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APPLICATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO POPULATION STUDIES IN THE GULF: A CASE OF AL AIN CITY (UAE)

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ABSTRACT

This paper is the first ever attempt to study population distribution in Al Ain city in Eastern United Arab Emirates (UAE) through integration of remote sensing and Geographic Information System (GIS). The remote sensing data used in this study included high spatial resolution (1 m) IKONOS imagery of February 17, 2001. For the population related studies IKONOS data offers number of advantages over other satellite images, e.g. it has high spatial resolution, it covers a larger area per image, it cost less per km^2, and available on a more regular basis. Such characteristics provide a mechanism by which population estimates can be updated with high accuracy and better rate of frequency. The average difference between the population recorded in the 2001 and that estimated from IKONOS images for Al Ain city is found to be equal to 5%.

GIS is used for modelling the relationship among population variables and shows result obtained. Empirical model analyses results of this study show that the overall density of the city is consistent with location theories, i.e., declining population density from the Central Business District (CBD). The trend of higher-income people living in peripheries of cities is evident worldwide as it is in Al Ain.

Introduction

The notion of using remotely sensed data to identify housing structures for population work has existed for well over a half-century in the literature (Carls, 1947), e.g. U.S. Census Bureau explored the feasibility of using aerial photography in an effort to locate human habitats in remote rural areas in order to reduce the decennial census reference.

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Remotely sensed data offers the means to measure spatial attributes of the urban landscape. In the past, researchers remain depended on “Aerial Photographs” because of their fine spatial resolution to get accurate data about size of houses and their volumes and consequently estimates of population (Adeniyi, 1983; Lo and Chan, 1980). Aerial photography is not allowed to be exported from some countries, but satellite images are occasionally available and can be collected from anywhere. One meter resolution satellite sensor usually covers a wider field of view compare to aerial photographs, meaning that satellite data are usually less expensive than aerial photographs per km^2. In addition to that, remotely sensed data provide a wider spectral coverage (number of bands). Due to these advantages, there is a general trend towards using remotely sensed data for census studies (Brugioni, 1983; Iisaka and Hegedua, 1982; Lo, 1995; Lo and Chan, 1980; Lo and Faber, 1997). While these efforts have shown promise, they have all lacked the use of high-spatial resolution imagery. This work extends previous studies that have tested the accuracy of the resultant population estimates using remote sensing.

Progressively switching over of remotely sensed data obtained from government sponsored satellite programs, such as LANDSAT, SPOT, RADARSAT, IRS to commercial satellites such as IKONOS, QuickBird, and OrbView after 1999 has improved the state-of-art. These satellites promised to provide unprecedented access to accurate and timely information (Baker *et al.*, 2001). This paper is an attempt to:

- test the application of remote sensing and GIS to population studies,
- view the distribution of citizens and non-citizens in Al Ain City of UAE, and
- test the population density model.

Geographic Information System (GIS) for Population Studies

The use of GIS for population studies ranges from creation of maps to modelling the relationship between population variables (Baudot, 2001; Forbes, 1984; Langford and Unwin, 1994; Martin, 1989; Rhind, 1991). In this study, GIS is used for both options i.e. for creation of maps and modelling. The creation of maps is a straightforward process in GIS. Modelling in GIS environment has taken different approaches ranging from loose to very strong coupling. Loose coupling involves importing or exporting data from separate configured software, e.g., linking ARC/INFO with epidemiological models (Gatrell and Rowlingson, 1994). This study falls within this context. While very strong coupling might include embedding a model entirely within GIS or GIS embedded entirely within a model. The GIS part in this study deals with using a low cost GIS software (ArcView 3.1) to carry out some modelling related to population density. Batty and Xie (1994) used ARC/INFO, which is considered a high cost GIS software that is not affordable by many census departments. Previous studies have shown the importance of integrating remote sensing with GIS for population studies (Donnay, 1992; Harris and Ventura, 1995; Wilkinson, 1996). The integration normally takes the form of using remote sensing data as a source of data or using GIS as *in-situ* tool (Sadler and Barnsley, 1990). Remote Sensing and GIS results of analysis have been integrated for further spatial analysis.

Population measures

Population density, geographical mean centre of population, Lorenz curve, index of concentration, Gini concentration ratio, and population density models are the population measures used in this study. For better understanding, a brief point-wise theoretical background about these measures are given below.

1. Population density is a measure of population distribution and one of the most commonly used tools in the geographical analysis of population.

2. The geographical mean centre of the population represents the centre of population gravity for the area. The calculation of the mean centre or the centre of gravity of the population uses the following formula:

   $X = p_i x_i / P \qquad Y = p_i y_i / P$ (1)

   where p_i is the population at a point *i*, and x_i and y_i are its vertical and horizontal coordinates, and P is the total population of the area.

3. The Lorenz curve has been used to depict the state of concentration of population and other demographic aggregates. A diagonal line represents an equal distribution, and the greater the deviations of the Lorenz curve from this line, the greater the inequality.

4. A measure related to distribution of population is the index of concentration**.** The index of concentration is simply the maximum of the set of values of the difference between the cumulative percentage of population and the cumulative percentage of the areas. Therefore:

   The index of concentration = ½ Ó | Xp_i -Yp_i | with i from 1 to n (2)

   where Xp_i is the percentage of population and Yp_i is the percentage of the areas.

5. A related concept, and a very useful measure of population distribution in space is the Gini concentration ratio (Gi). The ratio measures the proportion of the area under the diagonal line relative to the area that lies between the Lorenz curve and the diagonal line. This is given as follows:

   Gi = Ó(X_i Y_{i+1}) – Ó(X_{i+1} Y_i) with i from 1 to n (3)

   where X_i is the cumulative percentage of population and Y_i is the cumulative percentage of the areas.

The basic population density model is based on relating density to distance from the Central Business District (CBD) as a negative exponential function (Clark, 1951; Greene and Barnbrock, 1978; Wang, 1999). Population density at distance r from the CBD is defined as ñ(r), then

ñ(r) = K exp (-ër) (4)

where K is a scaling constant and ë is a friction of distance parameter or in this case a percentage change in density for small change in distance. The model can be solved by using the following:

log ñ(r) = log K - ë r (5)

Limitations of using remote sensing for population studies

Despite the positive developments in remotely sensed data (high spatial, spectral, and temporal resolutions), there are still some limitations with respect to the use of these data for monitoring urban areas in general (Donnay, 1999; Ehlers, 1995) and population studies in particular (Baudot, 2001). The limitations include:

Spatial resolution: The single most important technical issue in urban remote sensing is the spatial resolution of the image data (Welch, 1982). The last thirty years have seen development in the spatial resolution of satellite images form 80 m (Landsat MSS) to 10 m (SPOT HRV) and to 1 m (IKONOS). The improvement in spatial resolution allows greater discrimination of the urban fabric. However, the use of very high spatial resolution images bring with them some major problems such as availability in panchromatic mode and large size (storage, processing time) (Donnay *et al.*, 2001). Although some solutions like image fusion and image compression had been made to minimize and solve these problems. These solutions are not commonly available for practitioners in the census field.

Image classification: The heterogonous nature (mixed pixels) of urban environment and the possibility that identical spectral reflectance values can correspond to very different land uses and functions poses a classification problem (Baudot, 2001). Efforts have been made to solve these problems, for example, by coupling automatic and semi-automatic classification, improving the results achieved using traditional per-pixel classification algorithms by using a priori probabilities or a posteriori processing, using of new algorithms such as soft classifier-Bayesian probabilities-fuzzy sets, combining spectral data with measures of urban form and texture, and using of knowledge–based methods and artificial neural networks (Zang and Foody, 1998). However, these techniques are experimental and not yet included in standard image-processing software (Donnay *et al.*, 2001).

3D nature of urban areas: Imaging 3D buildings from satellites suffers from three problems. The first one is related to displacement of buildings from their true location (relief displacement), the second one is related to obscuring of lower buildings by higher ones, and the third is related to shadow (Hartl and Cheng, 1995). Although efforts have been made to minimize these problems, up-to-date images such as those from IKONOS suffer from these problems.

Due to the above limitations, remote sensing has to be used in conjunction with other sources of information (maps, census data, field survey) and GIS to provide better results (Mesev, 1998). In addition to that, visual interpretation has to be used to strengthen the digital image classification.

The Study Area and Data Sources

Al Ain is the largest city in the Eastern region of the UAE (Fig. 1). It is located approximately between latitude 24° 03′ and 24° 22′ North and longitude 55° 28′ and 55° 53′ East. The population of Al Ain has increased from 121,300 in 1983 to 260,175 in 2001, making it the fourth largest population center in the UAE after Abu Dhabi, Dubai, and Sharjah. Residential land use in Al Ain represents 38% of its area (equivalent to 6,308 hectares) (Al Ain Master Plan, 1986). The rest of the land use (62%) is divided between commercial, industrial, agricultural, open space, and other uses.

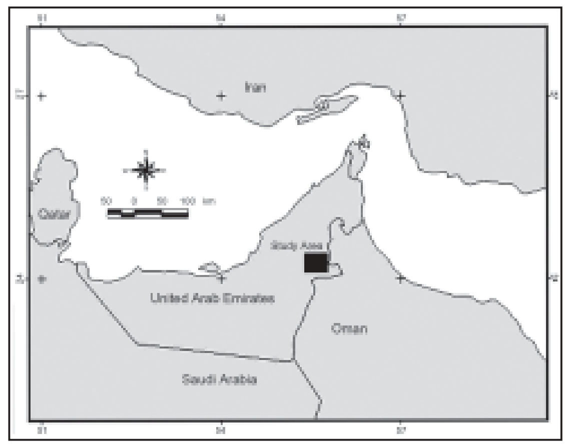

Fig. 1. Location of the study area (Al Ain, UAE).

During the early 1980-90s, the UAE had a high demand for employees and workers from abroad (non-citizens) to work in construction and other types of jobs. Large amount of non-citizens were attracted to the country, because of good salary (pulling factor), and this affect on the number of population. It is expected that the non-citizens ratio of the population will decrease in the future. This is because the majority of the big infrastructure projects have been completed (e.g., roads, schools, hospitals, houses) and new regulations governing foreign workers have been put into place such as privatisation of education and health services (pushing factors). With the general increase of population in Al Ain and the expansion of residential areas, the understanding of its population density and distribution are important cornerstones for planners and decision makers.

The remote sensing data used in this study included high spatial resolution IKONOS imagery acquired on February 17, 2001 (Space Imaging, 2003) obtained from the Department of Geography, UAE University. The IKONOS satellite collects one-meter spatial resolution black-and-white (panchromatic) images and four-meter spatial resolution colour images. Such high spatial resolutions are sufficient enough to identify buildings and classify them as homes, warehouses, offices, malls, etc.

GIS data such as roads and boundaries of districts was obtained from Al Ain Town Planning Department, and population census (2001) was obtained from Abu Dhabi Planning Department. Specifically, in this study a test is carried out to determine the suitability of alternative remote sensing image sources that were not considered in the earlier work, especially IKONOS images.

Methodology

Remote sensing methodology

IKONOS images (panchromatic and multi-spectral) were registered to geographical data such as roads and district boundaries in the area. Houses were counted visually from the panchromatic image in each district and the accuracy of counting was assessed. Number of population was calculated by multiplying the number of housing units by the average family size (Table 1). Houses and other urban features were on-screen digitised to help in updating of land use maps of the area.

The multi-spectral IKONOS image was supervisedly classified to determine land use types. Taking ground truth measurements for the classified categories assessed the accuracy of classification. The land use map was used to aid in calculating residential areas and consequently net population density.

GIS methodology

GIS integrates geographic and attribute data about population (Table 2). The geographic database includes boundaries of districts from which areas, centroids of districts, and distances from the Central Business District (CBD) were calculated (Table 3). Attribute data initially included population for each district. Additional attribute calculated within the GIS environment included density, percentage of areas, percentage of population, cumulative percentage of areas and population (Table 2). All of the attribute data were used in calculating population measures such as population density, mean centre, Gini concentration ratio, and the index of concentration. The built-in mathematical operators within the GIS such as multiplication, division, addition, subtraction, logarithmic, and exponential functions were used extensively for calculation of population measures. In case of drawing graphs, such as Lorenz curve, attribute data from GIS were dynamically exported to Microsoft Excel.

Population for each district (P_i) in the study area was keyed-in from the census data and the area for

Table 1: Population estimation from IKONOS image (with 9 persons as an average family size)

Name of District	Population from 2001 census	Computed population from IKONOS image 2001	Difference	Percentage of the difference
Al Khabisi	19772	20988	-1216	-6
Al Muwaiji	16831	14031	2800	17
Falaj Haza	5659	5436	223	4
		Average	1807	5

each district (A_i) was computed from GIS. The population density at each district (ñ$_i$) was then computed as equal to the population at each district divided by its area (ñ$_i$ = P_i/ A_i). The overall crude density was calculated by dividing the total population of all districts by the total area of all districts (Table 4). To calculate *the mean centre* (Equation 1), or the centre of gravity of the population, the column of population for each district was multiplied by the x_i and y_i coordinates of the centroid and divided by the total population (population* x_i / total population, population* y_i/ total population) (Table 2).

To draw the *Lorenz curve*, the spatial sub-units (districts) of Al Ain are arranged individually according to the population density, from places with the highest densities to those with the lowest densities (Table 3). The cumulative percentages of areas were plotted against the cumulative percentages of population. For comparison, a diagonal line was drawn at 45^o to show the condition of equal distribution.

To calculate the index of concentration (Equation 2), the population and area share of each district in Al Ain were calculated in the GIS environment and saved in two columns. The two columns represent the percentage of population and percentage of areas and they are adding up to 100 each (Table 2). The corresponding rows of the two columns were subtracted and the absolute values entered in a new column. The index of concentration equals the total for this column divided by two.

Table 2: Attribute of population

Field	**Meaning**	**Use**
District	Name of district	For query
Id	Identification number	Identifier
Citizens	Citizens	Density maps for citizens
Non_citizens	Non Citizens	Density maps for non-citizens
Population	Population	Calculation of population density
Area	Area in square kilometre	Calculation of population density
Net area	Residential area	Calculation of net density
Density	Population density per square kilometre	Solution of the population density model (Equation 4,5)
Distance	Distance from CBD in kilometre	
Density-perc	Percentage of difference between crude density and net density	Evaluation of the difference between crude density and net density
X_km	X coordinate of centroid of district in kilometre	Calculation of distance from the CBD and mean centre of population (Equation 1)
Y_km	Y coordinate of centroid of district in kilometre	
Pop_perc	Percentage of population	Calculation of the index of concentration (Equation 2)
Area_perc	Percentage of area	
Pop_cumul	Cumulative proportion of population	Drawing of Lorenz curve and calculation of Gini concentration ratio (Gi) (Equation 3)
Area_cumul	Cumulative proportion of area	

Table 3: Example of output: Districts with the highest population density

Name of District	Citizens	Non_ Citizens	Population	Area	Net area	Density	Distance from CBD
ALJAHLI	676	6395	7071	1.88	1.49	3761	4.09
CENTRAL DISTRICT	3083	34254	37337	11.98	7.51	3117	0.00
AL MUTAWA'A	558	2333	2891	1.18	1.13	2450	3.46
AL KHABISI	6654	13118	19772	8.41	7.90	2351	9.53
AL JIMI	5611	19673	25284	11.47	9.35	2204	6.65
ALMUTAREDH	1869	9862	11731	6.05	5.01	1939	5.24
SANAIYA	0	35086	35086	22.38	22.38	1568	7.72

To calculate the Gini concentration ratio (Equation 3), the cumulative percentage of population column and the cumulative percentage of the areas column (Table 2) were used. Two columns were added to save the results from multiplication of the cumulative percentage of population with the cumulative percentage of the areas (Table 2). The totals for these two columns represent the values needed to calculate the Gini concentration ratio (Equation 3).

From the various available methods for linking spatial models to GIS, in this study, GIS and *Microsoft Excel* were used to solve the population density model using Equations 4 and 5, where interaction between the two software was made dynamically. To solve the model in a discrete form (Equation 5) we need to define population, area, density, and distance from the CBD. The distance from CBD was calculated by determining first the centroid of each district in the area and then running a macro to compute the distance from the CBD to each centroid (Table 3). Results from the calculation were passed to Microsoft Excel to display the model results. Programs were written to carry out calculation and exporting and importing data between *Microsoft Excel* and ArcView.

Analysis

Remote sensing: Population estimation and land use classification

Al Ain is divided into districts and each district is subdivided into communities. To test for estimation of population from panchromatic IKONOS image, 3 residential districts (18 communities) were taken as a pilot study area (Table 1). The districts were selected because of the clarity by which their boundaries can be delineated on the image. They represent varying conditions of old houses and new ones, and there was no group population living in hostels or military barracks in the area. The difference between observed houses from field surveys and that counted from IKONOS image was found to be between 2 and 71 houses with an average difference of 16 houses (8 %) for the 18 communities. Counting of houses was easy from the panchromatic IKONOS image in all districts except the old ones such as *Al Meryal and Majlood*. Houses were easily counted from the image because of their well-defined shape, distinguishable size, contrast with their surroundings (concrete roofs had high brightness), widely spaced, and prior knowledge with the area. Fig. 2 shows how the IKONOS image would help visualize the landscape and how "easy" counting the houses really was. However, problems were encountered in counting houses in old districts that include higher housing density, merger of some houses, and mixture with palm trees. These problems do not represent a severe limitation on the use of remote sensing in general and for this study. The problems were minimized by field survey (*in-situ* measurements) and by overlaying cadastral maps over the satellite image under the GIS environment.

Fig. 2. Portion of the IKONOS image of the area showing how easy houses can be counted.

The average difference between population of 2001 census and that estimated from IKONOS image was found equal to 5% (Table 1). The average difference of 5% is considered good and this is due to the fact that errors in counting houses in some districts were compensated by errors in other districts (Table 1). The result indicates that remote sensing images, especially high spatial resolution ones, could be used for population estimation. The advantages of remote sensing are in the accuracy and frequency by which population can be estimated and updated.

Population density for districts is based on dividing population of each district by its area. This may sometimes provide misleading information for planners and decision makers, because population within each district are not equally distributed. Commercial, industrial, agricultural, and open lands within each district have to be put into account for better evaluation of the actual location of people and determination of the net density (Batty and Xie, 1994). In this study, remote sensing was used as a tool to identify different types of land uses. The multi-spectral IKONOS image was classified using *Maximum Likelihood Classification algorithm* with a total of 450 training sites for different land uses (agriculture, desert, built-up, high land, road). Accuracy assessment was done by comparing classified land uses with the actual ones in the field. For this purpose, 300 truth-sites (reference values) were compiled as *in-situ* measurements. The overall accuracy of the classification was found to be 91% and the *Kappa Index* of agreement was 89%. The majority of misclassification was in urban areas and this is due to the mixture of buildings with trees, parks, roads, and other urban features. The results from the classification were integrated with a GIS database under *ArcView* for further analysis. It has to be pointed out that the classified image when displayed as a map is not quite the same as a conventional cartographic product based on census tracts, but it is usually closer to reality than that based on administrative segmentation which is often somewhat artificial (Baudot, 2001). Within GIS, the cadastral map of the area was overlaid with the thematic classified image to separate residential areas from other built-up areas and to calculate population within each residential area.

GIS: Population density and distribution

Areas classified from remote sensing as residential (net area) were derived for each district and the result was added to the attribute of the districts (Tables 2 and 3). Crude density (population/ area of each district) and net density (population/ residential area of each district) were calculated. The crude density for the whole region was found to be equal to 402 persons km^2 (Table 4). The density for each district varies between 3761 persons km^2 at the CBD to 2 persons km^2 in some districts (Table 3) with an average of 760. It is always the case, that urban areas have much larger densities than rural settlements, with city centre (CBD) representing the foci of most intense population concentrations (Fig. 3). The variation of densities between districts and the average density were similar to other Gulf countries. For example, population density within Qatar was found to vary between 2973 and 4 persons km^2 (Fakhru, 1998), while *Matrah* district in the Sultanate of Oman, has an average density of 915 persons km^2 (Kaid and Mokhtar, 2001).

The net density of the city was found to be equal to 444 persons km^2 (Table 4) and is not sharply different from the crude density. The percentage of the difference between the net density and the crude density for each district was found to vary between 1 - 74% with a mean of 16% and standard deviation of 18%. The difference is due to the fact that some districts have more non-residential areas (e.g. agriculture, open areas) while others have less and also the administrative nature of the districts (changing sizes). The result indicates that population planning and distribution of resources based on crude density only will result in wrong decisions.

Table 4: Summary of population in Al Ain, 2001

	Population	**% of population**
Citizens	82298	31.6
Non-citizens	177877	68.4
Total	260175	100
Total area *	646.497 square kilometre	
Residential area	586.046 square kilometre	
Crude density	402 persons per square kilometre	
Net density	444 persons per square kilometre	
Centre of gravity of the population	(371547.736, 677378.329)	

* Two districts out of 35 with no population were excluded from the area

Districts with high densities were found to be allocated between valleys (Fig. 3), with the exception of the industrial areas in the south. This implies that natural factors such as valleys have effect on the distribution of population in Al Ain in the past. In the last few years, natural factors such as valleys and sand dunes are not constraints anymore. This is evident from the reclamation of large sandy areas beyond the valleys as new residential quarters (Fig. 4). The day distribution of population in Al Ain is largely governed by regulations and master plans set by the Al Ain Town Planning Department rather than by natural factors. Considerations for natural factors such as conservation of environments are incorporated in the master plan (Al Ain Master Plan, 1986).

The centre of gravity is very important in determining the movement of population in Al Ain as the city grows. The centre is found at a distance of 4 km from the CBD; this indicates that there was expansion and movement of people away from the city centre in the western direction (Fig. 3). The prevailing increase of population in the western direction may be attributed to many factors. For instance, in the east, the city cannot expand because of the political boundary with the Sultanate of Oman. In the south the industrial area and conservation zones such as *Hafeet Mountain* and the zoo represent limiting boundaries for residential areas. In addition to that, there are more attraction nodes in the western direction, for example, the location of *Al Maqam* Palace, UAE University, *Tawam* hospital, and water and electricity lines from Abu Dhabi.

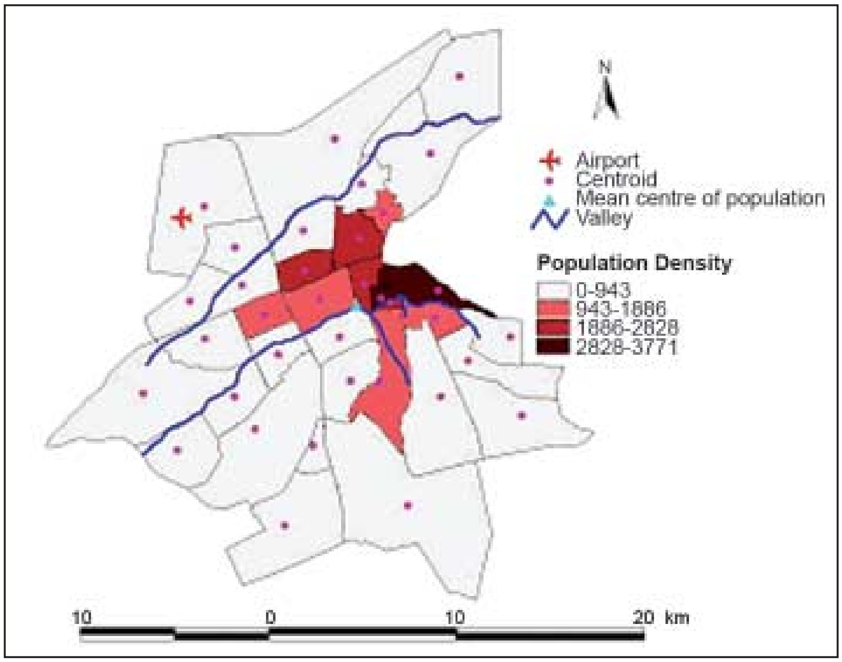

Fig. 3. Population density in Al Ain (2001).

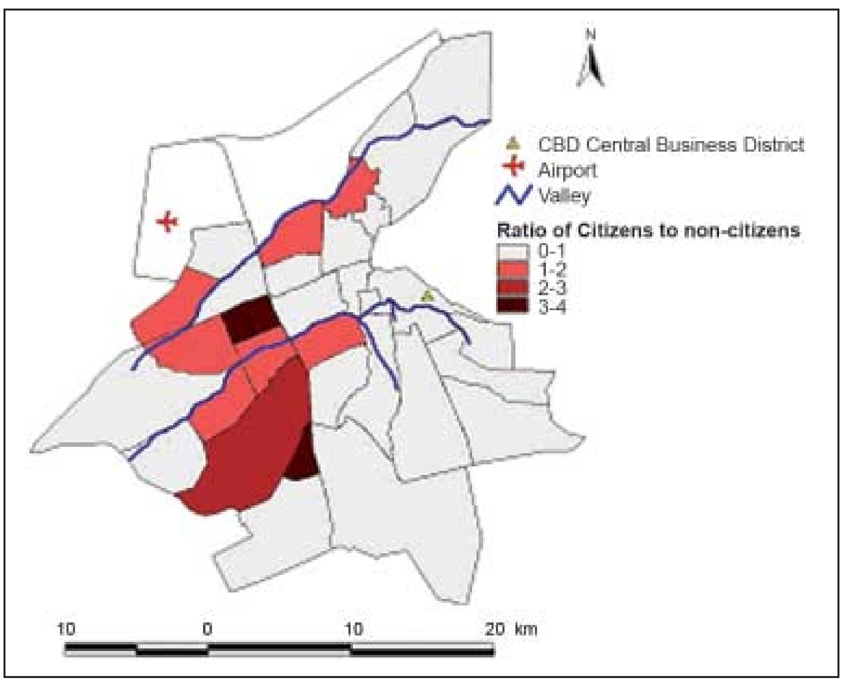

Fig. 4. Ratio of citizens to non-citizens (expatriates) in Al Ain.

If the population of Al Ain was evenly distributed, a graph made on the basis of cumulative percentage of the areas plotted against the cumulative percentage of population would be a perfect diagonal, i.e. there will be no distance between the *Lorenz curve* and the diagonal; the *Lorenz curve* and the diagonal would overlap. Since the population of Al Ain is unevenly distributed as evident from Table 5 that the *Lorenz curve* and the diagonal do not overlap (Fig. 5).

Table 5: Relationship between percentage of population and area occupied (e.g. 93% of population live in 41% of the total area of the city)

% of population	% of area
93	41
75	29
52	11
37	7

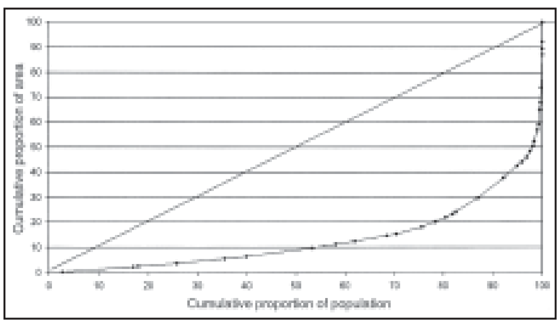

Fig. 5. Lorenz curve for population in Al Ain.

The average *index of concentration* in Al Ain (0.55) showed that there is a concentration of population in certain districts (Table 3). An *index of concentration* of zero indicates equal distribution of population and there is no concentration in certain districts. Thus, the *index of concentration* tells us algebraically what we can see pictorially from Fig. 5. The average index of concentration (0.55) in Al Ain is almost similar to that in Sultanate of Oman (0.54) (Kaid and Mokhtar, 2001). As has been defined above, the *Gini concentration ratio (Gi)* measures the proportion of the total area under the diagonal that lies between the diagonal and the *Lorenz curve*. The *Gi* for Al Ain was found equal to 0.732 which also indicates a very uneven population distribution in Al Ain.

Distribution of citizens and non-citizens

The assumption made in this study is that citizens live near the CBD and expatriates (non-citizens) live far from the city centre. The assumption is based on the fact that citizens existed before expatriates and the majority of the life facilities such as water, oasis, forts, hospitals, schools, commercial activities (*Souk*) were near the CBD. To verify this assumption attribute data about citizens and non-citizens were added to the database under GIS. Density maps, graphs, and summary tables were produced for citizens and non-citizens. Analysis shows that the assumption made is invalid i.e. citizens were found concentrated in periphery districts (Table 6 and Fig. 4).

Citizens in Al Ain represent 32% of the total population and non-citizens represent 68%. Higher percentage of non-citizens was also observed in some other Gulf countries; for example, in Qatar non-citizens represent 80% of the total population (Fakhru, 1998). The average rate of change in the number of citizens was found to increase at a rate of 22.7 % with the distance away from the CBD (Table 6). This is because in the last few years (after 1980s), citizens came under high income category because they are not largely depend on the agricultural oasis near the centre of the city. In addition to that, all new developed residential areas occurred at the periphery of the city. These areas motivate a large number of citizens to shift their residence from the city centre to the periphery of the city. Attractive factors included large plots (1000 $\times$ 1000 m and more), a well-equipped infrastructure (roads, electricity, water, telephones), good facilities (schools, clinics, mosques, parks), privacy, and quietness of the area.

Table 6: Variation in the number of citizens, non-citizens, and number of cars with the distance from the CBD

*Distance from CBD (kilometre)	Citizen	Percentage of citizens	Rate of change	Non-citizens	Percentage of non-citizens	Rate of change	Total population
0-8	21891	20.6		84535	79.4		106426
8-14	38291	31.8	11.2	81953	68.2	-11.2	120244
14-22	22116	66.0	34.2	11389	34.0	-34.2	33505
Total	82298			177877			260175

*Distance from CBD (kilometre)	Car for citizens	Percentage of cars for citizens	Rate of change	Car for non-citizens	Percentage of cars for non-citizens	Rate of change	Total cars
0-8	6337	44.1		8022	55.9		14359
8-14	8619	68.5	24.4	3957	31.5	-24.4	12576
14-22	5630	95.9	27.4	242	4.1	-27.4	5872
Total	20586			12221			32807

*The distance from the CBD is subdivided into 3 zones in order to suppress local irregularities. While the distance ranges were selected to divide the area into 3 equal number of observations.

On the other hand, non-citizens were found largely clustered near the CBD. The average rate of change in the number of non-citizens was found to decrease at a rate of 22.7% with the distance away from the CBD (Table 6). This is due to the fact that the majority of houses near the city centre are of low rent (old houses, small area) e.g. in *Al Jahili*. In addition, living near the city means lower travelling cost. Another indicator that more citizens are living at the periphery of the city is income. There is no direct data about income, therefore, it is deduced from the number of cars own by each group. The overall average of ownership of cars in the city is one car for every 8 persons. For citizens, the average is one car for every 4 persons while for non-citizens it is one car for every 15 persons (Table 6). This means that generally citizens have more income than non-citizens. Moreover, as the distance from the CBD increases, the number of cars owned by citizens increases at an average rate of 26%, while for non-citizens this figure decreases at the same rate (Table 6).

The pattern of distribution of citizens (majority high income people) and non-citizens (majority low income people) was found to coincide with the concentric zone model (Burgess, 1925). The model was based on Burgess's observations of Chicago during the early years of the 20th century. An important feature of this model is the positive correlation of socio-economic status of households with distance from the CBD i.e. more affluent households were observed to live at greater distances from the central city. In the case of Al Ain, more citizens (high income people) are living at greater distances from the centre of the city (Table 6). The conclusion from this analysis is that citizens prefer luxurious areas at the periphery of the city. On the contrary, the majority of non-citizens put into consideration "savings" at the top of their agenda, and they prefer to live in areas where they can minimize spending in rent and travel.

Population density model

The overall relation between population density and distance from the CBD between zero and 22 km indicates that as distance from the CBD increases, the population density decreases exponentially (Table 7 and Fig. 6). Very close to the CBD (below 5 km) the decline is high, but with increasing distance from the CBD the decline is lower. The intercept of the curve in Fig. 6 indicates that if the distance from the CBD is zero, the population density is 3681 persons km^2. The model does not provide a good prediction at this extreme point. The relation is not considered strong because the coefficient of determination (R^2) is low (0.4445). This coefficient measures the proportion of variation in population density, accounted for by distance from the CBD. This means only 44.45% of the variation in the population density can be accounted for by the exponential function of the distance from the CBD. This indicates a poor relationship between population and distance from the CBD (Table 7). Previous study by Batty and Xie (1994) showed that the overall performance of these models when applied to the Buffalo region in Western New York is also poor.

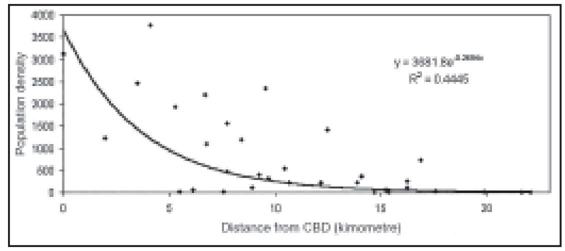

Fig. 6. Variation of the population density with distance from the Central Business District (CBD) in Al Ain.

Conclusion

The integration of remote sensing data with GIS technology for population studies is vital because each has strength in certain aspects related to population studies. Since this study utilized both remote sensing and GIS, it can be said as integrated approach to study population in Al Ain City, UAE. Remote sensing was used mainly to estimate the population and classify land use types whereas GIS was used for modelling the relationship among population variables and the whole study provides a typical approach to obtain the geographical distribution of population in one city in the UAE. This approach can be replicated for other urban

Table 7: Relationship between population density ñ(r) and population P(r) with distance r from the CBD (number of observations is 31)

Distance from CBD (km)	Model	Coefficient of determination (R^2)
0 - 8	$ñ(r) = 4467\ e^{-0.427\ r}$	0.2325
	$P(r) = 17958\ e^{-0.2938\ r}$	0.1941
8 - 14	$ñ(r) = 2506\ e^{-0.1561\ r}$	0.0853
	$P(r) = 88079\ e^{-0.2419\ r}$	0.2187
14 - 22	$ñ(r) = 91561\ e^{-0.4663\ r}$	0.3501
	$P(r) = 421651\ e^{-0.372\ r}$	0.2664
0 - 22	$ñ(r) = 3681\ e^{-0.2694\ r}$	0.4445
	$P(r) = 2025\ e^{-0.1841\ r}$	0.3126

areas in the Gulf countries. Where 93% of the population is found concentrated in 41% of the total area of the City, this study has also proved that the population is not evenly distributed in Al Ain. Newly developed residential areas at the peripheries of the city attracted a large number of high-income people (majority citizens). On the other hand, the majority of non-citizens (expatriates) were found largely clustered near the Central Business District and there is a positive correlation between the location of high-income people and the distance from the CBD, i.e., as the distance from the CBD increases, the number of high-income people increases.

Remote sensing and GIS technology is slowly becoming cost effective, easy to use, and a viable technology that can produce fast, reliable, and low-cost alternative for population estimation. Therefore, its use by census departments, especially in highly developing countries is the need of the present time. The remote sensing on its own provides no information relating to population metrics and it needs to be combined with census data and ground survey in a GIS environment.

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