REMOTE SENSING AND GIS FOR FOOD BANKS

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Commission IV, WG IV/9

KEY WORDS: Food Banks, Food waste, Remote Sensing, Geographic Information System (GIS), UAE

ABSTRACT:

Food banks play an important role in sustainability (saving food-reducing waste), economy, and social cohesion. Investment in food banks supports compassion, generosity, solidarity, and hospitality. The objective of this study is to demonstrate how remote sensing and geographic information system (GIS) could be used to address social and environmental problems such as food banks. In many cases data about socioeconomic is gathered using sample qualitative surveys/interviews and this lacks spatial reference. Moreover, even this data may not be available for researchers in the same way as in this study. Remote sensing was found as an effective tool and proxy to extract socioeconomic indicators such as size of building, distance between houses, streets width, and scarcity of trees/greenness (vegetative indicator). The indicators together with GIS multi-criteria and weighted overlay were used to find suitable food bank locations. The research aligns with the United Nations Sustainable Development Goals number 2, 11, and 12. Beneficiaries of this study may include charitable organizations, food producers/consumers (restaurants, hotels, individuals), and environmental departments (water, energy, waste). The methodology used in this study could be adopted by other researchers around the globe.

1. INTRODUCTION

Food waste is a global problem that impacts food security, water, land, energy, labor, economy, climate, and environment. According to estimates from The Food and Agriculture Organization (FAO) of the United Nations, around one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year (FAO, 2021). In United Arab Emirates (UAE), the value of food waste is estimated to be around $4 billion (14.69 billion dirhams) annually (Guiding Pick, 2017). The United Nations (UN) called for reducing food waste through various Sustainable Development Goals (UN-SDG). For example, goal number two (SDG 2) "Zero-Hunger," goal number eleven (SDG 11) "Sustainable Cities and Communities," and goal number twelve (SDG 12) "Responsible Consumption and Production." (SDG, 2022).

One method to reduce food waste is to establish food banks that can attract extra food. There are many food banks around the globe, for example, in United States of America (USA), United Kingdom (UK), and Ireland. "Feeding America" program (with 200 food banks, provides meals for 46 million each year) has database showing food insecurity rate, estimated program eligibility among food insecure people, average meal cost, and additional money required to meet the food needs (Feeding America, 2019). Feeding America determines food insecurity rates based on indicators such as poverty, unemployment, homeownership, income, and disability prevalence (Feeding America, 2019). The indicators can be used to estimate food insecurity at different levels. Cloke et al. (2016) analyzed food banks in UK and found that Trussell Trust as the biggest organization that runs food banks in UK (over 400 food banks, provided more than one million 3-day parcels of emergency food supplies to people in need). Food Cloud organization in Ireland distributed over 100 million meals since 2013 by rescuing more than 42,000 tons of food from going to waste, over 135,000 tons of C^1O_2-equivalent have been avoided (Food Cloud, 2021). The users of food banks are diverse and include many reasons such as unemployment, inability to resolve the collective impacts of cost-of-living increases, low wages, benefit reductions, and increasing indebtedness (Cloke et al., 2016).

In UAE, food banks had been established as part of Mohammed bin Rashid Al Maktoum Global Initiatives-MBRGI (UAE Food Bank, 2021). The banks include warehouses equipped with refrigerators, dryers, freezers, and refrigerated vans (Wam, 2020). They support needy individuals locally and internationally (Microsoft Network, 2022). The banks get donation from restaurants, hotels, supermarkets, food factories, farms, caterers and suppliers, and animal sacrifice companies (Microsoft Network, 2022). The FAO's (2011) advice for hygienic food is followed out by all banks.

Cloke et al. (2016) and Webster (2014) considered food banks as pivotal axes in the contemporary gift economy despite their apparent associations with aspects of neoliberal subjectification (Booth, 2014). Despite the widespread use of food banks, some academics have doubts about them(Lambie-Mumford, 2013). For example, some authors argue that food banks do not address the root causes of the significant increases in food poverty or unemployment, erode welfare safety, divert states from providing food security to their citizens, and have become iconic of social injustice and welfare failure (Cloke et al., 2016; Tarasuk et al., 2014). In UAE, the main objective of food banks is charitable food and is not replacement for welfare entitlement. Those who entitle to welfare received monthly support. For example, Abu Dhabi Emirate paid on average 75 million UAE Dirham (AED) per month as social aid (Abu Dhabi Statistics Center, 2020). Recipients include 4206 males (30%) and 9805

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females (70%) (total 14,011). The reasons for support include age (old people), handicapped, health disability, widowhood, divorce, married to foreigner, prisoners' families, and orphanhood. Based on this, food banks can serve other sectors of community who need help and can support many people during disaster or pandemic. For example, the COVID-19 pandemic resulted in loss of jobs, illness, and benefit payments that fail to cover the cost of essentials like food, rent, and bills. Food banks in many countries have seen an increase in emergency food need (Wandsworth Foodbank, 2020). Some governments, such as UK and USA provide supermarket vouchers for children on Free School Meals (FSM) "Closing the Meal Gap for schools" that helped some in lockdown, but many families with low incomes did not qualify (Feeding America, 2019; Wandsworth Foodbank, 2020). Wandsworth Foodbank (2020) works using a voucher referral system based on income that is not covering the cost of food and essentials. A similar system could be adopted in UAE. There are 122,117 students in Al Ain region during 2018–2019 with almost equal ratio of females and males with 48.4% in government education and 51.6% in private education (Abu Dhabi Statistics Center, 2019).

There is a need to draft rule that encourage big food generators such as hotels and catering restaurants to distribute surplus food. Such rules are implemented in many countries. For example, in 2016, France passed a law making it illegal for supermarkets with floor space over 400 square meters to throw away unsold food approaching its best-before date. Large supermarkets are now required to donate the food they no longer sell to charities (Chrisafis, 2016). Food donors could receive incentives such as tax benefits, reduced waste disposal costs, promotional and reputational opportunities (Diprose and Lee, 2021). Public awareness and training to staff at the donors' premises, community partners, and food banks play a key role in shaping the quantity and quality of food donated (Diprose and Lee, 2021). This may include training of staff at the donors' sites on how to care about food and implement quality assurance/quality control (skills-food sorting) and respect to human dignity (during distribution) for staff at food banks. Preparation of infrastructure for food banks is important as public awareness. This includes finding more volunteers, lorries and vehicles with chillers, warehouses, fridges, and space to deal with an increase in donations from shops and food companies. Food banks could use electric cars, solar energy, and recycled papers to reduce carbon emissions.

Remote sensing images are widely used in urban planning and population studies. For example, for census, population estimates (Iisaka and Hegedua, 1982), population dwelling unit estimation (Lo, 1995), quality-of-life assessment, and creation of urban deprivation index (Cabrera-Barona et al., 2016). Duque et al. (2015) used land cover and texture metrics derived from remote sensing data to measure intraurban poverty. The quality-of-life indicators such as greenness and width of roads could be used to identify deprived areas and consequently determining suitable food bank locations. The advantages of remote sensing include covering a wider field of view, repetitive coverage, and wider spectral coverage (number of bands). The availability of free satellite images such as Landsat and Sentinel 2 makes remote sensing more attractive tool especially in developing countries where there is lack of census data.

At many stages of food banks, including but not limited to food bank site selection, study of the socioeconomic state of the population, spatial analysis, data visualization, and improving policy advocacy, the geographic information system (GIS) is regarded as a significant tool. GIS was used by Eckert and Shetty (2011) to design and quantify access to food retail. Based on centroid locations within each census block and a typical one-mile radius surrounding each block group centroid, Curran and Armenia (2021) employed spatial analysis to identify food service gaps, or "food deserts," in Central Florida. They defined high-need food assistance deserts as areas where more than a 36 percent of the population's income falls under 200 percent of the poverty line and the block group population centroid is more than a mile away from the nearest food assistance location. They concluded that geographic characteristics are significant predictors of food assistance deserts and proximity of a population centroid to the nearest food assistance location.
Waity's (2016) used GIS to map the effects of spatial inequality on servicing populations in Indiana, USA, who are food insecure. In their thorough study of the use of GIS and mapping for the food industry, Sweeney et al. (2016) discuss how mapping may be used for food justice, food trade, consumption, land use, food choice, consumer behavior, food safety, agricultural systems, and urban agriculture.

An impressive example of how GIS is used to help determine the rate of food insecurity and anticipated program eligibility among food insecure persons is the interactive map "Map the Meal Gap" made by the Feeding America program. In a joint initiative, Davies et al. (2017) created an exploratory database of more than 4000 food sharing activities in 100 cities that utilized GIS, internet, and digital technologies (SHARECITY100 Database). A part of the database focused on forms of exchange in the food sharing arena and used GIS to display locations of food gifting (donate/share). Initiatives for sharing meals were made visible to one another through the project, which also helped them bond. It also demonstrates how technological activities organize tools, language, meanings, and comprehensions over time and location. Food organizations use GIS to locate children in need of food (students enrolled in meal or reduced meal programs) and identify food insecurity in schools and districts (Hoffman et al., 2021). The website for the Sustainable Development Goals (SDGs) of the UN includes geospatially linked data by objective, demonstrating the significance of GIS for all 17 SDGs and not just for food banks (SDG, 2022).

Since the majority of research on the use of remote sensing and GIS for food banks is done outside of the UAE, this study attempts to address a gap in the body of knowledge specific to the country. The only food bank in the UAE is in Dubai. Such a facility is required in other places like Al Ain and Abu Dhabi. The objective of this study is to utilize remote sensing and GIS to select suitable food bank locations. It is necessary to locate distribution hubs close to the areas where those in need of food are located. When establishing a food bank anywhere, several elements must be taken into consideration, such as purpose, target users and their locations, infrastructure, etc. Identifying food bank locations play a major role in allocation of resources by charities and community groups. Additionally, it assists a municipal planning department in achieving its objectives of resource efficiency, transportation reduction (cost effective), and carbon footprint reduction.

2. METHODOLOGY

The study was conducted in Al Ain City in UAE. Al Ain is located approximately between latitude 24° 03′ and 24° 22′ North and longitude 55° 28′ and 55° 53′ East (Figure 1). The population of Al Ain region is around 0.77 million making it the fourth largest population center in the UAE after Dubai, Abu Dhabi, and Sharjah. (Abu Dhabi Statistics Center, 2020).

Raster data used in this study included Landsat OLI satellite image (2020) (30-meter resolution) and Digital Elevation Model (DEM). The image and DEM were downloaded from Earth Explorer web site (https://earthexplorer.usgs.gov/). In addition to this, WorldView image (2014) was obtained from UAE University. The WorldView image was used because it provides better spatial resolution (1.84 meter) and this helped in identification of urban indicators such as size of houses.

Vector data used included population, districts boundaries, locations of food sources (hotels, cooperative shops, malls), and roads. The vector data was obtained from Al Ain Municipality. ArcGIS software was used for image processing and spatial analysis.

A land use map was generated from Landsat 8 image using supervised classification (maximum likelihood algorithm). Four types of land uses were identified, namely built-up, desert, green areas, and high land. The classification accuracy was assessed using 500 random points and a confusion matrix was generated. The matrix calculates errors of commission (user's accuracy) and omission (producer's accuracy) and derives an overall accuracy and kappa index of agreement between the classified image and the ground-truth random reference points.

There are many factors affecting the selection of a suitable location for food banks. For example, poverty, unemployment, homeownership, income, and disability prevalence (Feeding America, 2019; OCSI, 2011). Unemployment is found as the main factor of food insecurity. Food insecurity could vary from year to year depending on change of residence for some people (Feeding America, 2019). Lloyd (2010) used additional factors such as access to cars, non-owner-occupied households, and rooms per person (overcrowding). Majority of the data used by Feeding America (2019) or Lloyd (2010) to determine food insecurity is not available to the authors. Therefore, some proxies extracted from satellite images were used.

The following criteria was used to select suitable food bank's locations:

1. Population: In districts with percentage of expatriates greater than 80%. This criterion was based on the fact that many expatriates have low income such as workers and represent the majority of those who received food from the UAE Food Bank (Dubai Media Office, 2021). A series of tests had been made with various percentages and 80% was found the most appropriate. Percentage of expatriates provides indirect way for non-owner-occupied households, and this is one of the four variables utilized by Lloyd (2021) to measure deprivation. Another proxy that was used to identify low- and middle-income households is remote sensing. Remote sensing images from WorldView and Google Earth were used to extract deprived areas based on indicators such as size of lot and building (small size), low height (no shadows), distance between houses (narrow set-back), streets/lanes width (narrow), scarcity of trees/greenness (vegetative indicator-Normalized Difference Vegetation Index-DVI), dim appearance (woody roofs), while high-income houses appeared as white, with gardens/pools, and parks/cars.
2. Land use: In districts with high population density. Existing district boundaries do not provide accurate population density. Density is calculated by dividing the total population in each district by its area. However, some areas are vacant or covered by other uses e.g., green areas. Therefore, the Landsat 8 satellite image of 2020 was classified, and only built-up areas are used in the calculation of the density (net population density).
3. Elevation: The elevation in Al Ain city ranges between 160 and 1132 meters. Majority of the current built-up areas are in elevation ranged between 160-375 meters. Food bank locations should be within this range. The Digital Elevation Model (DEM) was used for this criterion and Extract by attribute function in ArcGIS was utilized.
4. Roads: The food banks should be within 2 kilometers (walking distance) from roads. Such locations provide easy accessibility to large number of people putting into account that Al Ain has good public transportation system (buses). In addition, location of food banks near roads will reduce transportation cost for producers and donors. For this purpose, buffer function was used. It was found that all the six districts fall within this buffer zone and this indicate that Al Ain is well connected by roads.
5. Access to public sector facilities (proximity to services). This variable was used by Noble et al. (2002) as one of the Multiple Deprivation Measures. In this study, buffers of 5 kilometers were used to measure access to hospitals, schools, and parks. Districts that are not covered by the buffer are considered deprived ones. Nowadays the majority of businesses are done online. Online banking, purchasing goods and services, ordering medical services, and paying utility bills are all options available to people. This means that customers will no longer need to spot a business or go to a potential store or professional service. However, this is valid for people who have access to the internet. Deprived people may not afford to pay monthly internet fees or have mobile phones that support online transactions. Therefore, still there is a need to allocate services in proximity to where they live.

All layers (factors) were converted to raster format and reclassified to a common scale that ranges between very low (1) to very high (5). Five experts were consulted on setting weight for the factors. The average weight was calculated and found equaled 0.2 for Land use/Land cover, 0.3 for population, 0.4 for percentage of expatriates, and 0.1 for Elevation. Weighted overlay function in ArcGIS was used to rank districts according to their suitability for food bank location.

3. RESULTS

The overall classification accuracy is 96% and kappa statistics is 0.937 (Table 1). Desert occupies 48% of the city and built-up areas represents the second largest land use type (Table 2). Built-up areas were extracted from the land use and utilized in the calculation of the net population density. Based on the criteria specified in Section two, six districts had been identified as potential locations for food banks (Table 3, Figure 1). In a model developed by Curran and Armenia (2021), population density is found not a significant predictor of food assistance but the model is responsive to poverty, area, and race. Therefore, districts with the highest percentage of expatriates such as Sanaiya and Al Khrair are more suitable for the location of new food banks (Figure 1). The result obtained is consistent with Coleman-Jensen (2010) findings that low- income communities have a higher need for food help and that these communities are more

likely to be located close to food assistance facilities. The elevation in the potential food bank areas was found between 251 to 374 meters (Figure 2). Weighted overlay ranked districts according to number of people, percentage of expatriates, land use, and elevation (Figure 3). The result shown in Figure 1 was evaluated by five experts in urban planning. Eighty percent of them agreed with the analysis result and recommend Sanaiya and Al Khrair districts. However, the other two experts felt that Al Mutawa'a and Al Jahli should be given priority for allocating food banks because of their central location and hence easy accessibility to other districts. Availability of vacant land needs to be considered. In fact, every lot in the city has owner even the land is vacant. The farms in the city center could be bought from their owners (compensation) and converted to food banks (Figure 4). The owners of the vacant land in the south-east of the city could also be compensated (Figure 4).

Food banks could be located in areas that need food, especially with more deprived children. The most important phase of human body built-up is during early age and poor health and a decline in school performance are the most common effects of limited access to nutritionally adequate food (Coleman-Jensen, 2010). There is no data about age groups to identify which district has more children. Therefore, districts with a higher female percentage could be given priority in the location of food banks based on the assumption that a large portion of the females represents families (Table 1). A database about needy students in schools coupled with GIS could be developed and used for FSM distribution. Potential sources of food identified include hotels, corporate shops, and malls (Figure 1). Corporate shops and malls could support food banks with nonperishable food such as dried, tinned/canned (fish, meat, vegetables, fruit), prepacked, long-life milk and juice, biscuits, and snacks. Extensive remote sensing visual interpretation was used to differentiate between districts using indicators such as width of roads, size of lots, and degree of greenness (Figures 2, 3).

Class	Built-up	Desert	Green areas	High Land	Total	User Accuracy
Built-up	100	1	4	0	105	0.95
Desert	1	262	2	1	266	0.98
Green areas	2	0	55	1	58	0.95
High Land	3	5	0	63	71	0.89
Total	106	268	61	65	500	0
Producer Accuracy	0.943	0.978	0.902	0.969	0	**0.96**
Kappa	**0.937**					

Table 1. Confusion matrix.

Class	Area (Sq. km)	Percent
Built-up	195	25
Desert	366	48
Green areas	106	14
High Land	100	13
	767	100

Table 2. Land Use/ Land Cover breakdown.

District	Population	% Expatriates	% Female
Central District	37346	92	29
Sanaiya	35086	100	1
Al Mutaredh	13020	84	33
Al Jahli	7071	90	31
Al Khrair	7018	100	5
Al Mutawa'a	2891	81	41

Table 3. Districts with a potential need for food bank.

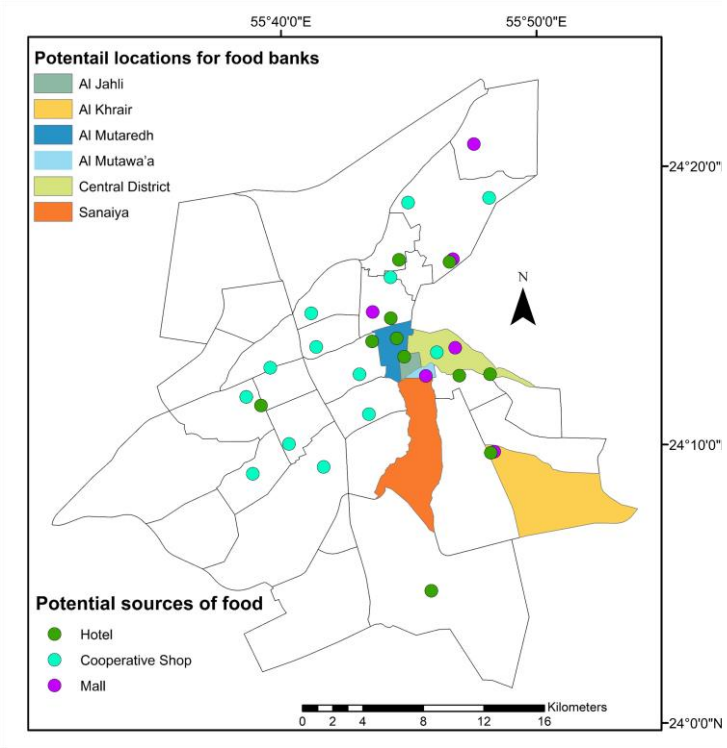

Figure 1. Potential districts for food banks.

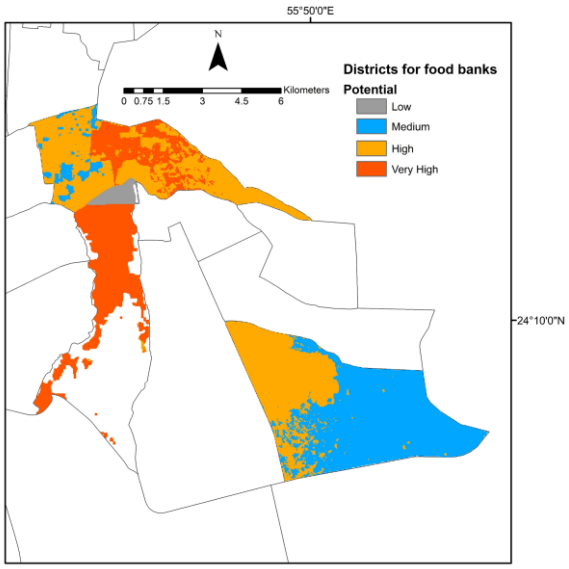

Figure 3. Ranking of districts for food bank locations.

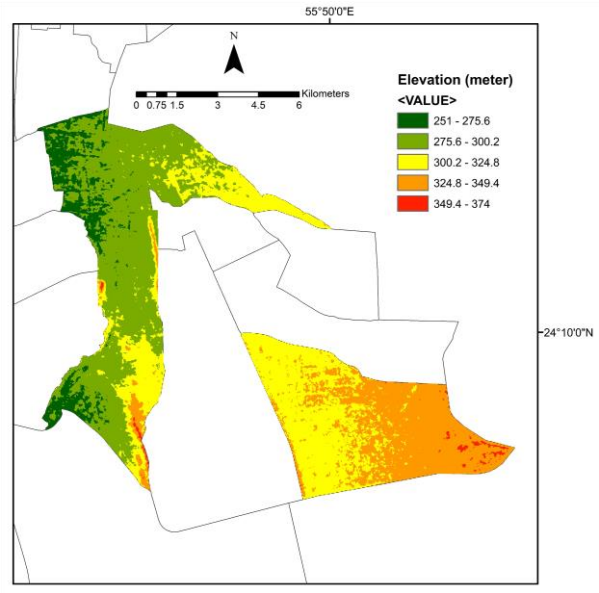

Figure 2. Elevation at the potential districts for food banks.

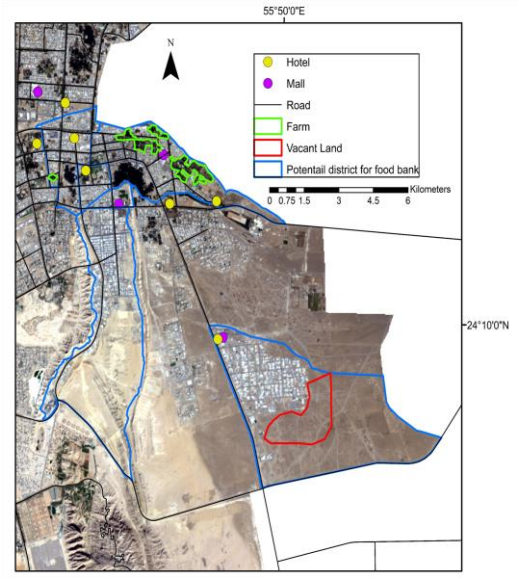

Figure 4. Potential farms and vacant land for food bank building.

4. CONCLUSION

Suitable locations for food banks determined in this study are based on proxies and not a direct or meaningful measure of deprivation. The census at the block level is thought to be more accurate, although the study is based at the district level. Expatriates change where they live depending on many factors such as rent or change in location of work or need for a bigger house. This creates a challenge in building a GIS database for users of food banks (change in space and time). The GIS database could be extended to include updated socioeconomic indicators such as unemployment (data changed due to COVID-19 pandemic). Updated and high-resolution satellite images and machine learning could be used to help in extracting socioeconomic indicators. Deprivation indices could be developed to identify areas with limited access to services. The results from the research could be used to help in saving the environment, saving money, and translating the UN-sustainable goals (Zero-Hunger, Sustainable Cities and Communities, Responsible Consumption and Production).

CONTRIBUTION

Yagoub and Naeema came with the idea and crafted the research proposal. The rest of the co-authors are students. They were involved in research design, literature review, and in building geographic information system (GIS) database.

ACKNOWLEDGEMENTS

The authors are grateful to UAE University Research Affair for funding this research (Grant number 1958) under the Sustainable Development Goals (SDGs) Research Program. The views and conclusions are those of the authors and should not be taken as those of the sponsor. Mr. Shehab Majud is acknowledged for following up with the editing process

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