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Proposed Nodal Hierarchy in Kenya Urban System

"GIS Integrated with P-median Clustering Based Approach"

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ABSTRACT

Kenyan urban system has experienced an early dominance of few major cities because of resource allocation, and colonization policies. The consequences of urban growth continued after independence, extended the gap between major cities and the rest of the urban system. That led to weak linkages among the entire urban system. This paper seeks to suggest efficient hierarchical urban system for governmental service providing with minimum cost. This is accomplished by analysing the Kenyan urban system based on the 2009 census of population and housing results. The cities potential in the urban system is evaluated, besides defining the dominating linkages among cities. This enables the illustration of urban system centralism problem in Kenya. Then a P-median clustering approach is used to propose an optimum hierarchy among cities in the system. Paper results demonstrate the flexibility of mathematical models, where the results could be re-checked as additional information became available. That is guaranteed by the use of composite weighting function. Where the use of the composite weight factor gave results closer to actual precipitation. That showed a great congruence with the results of the logical analysis of contract selection, as depicted in the selective proposed nodal hierarchy. Thus, it is suggested that policy planners need to consider as much weighting factors to avoid shortcomings in the existing urban governance policy.

Key Words: urban system, urban hierarchy, gravity model, P-median clustering approach, combined weighting factor.

1. Introduction

The urban system embodies the important points of interaction among places where the majority of population, economic and social activities are concentrated. The spatial analysis of organization and interaction among sites is important in urban geography studies. The general theory of spatial distribution analysis is based on the distance factor, as clarified by “Garner”, that can be modelled by linear or nonlinear parameters (Garner, 1967). All locations have degrees of accessibility, as some locations are more accessible than others.

The importance of cities is based essentially on their connections with other cities in urban system along with their sizes. Emerging literature for analysing urban networks via diverse methods using infrastructure networks, and other location privileges. Correspondingly, the main challenge is to collect the appropriate data, which illustrates inter-city connections to analyse the urban network more efficiently. Human settlements tend to gather depending on the extent of space savings. Thus urban node location efficiency follows the principle of least effort, which means reducing the effect of its distance from the rest of the urban system.

The growth of human settlements in Kenya since the early colonial period in the late 18th century has been affected by many social, economic and environmental factors. The pattern of urban centers development has changed significantly with colonialism. After independence in 1963, Kenya continued to suffer from the increasing urban population growth. Urban population reached 31.3% in 2009, and expected to exceed 50% by 2030. That rapid urban growth causes many problems in Kenya (Nabutola, 2012).

Urbanization studies and specifically analysing urban system from different perspectives, attracts the attention of researchers to identify the problems of urban system in Kenya after independence. The study of (Memon, 1976), concluded that urbanization in Kenya is a major obstacle to development and has been characterized by a high degree of polarization, both in terms of spatial distribution of size categories of urban centers, and regional geographical distribution. While Obudho, RA provided a series of studies about urban areas geography and spatial planning in (Obudho and Waller, 1976; Obudho and El-Shakhs, 1979; Obudho, 1981, 1986). A study of the secondary cities development in Kenya in the context of regional urban development policies (Otiso, 2005), concluded the failure of urban and regional development policies due to the absence of secondary cities in the country. The study was adopted in identifying secondary cities and determining their role in the official development policies during successive periods of independence.

While some studies have followed quantitative and mathematical techniques to build proposals that, address urban system defects and spatial relationships, based on spatial mathematics and statistical treatments. Obudho RA in (Obudho, 1986), analysed the structure of the urban system and the spatial interaction in post-colonial Kenya based on multivariate analysis (Factorial analysis) on 47 urban centers according to the 1969 census. The study suggested that a sub-urban system pattern could be supported by inter-connectivity and interaction through a network of rail and road transport and telecommunications. While the P-median algorithm is applied in determining the nodal connection hierarchy and suggested growth poles applied to the urban system in Sierra Leone (Harvey, et al., 1974).

Some studies used GIS software spatial analysis packages and tools, combined with statistical analysis programs, such as the study of (Du, 2000) for spatial analysis of the urban system in China, based on the application of gravity models and spatial interaction. The study applied relative weight to the socio-economic and geographical characteristics of cities.

Geographic Information System (GIS) is a powerful tool for integrating conclusions from individual data sets for geographic areas. Hence, this paper proposes a modified quantitative clustering approach to propose spatial modifications in urban systems. Kenyan Urban system is chosen as a case study. GIS and P-median clustering algorithm are integrated for that purpose. GIS is used to analyse different characteristic layers (Urban population, spatial distribution, road network, health service distribution, agro-ecological regions, and Isochrone) in Kenyan urban system. Each Characteristic layer is analysed, overlaid and integrated to estimate a combined weighting factor to the clustering cost-function of P-median algorithm, to achieve a hierarchical urban system in Kenya, ensuring less costly interaction among its units. The motivation behind selecting Kenyan urban system is to illustrate how the proposed approach can avoid the shortcomings in the current urban development policy that was based on population size of urban centers, which led to the current implications on urban linkages.

1.1 Data and Methodology

The study relied on the final results of the 2009 census of population and housing in Kenya (KNBS, 2009), in addition to the

2017 Kenya Census of Establishments (KNBS, 2017). As well as reports from international bodies such as the United Nations (NCPD, 2013) and (UN-HABITAT, 2016). The study also used digital maps of road network classes, health services distribution and isochrones regions in Kenya (*Kenya GIS Data*, 2016). In addition to the official maps issued in the census. The cities' population and their coordinates are collected from the 2009 census. The distance matrix among cities are extracted by QGIS 2.8.1 Wien program. The study followed the following framework as shown in Figure (1):

- The mutual interactions among cities of the system is calculated to estimate the relative weight of each city in the entire urban system that is termed "City Potential". The city potential distribution is analysed to check its regularity within the network and the distribution defects.
- A proposal was made to restructure the spatial matrix by selecting the best stochastic sites that achieve the least cost-based on several weight-measuring measures using P-median algorithm. The P-median clustering is performed on different scenarios, namely, based on either the gravity model or weighted gravity model. The gravity model is weighted by either the road network accessibility, or the isochrones region of the city.

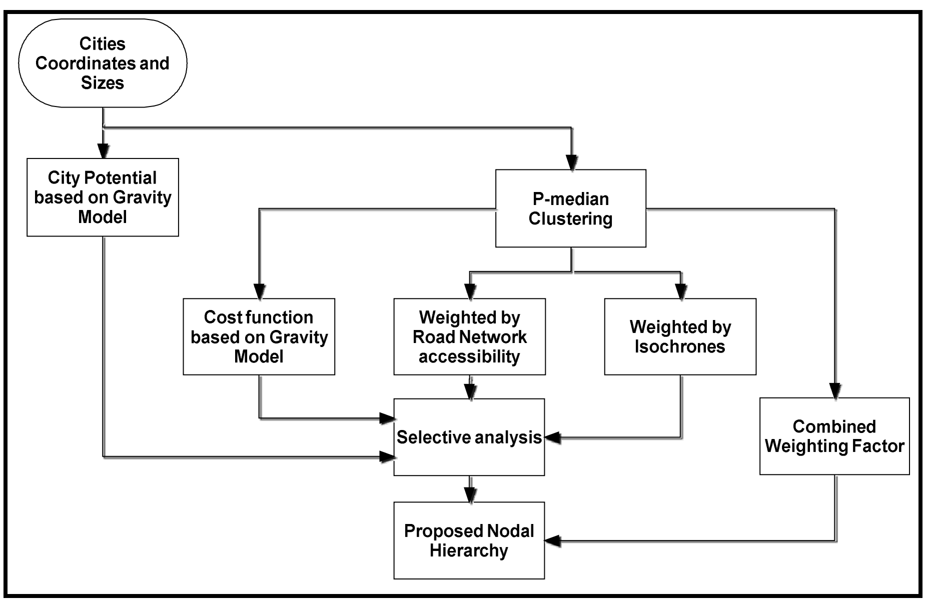

Figure 1. Research Methodology Framework.

- The clustering results in the above-mentioned scenarios are subjected to selective analysis, by choosing the main and secondary nodes in the network according to some measures.
- Finally, a combined weighting factor is applied to the clustering cost-function. The proposed nodal hierarchy is based on both combined weighting factor analysis and the selective analysis results.

2. Urbanization in Kenya

The colonial policies shaped the urban system characteristics in most African countries in terms of size and spacing. Urban nodes were based on the availability of natural resources and the suitability of environment for European settlers. Such policies were enforced with the African environment characteristics. The pattern of distribution of coastal cities and the selection of port sites as well as the pattern of cash crop centers distribution are direct examples of that policy. Even after independence, such policies continued due to the economical dependency on colonial countries.

The cities having administrative functions based on the administrative division of Kenya have greater weight in the urban system. This increases their acquisition of development opportunities than other cities. These administrative cities can be used to create developmental spots in their regions. The administrative cities are organized according to Kenya's latest administrative division into the national capital, provincial capitals and county capitals. Kenya is divided according to different administrative levels into 8 provinces; those are divided into 47 counties as depicted in Figure (2). Counties level is introduced by the new Kenyan constitution on 2010, as target areas for developments (KNBS, 2012).

The major cities have gained importance from their internal interaction in their systems and external depending on their importance and role. That widened the gap between the major and secondary cities. Moreover, secondary cities could not be distinguished from the central rural centers. Due to the monopoly of major cities in development processes and the deprivation of the rest of the cities in the system (Badr, 1997).

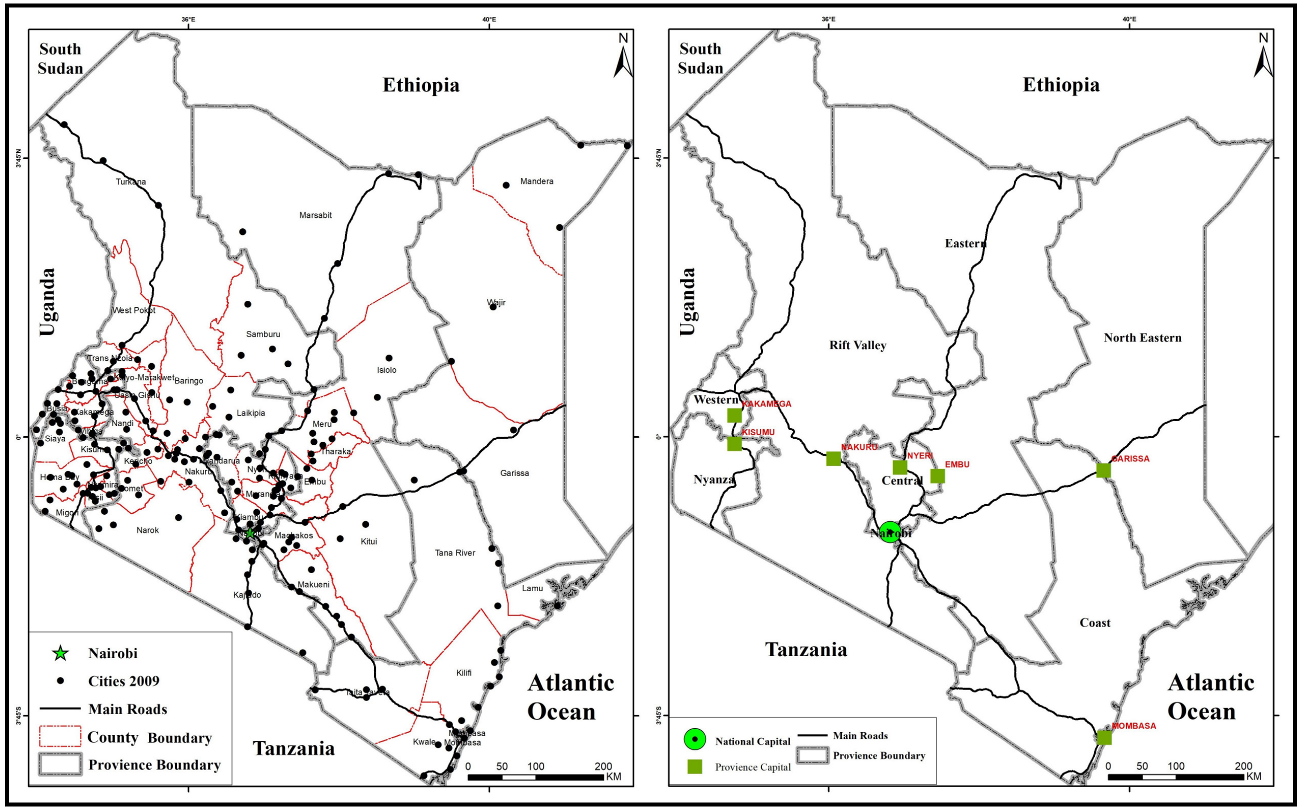

Figure 2. Administrative Divisions in Kenya 2009.

Source: https://www.wri.org/resources/kenya-gis-data, Accessed: 15-12-2017.

Kenya National Bureau of Statistics (KNBS), "Analytical Report on Kenya Population Atlas," Ministry of State for Planning, National Development and Vision 2030, Nairobi, 2012.

Kenya has experienced the problem of rapid urban population growth because of many factors, such as natural increase and rural urban migration to major urban centers, which have contributed to the acceleration of urban growth. Other factors and components of growth such as change of administrative boundaries of cities and reclassification in the rapid urban growth of major cities have also contributed to urban extension. The urban system in Kenya can be characterized as a bipolar style during the colonial period. Such situation has been deepened as a result of colonization isolation and separation policies on social and ethnic basis. The inability to supply facilities and basic services to the entire system, resulted in urban bias, which limited facilities and basic services to major urban areas (Ngeno, 1996).

2.1 Urbanization Indicators

The urban population size and its growth rates along with the number of urban centers have shown consistent growth, according to the official data of successive population and housing censuses. The urban population in Kenya reached 285,000 in 1948, representing 5.3% of the total population. The population grew threefold in 14 years, the urban population reached 747,651 representing 8.7% of the total population in 1962, on the other hand, the total population growth rate is about half of the urban population growth rate in the period from 1948-1962. Urbanization characteristics and trends in Kenya during the period from 1962-2009 are listed in Table (1).

Urban population exceeds a million in 1969, approaching 10% of total population, while urban population is doubled during the period 1969-1979, supported by growth factors, especially after the abolition of the colonial laws, which prevented rural migration to cities, and accelerated after independence when the Africans are allowed to migrate to urban areas without any legal and administrative restrictions (NCPD, 2013). The urban population growth recorded its lowest value during the period 1989-1999 recording 3.4% per year, as shown in Figure (3), this is guaranteed by the slight increase in level or degree of urbanization from 18.1% to 19.3% in 1989 and 1999 respectively.

Table 1. Urban population growth and category of urban centers by size in Kenya 1962-2009.

Year			1962	1969	1979	1989	1999	2009
Total Population (1)			8,636,263	10,956,501	15,327,061	21,448,774	28,159,922	38,412,088
Urban Population (1)			747,651	1,076,908	2,315,696	3,878,697	5,429,790	12,023,570
Degree of Urbanization %			8.7	9.8	15.1	18.1	19.3	31.3
Population growth rate % *			3.3	3.4	3.4	3.4	2.7	3.1
Urban Growth rate % *			6.9	5.2	7.7	5.2	3.4	7.9
No. of Urban Canters(1)			34	47	91	139	180	230
Category of Urban Canters by size (2)	**Million and over**	**No.**	0	0	0	1	1	1
		Size	-	-	-	1,324,570	2,083,509	3,109,861
		%	-	-	-	34.1	38.4	25.9
	100,000-999,999	**No.**	2	2	6	5	4	22
		Size	523,075	756,359	1,321,566	1,046,588	1,214,927	4,617,114
		%	70	70.2	57.1	27	22.4	38.4
	10,000-99,999	**No.**	5	9	24	40	62	97
		Size	105,712	79,267	717,855	1,080,726	1,508,180	3,665,486
		%	14.1	7.4	31	27.9	27.8	30.5
	2000-9,999	**No.**	27	36	64	93	113	110
		Size	118,864	153,282	276,275	426,813	623,174	631,109
		%	15.9	14.2	11.9	11	11.5	5.2

Sources:

(1) National Council for Population and Development (NCPD, Kenya Population Situation Analysis, Government of Kenya and United Nations Population Fund (UNFPA), Kenya, 2013,194, Table 11.3

(2) UN-Habitat, UN-Habitat Support to Sustainable Urban Development in Kenya, Report on Capacity Building for County Governments under the Kenya Municipal Program, Kenya, 2016, p. 9.

* Growth rate $r = [ln(P / P_o)] / Period$, where P, P_o are current and previous population sizes respectively..

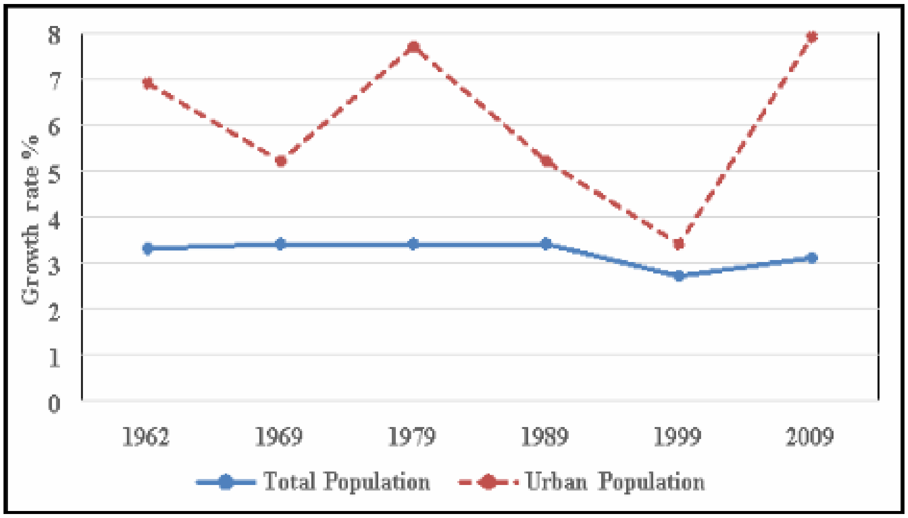

Figure 3. Total and Urban population growth rates in Kenya 1962-2009.

The highest urban growth rate is recorded during the period 1999-2009 reaching 7.9% per year representing more than double the total population growth rate during the same period. The degree of urbanization is doubled representing 31.3%, meaning that one of every three Kenyans live in urban areas (KNBS, 2009).

The large variation in urban population growth rates during the last two inter-census periods of 1989-1999 and 1999-2000 is due to the adoption of data analysis in 1999 on the definition of urban centers on the urban mass only, "the main urban areas that refer to the central and built-up area Urban with intensive land use and concentration of jobs and services", while urban locality change in urbanization analysis in Kenya was changed in 2009 where urban centers were used to include both "main urban" and "semi-urban" areas surrounding the former cities Land and agricultural gradually turned to grow to join the city (NCPD, 2013).

The results of detailed studies indicate that the components of urban growth, which include both natural increase, migration and urban reclassification are the responsible components for urban growth during the recent period. Urban reclassification have estimated their contribution as a component of urban growth by about 25%. It is expected that the significant proportion of the natural increase component due to the demographic characteristics of migrants, which rise fertility rates among the urban population as a whole, recorded a 3.2 child/female in the reproductive age compared to 5.5/Female reproductive age in the countryside and 5 children/female in the reproductive age of the national level (Hope, 2012). The natural increase in Kenyan cities is a challenge to service delivery and urban management (GORE and GOVIND, 2014).

The Number of urban centers' category by size in Kenya during the period 1962-2009 is demonstrated in Figure (4).

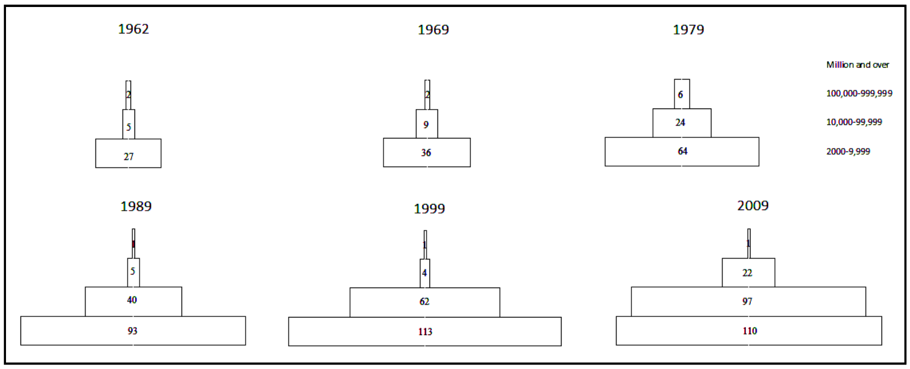

Figure 4. Number of urban centers category by size in Kenya 1962-2009.

It is clear that there was no million-inhabitant cities until 1989. Furthermore, only on city "Nairobi" exceeded a million during the period 1989-2009. Although the number of small cities with population less than 10,000 inhabitant are growing continuously, their respective share in total urban population is continuously decreasing. On the other hand, the medium size cities are gaining higher percentage of urban population along with the number of cities in this category. Meanwhile, the total urban population in the 97 medium size cities is approximately equal to the size of "Nairobi". This emphasis the dominance of Nairobi on the urban system in Kenya.

2.2 Geographical Distribution of Urban Centers

The preliminary view of the distribution of the urban network structure in Kenya reflects a strong correlation between the distribution of cities in terms of concentration and size on one hand, and the distribution of agro-ecological regions, as shown in Figure (5).

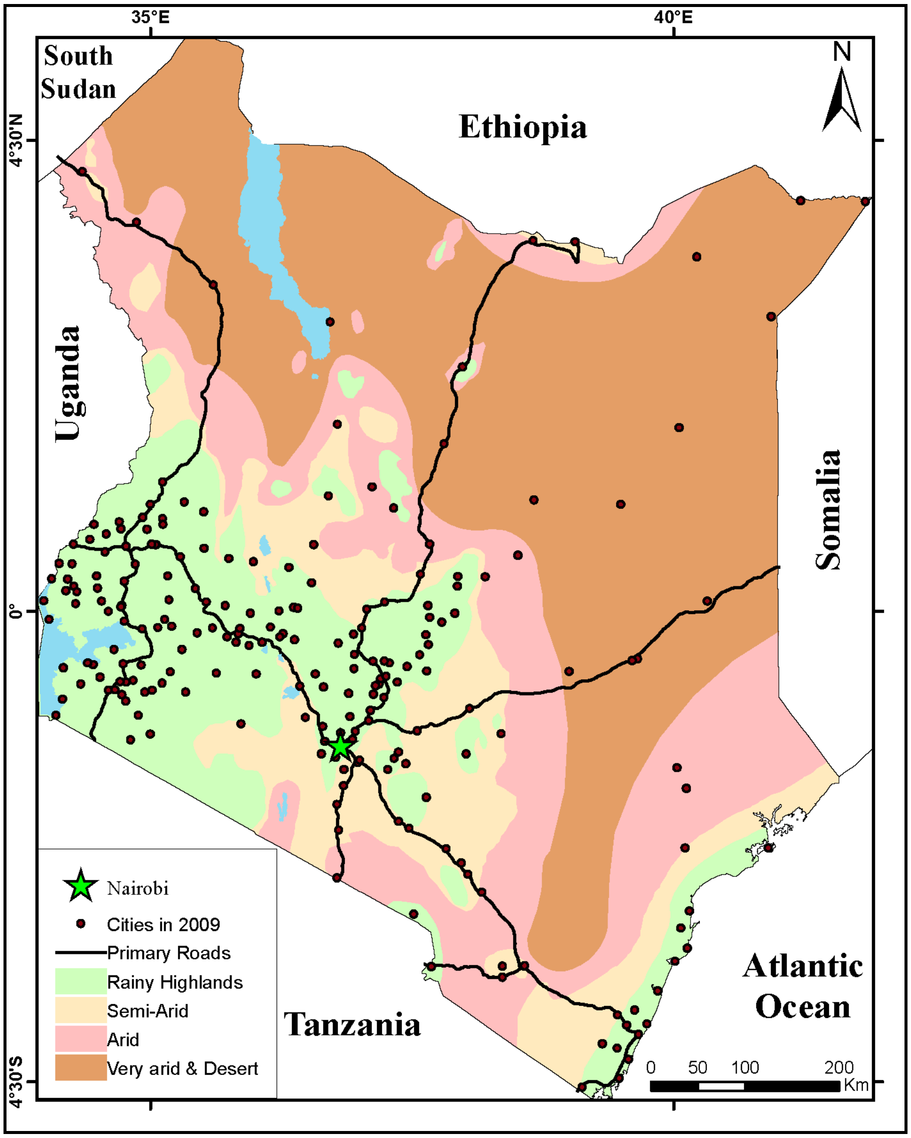

Figure 5. Cities Distribution According to Agro-climatic Zones, Kenya 2009.

Source: Braun H.M.; Sombroek, W. and van der B.: Exploratory soil map and agro-climatic zone map of Kenya, 1980, scale 1:1,000,000. In: Nairobi: Kenya Soil Survey (Exploratory soil survey report. Kenya Soil Survey no. E1). Soil Survey Institute, Netherlands (1982).

https://www.wri.org/resources/kenya-gis-data, Accessed: 15-12-2017.

This is a reflection of the natural environment conditions on their resources. Kenya can be divided into four main agro-ecological regions, namely, the rainy highlands, the semi-arid, arid, and desert and very arid regions (Braun, et al., 1982). Analysing the agro-ecological map of Kenya (*Kenya GIS Data*, 2016) shows that 158 cities, representing 85% of urban population, exist in the rainy highlands extending from the central region towards west, in addition to the south-eastern coast. In contrast, the rest of cities are scattered in the dry, semi-arid and desert areas in the northern and north-eastern Kenya regions.

The distribution of the urban network coincides with the main road network. The urban network is distributed among four primary axis, on a radial pattern extending from Nairobi. In addition to a linear pattern that appears in the south-eastern coast extending from Mombasa to Tanzania. Another linear axis that extends from south to north passing through Kissi, Kisumu, Kitale and Lodwar to South Sudan. The south-eastern primary axis extending from Nairobi to Mombasa, which runs along a good route linking the largest two cities in the system. While the second axis is in the eastern direction extending from Nairobi to Somalia and passes through Garissa. The third axis is from Nairobi to Ethiopia in the north direction and ends with Moyale in the far north of the country. The fourth axis is from Nairobi to Uganda, passing through Nakuru and Eldoret and ending with Malaba.

Correspondingly, Nairobi and Mombasa emerged as major urban centers, because of their strategic location as transport nodes. While the fertile highlands attracted a series of medium-sized cities. In contrast, north-eastern Kenya remains the least urbanized in the country. Nairobi, the Rift Valley, Coast and the Central provinces are the regions of colonial powers and urban classics. Secondly, the hierarchy is absent from the classical colonial network management centers. Most of the colonial administrative nodes continued to perform their administrative, with many economic, religious and political functions (NCPD, 2013).

2.3 Urban Hierarchy in Kenya

Since its inception, the urban system in Kenya has been characterized by a high degree of concentration in polar poles, both in terms of population size distribution and ranks of urban centers, or spatially in terms of regional geographical distribution at the state level. The urban centers witnessed numerical growth during the inter-census periods. In 1948, the number of urban centers reached 17, and doubled in the following census in 1962. The number of cities increased to 48 in the seven years since the previous census (NCPD, 2013). The highest growth rate of the number of cities is recorded after independence when Africans are allowed to migrate to urban areas without any legal and administrative restrictions. As showed at Table (1) the number of urban centers increased from 48 to 91 during1969 and 1979 respectively, The number of cities increased to 139 in 1989, and in 1999 reached 180, by 2009, the number of cities reached 230 cities according to the 2009 census of population and housing.

The Urban centers distribution according to their size category in Kenya during the period 1962-2009 is listed in (UN-HABITAT, 2016, p. 9), the urban centers in Kenya is categorized among four size categories as shown in Figure (6).

The cities with population size less than 10,000 had the largest number among cities in the system since the 1962 census, despite of having a small portion of total urban population about 5.2% in 2009. The next upper category, with population sizes ranging from 10 to 100 thousand shows consistent increase in their share in total urban population recording 30.5% in 2009. The combined group of small and medium-sized urban centers reached 207 in 2009 with a total population of 4.3 million, representing 35.7% of total urban population. Those Urban centers are expected to dominate Kenyan urban hierarchy in the future.

The small and medium-sized urban centers are the primary access point for migration from rural areas to major urban centers. Combating migration by providing employment opportunities, those cities can contribute achieving geographically balanced national urban development and stimulate national and regional economies in the, and can play a greater role in the provision of efficient services to increase the urban population besides assisting in poverty reduction (NCPD, 2013).

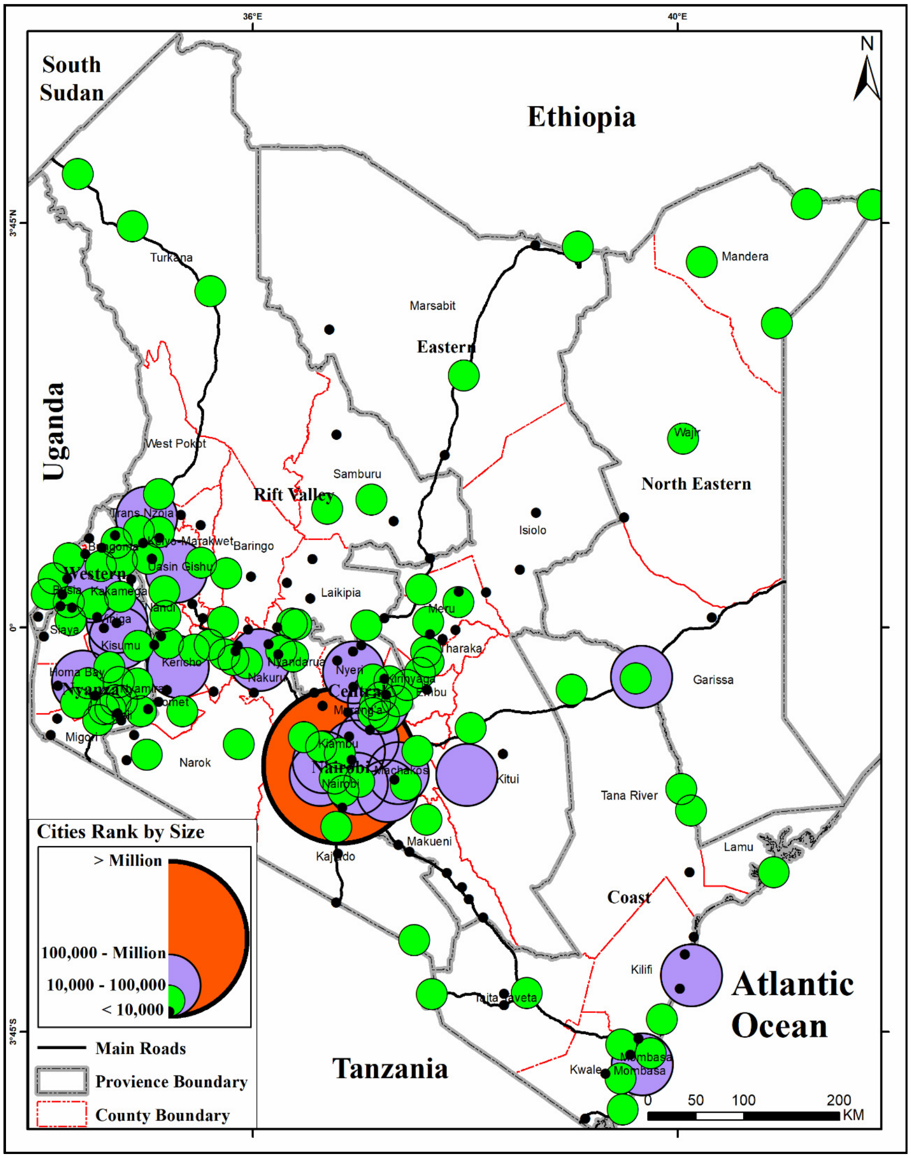

Figure 6. Cities Ranks by Size in Kenya 2009.
Source: https://www.wri.org/resources/kenya-gis-data, Accessed: 15-12-2017. Republic of Kenya (2012): Kenya Population and Housing Census (2009): Analytical Report on Urbanization, Volume VIII, Appendix 3, pp. 47-50.

Despite the dominance of large and million cities on the urban system in Kenya, with proportions of 38% and 25.8% respectively in 2009 of the urban population, but the number was limited to 23 cities in 2009, with only Nairobi exceeding three millions. The economic base of Nairobi does not support a large number of small cities around it and does not leave it with opportunities to expand its economic base, as the average income and productivity is proportional to city size. Despite the government policies for population redistribution, the dominance of Nairobi continues. Primacy index calculations for Nairobi with respect to the largest three cities, recorded a continuous increase from 1.6 in 1969 up-to 2.1 in 2009. Confirming the failure of Kenyan government policies to achieve urban balance and regional development (KNBS, 2009). While calculating the primacy index with respect to the largest ten cities recorded 1.22 in 1969 down-to 0.98 in 2009 (NCPD, 2013). This highlights the potential of developing medium size along with larger cities.

The distributive image of the current spatial structure, the capital centrality and economic dominance, and the increasing cost of spatial interaction are major problems facing Kenyan urban system (Harvey, et al., 1974). Those prevent the urban growth benefits in both network periphery and the surrounding rural areas. Moreover, there is a lack of medium sized urban centers that are ready and active in the network in many urban systems in agricultural communities. That reveals the need for reformulation of regulation of urban spatial system.

According to the laws and theories in urban geography, the more of population size entails more functions of the city. It is assumed that the size hierarchy is accompanied by a functional hierarchy. But the actual situation of Kenya's urban system does not reflect this correlation. Size hierarchy could not create a hierarchy of jobs and services. The correlation between size and administrative hierarchies are declined, while many cities did not succeed in achieving pluralism due to the failure of many development policies. Therefore, due to the absence of official data on the economic activities of the population in the 2009 census at cities' level. It is difficult to determine the functions of cities, while it was possible to infer the economic and service importance of cities through the availability of data on the administrative functions of cities and data on the distribution of industrial facilities and health services at the County level to enter the criteria for determining the nodal hierarchy.

2.4 Urban Governance Policy in Kenya

Urban development policies in Kenya since independence in 1963, have been based on the "growth poles" principle. That is implemented through the population redistribution and the development of small and medium-sized urban centers. The 1970-1974 policy continue to follow the same path as the former policies. The attempt to select the growth poles suffered from many disadvantages due to the lack of objective criteria in selecting the proposed cities, most of which were located in arid and semi-arid sites. As well as many obstacles such as lack of planning and institutional failure, poverty and weak development potential and central policies. While the constitution in 2010 stipulated that a "city law" should be drafted to address the problem of local governance. That remains a major obstacle to the enactment of urban development policy. In 2009, the census was determined according to local authority criteria. It was limited to the size discrimination criteria in urban center definition. The locality is considered urban if its size exceeded 2000 inhabitants. This criteria created a gap between the size of the city and its actual power. Only in major cities such as Nairobi, Mombasa, and Eldoret can be excluded from this shortage (Republic of Kenya, 2012). The local government in Kenya was restructured in 2013 to implement decentralization policy. The city councils of the new 47 provincial governments replaced the old municipalities and directly followed eight provinces. City councils are authorized to manage all the planning, development and preservation of the urban environment.

The Kenyan Urban development policy has already been developed in 2011 with dimensions and objectives, including improving the urban environment, developing basic and social services in urban centers and taking into account the dimensions of climate change and environmental conditions in the planning and development processes (Nabutola, 2012; NCPD, 2013). Policy makers in Kenya proposed the creation of five metropolitan areas in addition to Nairobi metropolitan region. Those regions comprise about 70% of Kenya's GDP. The motivation behind this proposal was the potential of those cities to drive economic growth, specifically in their metropolitan regions. The proposed new metropolitan regions include

Mombasa Coastal region, the linked of Nakuru–Eldoret metropolitan areas, and rich agricultural zones at Kisumu–Kakamega. The four metropolitan regions are located in the Northern Corridor urban belt that contain more than 75% of urban population in Kenya. The remaining two regions are proposed to be at the linked Kitui–Meru–Isiolo metropolitan areas, and Wajir–Garisa–Mandera city agglomeration. The six metropolitan concentration trend proposal may be susceptible to peri-urbanizing, which caused, primarily, the urban system problems in Kenya. The proposed infrastructure in those regions may lead to peri-urban settlements' growth in its vicinity. This will raise land prices and lengthen daily work trip to the urban core thus leading to traffic congestion. In addition to the consequent problems of urban sprawl (Cira, 2016).

This paper attempts to conceptualize the restructuring of the urban system in Kenya in order to avoid the negative aspects of previous urban policies and to fill their gaps by relying on realistic and objective criteria in the selection of cities, such as geographic location, spatial relations, proximity to road networks, and the degree of health services concentration. Taking into account the extent of interaction and attractiveness among cities in different size ranks. This enabled the classification of hierarchal ranking based on mathematical and statistical methods in the selection of centers as growth poles to achieve long-term national development goals of Kenya 2030 Vision.

3. Urban System Nodal Analysis

The cities within the urban system can be organized according to their population sizes and functions. Recently, there a tendency to analyse urban systems on a network-based instead of a size-based perspective (Lichen, et al., 2014). Regardless of their concentration or dispersion, there are mutual interactions among those cities. The city network theory claims that, fitting cities in a network, guarantees complementary relationships among cities. The cooperative activities are distributed among cities despite the size and spatial costs of each city in the network. The analysis of urban system as a network of cities allows to examine the real potential of the size and economic advantages of each of the cities within the framework of the regional system, supported by the spatial interaction among the points of the network, which enforces the advantages of some cities and addresses the shortcomings of others. The urban system nodal analysis framework is based on considering cities as nodes in the urban network. Urban system can be analysed according to two directions: the "horizontal" trend, which examines the form and pattern of spatial distribution through the analysis of maps, sizes and spacing. On the other hand there is a "vertical" trend in the analysis, which examines the organizational structure of the regularity of cities in their categories and their sizes, and both directions are related to each other (Garner, 1967).

Both “horizontal” and “vertical” direction results can be combined in one mathematical model for efficient urban system analysis. The proposed mathematical model is based on extracting some weight factors from the vertical analysis, then apply those weighting factors to the horizontal analysis results. The study of the existing nodal system aims at dividing urban system into smaller clusters, led by a major city connected to the first city, with direct relations that enable the first city to manage the entire system under a decentralized system governed by complementary relations and interactive links. Mathematical analysis is required to choose the appropriate nodes and their dependents in Kenya by determining the relative weight of each city within the system according to the matrix of urban interactions.

3.1 The Relative Potential of Kenyan Cities

The Kenyan system will be analysed starting with the model proposed in (Du, 2000) based on the 2009 Census of population and housing. The most difficult point in the analysis of Kenya’s urban system is the lack of data. The area of study encompasses 230 cities with population over 2,000 as sample cities.

The only required data for this model are the cities size and their coordinates. The distance matrix among cities are extracted by QGIS 2.8.1-Wien program. The linkages among cities will be calculated based on the Gravity Model, the interaction T_{ij} between two cities i and j is calculated by (Du, 2000) as:

$$T_{ij} = A_{ij} \cdot \left(\frac{\sum_{m=1, m \neq i}^{n} (p_m / d_{mi})}{\sum_{m=1, m \neq j}^{n} (p_m / d_{mj})} \right) \quad (\forall\ i \neq j\ , k \geq j) \tag{1}$$

Where

$$A_{ij} = p_i \cdot \left(\sum_{k=j}^{n} \frac{p_j}{\sum_{l=1}^{k} p_l} \right)$$

Where p_i is the population of the city i, d_{mi} is the distance between the city i and the city m, and n is the total number of cities. The linkage between two cities is the summation of the interdependency of both cities, i.e.,

$$L_{ij} = T_{ij} + T_{ji} \quad (\forall\ i \neq j \quad , L_{ii} = 0) \tag{2}$$

The importance of the city in an urban system is the aggregation of its linkages to the other cities in the system that is defined as the city potential G_i :

$$G_i = \sum_{j=1}^{n} L_{ij} \quad (\forall\ i \neq j) \tag{3}$$

It is found more suitable to calculate the relative potential, i.e., the share of the city in the entire system potential, as:

$$Gr_i = \frac{G_i}{\sum_{i=1}^{n} G_i} \times 100\% \tag{4}$$

The relative potential of Kenyan cities is shown in figure 7, it is obvious that there is a large gap between Nairobi and the rest of cities, furthermore, the linkages between Nairobi and any city j is larger than the linkages of other cities to the same city.

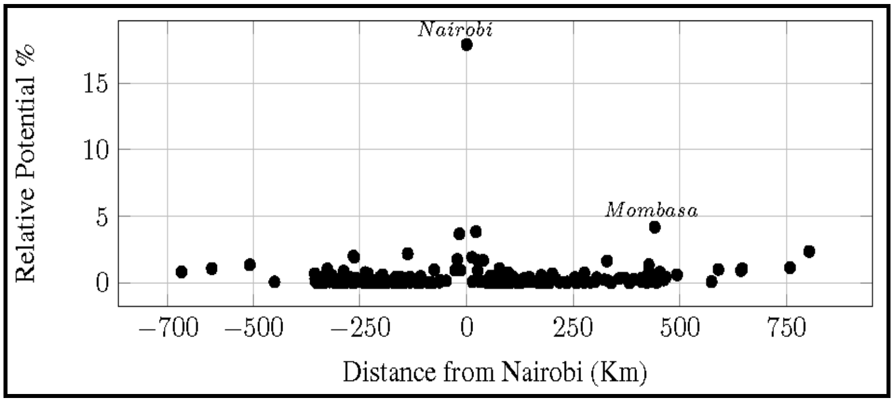

Figure 7. Relative Potential of Kenyan Cities.

This reveals a great dominance of Nairobi on the urban system, and highlights the centralism of the urban system in Kenya, that is characterized by an extremely higher potential prime center that dominates the entire system directly in a manner that all Kenyan cities are only subordinates to Nairobi.

For the sake of building up a significant developing urban system, a hierarchal structure and linkages among nodal cities is needed for the ease of governmental service providing. Optimum location of services aims to minimize the average access cost to reach the service. Each service is located at the node that has the potential to serve the dedicated users with minimum cost; users are concentrated on the surrounding nodes of the network (Biancardi, et al., 2008). This requires the cities network to be divided into a number of clusters forming regional subsystems, which is subsequently divided into further clusters. The great potential of Nairobi can be benefited in this hierarchy, as it is powerful enough to integrate all of the regional subsystems into a complete system such that the linkages from Nairobi to the high level nodal cities, and then to the low level nodal cities. Moreover, multi-node urban clusters lead to some forms of synergy, meaning that, proximally located cities are related to each other in a cooperative way, getting more benefits from the whole network than the sum of its individual parts.

3.2 Urban System Clustering By P-median Algorithm

Clustering is concerned with partitioning objects into homogeneous groups based on the available data (Köhn, et al., 2010). The P-median algorithm is one of the most powerful location allocation algorithms, it is widely used in diverse applications. Examples of P-median applications include facility location, cluster analysis, telecommunications industry, and political & administrative districting. Facility location is one of the potential applications of P-median clustering, defining a set of demand centers out of possible locations (Ushakov, et al., 2015). While cluster analysis defines the "best representatives" from a finite set of objects based on some measures of similarity. Administrative divisions of countries can be refined with the aid of P-median algorithm, based on the degree of relationship and infrastructural connections (Goldengorin, et al., 2013).

The P-median algorithm will be used as an optimization algorithm to cluster the urban city network in Kenya into *p* regional clusters with minimum linkage cost among the network. Consider the case of having *n* cities in the urban system, and it is required to choose *p* sub-regional hub cities for administrative services to be delivered to all of the cities with minimum cost, then the problem is two folded, first the *p* hub cities has to be chosen, those are called medians, then the rest *n - p* non-median cities have to be attached to one of the hubs.

This problem can be formulated as a binary integer programming problem such that the following constraints are maintained:

$$X_{jj} = \begin{cases} 1 & if\ point\ j\ is\ a\ median \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

$$X_{ij} = \begin{cases} 1 & if\ non-median\ i\ is\ attached\ to\ a\ median\ j \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

There are n possible values of X_{jj} , therefore

$$\sum_{j=1}^{n} X_{jj} = p \quad (7)$$

$$\sum_{j=1}^{n} X_{ij} = 1 \qquad \forall i \neq j \quad (8)$$

This means each city is only attached to one median. Then there is another constraint:

$$X_{ij} \leq X_{jj} \qquad \forall i, j \quad (9)$$

This means that if the city is a non-median, it will be attached to only one median, if the city is a median it will be attached to itself, i.e., medians can't be attached to each other, and the non-medians can't be attached to each other’s neither.

Taking the above mentioned constraints, it is needed to minimize:

$$\sum_{i=1}^{n}\sum_{j=1}^{n} S_{ij} \cdot X_{ij} \quad (10)$$

Where S_{ij} is the matrix representing the cost of attaching each city i to a city j, such that:

$$S_{ij} = \begin{cases} A_i \cdot d_{ij} & for\, i \neq j \\ 0 & for\, i = j \end{cases} \quad (11)$$

Where A_i is a scaling factor for the city i, and d_{ij} is the distance between the two cities i and j. In this paper the scaling factor will be the population size of cities as given in the 2009 census of population and housing. The above mentioned requirements can be implemented using the following algorithm:

(1) **Procedure:** Choose iteratively p medians out of n cities
(2) Set $X_{jj} = 1$, $\forall\, j\, median\, city\, index$
(3) $loop$: $\forall\, i \neq j$
(4) **If** S_{ij} is minimum **then** $X_{ij} = 1$, $Cost(i) = S_{ij}$ **else** $X_{ij} = 0$
End If
(5) **Set** $Total\, Cost \leftarrow$ Aggregate $Cost(i)$
(6) **Go-to** *loop*.
(7) **Close** *loop*;
(8) **If** $Total\, Cost$ is minimum *Stop iteration* **else**
End If
(9) **Go-to** top.
(10) **If** $X_{ij} = 1$ *attach* city i to city j
End If
(11) **End Procedure**

This is a lengthy iterative algorithm with exponential growing complexity, especially for large number of cities n. This complexity can be greatly reduced by limiting the iterations to those cities with relative potential ($\geq 0.25\%$) calculated by Eq. (4), which are mutually spaced by a distance greater than certain threshold distance (10 km). The optimization will be based on the chosen threshold values for both the threshold potential and the threshold distance among median cities.

The optimum choice of *p* value is obtained by iteratively choosing different values of *p*, then the highest silhouette index determines the optimum value of *p*. The silhouette index is a measure of how efficient the clustering is, in other words higher silhouette value indicates that the city is less costly to be connected to other cities within the same cluster, and costs a lot to be connected to other cities in other clusters. The silhouette index takes a value between ±1. If most cities have high values, then the clustering is efficient and the corresponding *p* value is accepted, while low or negative values indicate that the clustering can't be accepted by such number of *p* value (Starczewski and Krzyżak, 2015).

The silhouette index Sil_i is calculated for each city i, by evaluating the average cost of attaching the city i to all cities within its cluster a_i, in addition to the average cost of attaching that city to all cities outside its cluster b_i, then the silhouette index is calculated as:

$$Sil_i = \frac{b_i - a_i}{max(b_i, a_i)} \quad (12)$$

The average silhouette index Sil_i for all cities of the entire network is a measure of clustering efficiency. The silhouette index recorded a maximum in two cases of *p* value, 5 and 16 respectively.

The application of the above-mentioned P-median algorithm results in 5 medians (Nairobi, Mombasa, Nakuru, Kakamega, and Takaba). Those are considered as the four main cities under the umbrella of Nairobi as depicted in Figure (8).

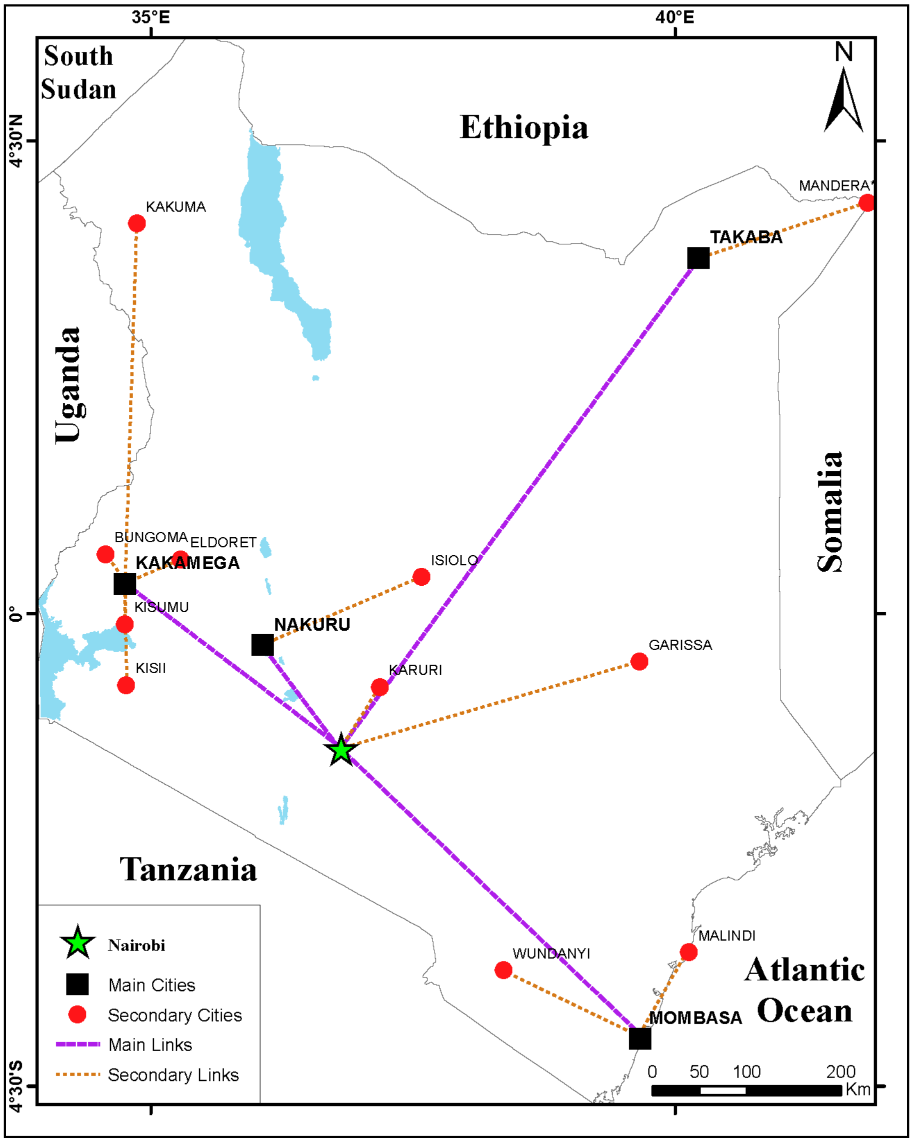

Figure 8. Proposed Nodal Hierarchy Based on P-median algorithm.

Those are termed (Main1). The 16 medians includes eleven cities in addition to the five medians in the case $p = 5$. Those eleven cities can be considered as the secondary cities (Eldoret, Karuri, Malindi, Kisii, Kisumu, Mandera, Bungoma, Isiolo, Kakuma, Garissa, and Wundanyi). It is found that despite of being secondary cities, both of Karuri and Garissa are directly connected to Nairobi, instead one of the main cities.

The P-median above mentioned results in Figure 6 (Main1, Second1) are based on city size and distance matrix only. Not to mention that, the cost of linking two cities is dependent on several factors, in addition to the distance between them and population size of each, those factors may include their proximity to road network, urban function of each, and other administrative issues, etc. The power of the P-median algorithm comes from its suitability to be held with the available data, then the results can be further fine-tuned as extra information appears.

The P-median algorithm can be benefited from analysing the road network; that may help in fine tuning the clustering algorithm by scaling the cost function S_{ij} by the city's accessibility to the road network, or by using the Isochrone regions determining the average time to reach all cities in the network from a specific region.

3.3 Road Network Accessibility

GIS can be used to analyse the road network along with the cities locations, by determining the nearest road type and distance to each city. The city i accessibility to the road network can be evaluated by multiplying the distance from that city to the nearest road r_i by a specific factor for each road type. The classified road network in Kenya is analysed based on the available digital maps in (*Kenya GIS Data*, 2016).

According to the Kenyan official road network in 2009, the road network is categorized into four class A, B, C and D as depicted in Figure (9), with relative weights of 4 down to 1 respectively. The number of cities within a finite set of distances from different road classes is listed in Table (2).

Table 2. Cities accessibility to road network.

Road Class	**Number of cities within a distance**					
	< 1 km	**1-2 km**	**2-3 km**	**3-4 km**	**4-5 km**	**> 5 km**
A	40	20	8	7	3	138
B	24	16	6	3	3	164
C	67	30	16	9	3	91
D	51	43	21	10	15	76

Source: Analysis of road network digital map (*Kenya GIS Data*, 2016) with QGIS.

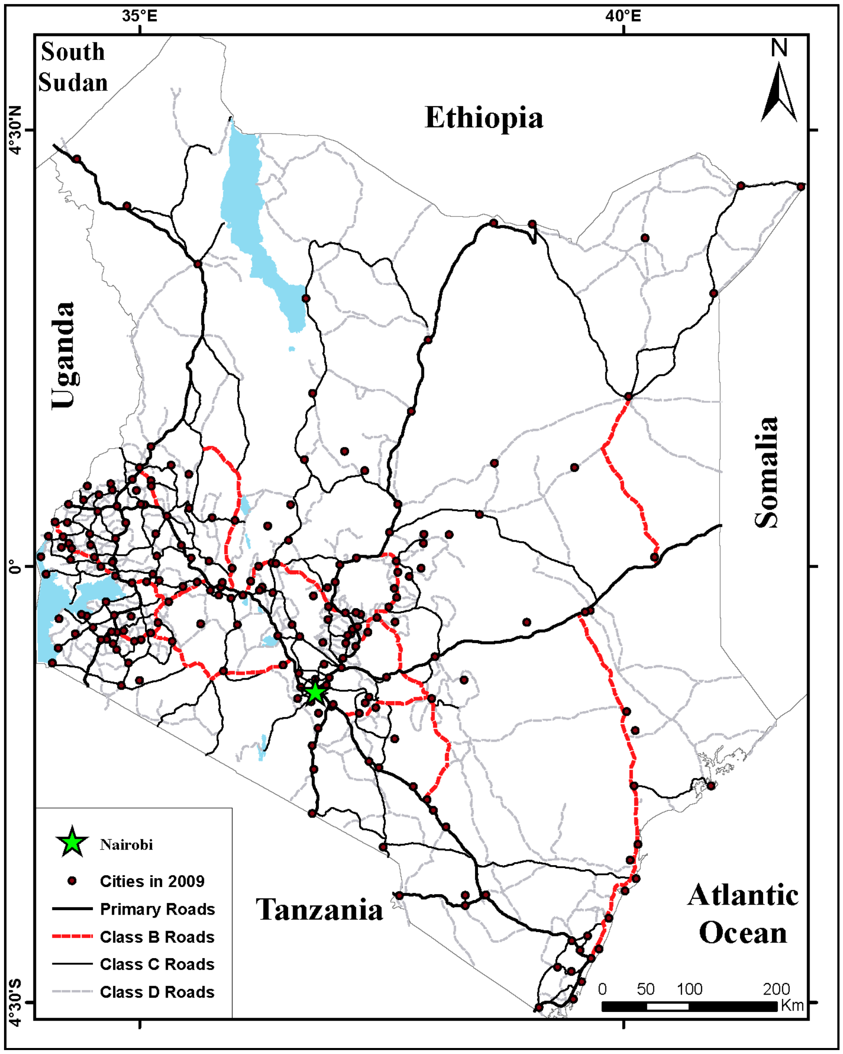

Figure 9. Road Network and Cities in Kenya 2009.
Source: https://www.wri.org/resources/kenya-gis-data, Accessed: 15-12-2017.

It is clear that 138 cities are away from the main network, by more than 5 Km, this highlights the need to upgrade the road network in order to link the urban network more efficiently. The relative weight of the cities within a distance of 5 Km from any road is dependent on that distance, meaning that the city within 1 Km is assigned (5), while the city that is at a distance 5 Km is assigned (1). The relative weight of each city, according to road network proximity, is determined by multiplying the distance weights to each corresponding road class weight, the maximum result is observed for each city, then the maximum product is divided by 5, this ensures that the relative weight of cities according to the proximity to road network will range from (1) to (5).

Weighting the cost function S_{ij} by the road network accessibility factor of each city, and applying the P-median algorithm results in four main cities under the umbrella of Nairobi, those are (Mombasa, Garissa, Juja, and Kisumu) as illustrated in Figure (10) and termed (Main2).

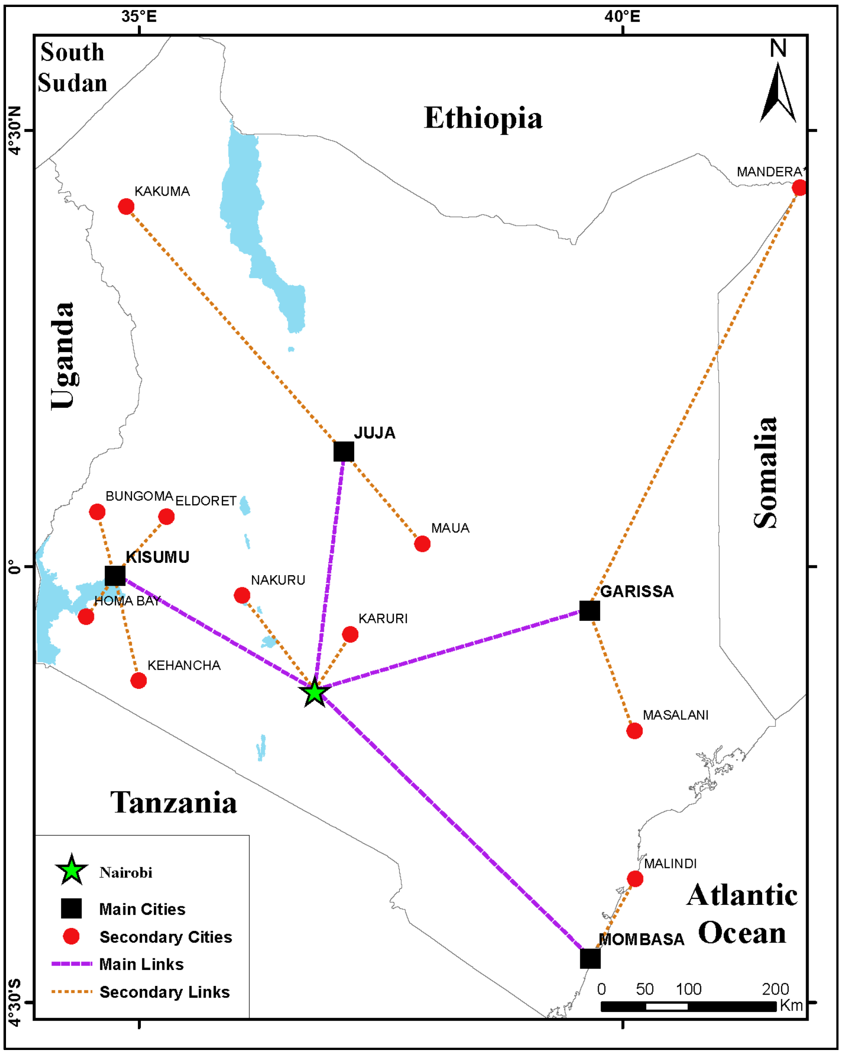

Figure 10. Proposed Nodal Hierarchy Taking the Road Accessibility into Consideration.

It is depicted also that there are eleven secondary cities termed (Second2), those are (Malindi, Masalani, Mandera, Maua, Kakuma, Kehancha, Homa Bay, Bangoma, Eldoret, Karuri, and Nakuru). It is found that despite of being secondary cities, both of Karuri and Nakuru are directly connected to Nairobi, instead one of the main cities.

3.4 Average Arrival Time

The accessibility surface of Kenya illustrate the estimated time to a city. Calculations was based in distances from roads, and the travelled distance, assuming standard speeds at different road types, and topography considerations. The isochrone map of Kenya is shown in Figure (11).

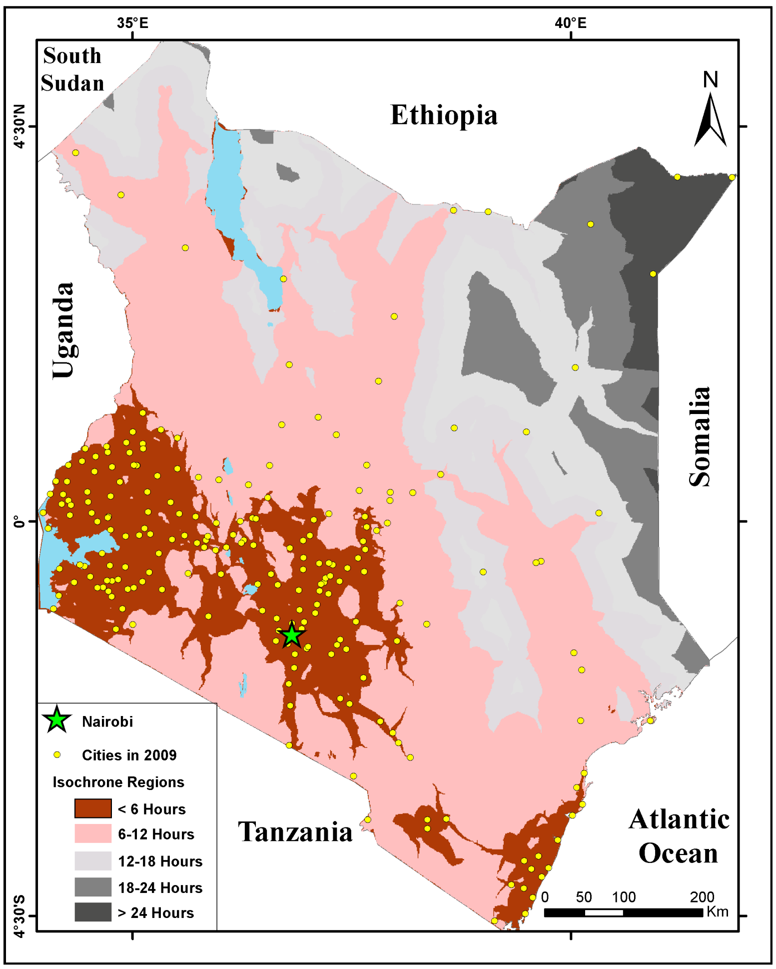

Figure 11. Isochrone Map in Kenya.
Source: https://www.wri.org/resources/kenya-gis-data, Accessed: 15-12-2017.

The isochrone map in Kenya is analysed and divided into five time intervals with a time interval of 6 hours to reach, such as the relative weight of the range less than 6 hours is assigned a weight of (5), followed by the 12-hour range with relative weight (4), then the 18-hour range and its relative weight (3), while the relative weight of the 24-hour range is determined by (2), and finally cities with larger times than 24-hours are assigned (1) relative weight.

Figure (12) illustrates also the outcomes of applying the P-median algorithm based on weighting the cost function S_{ij} by the factor corresponding to the average arrival time of each city, both types of nodes are termed (Main3 and Second3).

The four main cities connected to Nairobi, are (Mombasa, Garissa, Rhamu, and Kapsabet). The clustering results in twelve secondary cities, those are (Malindi, Wajir, Elwak, Mandera, Moyale, Nakuru, Juja, Kisumu, Eldoret, Kakuma, Karuri, and Isiolo). It can be noted also as in the preceding two cases, there are two secondary cities connected directly to Nairobi, those are (Karuri, and Isiolo).

It is obvious that some main and secondary cities appear in the above mentioned three scenarios, more over some cities interchange their roles among those scenarios, meaning that a main city in one scenario may appear as a secondary city in another scenario In order to select the main and secondary cities we have to perform a selective comparison among the three scenarios outcomes. The main nodal cities in the three scenarios are listed in Table (3), along with their relative potentials and the population concentration measures either by determining the number of cities within 100 *Km* distance or the total population within the same area.

It is obvious that the three scenarios agree about “Mombasa” as a main city, so it will be the first confirmed node. Garssia is repeated in both Isochrone and Accessibility based cost function, and consequently it is proposed as a main node. There are three competing nodes in the west, namely “Kakamega, Kapsabet, and Kisumu”, the large potential of “Kisumu” make it more suitable, besides, being on the main road network. The remaining node is to be chosen by comparing “Nakuru, Rhamu, Takaba, and Juja”. The large potential plus the population concentration around “Nakuru” make it more likely to be a main node in the network.

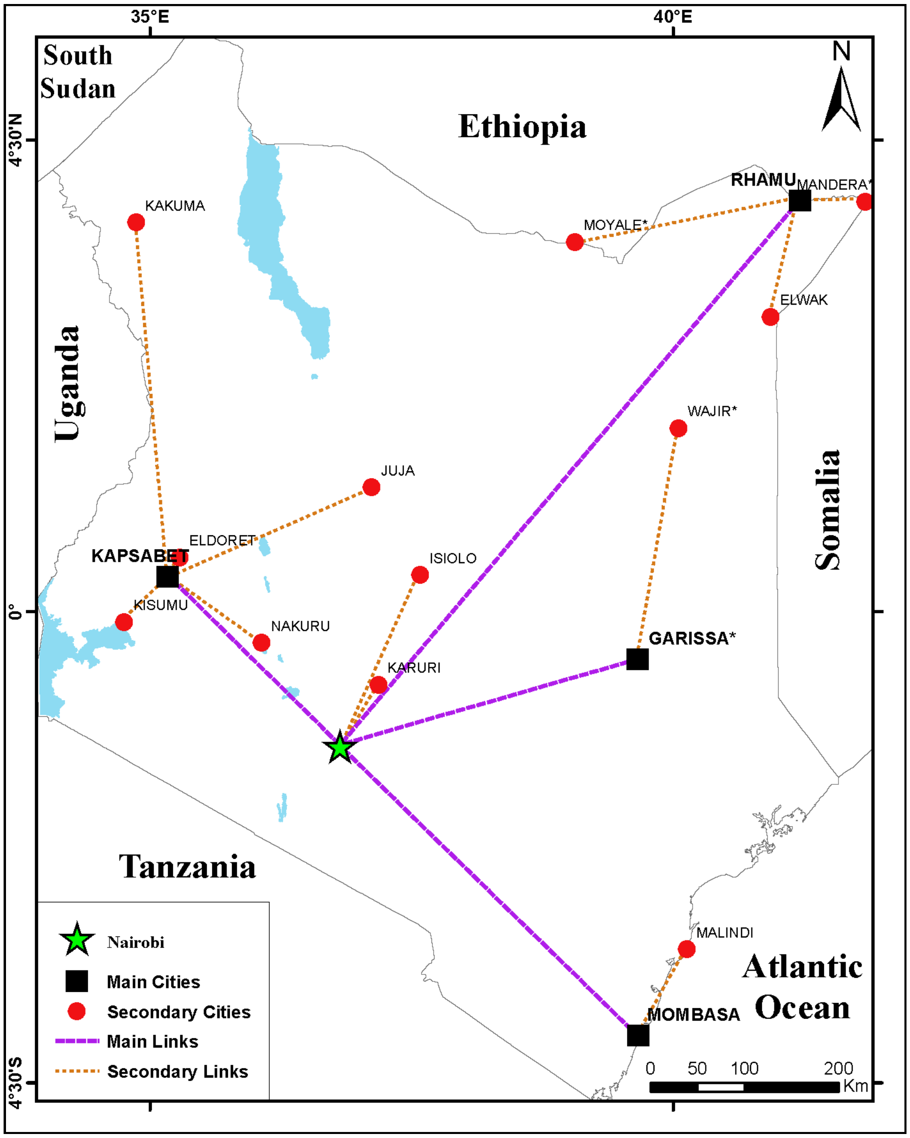

Figure 12. Proposed Nodal Hierarchy Taking the Arrival Time into Consideration.

On an attempt to propose the secondary level nodal cities, different sets of secondary cities according to the three scenarios are collected also in Table (3) along with the same measures mentioned in the main cities, besides, a measure of proximity to the road network, either by the type of the nearest road type or the distance from the nearest road.

Table 3. Main and Secondary Nodes in different clustering scenarios.

Cost Function Model	Nodes	Main Nodes	Relative Potential	Number of cities within 100 km	Total population within 100 km	Nearest Road Type	Distance to Nearest Road km
Gravity	Main Nodes	Mombasa	4.2	13	1227984		
		Nakuru	2.2	43	939754		
		Kakamega	0.9	59	1400735		
		Takaba	0.9	2	45842		
	Secondary Nodes	Kisii	0.8	19	270827	B	1
		Bungoma	0.8	23	262576	A	3
		Isiolo	0.7	8	124175	A	1
		Kisumu	2	66	1397809	A	2
		Garissa	1.7	4	139353	D	1
		Wundanyi	0.1	3	26902	C	2
Isochrone	Main Nodes	Mombasa	4.2	13	1227984		
		Garissa	1.7	4	139353		
		Rhamu	1.2	2	81729		
		Kapsabet	0.3	59	1309677		
	Secondary Nodes	Isiolo	0.7	8	124175	A	1
		Juja	0.8	8	119144	C	13
		Moyale	1	2	32110	A	1
		Elwak	1.1	1	24368	C	1
		Wajir	0.6	1	16838	C	1
Accessibility	Main Nodes	Mombasa	4.2	13	1227984		
		Kisumu	2	66	1397809		
		Garissa	1.7	4	139353		
		Juja	0.8	8	119144		
	Secondary Nodes	Bungoma	0.8	23	262576	A	3
		Kehancha	0.5	7	61269	C	6
		Homa Bay	0.4	16	251445	C	1
		Maua	0.3	9	124111	C	1
		Masalani	0.4	2	25705	C	7

It can be noted that both “Kisumu and Garissa” appear as secondary nodes in the Gravity model scenario, those are selected as main nodes in the above selective criteria. Five nodes repeated in all scenarios and not listed in Table (3) and Figure (13) those are “Eldoret, Karuri, Malindi, Mandera, and Kakuma".

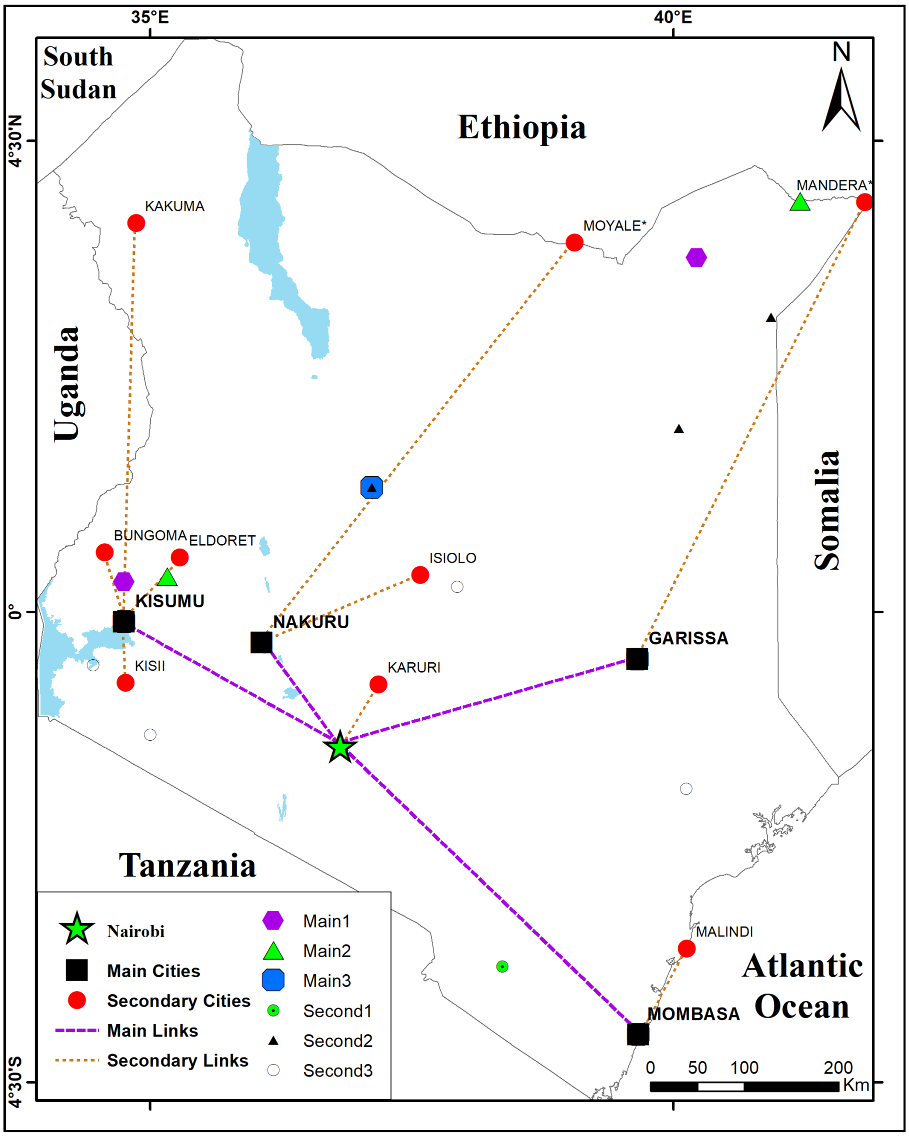

Figure 13. Selective Proposed Nodal Hierarchy.

The large number of cities and population concentration around "Bungoma" necessitate its choice as a secondary city. The rest of probable secondary cities can be divided spatially into three groups, the first of them is on the north-east, and it is composed of "Moyale, Elwak and Wajir", among them, "Moyale" is the closest to the main road network with nearly equivalent potential to "Elwak", that make it more suitable to be a secondary node city. The second group is at the central area of the country, the three competing cities are "Juja, Isiolo, and Maua", both "Juja, Isiolo" appear twice in the different scenarios, with nearly the same potential which is higher than that of "Maua", being near to the main road network make "Isiolo" more suitable as a secondary nodal city. The third group is in the west, the comparison is among "Kisii, Homa Bay, and Kehancha", among them "Kisii" has the highest potential and relatively closer to the road network, so it will be proposed as a secondary city. Based on the above mentioned analysis, the selective proposed nodal hierarchy of the urban system in Kenya is illustrated in Figure (13).

It is noted that the southern area between "Nairobi and Mombasa" doesn't have a secondary nodal city, it is logically accepted due to the combined dominance of the two largest cities in the country.

3.5 Combined Weighting Factor

The distributional pattern of city functions imposes the existence of population mobility and spatial interactions over time in the urban system, through the flow of traffic in transport networks, according to the isochrone map, which relies on three components: traffic origin, destination, and transport routes. According to gravity models, development target areas can be identified, based on several logistical, environmental and demographic variables, through indicators such as population size, jobs, productive activities, service activities, and management professions (Mosilhi, 2017).

This required the establishment of a database of some indicators to evaluate a combined weighting factor to each city instead of individual effects. The study applied the P-median algorithm by evaluating the combined weighting factor to each city. The weighting factor is evaluated according to six criteria and determined an equal relative importance of each criterion by a weight factor ranging from 1 to 5 and applied to all cities as follows:

- **The Geographical Location:** The relative weight of the sites was determined according to their importance among the coastal sites, those are assigned the highest weights were represented (5), followed by the sites on the transport nodes (4), followed by the river sites (3) followed by the border sites (2) while others without any of the above mentioned features assigned a relative weight (1).
- **Distribution of Service Industrial Establishments:** The detailed distribution of industrial establishments in Kenyan counties in 2017, along with the number of urban centers per county in 2009 is listed in Appendix (1). Counties are assigned a weight from 1 to 5 according to the total number of establishments in each county. The calculated weight for each county is assigned to all urban centers in that county. Considering the counties as uniform scales where the attractiveness of development for all urban centers are equal in the corresponding country, according to the criterion of the service industrial establishments' distribution.
- **The Health Services:** The availability of health services is one of the important criteria to assess the importance of urban centers through availability and distribution of different health services types, and was placed the weight of the assessment of the existence of the service (1) or non-existent (zero). While in case of availability of more than one health service, which is required to be observed in the measurement to know the relative importance of the centers and in this case the service takes a numeric assessment according to the number of services. The maximum number of health services in the vicinity of urban centers is found to be 50 in Nairobi, thus the number of health services within a circle of 5 Km around each urban center is divided by 10, such that relative weight of the health service is ranging from (5) down to (1).
- **The Administrative Function:** Cities are assigned relative weights according to their administrative function. According to the administrative division 2009, the urban centers are organized in a hierarchical hierarchy headed by the national capital Nairobi that is assigned (5), followed by the capitals of the provinces with relative weight (4) and then the capitals of the counties (3) and finally the capitals of the districts are

assigned a weight of (2), while those centers without any administrative roles are assigned (1). Figure (14) depicts the cities administrative functions in Kenya according to the 2009 census of population and housing.

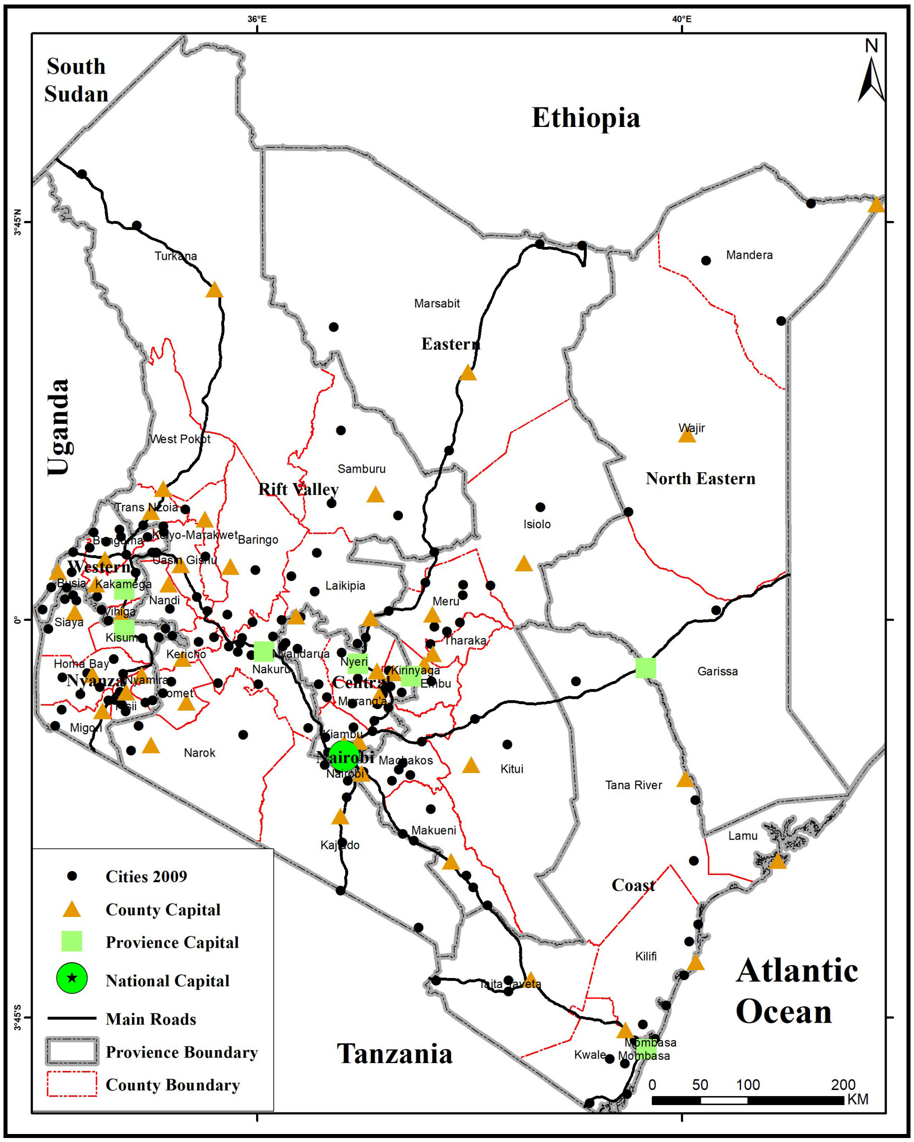

Figure 14. Administrative Roles of Kenyan Cities.

Source: Kenya National Bureau of Statistics (KNBS), "Analytical Report on Kenya Population Atlas," Ministry of State for Planning, National Development and Vision 2030, Nairobi, 2012.

- **The Proximity to Road Network and Average Arrival Time:** As discussed in earlier subsections. In order to evaluate the combined weighting factor for each urban center, according to the previous criteria, the arithmetic mean of the above-mentioned sex items is calculated for each center. The combined weighting factor is multiplied by the scaling factor A_i in equation (11) to be used with P-median algorithm.
  Depending on the modified cost calculation, the application of P-median algorithm results in a six clusters, with Nairobi as the head of them, as illustrated in Figure (15).

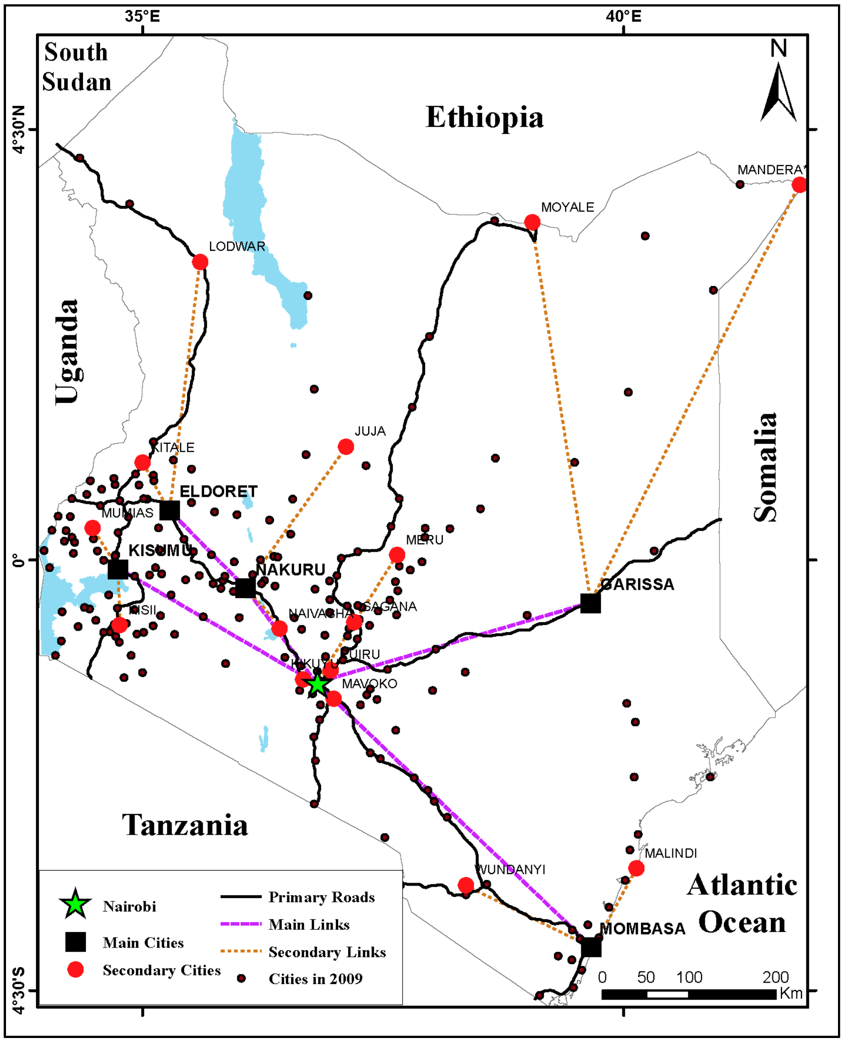

Figure 15. Proposed Nodal Hierarchy with Combined Weighting Factor.
Based on: https://www.wri.org/resources/kenya-gis-data, Accessed: 15-12-2017.

The other 5 main cities leading the remaining five clusters, these are (Mombasa, Nakuru, Kisumu, Eldoret, and Garissa). It can be noted that four main cities resulting from the combined weighted cost function are the same main cities resulting from the selective proposed network, in addition to Eldoret, that appear as a main city in the combined scenario, and a secondary city in the selective scenario.

The subsequent category in the hierarchy are found to be 15 secondary cities including five secondary cities connected directly to Nairobi, those are (Mavoko, Kuiru, Kikuyu, Sagana, and Mero). Four secondary cities appear in the two proposed scenarios, those are (Malindi, Mandera, Moyale, and Kisii). The remaining six secondary cities are (Wundanyi, Juja, Naivasha, Mumias, Kitale, and Lodwar).

4. Conclusion

Analysis of the urbanization indicators since independence till 2009 census data, shows that Kenya has increasing urban growth rates since independence, moreover, future projections indicate a continued acceleration of this growth. Despite urban planning efforts to counter the implications of this growth, many challenges are facing the urban system in Kenya, enforced with the weak institutional capacity in urban areas. That requires the development of national, realistic and sustainable urban development policies that ensure equitable distribution of services over a balanced urban system.

Data analysis showed that the urban system in Kenya suffers from an imbalance in the distribution of the city size categories. This imbalance resulted from the overwhelming domination of Nairobi. The largest number of cities fall in small size category, while main cities are limited in very limited numbers, during successive inter-censual periods.

The mathematical models showed a high degree of flexibility, where the results could be re-checked as additional information became available. It is evident when using combined weighting factor, assuming that all the effects were equal in effect, showed a great congruence with the results of the logical analysis of contract selection, as depicted in the selective proposed nodal hierarchy.

Therefore, the use of the composite weight factor gives results closer to actual precipitation. Furthermore, using weight factor optimization could result in more accurate model in a future study.

The results of the various clustering scenarios showed that there are some important nodes that have emerged in some scenarios as secondary cities, while they have emerged as main cities in other scenarios. Which emphasizes the importance of the development of these cities taking into account the weight factor, which caused the rank upgrade.

The need to improve the transport, and communication networks among the urban centers, mainly to strengthen regional interaction as one of the foundations of building a balanced and effective urban system, develop the regional resources at the nodes, including the actual development of them and to help them generate opportunities for development and growth in the centers surrounding it.

The paper suggested the development of many small urban centers to support the growth and distribution of services such as the nodes that have emerged in some scenarios as secondary cities, while they have emerged as main cities in other scenarios, namely, the cities of (Garissa, Takaba and Juja). Furthermore, the cities appeared as secondary cities in all scenarios are also potential nodes to be developed for the sake of system development such as (Eldoret, Karuri, Malindi, Mandera, and Kakuma). The policy aimed at increasing the rate of urbanization while ensuring the growth in small urban centers rather than large ones.

GIS proven effectiveness in integrating conclusions from individual data sets for geographic areas can help to further improve the paper results as more data is made available. Detailed economic indicators for urban centers in the system is essential in accurately identifying the suitable nodes for respective roles. Thus, detailed economic survey is suggested to highlight the economic potential of suggested urban centers to avoid shortcomings in the existing urban governance policy.

The study results could effectively support Kenya's current urban development policy. The urban system clustering into hierarchical classes with distinctive role for each class in the development process. Lowest class proposed cities can represent marketing intentions for their rural surrounding areas. The middle class cities are supposed to be mediators to support decentralization policies. While the proposed main cities are considered as major development poles attracting investments, supported by their polarization and competitive opportunities.

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Appendix (1)

Geographic distribution of Industrial Establishments in in Kenyan counties 2017, and number of urban centers per county in 2009

County	* Service Industries	* Secondary Industries	* Primary Industries	* Total Establishments	** Number of Urban Centers
BARINGO	1,464	197	35	1,696	4
BOMET	1,181	102	132	1,415	3
BUNGOMA	1,584	187	148	1,919	8
BUSIA	998	167	254	1,419	5
EMBU	1,281	182	79	1,542	3
GARISSA	787	368	32	1,187	4
HOMA BAY	1,870	85	101	2,056	7
ISIOLO	681	115	10	806	4
KAJIADO	1,717	191	34	1,942	8
KAKAMEGA	1,911	271	209	2,391	7
Keiyo-Marakwet	978	143	60	1,181	3
KERICHO	1,339	192	96	1,627	4
KIAMBU	3,672	638	398	4,708	6
KILIFI	1,571	227	14	1,812	6
KIRINYAGA	1,781	235	11	2,027	5
KISII	3,252	468	6	3,726	6
KISUMU	3,174	356	13	3,543	6
KITUI	2,251	236	21	2,508	3
KWALE	1,147	111	36	1,294	5
LAIKIPIA	1,601	153	27	1,781	5
LAMU	927	103	27	1,057	1
MACHAKOS	2,619	292	17	2,928	7
MAKUENI	1,519	112	109	1,740	8
MANDERA	526	68		594	4
MARSABIT	439	82		521	5
MERU	2,863	270	219	3,352	6
MIGORI	1,844	138	2	1,984	4
MOMBASA	5,071	734	50	5,855	7
MURANG'A	1,478	275	43	1,796	6
NAIROBI	40,798	8,509	594	49,901	5
NAKURU	3,080	701	703	4,484	12
NANDI	1,313	224	10	1,547	3
NAROK	1,049	98	4	1,151	4
NYAMIRA	1,570	163		1,733	3
NYANDARUA	1,945	141	8	2,094	6
NYERI	1,951	329	18	2,298	5
SAMBURU	820	143		963	5
SIAYA	889	89	38	1,016	6
TAITA TAVETA	683	148	6	837	4
TANA RIVER	473	49	1	523	5
THARAKA	942	123	4	1,069	3
TRANS NZOIA	1,657	144	16	1,817	3
TURKANA	979	293	2	1,274	3
UASIN GISHU	3,178	622	599	4,399	6
VIHIGA	1,057	106		1,163	2
WAJIR	514	72		586	3
WEST POKOT	714	212	3	929	2
Total	115,138	18,864	4,189	138,191	230

Source:

* Kenya National Bureau of Statistics (2017), REPORT ON THE 2017 KENYA CENSUS OF ESTABLISHMENTS (COE), Nairobi, Kenya, pp.30, 33, 44.

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الملخص العربى

مقترح للتراتب العقدي فى النظام الحضرى فى كينيا
(باستخدام نظم المعلومات الجغرافية
ونهج التجمع حول المواقع الوسيطة)

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شهد النظام الحضري الكيني هيمنة للمدينة العاصمة ولعدد قليل من المدن الكبرى منذ مراحل التحضر المبكرة، نتيجة للسياسات الاستعمارية القائمة على التحيز الحضرى وتركيز الموارد بالمدن الكبرى، وقد تفاقمت تداعيات النمو الحضرى بعد الاستقلال، مما وسع الهوة بين المدن الرئيسية وبقية مدن النظام الحضري وأدى ذلك إلى ضعف الروابط بين النظام الحضري بأكمله، وتهدف هذه الدراسة إلى محاولة الوصول لمقترح لنظام حضري متوازن وفعال يحقق اللامركزية بما يضمن إمكانية الوصول للخدمات العامة الحكومية بأقل تكلفة، ولتحقيق أهداف الدراسة تم تحليل النظام الحضري الكيني اعتماداً على بيانات آخر التعدادات الرسمية للدولة (تعداد عام ٢٠٠٩ السكان والمساكن)، ثم تم قياس الوزن النسبى لكل مدينة مع مصفوفة مدن النظام الحضرى وفقا لنموذج الجاذبية والتفاعل باستخدام تطبيقات برامج (Excel, QGIS)، وتم تحديد أهمية الوزن النسبى لكل مدينة بالنسبة لاجمالى أوزان المدن فى النظام الحضرى، وأكدت النتائج معاناة النظام الحضرى فى كينيا من مشكلة الهيمنة الطاغية والمركزية للعاصمة، إذ أن التفاعل بين أى مدينة والعاصمة أكبر بكثير من تفاعل نفس المدينة مع باقى المدن فى النظام الحضرى، وهو ما يعكس مركزية الخدمات فى الدولة.

بينما تم استخدام نهج التجمع حول المواقع الوسيطة (P-median clustering) لاقتراح التسلسل الهرمي الأمثل لمدن النظام، وهى طريقة لتقسيم المدن حول عدد محدد من المواقع الوسيطة بحيث تحقق أقل تكلفة للتفاعل بين المدينة الوسيطة والتجمع المدنى حولها،

وقد تم تطبيق هذا النهج على أسس تكلفة المسافة والحجم موزونة بحالة الطرق وإمكانية الوصول للخدمات الصحية كل على حدى، وأظهرت النتائج اتفاق السيناريوهات المنفردة على عدد معين من المواقع الوسيطة، وتمت مقارنة وتحليل نتائج السيناريوهات المنفردة وانتقاء العقد والمراكز والوصول الى مقترح هيراركى انتقائى، وأخيرا تم تطبيق معامل الترجيح المركب (Combined weighting factor) معتمدا على كافة المؤشرات المتاحة فى حساب التكلفة، وأيدت نتائجه مرونة النماذج الرياضية، حيث يمكن تحسين دقة النتائج عند توفر بيانات عن متغيرات ومؤشرات جديدة قابلة للقياس، ولذا توصى الدراسة بضرورة اعتماد مخططى وواضعى السياسات الحضرية على العديد من عوامل الترجيح لانتقاء العقد الحضرية للأنظمة لتجنب أوجه القصور في السياسة الحضرية الحالية وتداعياتها.

الكلمات الدالة : تحليل النظام الحضرى، هيراركية المدن، نموذج الجاذبية والتفاعل، نهج التجمع حول المواقع الوسيطة، معامل الترجيح المركب.

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