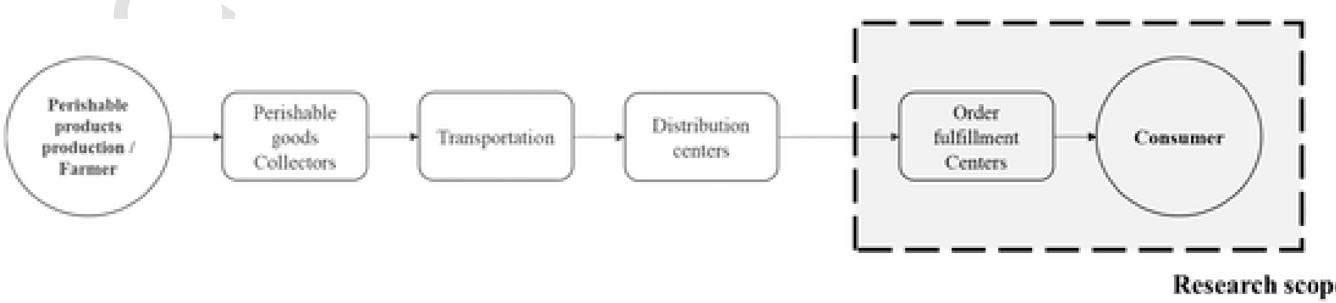


Fig. 3. Research scope.

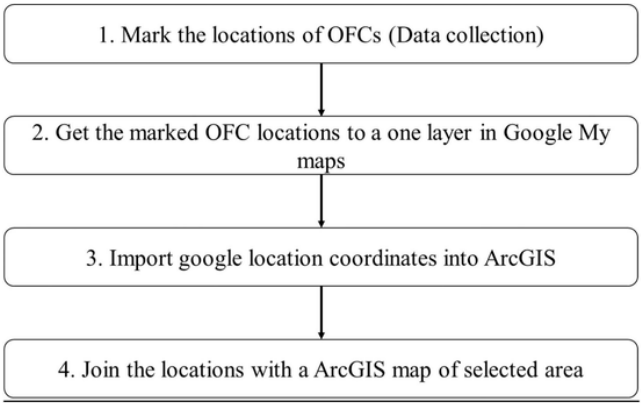


Fig. 4. Mapping process of the current structure of the order fulfillment centers.

- *Small scale vegetable shops and groceries*: The stores with only one outlet without a brand/trade name, and no customer services provided and less than three employees per outlet.
- *Medium scale supermarkets*: The supermarkets with one to four outlets and limited to district or province and a brand name. They offer customer services and sales representatives in outlets. They have three or more employees working per outlet.
- *Large scale supermarkets*: Mega/Large supermarkets with more than 50 outlets having island wide coverage and a popular brand name. They provide customer services and have sales representatives in outlets. They have more than ten employees working per outlet.

3.2. Step 2: Mapping the demand points in the selected administrative area

This step is divided into two sections as below.

- Central distribution center was selected by considering the population densities of the residential zones from the selected study administrative area. The residential zones were divided suitably according to the study population and the purpose or the population that is served by the central distribution center (DC) (e.g., for a central DC that serves a DS (Divisional Secretariate – regional administrative area) division, the residential zone boundary was selected as GN (Grama Niladhari – the smallest public administrative unit under DS) divisions of the DS division.The centrality measures that have been used are Closeness Centrality (CC), Betweenness Centrality (BC) and Eigenvector Centrality (EC), which can be referred and used to any study regarding optimizations of supply chain networks. Therefore, for the step 1, the Centrality Assessment method was used for the analysis.Closeness centrality measures the average length of the shortest path between the node and all other nodes in the graph. In here CC (xi) is the closeness centrality value for the (i) node while N is the total number of nodes and d (xi, xj) is the shortest direction between (i) and (j) nodes.

$$CC(x_i) = \frac{N-1}{\Sigma d(xi, xj)} \quad (1)$$

Betweenness centrality measures the degree of the node which function as a bridge between shortest path between two nodes. It can be identified also as the possibility of a node of being the central of a data cluster. Thus, it can be identified as the node which gives the lowest standard deviation of the shortest paths of the nodes. In here, BC (x_i) is the closeness centrality value for the (i) node and sd (x_i, x_j) is the standard deviation of the shortest paths from (i) node to (j) node.

$$BC(x_i) = \frac{1}{sd(xi, xj)} \quad (2)$$

Eigenvector centrality (also known as eigen centrality) is the influence of an influence of a node in a data cluster or a network. In this study the influence is the population density which results in higher scores to high population dense areas and low scores to low population dense areas.

$$EC(x_i) = pd(i) \quad (3)$$

Here EC (x_i) is the Eigenvector centrality value for the *(i)* node and pd*(i)* is the population density of the *(i)* node.Using these centrality measures the multi centrality scores were obtained using the following equations. In here S_{CC}, S_{BC}, S_{EC} are closeness centrality, betweenness centrality and eigenvector centrality Scores. $Rank_{CC}$, $Rank_{BC}$, $Rank_{EC}$ are the centrality values ranked (R) by ascending order derived using the Borda count method introduced by Wan, Hong, Huang, Peng, & Li [27].

$$S_{CC}(i) = N - Rank_{CC}(i) + 1 \quad (4)$$
$$S_{BC}(i) = N - Rank_{BC}(i) + 1 \quad (5)$$
$$S_{EC}(i) = N - Rank_{EC}(i) + 1 \quad (6)$$

Where: N = Number of locations, i = ith location

$$S_{All}(i) = Rank\ [W_{CC} \times S_{CC}(i) + W_{BC} \times S_{BC}(i) + W_{EC} \times S_{EC}(i)] \quad (7)$$

Where: W_{CC}, W_{BC}, W_{EC} = Rank weightages (S_{All}) = Weighted multi centrality score

- Demand points for order fulfillment centers are selected by considering the population densities which were created by the household clusters in the relevant administrative area. The population densities were mapped using the density per road/lane.

3.3. Step 3: Comparing the existing structure with the demand points

The comparison of the existing road infrastructure and the order fulfilment center locations determined from the data analysis (demand point of population density) were used to obtain the difference between the existing locations and the demand points and suggest the best location. A method of locating OFC locations was suggested considering the maximum walking distance range of a person, which is assumed to be 500 m.

3.4. Application of the model

The sample administrative area selected as a case study is the Kesbewa Divisional secretariat area, Colombo District, Sri Lanka. It is a middle-income locality with mixed urbanized land use patterns and diverse socio-economic structures (Fig. 5). The administrative area selected is characterized with a cluster wise population distribution and the potential to establish two OFC locations. The selected area has a population of 255,175 residents in approximately 61.94 km^2 with a population density of 4200 residents per square km as per the Census of Population and Housing in Sri Lanka. The model is validated using population density per sq kilometre, OFC locations and distance data of this area.

Primary and secondary data collected and used for testing the model are shown in Table 1.

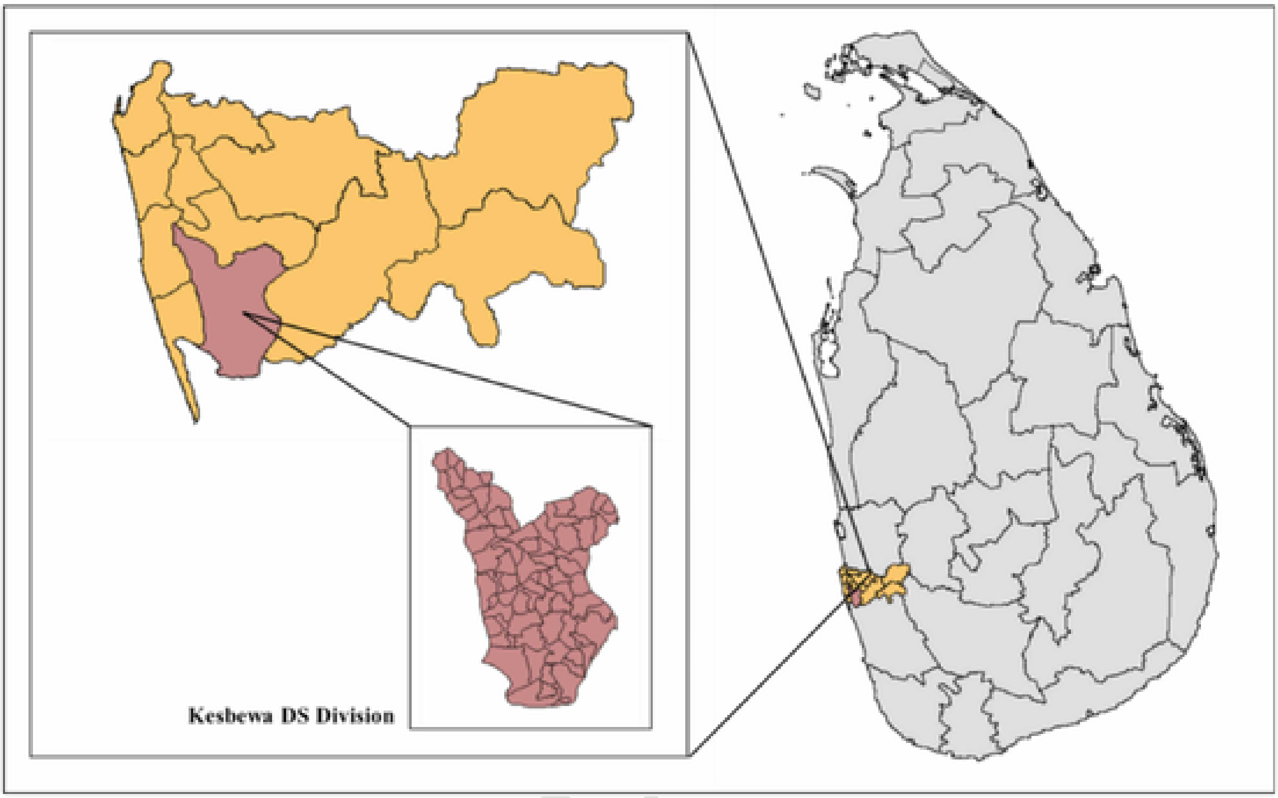


Fig. 5. Study area (Kesbewa DS Division), Colombo, Sri Lanka.

Table 1
Primary and secondary data collected and used for testing the model.

Primary data	Secondary data
• Maximum walking distance of a person to buy perishable goods. • Shortest direction data between GN divisions. • Existing structure of the perishable goods order fulfillment centers	• Area of the Kesbewa DS divison. • Areas of Grama Niladhari divisons in Kesbewa DS division. • Population of each Grama Niladhari Divisons in DS division. • Household data of GN divisions to map population. • GIS map data of Sri Lanka (DS & GN wise)

4. Results and Discussion

4.1. Comparison between the existing central distribution center and the analysis outcome for the central distribution center location

The existing location of the central distribution center is located in Bokundara Grama Niladhari (GN) division as the ‘Bokundara economic development center’. The best location was selected using the centrality assessment by taking similar weightages for every centrality indicator and this resulted Vishwakalawa GN division as the most suitable location. The results are shown in Table 2. (Please see Appendix A, B, C and D for each step of the process).

Table 2 presents the top twenty GN divisions which received the highest multi centrality scores. Vishwakalawa GN division was selected as the most suitable location to locate central distribution centre for perishable product supply and distribution in this area. Vishwakalawa GN division has recorded the highest scores in all centralities.

Table C1, C2 and C3 and D1 in Appendix show the centrality scores of each GN Division in Kesbewa DS area.

Table 2
The multi-centrality scores of each GN Division in Kesbewa DS area.

GN division	SCC (W_{CC} = 1/3)	SBC (W_{BC} = 1/3)	SEC (W_{EC} = 1/3)	S_{All}
Vishwakalawa	**70**	**71**	**71**	**70.677**
Mampe West	72	70	51	64.3
Wewala East	54	69	61	61.3
Makuluduwa	68	58	57	61
Suwarapola East	64	66	50	60
Bokundara	71	62	44	59
Kaliyammahara	60	63	52	58.3
Mampe South	59	73	42	58
Kolamunna	69	67	38	58
Kesbewa North	61	55	54	56.67
Mampe East	66	59	45	56.67
Thumbowila West	67	72	29	56
Paligedara	56	54	55	55
Mampe North	73	64	27	54.67
Thumbowila North	52	60	47	53
Suwarapola west	39	57	62	52.67
Katuwawala North	53	45	58	52
Erewwala West	45	40	68	51
Bodhirajapura	41	36	73	50
Mavittara North	65	49	35	49.67

The existing location which is Bokundara economic development center is also one of the locations that recorded a higher centrality score. However, ‘Vishwakalawa’ is more centrally located than ‘Bokundara’ and the closest to all locations with higher population densities.

4.2. Comparison of the existing OFC locations and the demand points obtained using the population density

From the first step, the existing OFC locations, which are obtained from the waypoints marked using the survey is shown in Fig. 6. In here, fifty-one (51) small scale groceries, nine (9) medium scale supermar-

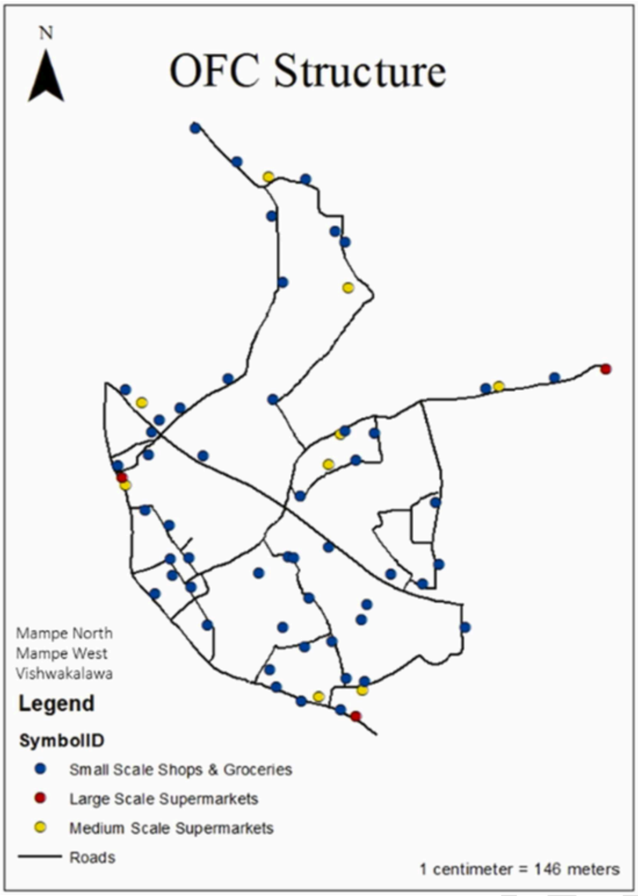


Fig. 6. Existing OFC locations.

kets and three (3) large scale supermarkets were recorded from the geo-referenced locations. It can be observed that the small scale OFCs are spatially clustered in specific areas, whilst in other areas they are dispersed., In contrast, the large and medium scale OFCs are few and more geographically dispersed, highlighting the central place hierarchical structure. Due to the clustered patterns of order fulfilment centers, there is a spatial mismatch in accessibility whereby some areas have better accessibility other others. This in turn disadvantaged certain areas through maximizing the travel distances to the nearest order fulfilment center.

Table 3
Road population densities of the selected sample.

Road Name	Population density
New Housing Scheme	83.50
Jaya Mawatha	67.85
Sirimangala Watta Road	64.00
Maharagama Road	51.46
Koskanatta Road	49.14
Hospital Road	37.00
Ganewatta Road	33.78
Vishwakala Watta	29.38
Halgaha Pokuna Road	25.50
Wewala Road	25.00
Bokundara Road	23.40
Vishwakalawa Road	21.36
Wata Mawatha	20.33
Old Kesbewa Road	20.00
Saranapala Road	15.00
Vidyala Mawatha	8.75
Colombo Road	2.57
Wekumbura Road	2.18

Three GN divisions in Kesbewa DS division are selected for comparison. The household data collected are presented in Table 3 for Mampe North, Mampe West and Vishwakalawa GN divisions in terms of population densities along the roads. The household populations were collected as population for each road in the selected GN divisions. The population densities of each road of the selected sample are shown in Table 3. Fig. 7 shows the comparison of the existing DC location and the derived DC location.

The population density differences can be observed between each roads. The 'Dot density map' demonstrates the distribution of the households (Fig. 8). In this step the only factor that was considered to select the order fulfilment centre is the population density. The population density is the most suitable parameter to predict the demand for perishables offered at OFCs. Therefore, the population density was mapped with a 50-meter buffer zones around each road in the selected study area. The roads were ranked considering the population densities.

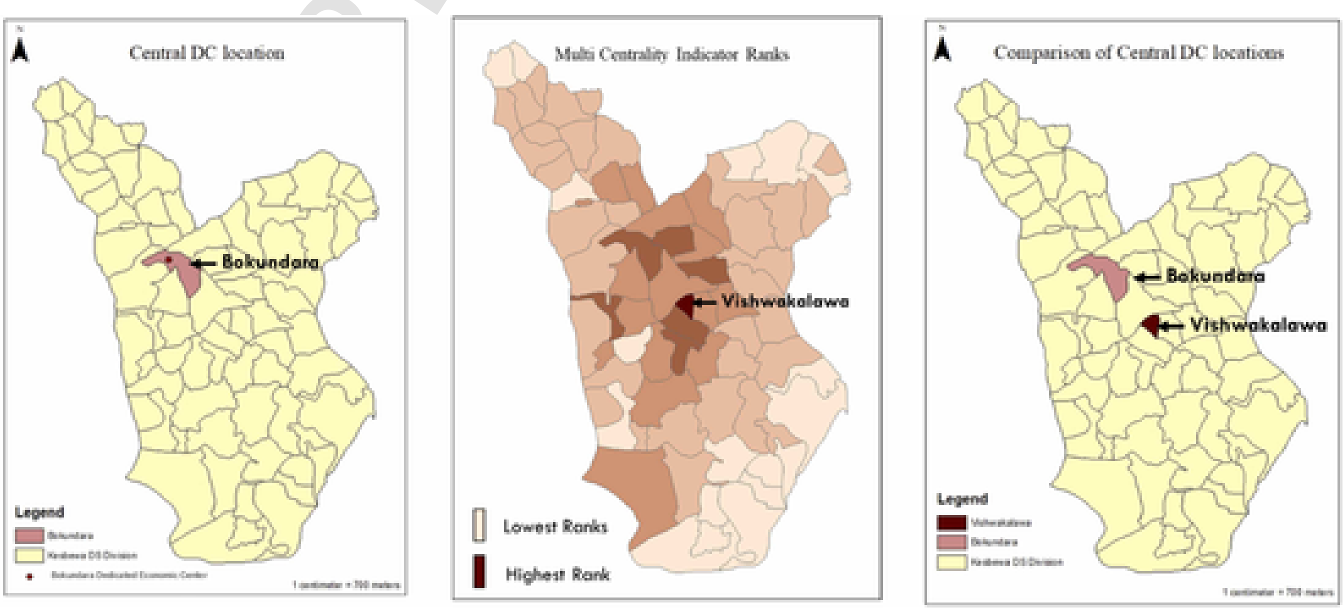


Fig. 7. Comparison of the existing Central DC Location and the derived DC location.

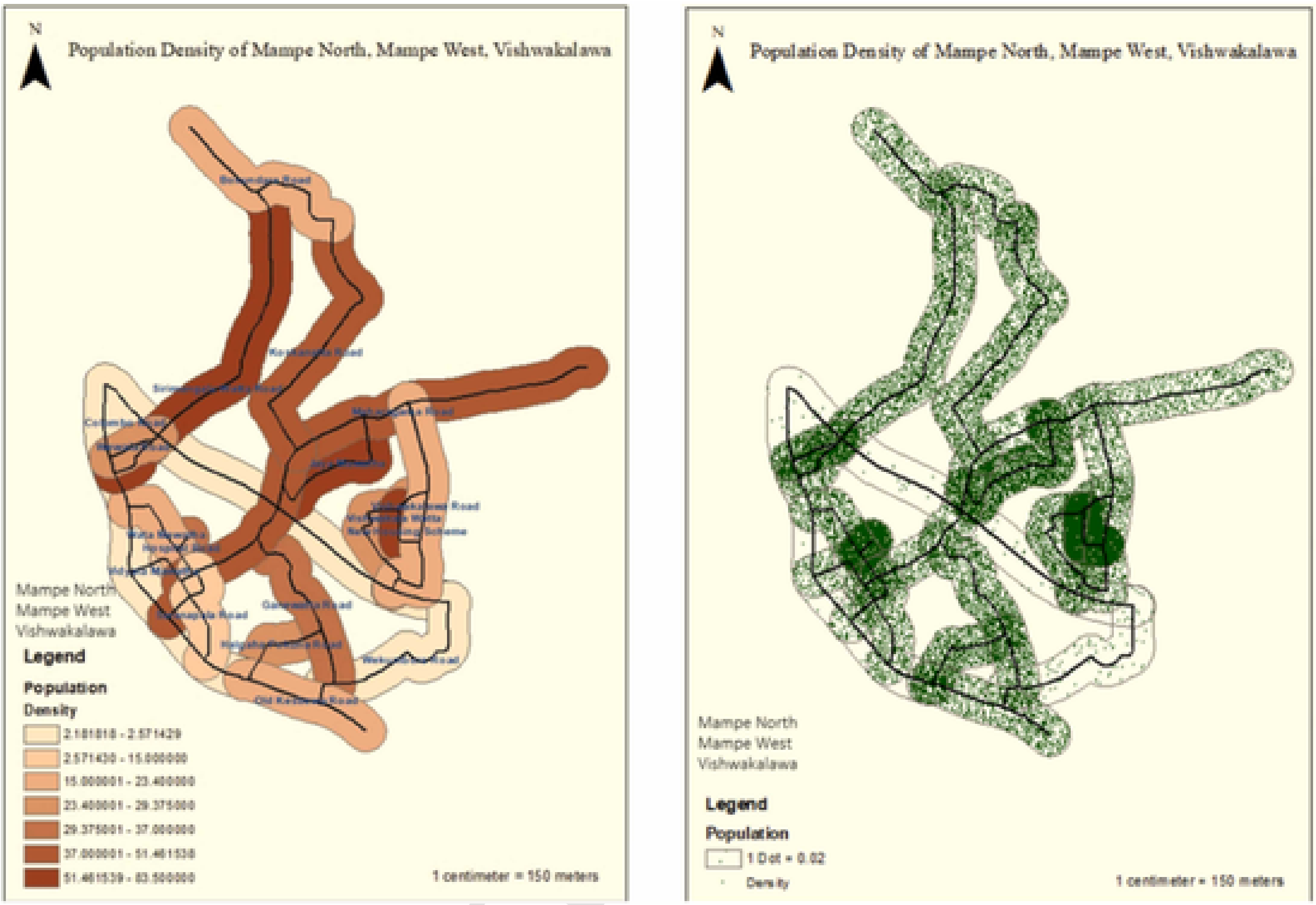


Fig. 8. Population densities of the road network of the selected study area.

Fig. 9 shows significant spatial variability in the distribution of order fulfilment centres and this distribution is inversely related to population density. This led to a spatial mismatch between the supply of OFCs and the demand for the service. In more densely populated areas, the order fulfilment centre coverage is limited by the small-scale shops and groceries. The medium and large-scale order fulfilment centres are only limited to less populated areas which have more commercial and economical activities with a high trip attraction and a high vehicle traffic flow.

The medium scale supermarkets are only located in low dense areas where there is a high economic activity concentration and a high volume of vehicle traffic. The medium scale supermarkets are not centrally located, and there is a very low number of large-scale supermarkets. Therefore, as discussed above the OFCs need to be located mostly in higher dense areas where there are more population dwellings (namely Jaya Mawatha, Sirimangala Watta Road, Maharagama Road) from which a high demand for perishable products are generated as proxied by the population density.

4.3. Validation of the model

The centrality assessment results were validated using a sensitivity analysis of selected data set by changing the values of weightages (see Fig. 10). Results of the sensitivity analysis are not significantly different from the results of multi-centrality indicator for similar weightages shown in Fig. 2. Therefore, the analysis results and the centrality assessment model are validated and deemed reliable. The population density as a proxy for demand for perishable goods is reliable indicating that higher the density the great will be the demand for perishable products.

The study has empirically shown that the Central DCs and the OFCs are not optimally located to align the the variability in population density. Given that there is a shorter lifetime of the perishable products, it is more value adding if the perishable product's order fulfilment centres are established nearer to the consumer. Further the trip attractions to urban centres can also be reduced which result in less vehicle flow to such areas. In this study, the OFCs can establish in the areas that have identified as population dense areas in the selected area (Mampe North, Mampe West, Vishwakalawa). From an operational point of view, either new OFCs can be established or the small scale OFCs can be replaced by large and medium scale OFCs to have a wider geographic coverage. For meeting the demand in the low population dense areas, the other alternative is to amalgamate large number of OFCs into a few, and those excess OFCs if any that exceed the demand needs can be shifted to areas of high demand. The OFCs can be located considering the maximum walking distance of a person and considering the highly populated areas as demand points. The OFCs locations can select within the maximum walking distance from the demand points and be located to cover one or few demand points from one OFC within the walking distance of demand points (population densities) following the method illustrated in Fig. 11.

When considering to locate a Central DC, the existing locations can be accepted as it is near to the Central DC location given by the model or in other words, the existing Central DC in Bokundara can be moved to Vishwakalawa. The approach presented in this paper can be used in location planning for establishing new OFCs given its simplicity and capability to generate multiple options for business to evaluate suitable locations.

Advancement of supply chain, logistics and transportation provides suppliers and distributors to keep their inventory at a low level and cre-

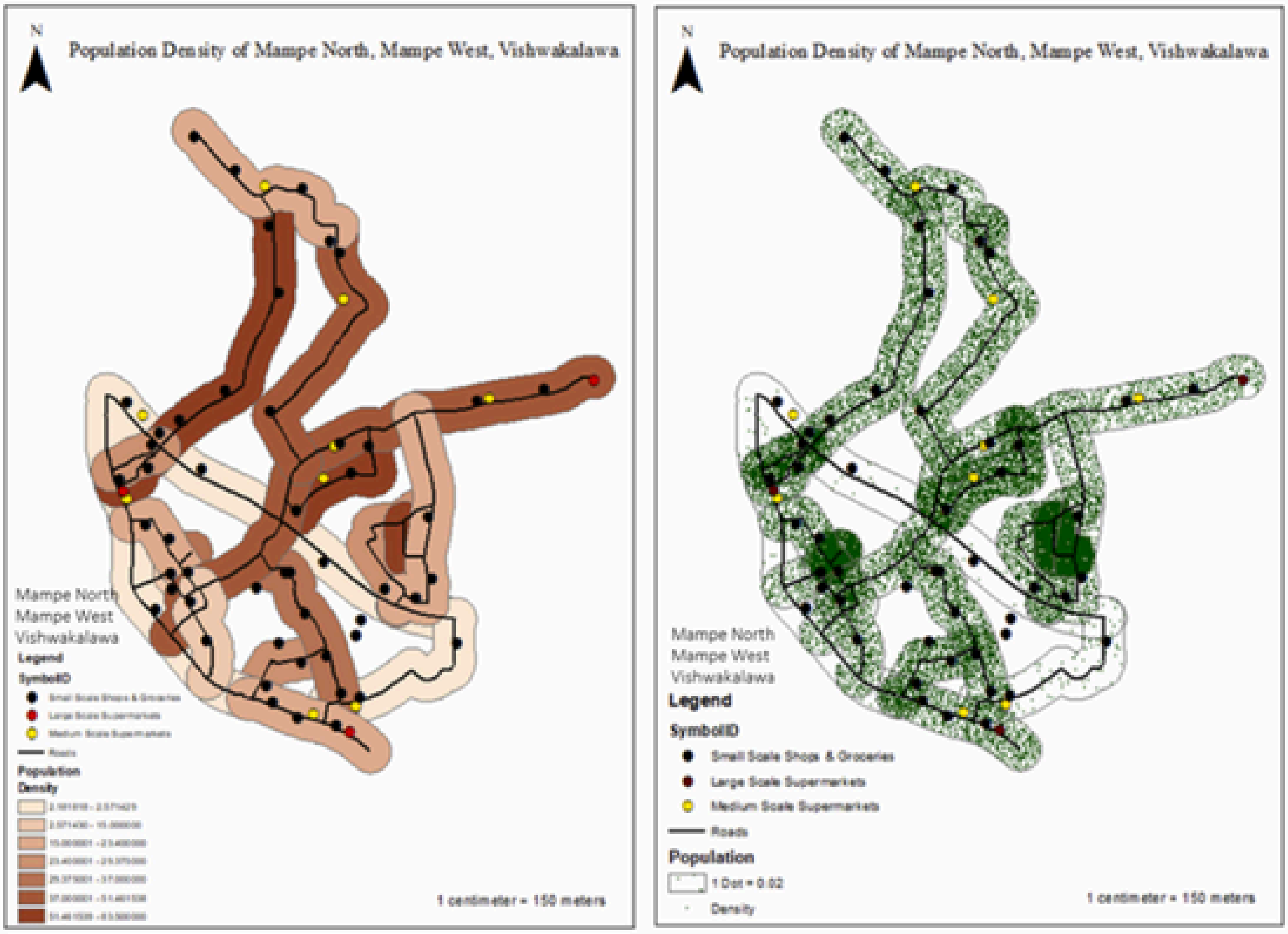
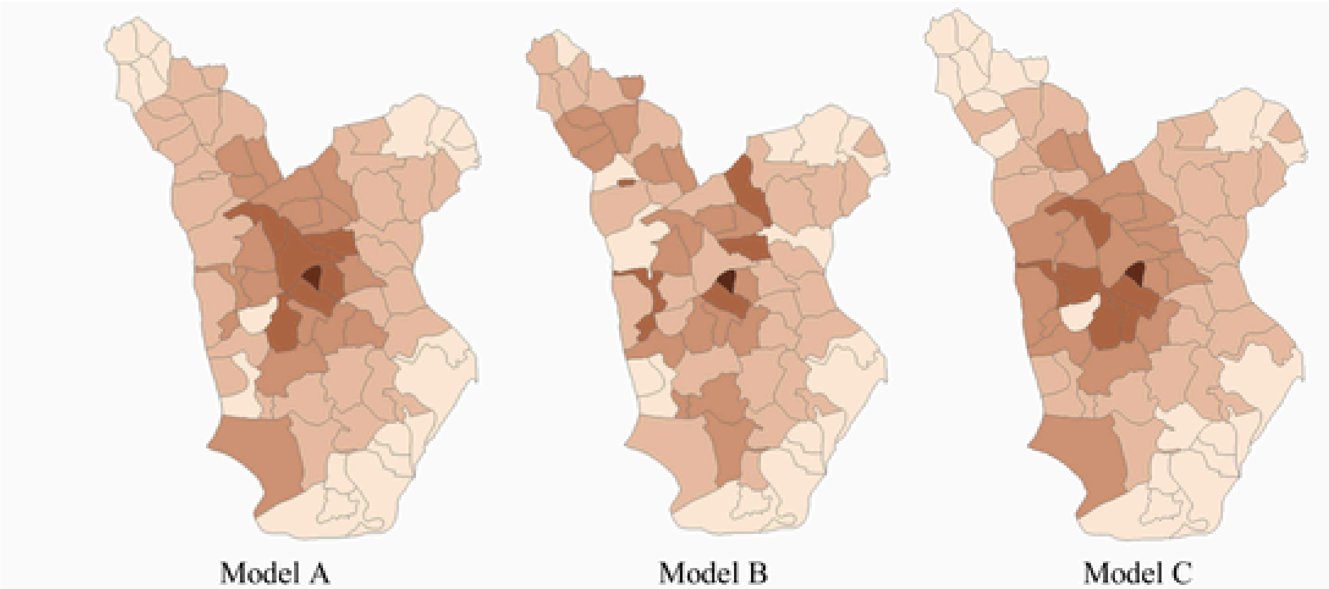


Fig. 9. OFC locations comparison with population density.

ates means of reducing inventory holding costs. Therefore, due the increased demand for goods and services, and its' frequencies, the volumes need to be stored to meet the demand are also reduced. On the contrary, frequent need of transportation by consumers to sales points results in increased traffic flow on the road and increased air and noise pollution [32]. This paper contributes to the location selection for distribution in the form of a DC or a warehouse. An important criterion in facility location problems is the ability of satisfying demands by the facilities that are planned to be located. The facility location model proposed in this paper can satisfy the whole demand of each customer and therefore it serves as a single facility addressing "non-divisible" demand [2]. Therefore, the findings complemented the decision support platform developed by Cramer and Fikar [17] which helps distribute local food distribution in an urban setting by providing a solution to the location selection decision, which was not addressed in the work, to operationalize the proposed distribution system. Liu, & Zhang [11] addressed uncertainty in demand in urban set up by constructing a distribution optimization model that can lower transport costs (the location of the distribution centre was taken as given). The uncertainty in demand is because the population in urban areas is distributed in different densities and the distribution has multiple distribution paths and distances. Therefore, locating a distribution center that can cater high demand density segments helps sustain demand. The proposed location decision model developed in this paper addresses uncertainty in demand and also lower transport cost. More importantly the decision on OFC location is critical in addressing major other issues which stemmed from suboptimal or unplanned distribution centres [22] that isthe perishable loss is proportional to the volume and the time which are affected by the distance and the speed of travel, and the time spent at each stop. Regional OFC proposed by this paper significantly reduces the volume, time and the distances, whereby the economic gains are accrued to the service provider and the customer. Perishable supply chain suffers from freight losses, high inventory and transportation costs. However, shipping perishable goods directly to final point of sales significantly reduce the total supply chain cost owing to savings from infrastructure construction costs, transportation costs to intermediary large cold stores, or consolidation centres, inventory costs, and freight losses [16]. On the contrary, Nalan Bilişik, & Baraçlı [19] however considered a high population density as a negative factor in DC location selection, arguing that low population density reduces the external effects such as traffic congestion and pressure on infrastructure. However, we argued that locating a DC in a high population dense area has shorter trips, consolidated deliveries, and frequent demand for perishables all of which contribute to lowering total operational costs.

5. Conclusion

Perishable goods distribution is a critical logistics problem given the perishability (nature) of the goods, and logistical constraints and the distance to markets from farm gate. The issue is further aggravated in urban areas as the demand points are multiple, and timely and efficient distribution is demanded. This paper presented a GIS based modelling approach to determine the arrangement of perishable goods order fulfilment center locations considering population density as a proxy measure for perishable product demand. The model comprised of three



	Model A	Model B	Model C
Rank weightage for Closeness Centrality (W_{CC})	0.6	0.2	0.2
Rank weightage for Betweenness Centrality (W_{BC})	0.2	0.6	0.2
Rank weightage for closeness centrality (W_{EC})	0.2	0.2	0.6

Fig. 10. Sensitivity Analysis.

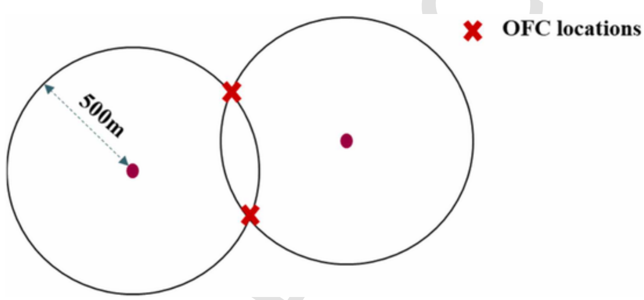


Fig. 11. OFC location selection method.

steps and, was applied to the Kesbewa Divisional Secretariat Division, Colombo District in Sri Lanka.

Results showed that the existing central DC was not located in the most suitable candidate area with a higher population density. Therefore, the model results concludes that the current OFC is less optimally located for perishable goods sales based on the centrality measure to fulfil service demand. In densely populated areas, the order fulfilment center coverage is limited to small-scale shops and groceries. The medium and large-scale order fulfilment centres were located in less populated areas.

Therefore, the facility planners and urban planners need to consider the population density as an important parameter for facility location decisions for logistics services such as perishable produce. The supply chain and logistics landscape are now technologically driven and operated on IT platforms in the advent of changing customer expectations and purchasing habits such as online ordering. By locating OFCs in close proximity to densely populated areas instigates consumers for frequent ordering due to less distance and short lead times, and also generates positive spillover effects. This can result in less vehicle movement owing to walking trip attractions to economic centres for physical buying of perishable goods. Online ordering systems can also be attractive to consumers as order fulfilment centres are in proximity. Therefore, IT platform firms can capitalize on this opportunity providing a way for other logistics firms, small and medium, to provide order fulfilment centres-based door to door logistics services. This in turn develops employment opportunities and market expansion with value added services. Reduction in individual trips owing to online ordering from order fulfilment centres also have environmental implications, less congestion and carbon footprint. The modelling approach provides direction for city and urban planners on location allocations, and, in the long run, can lead to a development of a network like order fulfilment centres within a region. This leads to greater economies in operations (both scale and density) and, from market point of view, a greater availability of perishable goods for consumers.

Further the paper provides a simple but practical solution to minimize wastage of agricultural perishable goods at the final sales point in perishable goods supply chain with the ease of demand planning and offers an opportunity for firms to maximize the product turnover. With this approach for location site selection for the perishable goods distribution centres, the urban pressure can be reduced by limiting the vehicle flow to urban areas destined for the purpose of buying perishable goods from supermarkets. The competition among supermarkets can also be reduced by identifying the demand points and the area of serving. In addition, the intermediary influences in the supply chain can be reduced by improving this solution to the direct supply to the distribution centres from the farm gate. Therefore, this paper also provides direction for future research. The modelling approach can be extended by incorporating additional other variables such as socio-economic characteristics of consumers, the ordering methods and developing an online operational system for perishable distribution as future research.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data from this study are available from the corresponding author.

Appendix. : Outputs of the Modelling Approach

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A. Current location of the Central Distribution Center (Bokundara Dedicated Economic Center, Kesbawa, Sri Lanka)

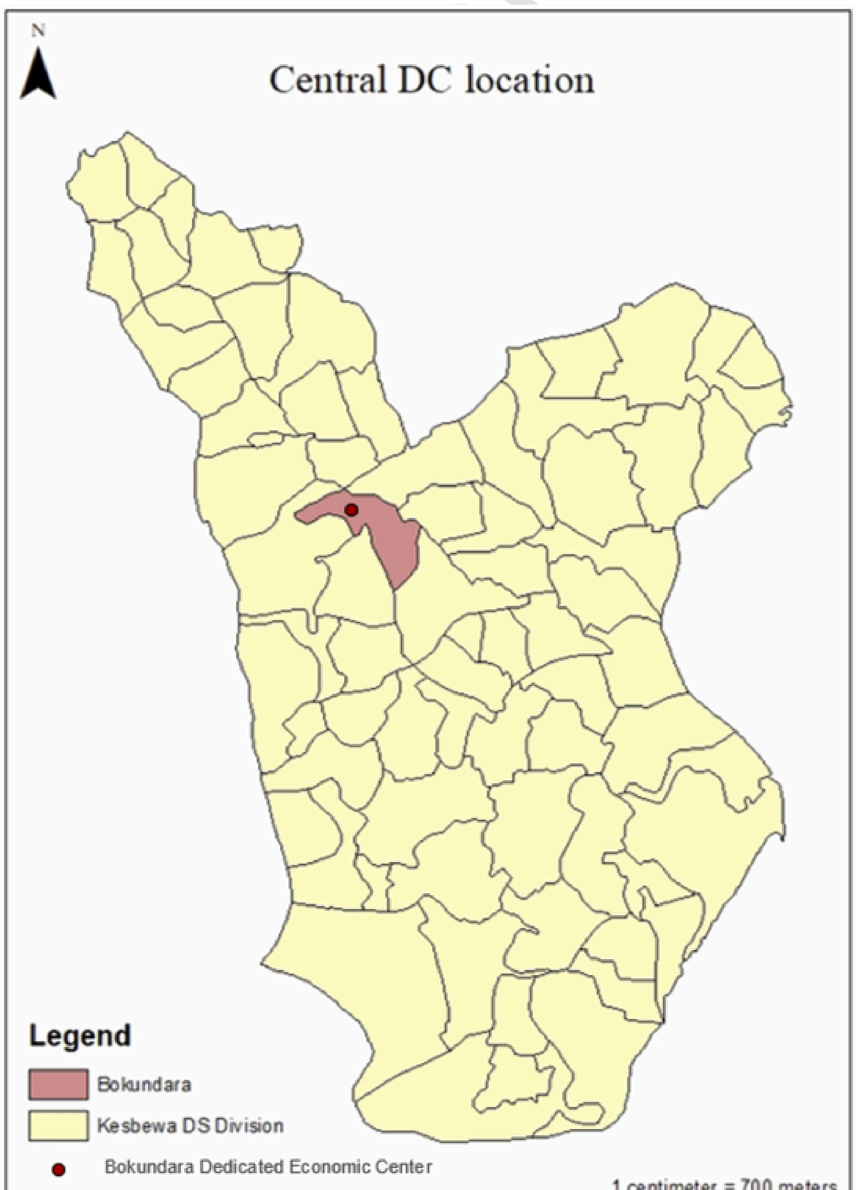

Figure A.1. - Existing Central DC location.

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B. Mapping demand points in the selected area to locate central distribution center and order fulfillment centers using centrality assessment method

B1.1 The population of the GN divisions and GIS maps to interpret the data (Source: Kesbewa Divisional Secretariat office, 2019)

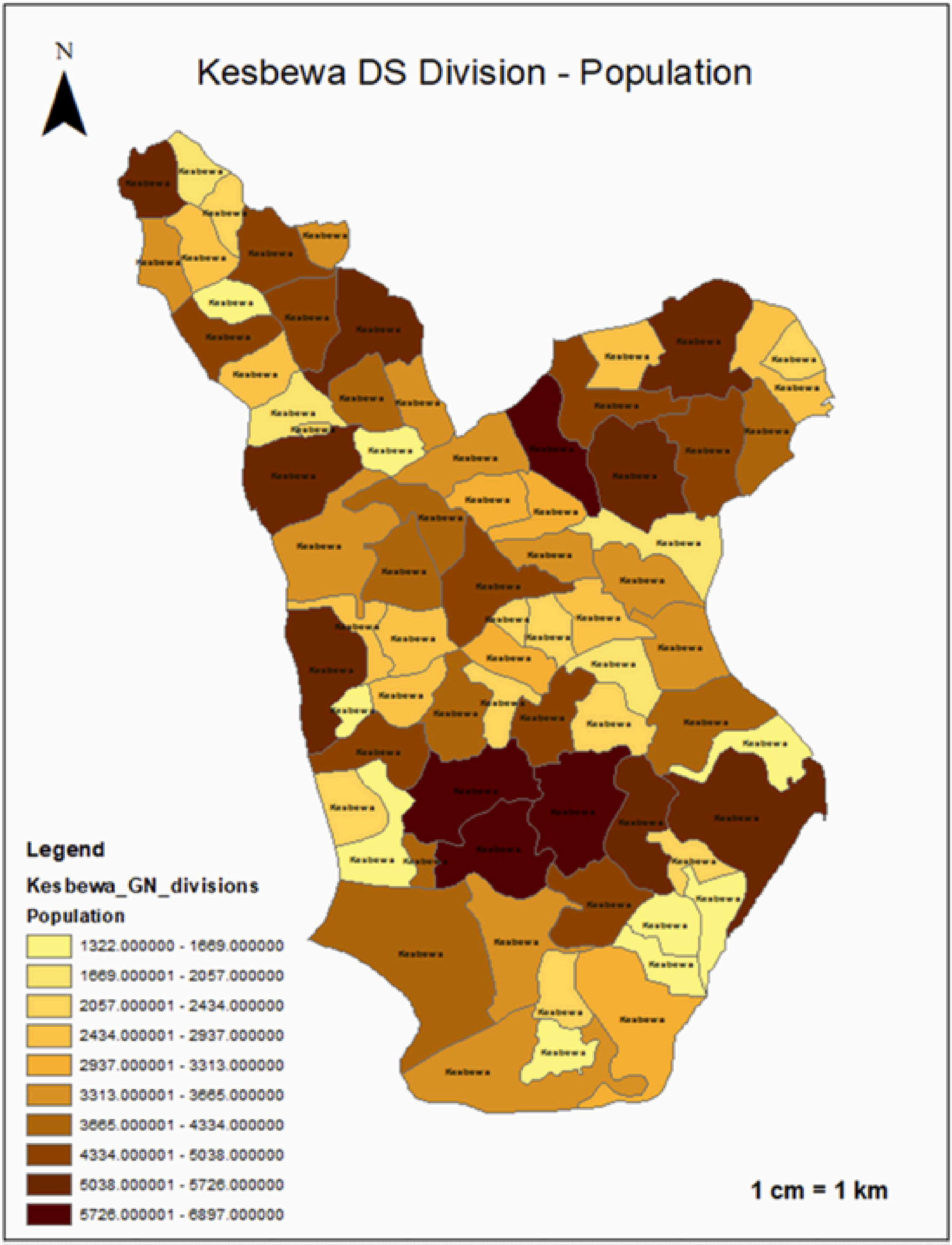

Figure. B1. Population map of Kesbewa DS division, Sri Lanka.

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B1.2 Population densities calculated by using areas of each Grama Niladhari divion

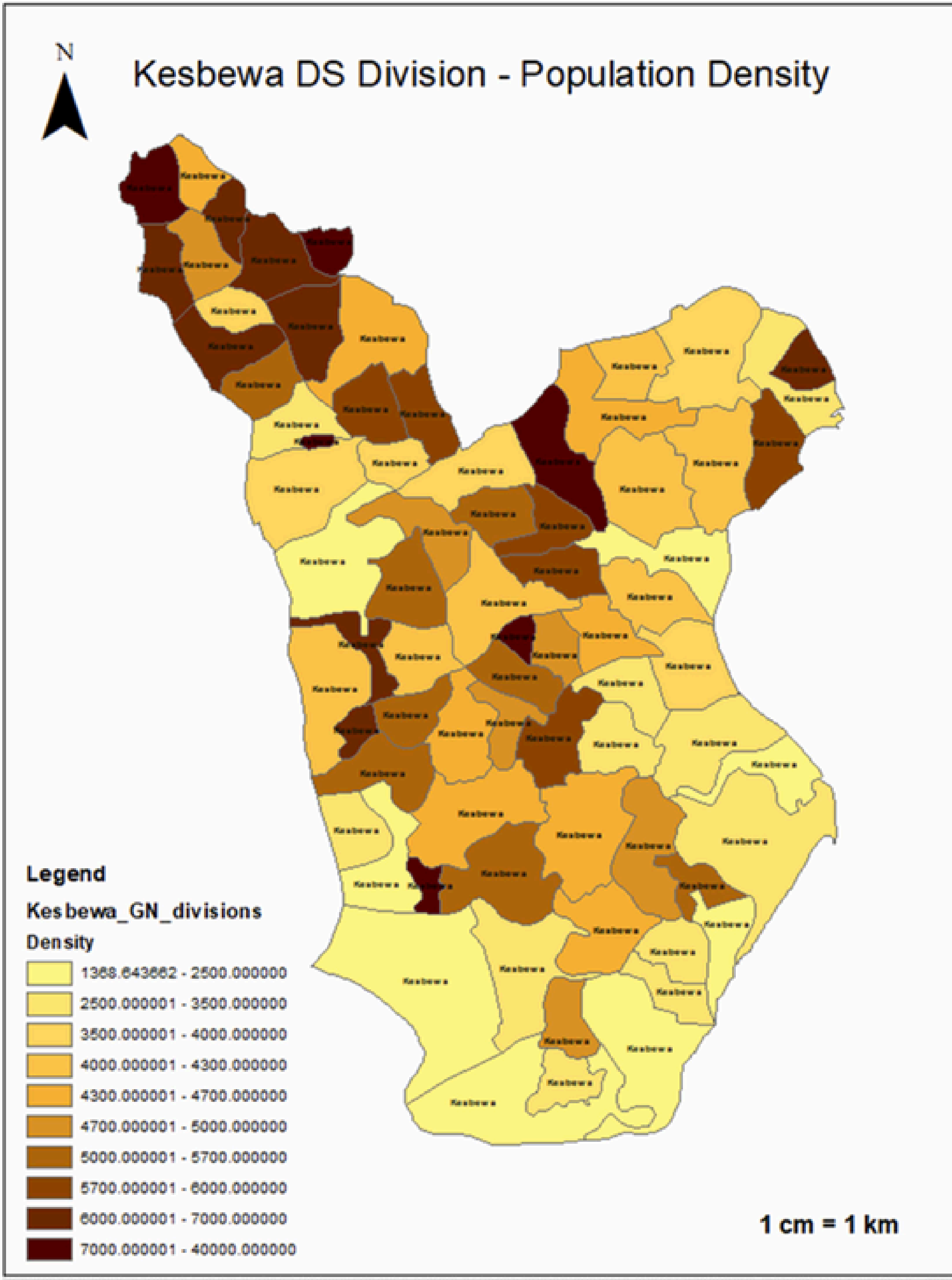

Figure. B2. Population density map of Kesbewa DS division, Sri Lanka.

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B1.3 Shortest directions/paths between GN divisions

Step 01: The shortest directions of center points of each GN division has calculated. To get the center point of each GN division the “Feature to point” tool in Data management tools in ArcGIS software was used. After applying Feature to point tool Figure B3 was obtained.

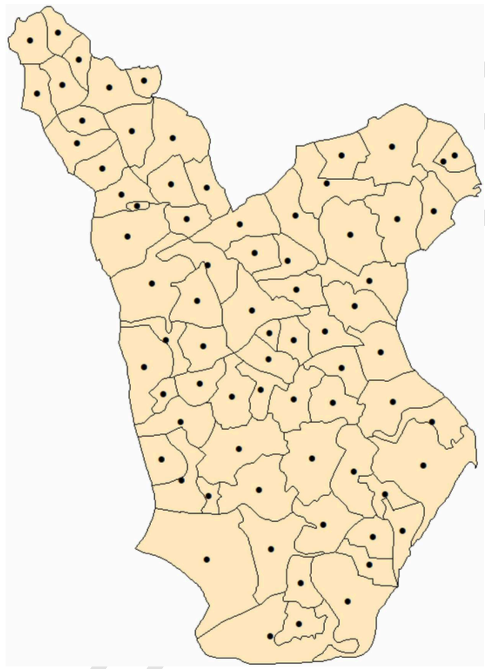

Figure B.3. - Center points of each GN by feature to point.

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Step 02: Then to measure the shortest directions between GNs, the feature to point layer with center points of GNs are imported from “Layer to KML” tool in the conversion tools in ArcGIS to Google my maps. Then the locations are marked in the google maps are shown in the Figure B5 below.

Figure B.5. - Center points of GNs in google maps.

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Step 03: After marking distances, the shortest distance between GN divisions were measured using google my maps direction/distance tool (Figure B6).

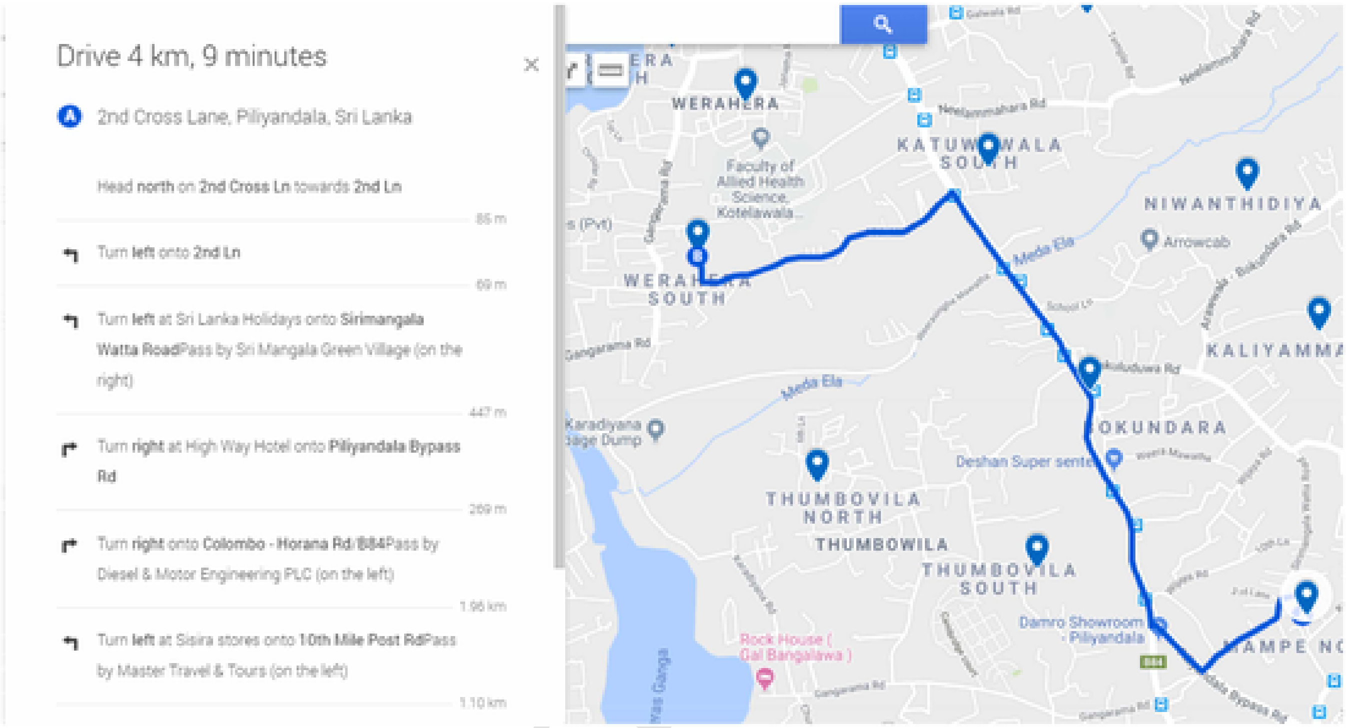

Figure B.6. Shortest direction measuring using Google My Maps.

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Step 04: After getting the shortest distance between GNs average shortest paths were calculated for further analysis (Figure B7).

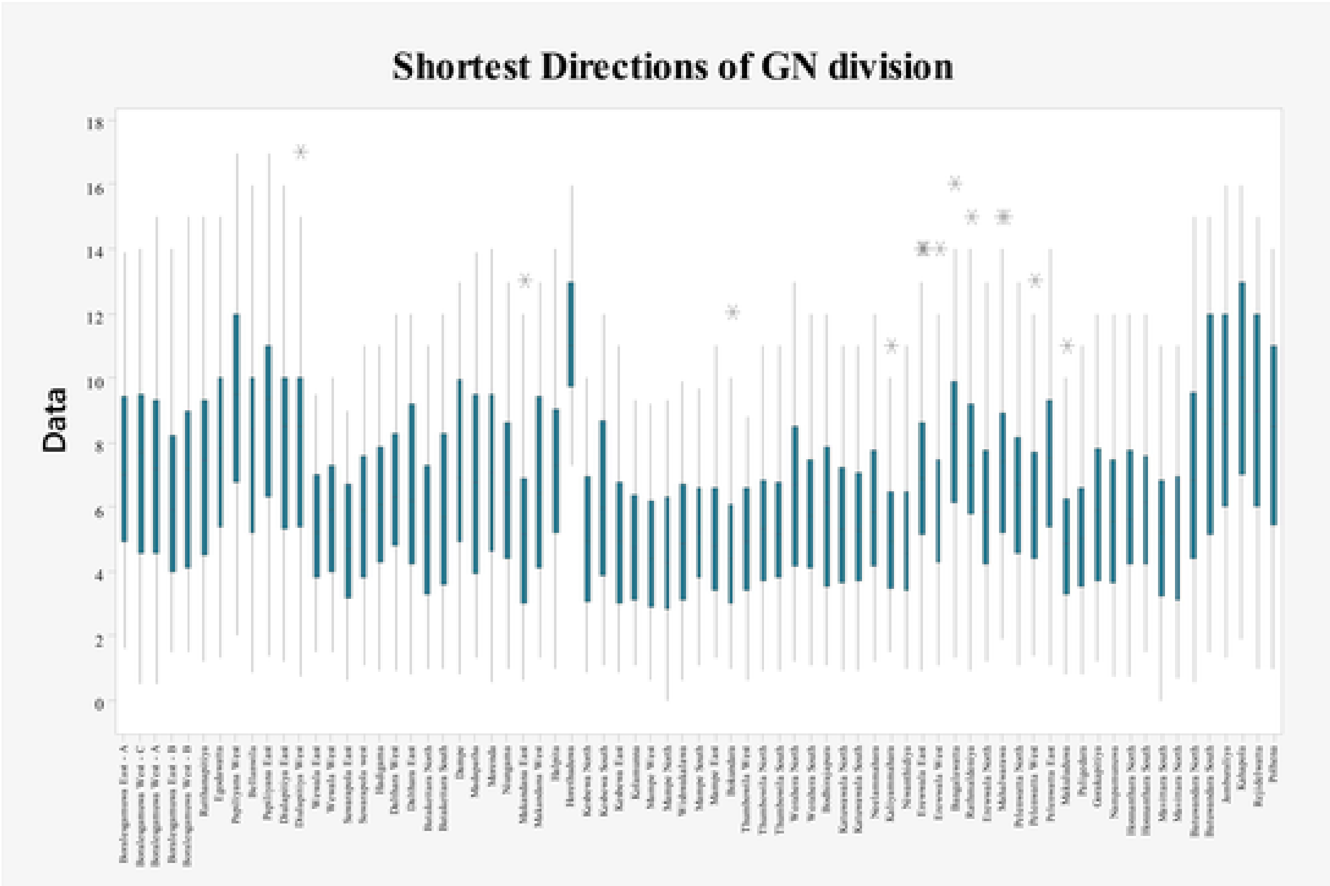

Figure B.7. Shortest distances of GNs and their variations by a boxplot.

C. Centrality assessment of the GN divisions in Kesbewa DS division

C1 Calculation of closeness centrality of GN divisions (Table C1)

Thumbowila West	0.201878592	7
Thumbowila North	0.18177228	22
Thumbowila South	0.184757506	19
Werahera North	0.154175589	42
Werahera South	0.170980765	27
Bodhirajapura	0.166243362	33
Katuwawala North	0.184119678	21
Katuwawala South	0.186697783	17
Neelammahara	0.166281755	32
Kaliyammahara	0.194174757	14
Niwanthidiya	0.196721311	11
Erewwala East	0.143583608	50
Erewwala West	0.168815944	29
Bangalawatta	0.122657581	66
Rathmaldeniya	0.137051489	57
Erewwala North	0.165137615	34
Mahalwarawa	0.136570561	60
Pelenwatta North	0.152704136	43
Pelenwatta West	0.163043478	37
Pelenwatta East	0.139076685	55
Makuluduwa	0.202588633	6
Paligedara	0.184994861	18
Gorakapitiya	0.173745174	25
Nampamunuwa	0.179707975	24
Honnanthara North	0.169751267	28
Honnanthara South	0.163154317	36
Mavittara South	0.191082803	16
Mavittara North	0.19791094	9
Batuwandara North	0.143870517	49
Batuwandara South	0.115495669	69
Jamburaliya	0.115644073	68
Kahapola	0.101280068	72
Rejidelwatta	0.123399302	65
Polhena	0.118284869	67

Results of closeness centrality of the selected GN divisions

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C2 Calculation of betweenness centrality of GN divisions (Table C2)

GN division	BC score	Rank
Boralesgamuwa East - A	0.319154151	54
Boralesgamuwa West - C	0.308763592	57
Boralesgamuwa West - A	0.305725708	61
Boralesgamuwa East - B	0.343117398	44
Boralesgamuwa West - B	0.319195698	53
Ratthanapitiya	0.297750872	62
Egodawatta	0.296392977	63
Papiliyana West	0.277870717	67
Bellanwila	0.288429791	64
Papiliyana East	0.276801622	68
Diulapitiya East	0.288375793	65
Diulapitiya West	0.271867717	70
Wewala East	0.484638487	5
Wewala West	0.47407676	9
Suwarapola East	0.477577929	8
Suwarapola west	0.427296041	17
Hadigama	0.405041569	23
Dalthara West	0.387585348	30
Dalthara East	0.340416182	46
Batakettara North	0.408698353	21
Batakettara South	0.36695138	37
Dampe	0.334843601	49
Madapatha	0.307251709	60
Morenda	0.315241474	56
Niungama	0.334424603	51
Makandana East	0.339777234	48
Makandana West	0.307926954	59
Halpita	0.3402988	47
Horethuduwa	0.480124876	6
Kesbewa North	0.41555186	19
Kesbewa South	0.354589296	41

Results of of betweenness centrality of the selected GN divisions (cont.)

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Kesbewa East	0.395054399	27
Kolamunna	0.479362534	7
Mampe West	0.48533808	4
Mampe North	0.473123032	10
Wishwakalawa	0.485594794	3
Mampe South	0.504333998	1
Mampe East	0.442881599	15
Bokundara	0.462849908	12
Thumbowila West	0.489638744	2
Thumbowila North	0.452007466	14
Thumbowila South	0.461931399	13
Werahera North	0.346016122	43
Werahera South	0.404713835	24
Bodhirajapura	0.359975198	38
Katuwawala North	0.390358066	29
Katuwawala South	0.399459267	26
Neelammahara	0.376455949	35
Kaliyammahara	0.463059244	11
Niwanthidiya	0.420462231	18
Erewwala East	0.348953531	42
Erewwala West	0.376848188	34
Bangalawatta	0.317028169	55
Rathmaldeniya	0.333582273	52
Erewwala North	0.357502699	40
Mahalwarawa	0.334603086	50
Pelenwatta North	0.359777033	39
Pelenwatta West	0.379832618	33
Pelenwatta East	0.342759068	45
Makuluduwa	0.4380074	16
Paligedara	0.414949829	20
Gorakapitiya	0.369827338	36
Nampamunuwa	0.381793623	32
Honnanthara North	0.394615512	28
Honnanthara South	0.406064182	22
Mavittara South	0.385654209	31
Mavittara North	0.399842409	25
Batuwandara North	0.308620334	58
Batuwandara South	0.254913046	72
Jamburaliya	0.249697601	73
Kahapola	0.272966951	69
Rejidelwatta	0.271602241	71
Polhena	0.27834942	66

Results of of betweenness centrality of the selected GN divisions

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C3 Calculation of eigenvector centrality of GN divisions (Table C3)

Kesbewa East	3023.26029	62
Kolamunna	4639.375255	36
Mampe West	5589.111518	23
Mampe North	4117.554493	47
Wishwakalawa	11737.67937	3
Mampe South	4808.626392	32
Mampe East	4989.071712	29
Bokundara	4878.526069	30
Thumbowila West	4218.807409	45
Thumbowila North	5089.939861	27
Thumbowila South	2185.933973	68
Werahera North	3385.656774	58
Werahera South	3851.030647	52
Bodhirajapura	38464.06768	1
Katuwawala North	5972.579421	16
Katuwawala South	3662.442694	55
Neelammahara	5989.700376	15
Kaliyammahara	5610.265936	22
Niwanthidiya	3817.82593	53
Erewwala East	4062.598577	48
Erewwala West	7038.423117	6
Bangalawatta	6359.611033	11
Rathmaldeniya	3666.644915	54
Erewwala North	4314.507294	42
Mahalwarawa	3434.939376	56
Pelenwatta North	4009.364197	49
Pelenwatta West	4244.540695	44
Pelenwatta East	5886.949864	18
Makuluduwa	5904.702599	17
Paligedara	5764.565725	19
Gorakapitiya	1870.901499	69
Nampamunuwa	4285.727426	43
Honnanthara North	3955.250095	50
Honnanthara South	3368.532817	59
Mavittara South	3126.379433	61
Mavittara North	4552.578078	39
Batuwandara North	2937.023852	63
Batuwandara South	3236.846911	60
Jamburaliya	1831.708784	71
Kahapola	1607.288129	72
Rejidelwatta	2739.71893	64
Polhena	4716.401015	34

Results of eigenvector centrality of the selected GN divisions

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D Ranking centralities and assessing multi-centrality indicator (Table D1)

GN division	S_{CC}	S_{BC}	S_{EC}	S_{All}	Rank
Boralesgamuwa East - A	16	20	64	33.33333333	42
Boralesgamuwa West - C	23	17	23	21	59
Boralesgamuwa West - A	22	13	65	33.33333333	42
Boralesgamuwa East - B	34	30	34	32.66666667	44
Boralesgamuwa West - B	26	21	46	31	46
Ratthanapitiya	21	12	60	31	46
Egodawatta	13	11	70	31.33333333	45
Papiliyana West	4	7	69	26.66666667	55
Bellanwila	11	10	66	29	52
Papiliyana East	3	6	39	16	67
Diulapitiya East	10	9	67	28.66666667	53
Diulapitiya West	12	4	41	19	62
Wewala East	54	69	61	61.33333333	3
Wewala West	43	65	28	45.33333333	24
Suwarapola East	64	66	50	60	5
Suwarapola west	39	57	62	52.66666667	16
Hadigama	36	51	48	45	25
Dalthara West	30	44	17	30.33333333	50
Dalthara East	29	28	4	20.33333333	60
Batakettara North	51	53	33	45.66666667	23
Batakettara South	44	37	49	43.33333333	26
Dampe	15	25	1	13.66666667	69
Madapatha	27	14	72	37.66666667	35
Morenda	20	18	7	15	68
Niungama	33	23	53	36.33333333	36
Makandana East	48	26	43	39	32
Makandana West	28	15	37	26.66666667	55
Halpita	18	27	9	18	65
Horethuduwa	1	68	8	25.66666667	58
Kesbewa North	61	55	54	56.66666667	10
Kesbewa South	35	33	36	34.66666667	40
Kesbewa East	62	47	12	40.33333333	30
Kolamunna	69	67	38	58	9
Mampe West	72	70	51	64.33333333	2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Vishwakalawa	70	71	71	70.66666667	1
Mampe South	59	73	42	58	8
Mampe East	66	59	45	56.66666667	10
Bokundara	71	62	44	59	6
Thumbowila West	67	72	29	56	12
Thumbowila North	52	60	47	53	15
Thumbowila South	55	61	6	40.66666667	29

Ranking of centralities (closeness, betweenness and eigenvector) and the multi-centrality indicator

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For this scenario the centrality indicators are considered as equal importance. Rank number 01 for the most suitable location resulted in as the Vishwakalawa GN division. As it can be seen the most central locations have scored higher scores and greater ranks in the sample.

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