Use of Geo-Spatial Data for Sustainable Management of Solid Waste in Niamey, Niger

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Abstract

Solid waste management continues to be one of the major issues facing municipal planners. As urban populations rise, so does the build-up of waste. Planners are thus forced to consider alternate and available means of disposal, especially by minimizing damage to the ecosystem and human population. This paper shows such alternatives by using GIS and remote sensing techniques to identify appropriate areas suitable for waste disposal at Niamey, Niger. It provides a selection of environmentally friendly disposal sites, thus supplying reasonable, convenient and administratively transparent solutions to the waste disposal problem.

Keywords: Solid waste management, GIS, remote sensing, landfill siting

1. Introduction

Municipal solid waste management is one of the major problems facing city planners all over the world. The problem is especially severe in most developing-country cities where increased urbanization, poor planning, and lack of adequate resources contribute to the poor state of municipal solid waste management (Obirih-Opareh & Post, 2002; Mato, 1999; Doan, 1998; Mwanthi et al., 1997). In Africa, rapid urban growth since the 1960s has put pressure on the land resources within the area surrounding the cities, and has led to increased generation of waste. The problem is aggravated by the open dump nature of disposing waste especially in the slum areas of most African cities. An example of this is found in the waste management practices in Tanzanian municipalities. Traditionally, their administrations permitted uncontrolled dumping in abandoned quarry sites with no provision for sanitary landfill, causing huge health problems (Mato, 1999; Hammer, 2003). A large part of the problem is inadequate financial and data resources for site selection and management; but the problem persists even in African countries like Kenya where the Nairobi City Council had provision for public collection, but found the system was available to only 10% of residents (Mwanthi et al., 1997). In Accra, Ghana, public administration of waste collection was also inadequate for a variety of reasons which led the administration to privatise the system, where private cost recovery seemed to indicate a better solution (Obirih-Opareh & Post, 2002). These problems have resulted in serious environmental and social complications (Mutatkar, 1995; Arinola & Arinola, 1995; Moore et al., 2003).

Niamey, with population increasing at about 4% per annum, is not an exception (Manu et al., 2003). Population growth and vigorous economic activity in and around the city has resulted in a serious waste crisis. There is arbitrary dumping of waste along roads, on empty house lots and drainage ditches (Figures 1 and 2). This practice exposes residents to health and environmental hazards. Perhaps Niamey city planners could address the waste management problem by making an initial selection of suitable waste disposal sites with minimal environmental impact. This could be in the form of large landfills requiring fewer mechanical and biological operations. Selection of such sites may be achieved at low cost using Geographic Information Systems (GIS) and remote sensing methods.

The use of GIS and aerial photography for landfill-site selection and management has been documented (Erb et al., 1981; Padgett, 1994; Atkinson, 1995; Hussey, 1996; Rubenstein-Montano & Zandi, 2000). Qumsieh et al. (1996) combined aerial photographs and topographic data to select waste disposal sites and facilities for Palestine. The major emphasis in Qumsieh et al. (1996) was placed on building an initial geographic information database of Palestine, and later linked this spatial information to selecting a landfill site.

Siddiqui et al. (1996), applied multiobjective planning techniques to find the suitable location for siting landfills in Cleveland County, Oklahoma taking into account physical and environmental characteristics using a geographic information system. In Kaohaiung city, Taiwan, Chang et al. (1997) combined GIS and mixed integer programming model to analyze several waste selection sites before selecting the final sites.

Muttiah et al. (1996) combined a Markov-chain-based simulated annealing algorithm with GIS techniques to locate potential waste disposal sites in the Indian Pine watershed in Indiana. Results showed that simulated annealing achieved the best results in selecting waste disposal sites, at the same time taking social factors into account. Kao et al. (1997) combined a multimedia network information system with GIS to improve municipal solid-waste landfill siting in Miaoli, Taiwan. The study showed good results when multimedia network (image, graphics, video etc.) are effectively combined. In the Golbasi region of Turkey, Basagaoglu et al. (1997) used GIS technology to identify sites for solid waste disposal. The authors used a set of conditions including environmental factors and overlays using ARC/INFO 7.1 to shortlist sites to meet desired criteria.

The literature suggests that countries around the world have successfully applied GIS and remote sensing to their urban waste management planning process. However, these effective planning tools – GIS and remote sensing have not been effectively used in most African cities, and certainly not in Niamey. There are no studies aimed at integrating these technologies into a planning process to improve the efficiency of municipal solid waste management in Niamey.

Thus, the purpose of this paper is to demonstrate the use of GIS and remote sensing techniques to identify appropriate areas which are suitable for reasonable, convenient, and administratively transparent waste-disposal siting in Niamey.

Figure 1: Arbitrary waste dumping site at outskirts of Niamey

Figure 2: Waste dumping site at outskirts of Niamey

2. Methodology

Niger, a former French colony, obtained its independence from France in 1960. It shares common borders with Nigeria, Benin, Burkina Faso, Mali, Algeria, Libya and Chad (Figure 3). Niger covers an area of about 1.26 million square kilometers with the population of 11 million in 2000 (Manu et al., 2003).

The overall per-capita gross domestic product (GDP) for Niger clearly suggests that it is one of the least developed countries of the world and that the economic well-being of its people is not improving. In Table 1 below, population and real GDP figures are drawn from World Bank (2002). Population figures are listed in millions and the total real GDP for the country is listed in billions of constant 1995 dollars:

Table 1. Real per capita GDP and annualised rate of change

Year	1980	1991	1995	2000
Population	5.59 M	7.98	9.15	10.85
Real GDP	1.833 B	1.858	1.881	2.197
Per capita real GDP	$327.91	232.83	205.57	202.49
Rate of change	-	-3.07%	-3.07	-0.30

Thus, for 15 years before 1995, per capita GDP fell by just over 3% per year; but, since 1995, Niger's per-capita change figure has levelled off, indicating the potential for trend reversal.

Niamey, the capital of Niger, the focus of this study, covers an area 460 square kilometers with overall population of 660,000 in 2000 (Table 2). It is evident in Table 1, that since 1960, the population of Niamey has been increasing rapidly at a very high rate. A higher rate (10.7%) was observed between 1960-1980. Subsequent increases in population were also recorded between the 1980-1990 and 1990-2000 intercensal periods, but a much slower rate in the later period. The geographical coordinates are latitude $13^{0}52^{'}$N, longitude $2^{0}12^{'}$E (Figure 3).

Table 2: Rate of Population Increase in Niamey from 1960-2000. Computed from Manu et al. (2003).

City	Population				Annualized Rate of Increase (%)		
	1960	1980	1990	2000	1960-1980	1980-1990	1990-2000
Niamey	30,000	230,000	430,000	660,000	10.7	6.5	4.4

Figure 3: Map of Niger

3. Data

Data from Landsat ETM+ imagery of 16th October 2001 were used as overlays to show topographic details in relation to digitized road-network data from black and white aerial photographs of March 1989 obtained from Service Topographique du Niger, as shown below in Figures 4 through 6.

The digitized aerial photography of the road network is unlikely to be dated information, since road networks do not change much during the space of only a decade. The road-network data were used merely as a background reference to show the significance of the more recent Landsat imagery on topography.

4. Data Processing

The Landsat ETM+ satellite data was processed using ERDAS IMAGINE 8.7 image processing software. The image was imported into ERDAS using NLAPS importing format. Two steps were taken to process the data. In the first step, the image was imported into ERDAS IMAGINE's standard image format (.img). The image was subset from the floating scene to emphasize the study area and then later displayed as false-color composites with bands as follows: Band 4 for red, band 3 for green and band 2 for blue and later enhanced using histogram equalization techniques. Masks of known water-body, tiger-bush and greenbelt areas were created by using spectral characteristics. Road networks were manually digitized using visual interpretations. The locations of open markets and water towers in the study area were identified from GPS mapping and ground surveys.

The second step involves the processing of the topographic data. The procedures used are described in Manu et al. (2004). A 1:50,000 scale topographic map of Niamey was scanned and on-screen digitizing was performed to collect the xyz values for the entire study area. These points were later imported into Environmental Systems Research Institute (ESRI) ARCGIS 8.3 Spatial and 3D Analyst extensions to create a Digital Elevation Model (DEM) of Niamey. The DEM was also exported as a .tif file and brought into ERDAS IMAGINE for further processing. To allow for the integration of the satellite and DEM data, the DEM was co-registered to the satellite image using Universal Transverse Mercator (UTM) reference system. The spheroid and datum were also referenced to WGS 84. The road networks (vector), satellite and DEM data were further exported into ERDAS VIRTUAL GIS for 3D processing of the landscape to show potential areas suitable for the selection of the landfill sites for Niamey and its surrounding area. All the buffering operations and final selection of the appropriate sites was done in ESRI ARCVIEW GIS Spatial Analyst extension software.

5. Solid Waste Site Selection Criteria for Niamey

A number of essential factors are considered in locating landfill sites. Such factors include both physical and social environments. McKechnie et al. (1983) documented six factors that constitute these essential factors: topography, climate, hydrology, cover material (land cover), geology, and land uses. Due to data constraints, we used topography, hydrology, cover materials, existing housing and land development (roads etc.) of the area as guides to site selection. Criteria were specified to assume that dumpsite would be outside the buffer zone of the hydrology, forested areas, roads and existing housing. These criteria were:

- 300 meters away from the main road
- areas less than or equal to 230 square meters based on the contour map
- minimal noise contamination from truck movement
- 300 meters away from water bodies
- located in area not crossed by major roads.
- not located in areas of active agricultural land or near land under development.
- 40 kilometers away from the nearest population centers

Different layers relating to these criteria are used to compare maps and locate areas which conform to the criteria. It should be emphasized that these were the criteria used to solve the siting problem at Niamey. The nearest population centre is plainly the city of Niamey itself. If these criteria were to be applied to other siting problems, it would be necessary to modify them in light of the new geographic and demographic constraints. Thus, for some urban areas, it may not be possible to find a site more than 40 kilometres from the nearest population centre; but siting may be possible if the critical separation is reduced to 20 kilometres.

6. Results and Discussion

Results of the study are shown in Figures 4, 5, 6 and 7. Figure 4 shows overlays of different layers such as water, road networks, wells, market centers and vegetation. Figure 5 shows results of two Boolean operations performed using the topographic data. One is the area with height less than or equal to 230 meters, and the other with area greater than 230 meters. Figure 6 shows an overall selection of landfill sites for Niamey taking into account the criteria listed above including overlays conforming to these criteria. The final landfill sites also fall within the topography of 230 meters or less. It also shows buffer of 300 meters distances away from the major road network, water, and vegetation (tiger bush). Figure 7 shows a 3D model of Niamey and its environs. It shows the landscape in three-dimensional perspective on cultural and natural spatial features. In particular, the recommended site shown in Figure 6 is relatively distant from the Niger River and at considerably higher elevation, thus minimising the risk of flooding. Viewing the model at different angles and perspectives thus shows how the site visually affects the land and how negative impacts may be avoided.

A look at Figures 4 through 7 and associated discussion above shows how easy it should be to make objective decisions on the siting problem. The overlay procedure recommended here provides a quick method of seeing, and of demonstrating to popular audiences, the problems and advantages of alternative sites. It thus provides what is needed for the development of a reasonable, convenient, and administratively transparent planning process for waste site selection.

The general result should be to find a site at minimum cost which can be operated at minimum cost without risk to people or economic activity. Niamey's population increase rate, though moderated in recent years, has been large by world standards. Wherever there are people there is waste; and if population pressure increases quickly, the bad effects on the environment as well as on the human population itself will multiply. In African municipalities, traditional methods of handling waste (use of abandoned land of whatever quality) assumed small populations which would have negligible impacts on the environment and the health of those populations. Under modern conditions of rapid urbanization and population growth, however, continuation of the traditional method is no longer sustainable. Wastes will cause leaching of chemicals into the groundwater causing potable water supply problems, contaminate local water flows thus preventing the use of alternative water supplies, breed insects which result in disease transmission, and cause problems for continued human economic activity. Rational site selection is thus very important and can no longer be ignored, especially in developing countries like Niger, where the viability of the population depends on business activity.

7. Conclusions

This study has shown how GIS and remote sensing techniques may be used to protect the health and safety of Niamey, by showing how city planning managers may minimise the impacts of waste disposal on the environment and the economy. A point made in this study is that site planning should minimise impacts by siting the waste disposal facility under a list of rough criteria which specify that the site minimise impacts on local populations. Finding such sites may be very difficult, owing to conflicts with interest groups over alternative land uses.

There is general recognition that the siting decision faces what has come to be known as the 'Not in My Backyard' (NIMBY) syndrome, in which every siting proposal immediately runs into a backlash from potentially affected communities (Lober & Green, 1994, Wright, 1990). These kinds of conflicts are found in every country on such issues, because everyone is concerned about the value of his own property and the ability to enjoy it. The problem is not that sites may be found to which no protest will arise, but rather that sites should be found which minimise conflict, so as to minimise both the actual as well as the perceived risks of waste disposal.

As shown from the brief review in Table 1 above, Niger faces severe economic problems which must be understood to hamper its response to environmental management. However, these data also show that Niger may well recover in the near term, thus making possible the improvement of its planning process.

Although no siting proposal can be absolutely acceptable for its capital city, much can be done to minimise objections without actually detailing the activities of opposition groups. Conflict-minimising procedures must be systematic, comprehensive and administratively transparent to avoid the accusation that the Government helps some at the expense of others. The best way to handle such problems is to develop a systematic and computerised administrative management regime which can show everyone that everything was done to minimise negative impacts and thus demonstrate the administrative transparency of Government procedure. The best way to do this, as argued in this study, is to employ overlay comparison procedures using remotely sensed imagery in relation to existing topographic data and road networks to achieve the sustainable management of solid wastes at Niamey.

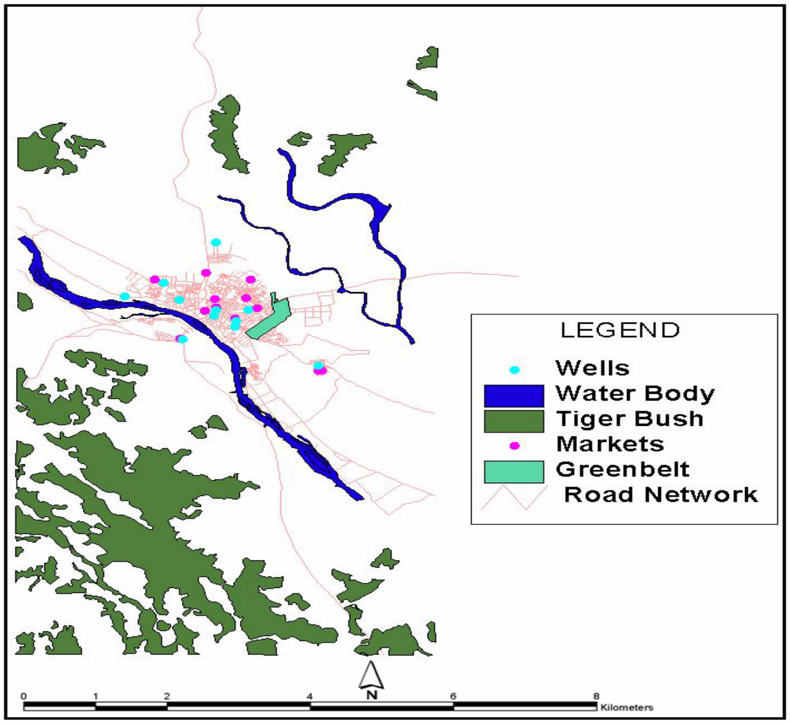

Figure 4: Overlay of different spatial layers

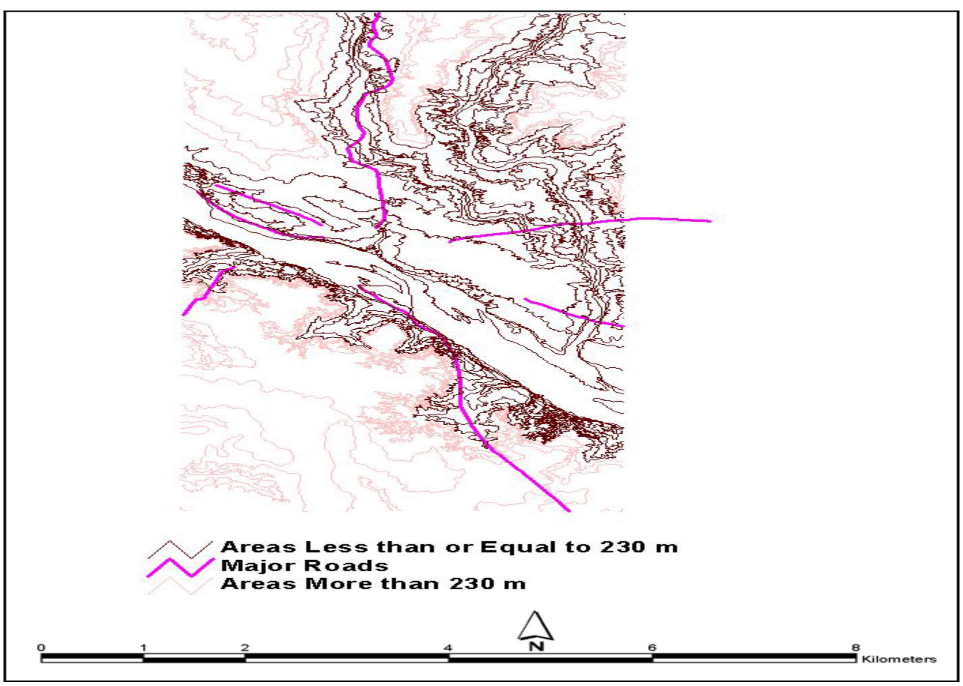

Figure 5: Boolean operation showing different elevation values with overlay of major roads.

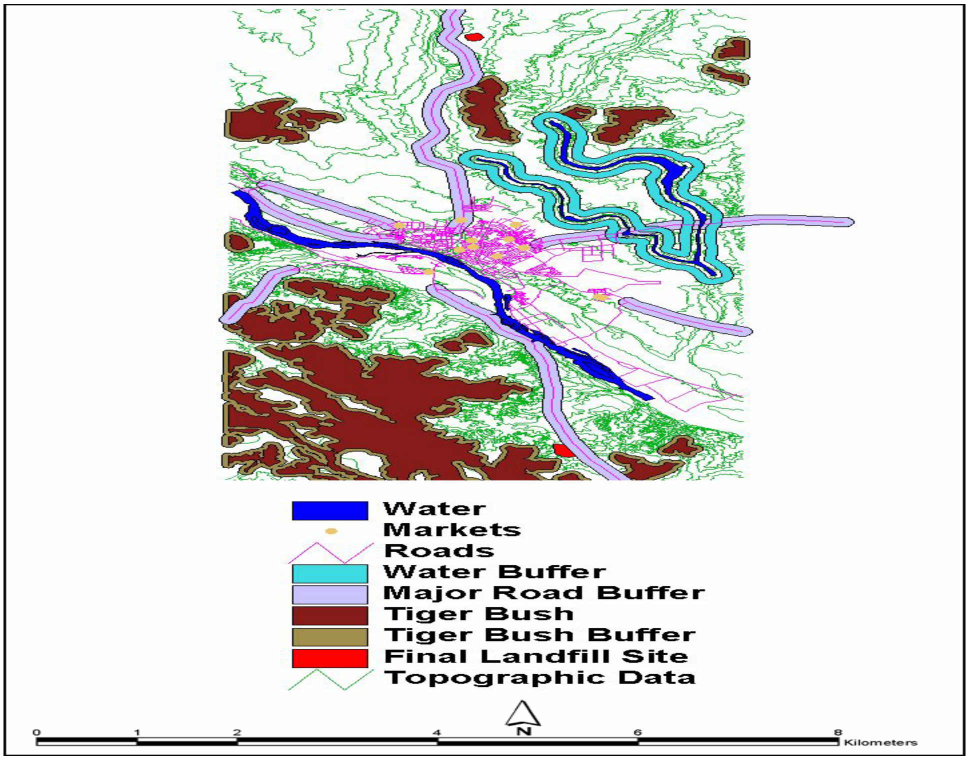

Figure 6: Final landfill site for Niamey

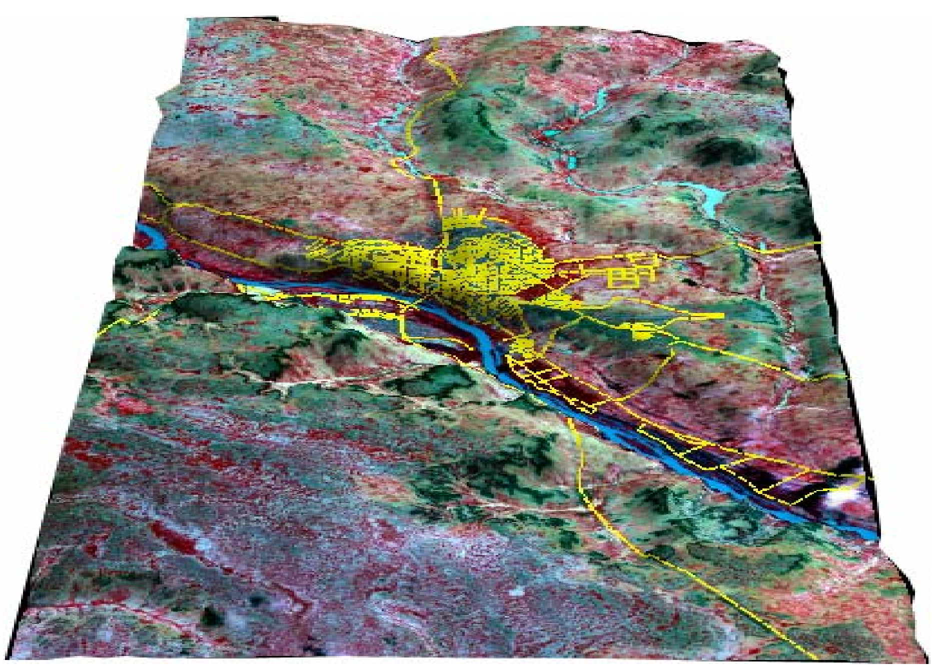

Figure 7: Three dimensional view of Niamey and its environs. The view was created by using ERDAS VIRTUAL GIS software with vertical exaggeration of 9. This was done by overlaying Landsat ETM+ satellite imagery of October 16, 2001 onto a 20 m grid cell digital elevation model. Road network of Niamey shown in yellow is overlaid onto the landscape to show the extent of the area in relation to the surroundings.

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