Assessing Spatial Inequality and Accessibility to Schools in Urban Areas: A Case Study of Aseeb, Oman

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Abstract

In most developing countries, the spatial structure of educational facility distribution fails to produce optimal location of services, thus successive reforms and planning have sought to make service accessibility and coverage more efficient and equitable. The main aim of this research was to investigate the spatial pattern of school distribution across Aseeb Wilayat in Muscat, Oman, focussing on how to quantify the association between population density and school distribution. Several GIS methods and procedures were undertaken, including the assessment of the spatial pattern of school distribution and average distance using average nearest neighbour (ANN), Moran's I to examine the degree of spatial clustering of school locations and the Thiessen polygon method to construct a geographic zone around each school which could serve as catchment area for school enrolment. The ANN ratio was less than 1.0 (0.606), indicating that the school distribution is spatially clustered ($p < 0.000$). There was also a significant autocorrelation of school locations and the observed clustered pattern could not be due to random chance. Thiessen polygons revealed a clear relationship between school location and population concentration, with larger polygons around school locations where the population density is low and small polygons within administrative areas with a higher population size. Although the educational system of school catchment area has not been established or authorised as yet in Oman, the constructed polygons provide effective strategies to geographically create primary admission criteria for school placement and attendance. Educational authorities, planners and policy makers could benefit from this powerful technique in reducing spatial inequalities between areas and urban zones in terms of school accessibility.

1. Introduction

Since 1970 when an era of development began in Oman, explicit strategies have been developed to enrich the quality of public education systems. The Omani strategies of public education are based on combining both equity and quality criteria to sustain the highest performance of the educational system. Spatially, the majority of Omani children have suitable accessibility to schools, attaining advanced learning skills and knowledge. In addition, the priorities of the strategy of quality is to establish the required educational infrastructure as well as expanding school provision and coverage. During the last 40 years, the progress of pre-university education has been identified as one of the most important achievements of human development in Oman. For instance, from 3 primary boy schools before 1970, the number of schools (from grade 1 to 12) in 2008 were 1300 across the country providing education for more than 600,000 students, with approximately 50% of students being female. Furthermore, the attendance level is similar or better than most Middle East and Northern African countries (Ministry of Education, 2012), with 98% of children enrolled in the schooling system. Nonetheless, the educational system needs more improvements, essentially in terms of geographical distribution, urban planning and spatial accessibility.

In Oman, public education is characterised by higher quality and increased governmental spending. As a result, the standard of learning and teaching in the pre-university schools has improved. Expat parents whose language is not Arabic usually send their children to international private schools, most of which are located in the capital Muscat. To cater for the increased demand, international schools operate in two shifts, a morning shift (from 8 am to 2:30 pm) and an afternoon shift (3:00 pm until the evening). The education as a process occurs in a place and students live within areas and geographic zones. Consequently, analysing the relationships between parts of the educational system is crucial to understand the educational facility distribution and provision. Choosing a certain school location is always an issue, particularly in urban areas where the mode of travel and distance influence the decision. In most Gulf State cities, students prefer to travel short distances, selecting schools close to their homes as their mode of transport is usually public transportation or private cars as cycling is not a promoted activity. The neighbourhood system of public schooling distribution is an important policy, considerably affecting spatial and temporal distance to schools.

The main aim of this study was to analyse and explain the spatial distribution patterns of private and public schools, investigating the school service coverage and provision across the Aseeb urban area within Muscat, the capital of Oman. To achieve the study aim, the main research question was: To what extent are the school locations and the area boundaries that define their constituencies constructed based upon minimising travelling distances? The working hypothesis was that within a given school zone, access to the school is related to the density of the school population (i.e., total population or population under eighteen within an area unit). Across Oman, official school catchment areas have not yet been created. Consequently, there is no governmental educational guidance for allocating students to schools, with parents being the main decision makers in selecting suitable schools for their children. The allocation of students to schools occurs spatially in a random fashion. Nonetheless, the geographic system of school catchment areas has never been investigated. This paper is the first attempt to spatially analyse school locations and distribution in Oman based upon proximity and distance measurements.

The study findings have implications for planners and policymakers in Oman, suggesting designing school catchment areas across urban boundaries. Furthermore, this article illustrates a case study of the application of geographical information systems (GIS) techniques in school distribution patterns in urban areas of a developing country. The use of GIS provides clear avenues for change for local educational planners and key stakeholders. For example, the maps that depict the relative locations of school urban districts could aid local planners and decision makers in preparing for their future allocation and building of new schools.

2. Literature Review

Educational costs are influenced by school neighbourhood, proximity and distance to residential areas and road networks. A catchment area is the place from which residents are attracted to use a particular service such as health, business or educational services. The school catchment area could be an administrative zone from which student is eligible to attend a school which is located within the area (Waslander and Thrupp1995 and Talen, 2001). Authorities reduce the cost of the education process by designing a neighbourhood schooling system based on spatial proximity and population size in each administrative area (e.g. district, municipality and block).

Spatial inequality refers to the variations among areas and geographic zones in terms of the distances from a specific demand point (residents or households) to the desirable service facility (e.g. school, hospital, mall). In terms of accessibility to facilities, spatial inequality describes the situation where facilities (e.g. schools or hospitals) of specific services, such as health or educational services, are not distributed evenly among administrative areas (districts, neighbourhoods, or municipalities) (Zenk et al., 2006). Measuring and addressing the distribution of facilities over the space are major concerns. According to the geographic theoretical basis, the spatial equity of desirable facilities, such as schools, means the distances between the population and facilities should be shorter. In contrast, the distances between households and services should be longer regarding the non-desirable facilities such as factories, fuel stations, landfills and recycling locations. Reducing spatial inequalities among population and administrative units has to be the first fundamental aim in the educational strategy and plan.

Spatial accessibility is defined as the total distance or travel cost from a facility location (schools, hospitals or malls) to service delivery, such as district centroids or blocks. Measuring the spatial accessibility can be achieved according to various methods, such as the gravity model or shortest path, which calculates distances between the area unit centroids and service point locations (Luo and Wang, 2003 and McGrail and Humphreys, 2009). The equity of service distribution across urban administrative units has been extensively investigated, especially regarding public facilities (Mansour, 2016, Taleai et al., 2014 and Tsou et al., 2005). Various approaches were identified (Geurs and van Wee, 2004) to measure spatial accessibility, which are distinguished as infrastructure, location and utility approaches. The first approach depends upon physical distances between infrastructure locations (facilities) using simple calculation methods such as Euclidean or Manhattan distances. Location based measures compute the changes in accessibility level due to changes in administrative boundaries, incorporating spatial features of land use. For instance, the gravity model and contour measures can be used to identify the number of facilities within

1 km² or the number of points within 10 minutes from the motorway network.

Utility accessibility measures are based on theoretical backgrounds since they link service accessibility to human behaviour and socioeconomic attractiveness. The last decade has witnessed a growing body of scientific literature addressing service planning and delivery, particularly school accessibility (e.g. Nyonatoret et al., 2005 ad Chin and Foong, 2006). A GIS approach was used to create a query system which evaluated a selection of spatial locations of shopping mall centres. The suggested approach introduces optimal solutions to common locational problems, particularly minimum distances, maximum demand coverage and household income (Cheng et al., 2007). The relationship between demographic characteristics and store locations was examined and GIS methods were used to the predict catchment area of convenience stores in west Jakarta, Indonesia (Widaningrum, 2015). The spatial equity of local services allocation in urban areas, based on household level scale, has been addressed by Omer (2006). He pointed out that data of urban utilities and boundaries on a finer scale provided robust basis for accurate spatial analysis of service provision and accessibility.

Another example of service accessibility planning is bus mobile offices (Neutens et al., 2011). The association between service accessibility and demand points was measured and the analysis was mainly based on a GIS multi-criteria approach to depict the spatiotemporal variations of public service provision in Ghent city, Belgium. The findings of the analysis indicated that time interval was crucial in determining alternative bus stop locations. In the response to the question "how location affects education?" (Gordon and Monastiriotis, 2007), school location is considered an important factor of residential choice, particularly with an open enrolment system. Analysing the spatial aspects of school choice fundamentally contributes to an overall understanding of the geography of education. To explore the influences of socio-demographic and spatial variables on school enrolment policies, Brasington et al., (2015) conducted a GIS modelling of the open enrolment policy adoption in Ohio, USA. The results showed that the most influential variables are school districts, competitive environment, financial support and demographic characteristics.

Several GIS techniques were used by Singleton et al., (2011) to create school catchment areas, in particular kernel density estimation (KDE) and percent volume contours. The relationship between school and living area was examined, revealing that a higher percentage of year 7 pupils were enrolled in schools located outside of their neighbourhoods (Parsons et al., 2000). Similarly, it was found that pupils in urban areas travel long distances to their schools compared with those living within villages and rural communities. Social characteristics of school catchment area have a direct influence on the parents' choice of school. However, such socioeconomic variables and spatial structure of school local communities have not been addressed. In most developing countries, it is quite difficult to define or even strictly determine the geography of school catchment areas (Pearce, 2000). The relationship between district size and school size was discussed by (Pianta et al., 2002), who revealed that school size is quite correlated to district size and larger schools usually are constructed within larger districts. Wati and Tranter (2015) attempted to identify the explanatory variables impacting students cycling to school within the Southeast Queensland state in Australia. They found that almost more than half of primary and secondary school students were enrolled in schools located in another catchment area to that designed according to their residential zones. Choosing a school which is located out of the designed catchment area is particularly related to parent/guardian employment locations. In addition, private motorcars were a major travel mode specifically among students who attended primary schools, while cycling was considered a minor travel mode among the majority of students.

3. Materials and Methods

The spatial dataset includes administrative areas (spatial zones), school locations and the street network. The spatial hierarchy of administrative boundaries in Oman consists of eleven governorates (Provinces) as the higher geographic level (Figure 1), which are comprised of wilayats (similar to counties); in total, there are 61. For instance, the Muscat Governorate comprises six wilayats: Muscat, Mutrah, Amerat, Bausher, Aseeb and Quriyat. In addition, there are three administrative divisions within each wilayat (districts, block, Hila). Aseeb Wilayat consists of 20 districts with a population of 348,965 residents in 2014 (NCSI, 2016).

This study focuses on kindergarten (pre-school), primary and secondary schools within the Aseeb Wilayat. The data set includes administrative boundaries (areal units), the school locations, the motorway network, and population size of each district, with the total number of schools being 146, of which, 95 are private and 51 are public schools (Figure 2). All spatial and demographic data were obtained from the National Center for Statistics and Information (NCSI). The spatial data are in vector data model format and all layers were georeferenced in UTM Projected Coordinates System

GCS_WGS_1984 and Zone 40N. The study methodology relies on applying different GIS techniques to examine the spatial patterns of school distribution, in particular analysing spatial accessibility to school locations according to the population concentration. More specifically, the service coverage and provision across the Aseeb Wilayat were explored regarding service accessibility through quantifying distances and proximity measures.

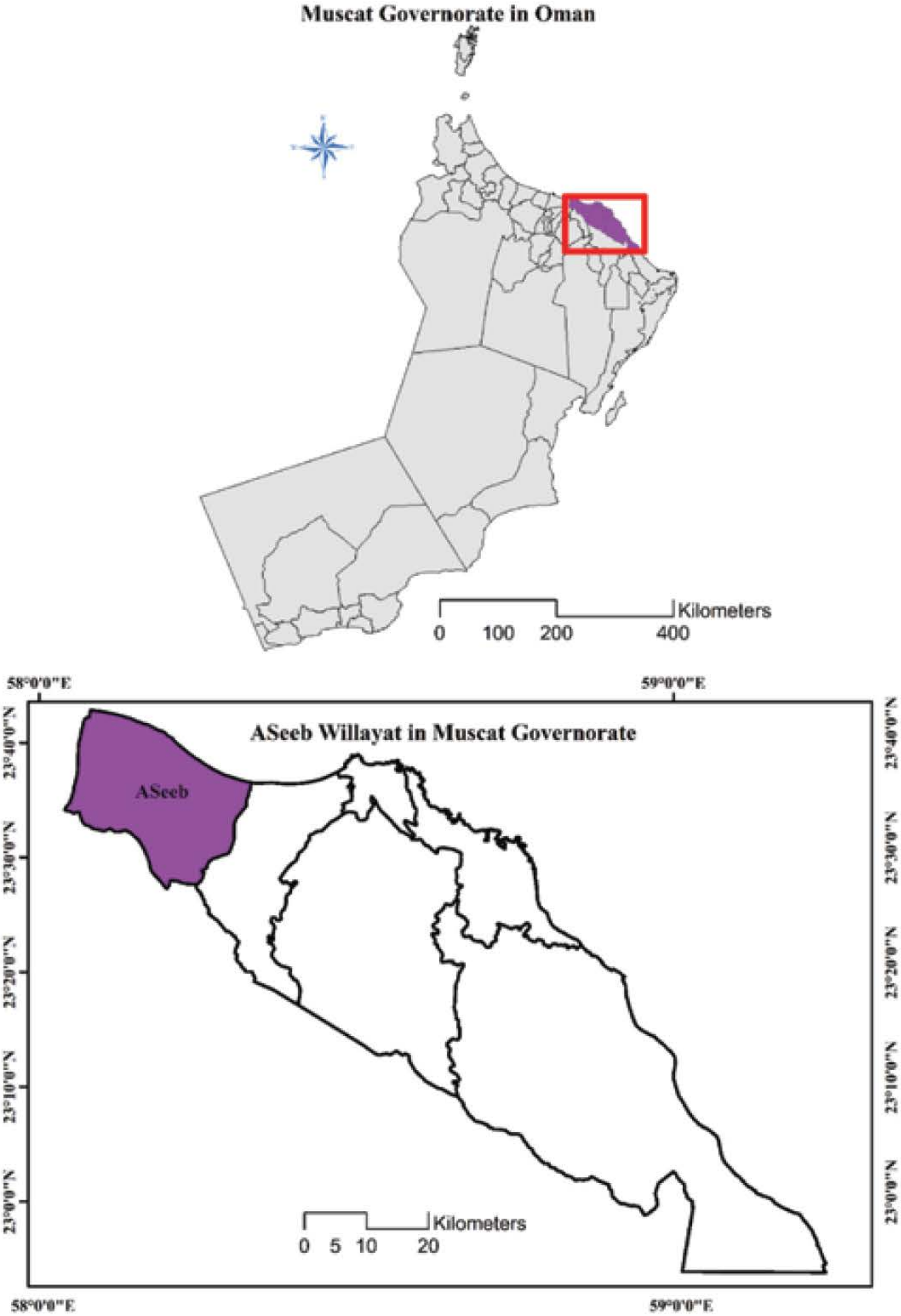

Figure 1: Location map of the study area; Aseeb Wilayat in Muscat Governorate, Oman

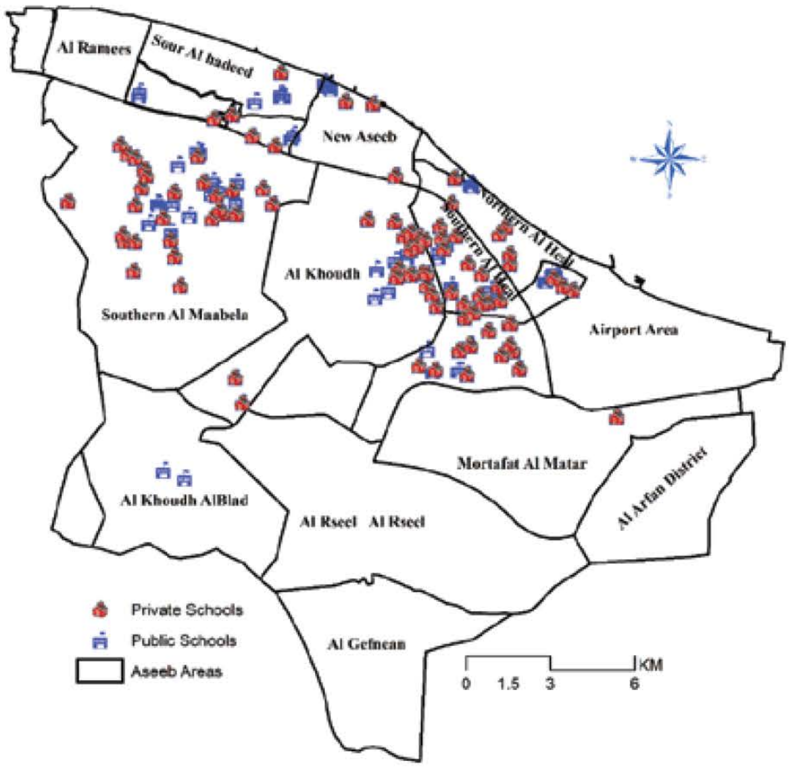

Figure 2: Distribution of number of schools in each district across Aseeb Wilayat

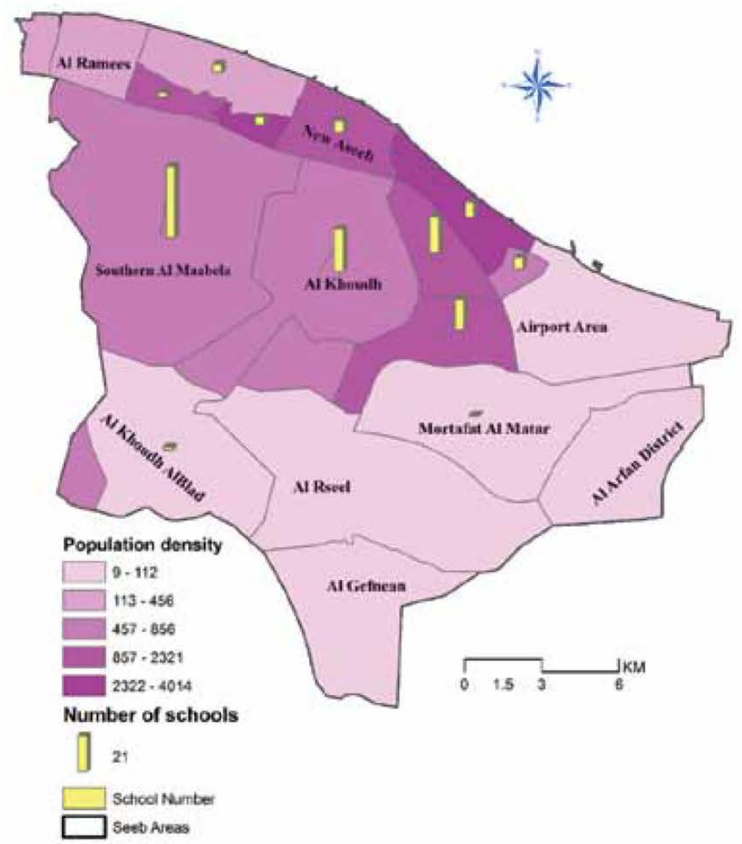

Figure 3: Spatial distribution of school count relevant to population density in Aseeb districts

3.1 Distance Measurement and Distribution

To assess the spatial pattern of school distribution across the study area, the average distance between each school and its neighbours was calculated using the ANN technique. This technique measures the distances between each spatial feature centroid and its nearest neighbour centroids. It is a well-known tool for assessing spatial distribution and accessibility to facilities (Lovett et al., 2014).

3.2 Measuring Spatial Autocorrelation (Moran's I)

In this study, Moran's I measures the spatial autocorrelation of school cluster patterns by inspecting the relationships between a given point (school) and their neighbour (surrounding schools). The method has been used widely to examine spatial pattern, particularly assessing distribution of public services in urban areas (e.g. Talen and Anselin, 1998 and Hare and Barcus, 2007). Similarly, Moran's I has been used to assess the equity of spatial accessibility and provision in urban neighbourhoods (Smoyer□Tomic et al., 2004). The theoretical basis for the Moran's I test is the measurement of the proximity relationship between school locations (as points within polygons), a crucial measurement to examine whether the spatial pattern of school distribution is clustered, dispersed, or random.

3.3. Thiessen Polygon

This method was introduced by Thiessen (1911), where he considered the representative areas of precipitation. In this research, the method was applied to create a polygon around each school as follows:

- the points (school locations) were joined by straight lines to form triangles
- bisecting the edges of the triangles to form the Thiessen polygons
- calculating the area enclosed around each school location.

4. Results and Discussion

4.1 Spatial pattern of school distribution

To identify the spatial characteristic of distances between schools within the Aseeb Wilayat, the ANN tool was applied to all public, private and all schools across the Aseeb districts. The statistical output of the test for the three school categories is summarised in Table 1, with the results of the public and private schools displayed in row 1 and 2, where the p-value (p = 0.00) in both categories was significant. The ANN ratio (or index) is less than 1.0 (0.35 and 0.73), indicating that the school distribution is spatially clustered. The Z values for both are very low (- 8.89 and – 4.87), indicating that the schools are not randomly distributed. The same analysis test was performed for all schools (public and private schools together) across the study area and the results indicated that the spatial distribution pattern of the schools is clustered (ANN index is 0.60 and z-score is -9), with less than 1% likelihood that this cluster pattern could be due to random chance. so Moran's I autocorrelation test was performed to measure the degree of clustering based on school locations. Spatial autocorrelation occurs when the distribution of feature values of the observed variable is not random across the study area. The results presented in Table 2 indicate that school sites are spatially clustered as would be expected if underlying spatial processes were random. The Moran's I coefficient was 0.07, the z-score was positive (2.56) and the p-value was statistically significant (0.01). All results are spatially statistically significant with a 95% confidence level.

4.2. Population Size and School Accessibility

Delivering school services to densely populated areas is probably more realistic and easier than to disperse households. Although there is no zoning system for school attendance in Oman, the administrative districts and areas with the largest amount of buildable residential land and settlements include the highest number of public and private schools.

Table 1: the values of the ANN index and z-score

School Types	Nearest Neighbor Ratio	Z-Score	P-value
Public schools	0.354	-8.898	0.000
Private schools	0.735	-4.874	0.000
All schools	0.606	-9.059	0.000

Table 2: The outputs of the Moran's I autocorrelation test

Output Indicators	Values
Moran's Index	0.072
Expected Index	-0.006
Variance	0.000
z-score	2.567
p-value	0.010

Figure 5 illustrates the spatial distribution of population density in each administrative area in relation to the number of schools. There are obviously some administrative areas with no constructed schools, 8 out of 20 do not contain any schools and these are mainly located in the south and southeast of Aseeb Wilayat.

These findings support previous reports of variations in service and school accessibility. For instance, Omer (2006) pointed out that spatial accessibility to urban parks varies from one district to another and was based on social groups. Similarly, Talen (2001) indicated such significant variations and spatial inequities in access to schools by county and school zones. However, it is important to utilise appropriate techniques within the GIS platform, since the spatial accessibility measurement is influenced by choice of GIS methodology (Talen and Anselin, 1998) (Figure 3). Three administrative districts adjacent each other with no schools, Al Gefnean, Al Arfan district and Al Rseel, were characterised by lower population density and large urban land size. The airport area district was another administrative unit with no schools, located in the northeast of Aseeb Wilayat. The Al Manouma and Al Ramees districts located in the northwest where the area size is small, but with a high population density.

In addition, the university area district located in the middle of Aseeb Wilayat does not include any public or private schools. In general, the number of schools increases when the population density increases, which could be as a result of urban land availability in each administrative area, since the urbanisation policy does not restrict any horizontal growth of residential areas. Although transportation could be provided in terms of attending schools, both students and parents prefer to attend schools that are located near to their houses. To investigate the spatial relationship between school location and accessibility, the near distance tool and Euclidean distance were applied. The total number of schools in Aseeb Wilayat is 145 and almost 31 schools (21.3%) were less than 1 km from the administrative area, with 45 schools (31%) more than 2 km from the centre of the districts and 69 schools (47.5%) located further away from the centre of the administrative districts (between 1 and 2 km).
The maximum distance from district centroid is 3.7 km, with a minimum distance of 0.11 km. To identify districts with higher and lower school service coverage, school accessibility was calculated across the study area (Figure 4). All districts located in the middle of Aseeb Wilayat had higher accessibility to all school types, particularly Southern Al Maabela, Southern Al Heal, Al Khoudh, and Southern Mawaleh. There were three districts located along the sea costal line with high school accessibility, Sour Al hadeed, New Aseeb, and Southern Al Heal. Similarly, but away from the sea coast, were Northern Al Maabela and Al Shardi districts with higher school accessibility. However, most of these districts were characterised as small size administrative areas, except southern Al Maabela and Al Khoudh that are relatively larger.

The accessibility was lower in Al Rseel, Al Gefnean and Al Arfan located in southwest Aseeb Wilayat. Similarly, the airport area and Mortafat Al Matar in the northeast and the smallest areas (Al Manouma and Al Ramees) in West eastern. Accessibility is directly proportional to population density, where areas with a lower population density of school-age population have lower access, and areas with a higher density of school-age population have higher access. This pattern is revealed even more explicitly when we look at the distinction between administrative areas according to population distribution and density. The areas with higher population size and density show high accessibility to schools and higher service coverage.

4.3 School Proximity to Major Roads

The analysis of spatial equity requires the evaluation of the variation of school accessibility based on proximity to major roads within Aseeb Wilayat. Given the absence of data on road travel speeds, the school proximity to the nearest major roads was measured. According to the finding, the schools are classified into three groups: schools located close to the roads (less than 1 km), schools 1 to 2 km from main roads and schools further than two metres. Figure 5 displays the distribution of school proximity to the main roads and it is clear that most schools within the southern Al Maabela and Al Khoudh areas are located further than 2 km from the main network roads. In addition, a few schools within New Aseeb and Sour Al Hadeed areas initially belonged to this category of a greater distance from major roads. Schools 1 to 2 km from major roads were located within areas such as Southern Al Maabela, Al Khoudh, Southern Al Mawaleh, and Southern Al Heal.

In contrast, there were 56 schools located less than 1 km from major roads, which were concentrated mainly in three areas (Al Khoudh, Southern Al Mawaleh, and Southern Al Heal areas) in the middle of Aseeb Wilayat.

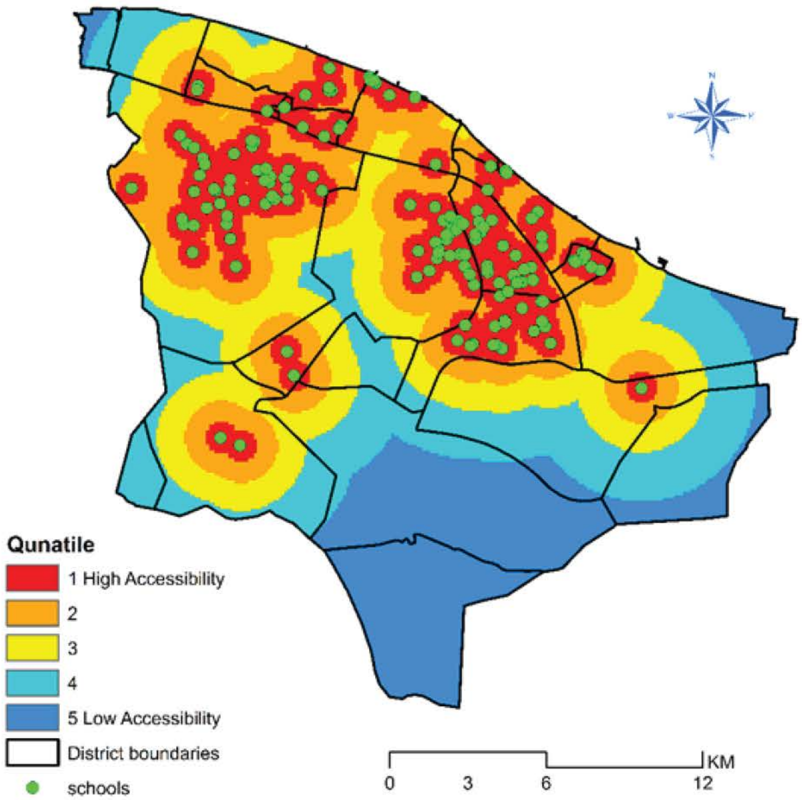

Figure 4: Accessibility to schools across districts of Aseeb Wilayat

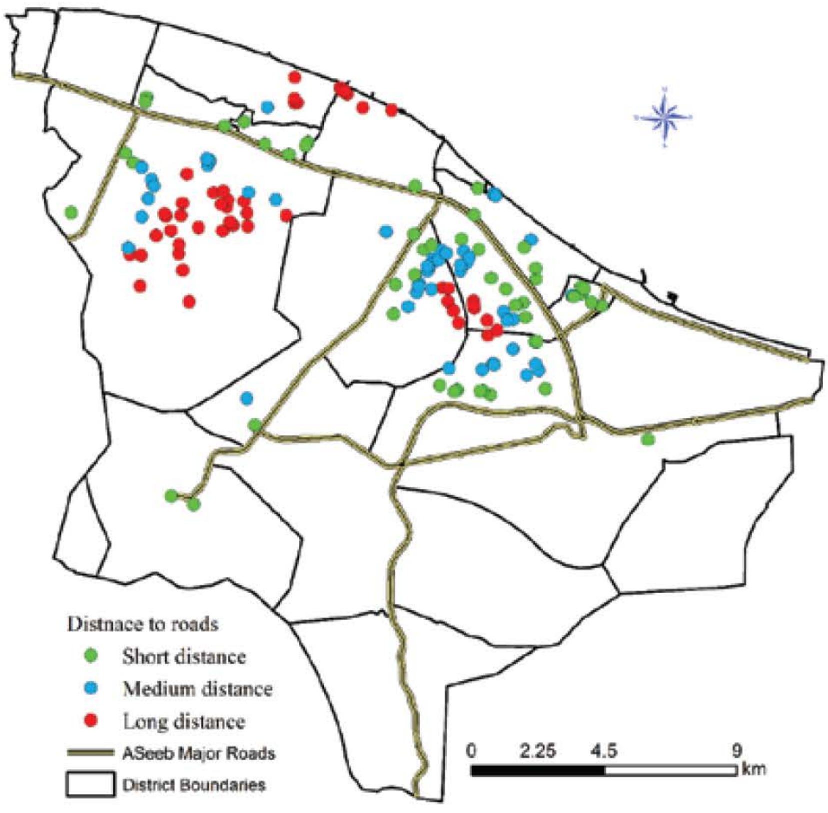

Figure 5: School proximity to the major road network across Aseeb districts

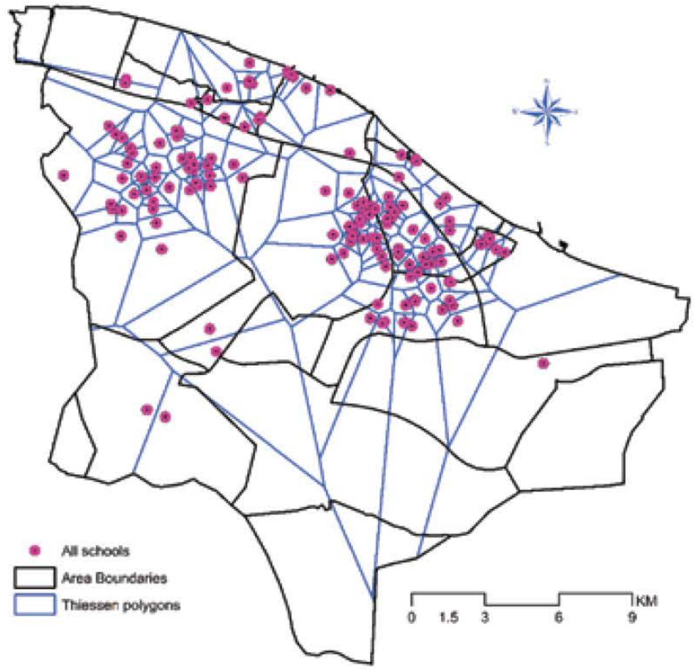

Figure 6: Thiessen polygon boundaries around schools in Aseeb Wilayat

4.4 Designing School Catchment Areas

The Thiessen polygon is usually applied to determine a mutually exclusive partition of geographical places or administrative regions, it divides an area into zones so that all locations closest to a specific point are enclosed within a single polygon (McDonnell, 1995). In addition, the method can be used effectively as an interpolation technique for estimating unknown points or area units. Thiessen polygons are constructed around school points so that each school location within a polygon is closer to all its contained points than to any other (Aronof, 1989). Figure 6 illustrates the division of Aseeb Wilayat into a number of separate catchment areas.

The polygon around each school location represents a hypothetical catchment zone and it could be used as a geographic boundary for pupil enrolment. Fundamentally, the distribution matches the spatial distribution pattern of schools. The largest polygons are located where there is a lower proportion of population density. The smallest Thiessen area indicates a clustered pattern and higher population density. Furthermore, this spatial pattern seems sensible as the catchment polygon increases with the sparser distribution of schools. For instance, schools in areas of low population density have a larger catchment polygon that is less sparsely populated. However, a weakness of this is that the constructed school catchment area is limited to the size of the school based on the number of enrolled pupils. It seems intuitive that a larger school will have larger catchment area compared to smaller schools. Consequently, and due this assumption, it is not enough just to rely upon spatial distribution pattern of the school locations across the study area.

5. Conclusion

The present study explored and quantified school distribution patterns within an Omani urban environment. In addition, it investigated the associations between the spatial pattern and demographic variations, particularly population distribution and spatial accessibility. The results indicated that there was a significant clustered pattern of schools, particularly where there was a higher population density, therefore, delivering school services based on administrative districts across Aseeb Wilayat is not spatially equal. This pattern also highlighted some critical areas, such as the districts located in the south and southwest of Aseeb Wilayat, with a lower population density and long distances to access school services.

Apparently, most schools in the Muscat Governorate have been established within, or at least close to, residential areas to achieve a short distance between school locations and students' homes, so it is very likely that school density is related to pupil attainment through school location decisions. Measuring school proximity to the nearest major roads was valuable in calculating the physical distances from school locations to major roads as a travel indicator. The schools were classified into three groups, with most schools located within Al Maabela and Al Khoudh districts further away (greater than 2 km) from the main network roads. Private school buses and parents' cars were the most widely used travel mode to school, but public transport, especially for long distances, is still developing. Accordingly, and to reduce the total journey time, the design of a catchment area system would effectively help to reform and reduce the spatial inequalities in school accessibility between districts.

This research advocates that Omani educational policies aiming to raise school service qualities should pay particular attention to the effects of urban planning and equity of school service delivery between administrative areas. A greater effort should be made to improve the equity of spatial accessibility to schools. These findings also have important implications for developing school catchment areas across Omani urban districts, playing essential roles in determining student allocations and enhancing parental choice. In terms of educational provision, the analysis outcomes can also be used to help policy makers to mitigate inequalities in school service accessibility. This study was limited by the absence of attribute data on residential addresses of enrolled students in each school. Similarly, data on population age groups at the district level was not available, consequently the total population in each district was used instead to calculate population density. Despite the drawbacks regarding data availability, this research has provided an extremely valuable insight into spatial planning of educational services in Omani urban areas. Moreover, this is the first study to investigate the effects of land use structure and population distribution on school service provision and accessibility in Oman. Further studies are required to apply different techniques of spatial modelling when ancillary and demographic attribute datasets of population and schools at administrative levels are available.

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