GIS mapping and Analysis for informal settlement upgrading in Cape Town –A case study of Monwabisi Park

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Abstract

This paper specifically focuses on introducing GIS spatial analysis and the subsequent thematic mapping in relation with informal settlement upgrading based on information gathered from the residents of the informal settlement. Furthermore, the application of GIS spatial analysis in different informal settlement problems is demonstrated. This research outlines the investigation of mapping and spatial analysis in Informal settlements upgrading using GIS, making use of five different analysis methods: Buffer analysis, thematic mapping, Thiessen polygons, distance mapping and Multi Criteria Evaluation. The case study area is Monwabisi Park in Cape Town and the data was collected by Violence Prevention through Urban Upgrading (VPUU). The study has revealed that the use of indigenous knowledge in GIS analysis for upgrading could be very valuable in making scientific and alternate decision during informal settlement upgrading process.

Key words: Informal settlements, Buffer Analysis, Distance Matrix, Thiessen Polygons, Thematic Mapping, Multi-Criteria Evaluation (MCE)

1. Introduction

The use of Geographic Information Systems (GIS) in informal settlement upgrading has rapidly increased throughout the world (Zeilhofera and Topanottib, 2008; Huchzermeyer, 2003; Abbott, 2003). This is because structured planning makes use of both spatial and attribute data which are supported by GIS. Nayak et al (2009: 290) describes GIS as:

"A computer assisted system for the acquisition, storage, analysis and display of geographic data".

Shoba and Ra sappan (2013: 1) also describe GIS as follows:

"A computer tool for capturing, storing, querying, analyzing and displaying spatial data from the real world for a particular set of purposes".

Data storage, management and processing are powerful capabilities of GIS that can be utilized in informal settlement upgrading. GIS software is capable of collection, storage, management, retrieval and analysis of geographic information (Toosi et al, 2005). It is also able to output data in various formats e.g. maps which can be useful in decision making and urban upgrading processes.

This study utilizes indigenous or local community knowledge which have been integrated with other data (such as stakeholders' perspectives) which would eventually be analysed by GIS. This more inclusive access to data, as well as provision of data, empowers communities who would otherwise not have had any say in the process. (Musungu & Motala, 2012).

Spatial analysis is used to process this data into useful and meaningful information, which can be used in helping to take effective decisions during the planning process. Evaluation of environmental impacts caused by informal occupation and flood mapping are some of the applications of GIS in informal settlements, that have been carried out in previous studies (Zeilhofera & Topanottib, 2008, Abbott & Douglas, 2003, Huchzermeyer. 2003). The focus tended to be on GIS mapping, with less emphasis been placed on the application of spatial analysis. This study, which was requested by an organization (VPUU) that works closely with the community being analysed, showcases the use of various types of spatial analysis in informal settlement upgrading.

1.1 Background and motivation

Khayelitsha is Cape Town's biggest township, which was created for the black population as a result of South Africa's apartheid legislation. It is located in the province of the Western Cape, on the south-east of Cape Town's metropolitan area. The informal settlement of Monwabisi Park is the site of this study, and lies on the south-east side of Khayelitsha (Figure 1).

Figure 1. Geographical location of Monwabisi Park

Initially, Monwabisi Park was reserved for landfill purposes. It was occupied in 1997 by some residents from Harare, a suburb of Khayelitsha. The exact population of Monwabisi Park is unknown because of its dynamic nature as an informal settlement. In 2012, a study showed that the population was approximately 6,000 households.

Like most informal settlements in South Africa, Monwabisi Park faces service provision challenges. These include the following:

a) The absence of a proper drainage system: This is most evident during high levels of flooding. During heavy winter rains in Cape Town, there are not enough drainage systems to channel the run-off water.

b) Lack of formal electricity: This results in a high rate of informal electrical connections to households.

c) Lack of essential services: Not all households have facilities like toilets, running water and proper refuse collection facilities.
d) Inadequate roads: existing paths were only designed for pedestrians. Cars were not catered for, making it difficult or impossible for emergency service vehicles to gain access.

In early 2013, Monwabisi Park was identified as the study area by Violence Prevention through Urban Upgrading (VPUU), the research partners and initiators of this project. VPUU is a group based in the City of Cape Town, and uses social engagement and town planning as tools in fighting crime in Khayelitsha, mainly to improve living conditions of residents. Having done GIS mapping in previous projects, they approached the authors to explore further GIS mapping and spatial analysis that could improve on what they had done already. VPUU, together with the community of Monwabisi Park, collected the data through questionnaires and mapping each household structure. This is a more democratic application of GIS, which allowed the community to participate and contribute to the body of knowledge known as Participatory GIS (PGIS). Laituri (2003: 25) describes Participatory GIS as:

"A confluence of social activity such as grassroots organizations and government decision making with technology in specific places or grounded geographies".

Quan et al. (2001) also describes PGIS as follows: "Participatory GIS is the integration of local knowledge as well as stakeholders' perspectives in a GIS". The incorporation of indigenous knowledge of the area in the decision making process is emphasized so as to empower the community (Musungu & Motala, 2012).

2. GIS in informal settlement upgrading

In 1983, the Voluntary Association for International Service was invited by the Catholic Church to provide technical support in Belo Horizonte town upgrading, in which they decided to use GIS. This resulted in Brazil being the first country to utilize GIS in informal settlement upgrading. (Abbott, 2003). It was effective at alternate decision making, during the upgrading process. The successful application of GIS in Brazil created more interest in its application as a planning tool in informal settlement upgrading. In addition the use of GIS in urban upgrading expanded throughout the world, in both developed and developing countries (Brown-luthango et al, 2013, Dubovyk et al 2011, Abbott, 2003).

In 1996, an adaption of the modified method used in Brazil, was applied in Cape Town informal settlement upgrading, and it was the first time GIS was used in South Africa to help in informal settlement upgrading (Abbott, 2003). The project was successful and lead to more recognition of GIS in upgrading informal settlements. This was followed by other scholars who have used GIS in informal settlement upgrading (Abbott & Douglas, 2003, Huchzermeyer. 2003, Zeilhofera & Topanottib, 2008, Musungu et al, 2012).

2.1 GIS analysis

The following section introduces different spatial analysis techniques that can be used during the informal settlement upgrading process. This is by no means an exhaustive list, but was chosen so as to showcase techniques that were not previously considered by VPUU.

a) *Buffer Analysis:* This type of analysis is used in the modelling phases of urban planning and upgrading (Toosi et al, 2005). It is an analysis method which uses database information to generate zones of a certain width around selected features of interest. In order for a buffer analysis to be effective, the created buffer zone map has to be overlaid with other layers.

b) *Spatial Query:* Decision-makers make use of spatial query function to extract meaningful information from stored data. The ability of GIS to respond to questions of spatial patterns, queries on location and trends, is dependent on spatial query functions (Toosi et al, 2005). A query is only able to retrieve information which has already been stored in a database. GIS queries can be classified into query by attribute, and query by geometry (Jovanovic & Njegus, 2008). Spatial query plays a vital role in production of thematic maps.

c) *Multi-criteria Evaluation Analysis (MCE):* MCE employs a structured approach to examine a set of alternatives. This is achieved by ranking alternatives that are more suitable to the least preferable objectives (Malczewski, 1999). The preference of alternatives relative to one another is indicated by weights, which are derived from different MCE methodologies. These include ranking, rating, pairwise comparison and trade-off analysis (Malczewski 1999, as cited by Musungu et al, 2012). In studies carried out by Musungu, et al (2012) and Yahaya (2010), the parwise comparison method (PCM) proved to be the best method for risk assessment and mapping in informal settlements, and for assessment of flood vulnerability. The present study uses the methodology of Musungu et al (2012) to combine PCM with PGIS to assess disaster vulnerability.

d) *Thiessen / Voronoi Polygons:* Theissen polygons which are also known as Voronoi polygons are often used in accessibility studies (Brabyn & Skelly, 2001). Accessibility can be seen as “the proximity of one location to other specified locations” (Kwan and Weber, 2003, p. 341). Thiessen Polygons use a general assumption that the area inside any given polygon is closer to that polygon's point than any other based on certain criteria.

3. Approach

The main aim of this study was to apply additional analysis on the spatial data captured by VPUU, so as to optimize the use of GIS on the rich data that came out of the participatory mapping of Monwabisi Park. The existing analysis that was done was largely restricted to thematic mapping of individual attributes.

After consultation with VPUU to understand their broad operational aims, data capture methods, and GIS methods they employed, different types of spatial analyses that they had not used before were identified that might be useful. These were: buffer analysis, Thiessen polygons, Multi-criteria evaluation analysis, and thematic mapping.

3.1 Enumeration and Mapping

For this project, the data was captured by VPUU, using field- and office work. The data was collected from all the households in Monwabisi Park; furthermore some of the residents were involved in the data collection process. Before commencement of fieldwork, outlines of households were digitized, to create a polygon shapefile. During the fieldwork, each team of four data collectors had the following responsibilities:

- one person interviewing the respondent of the household;
- one person sticking Survey Number on the shack;
- one person taking photographs of the household and interviewee; and
- one person capturing the coordinates of the shack with a hand held GPS

A preliminary exploration of the questionnaire data showed the characteristics in Table 1.

Table 1. Characteristics of data provided by VPUU

Data	**Data Type**	**Content**
Spatial Location of households	Polygons	Geographical location of households
Socio-economic Demographic Data	Text/ Attribute Data	Socio-economic & Demographic information
Monwabisi Park Sections	Polygons	Polygons dividing Monwabisi Park into four sections
Contour Line	Line	Elevation of Monwabisi Park terrain

The data had to be cleaned and the household shapefile then had to be joined to the attribute data. Due to irregularities between the handwritten responses, the captured attribute data, and the numbering of the polygons in the shapefile, 1127 records (either lines in the attribute table, or polygons in the shapefile) could not be used. This resulted in a shapefile containing 5125 polygons representing households with attribute data.

The selection of GIS analysis method was dependent on a particular problem that was to be analyzed. For instance using a 100m buffer, to analyze how many households of children between ages of 0-5 are within a 100m from crèches.

4. Results and discussion

4.1 MCE investigating disaster vulnerability

The following alternatives were derived for types of exposure to hazards, based on responses to the questionnaire:

- No disaster
- Only fire
- Only flooding
- Fire & flooding

After discussions with VPUU, who represented the community for input on this analysis, the levels of exposure to these hazards in Monwabisi Park were ranked in order of preference. After completion of ranking, a pairwise comparison was carried out in order to derive weights for each alternative. In this analysis, the highest weight was allocated to the best case scenario and the lowest weight to the worst case scenario. Disaster vulnerability weights are illustrated in Table 2 below. The weights were then allocated to the individual households based on their responses. For instance, if a particular household experienced no fire, a weight of 0.246 was allocated to that household. Figure 2 shows the resulting map, covering section M, C, B & A of Monwabisi Park (these sections were demarcated by the community), which used a nearest neighbor interpolation method to create a raster vulnerability surface.

Table 2. Vulnerability weights for hazard exposure

EXPOSURE TO HARZARDS	
Alternatives	**Weights**
No Disaster	0.492
Only Fire	0.246
Only Flooding	0.164
Fire & Flooding	0.098
Sum	1.000

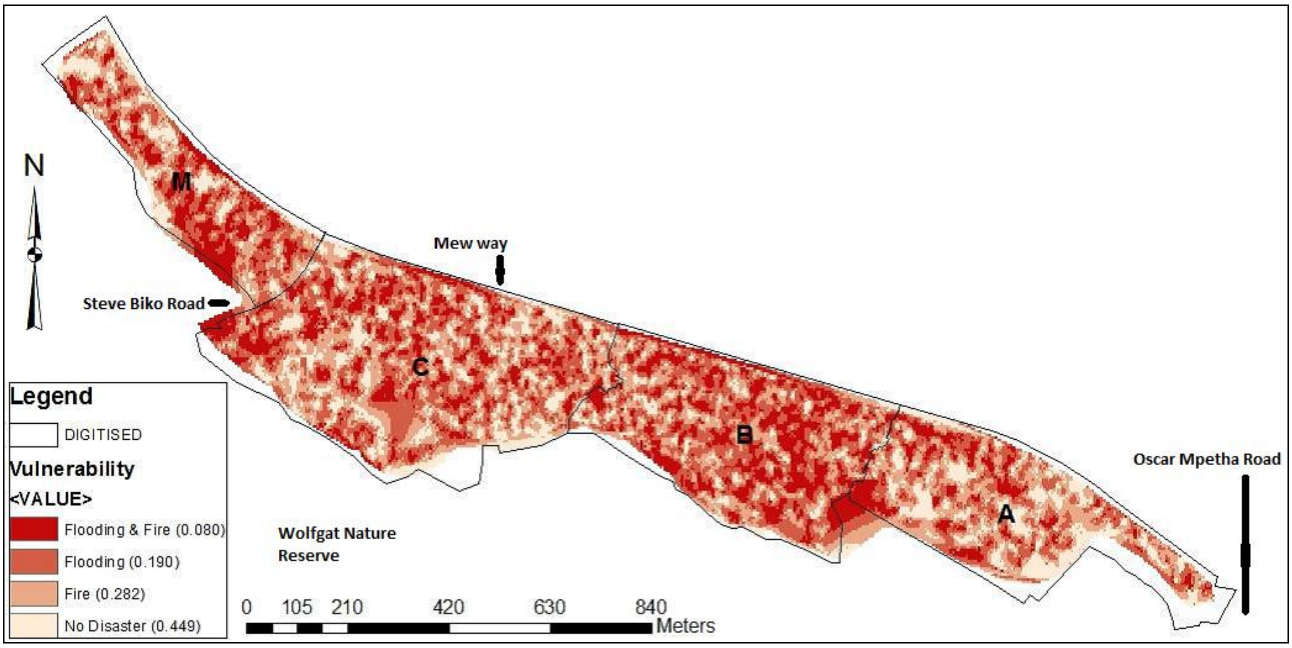

Figure 2. Map showing vulnerability based on type of exposure to a hazard in section M, C, B & A of Monwabisi Park

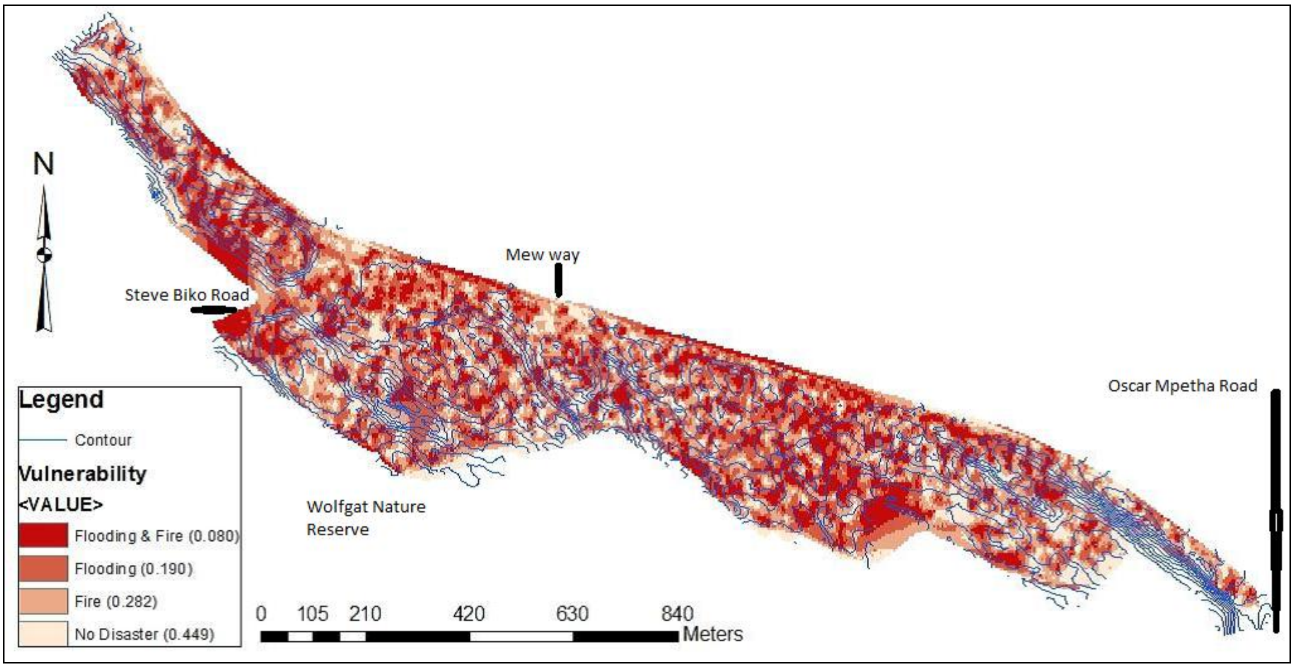

Figure 3. 2-meter contours lines overlaid on a vulnerability surface

Like most informal settlements in Cape Town the residents of Monwabisi Park were exposed to fire and flooding. This finding was in agreement with that of the study carried out by Musungu et al (2012) and Douglas et al. (2008). Figure 2 shows the vulnerability of households to flooding and fire. It was noted that the majority of households were prone to flooding, and that they were also randomly dispersed.

In discussion with VPUU, it emerged that heavy rainfall contributes to flooding as the material used to construct households is of poor quality. These households are constructed from timber and corrugated metal. It appears that households nearby the surrounding main roads are regularly flooded during heavy rainfall, due to poor construction material. This is the case because the roads are situated on higher altitude terrain (Figure 3), and a proper drainage system along the roads assist in channeling storm water away from them, towards the shacks in Monwabisi Park.

4.2 Buffer analysis and thematic mapping investigating fire disaster

After being advised by VPUU, fire disasters were categorized into two groups. These are: fires that occurred where formal electricity was used (this constituted 26% of households that experienced a fire); and fires that resulted where informal electricity was used (this constituted 74% of households that experienced a fire). An informal electricity connection is the result of electricity being illegally acquired.

Thematic mapping was used to represent different combinations of factors contributing to fire, and this is shown in Figure 4. Houses that did not experience fire were colour coded according to the energy source they utilized. Light blue and dark blue polygons represented houses that did not have a formal electricity connection, whereas yellow polygons represented households that had formal electricity. Households that experienced fires were either coded as pink (with formal electricity) or red (with informal electricity or used flammable material such as paraffin, gas or candles for lighting or cooking). 50% of Monwabisi Park households used formal electricity, most of them being residents who arrived first at the settlement.

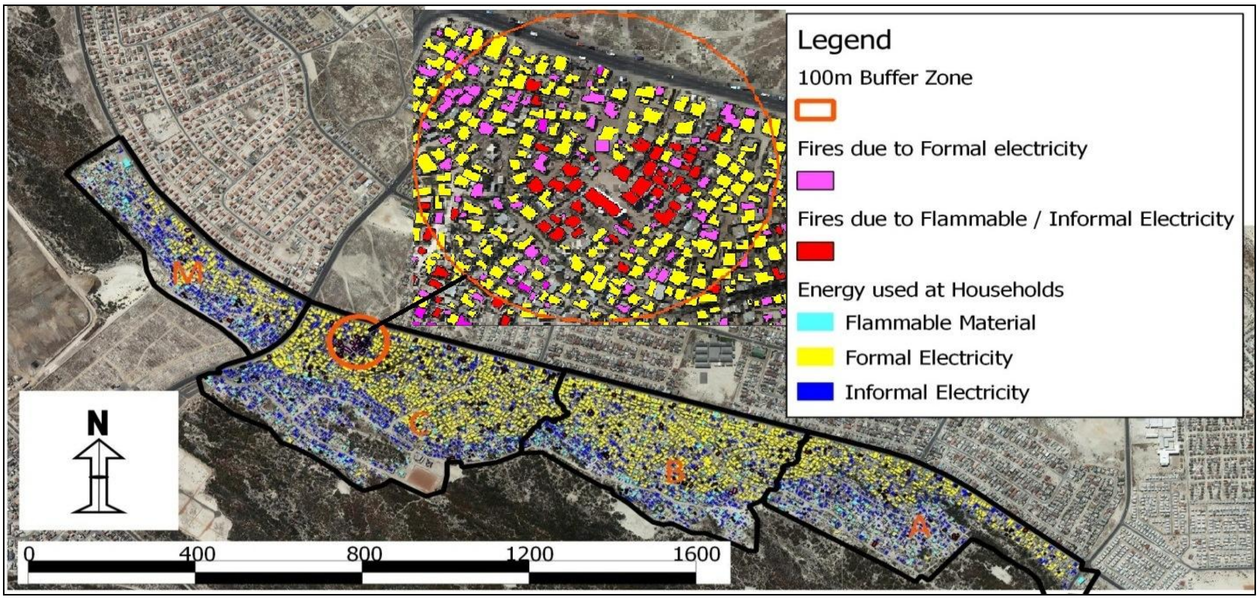

Figure 4. 100m buffer, Fire disasters mapped to type Energy source used. Section M, C, B & A of Monwabisi Park

A 100 meter buffer zone was executed around a household that experienced fire, to check the number of households that would be affected if the spread of fire is within this range. There was a correlation between fire and flammable energy sources used at households (Figure 4).

4.3 Thiessen polygons, distance matrix and statistical analysis investigating crèche accessibility

Households were identified that had children between the ages of 0 to 5 years (with an assumption that all these children went to crèche). A Thiessen polygon analysis was employed to identify the number of these households that could be accommodated by the nearest crèche. This analysis was combined with a distance matrix, showing the distances that these children would have to travel (by foot in the majority of cases) to get to their nearest crèche. The distance matrix results are presented in table 3. It is evident from the mean distances that crèche 1316 has more households being located away from it, with an average distance of 327 m travelled, while crèche 6752 has more households closer to it, with an average travel distance of 102 m. Moreover an additional crèche is needed in the vicinity of crèche 1703 to reduce the large number of children being accommodated by it.

Table 3. Number of households in a Polygon and average distances travelled

	Thiessen Polygons	**Distance Matrix**
Crèche	**% of 0-5 years old households within Polygon**	**Mean (metres)**
1316	6%	327
1703	22%	216
2568	8%	149
2774	21%	141
5528	9%	121
6752	10%	107
5791	20%	267
6476	4%	102

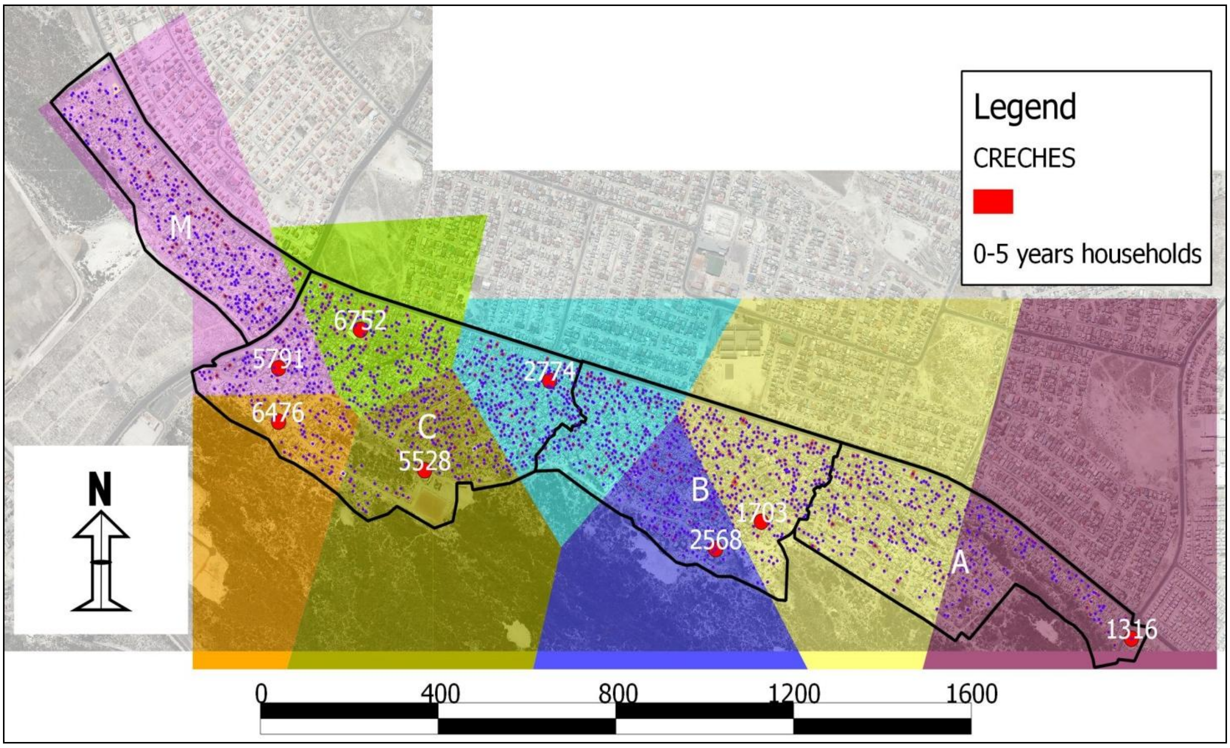

Figure 5. Thiessen Polygons, 0-5 years old children households and crèches

5. Conclusions

GIS technology has the ability to assist in improving the quality, and efficiency of informal settlements. It offers a broad range of benefits, which are realised from data collection processes to display of results as maps, graphs and tables.

Five different methods of GIS spatial analysis were applied on Monwabisi Park spatial data, in order to assist with decision making for urban upgrading. The different types of analyses were buffer analysis, Thiessen polygons, MCE, distance matrix and thematic mapping. The resultant maps produced different results, depending on the type of spatial analysis employed and the purpose of the resultant map.

During the analysis, the attribute data and the polygons that did not join were excluded, representing a waste of effort. A more sustainable and reliable method of capturing data from the communities should be developed, so as to prevent wastage in the data collection process.

Discussions with VPUU assisted the principal author to get a clear understanding of the data captured, moreover the indigenous knowledge that the residents had about the study area assisted in the production and interpretation of maps. This study assisted VPUU in understanding the complexity of the participatory data collection process and its flaws. This could help them to create a more robust data collection process. The data analysis, on the other hand, showed VPUU and their community partners the power of GIS analysis. Being able to identify trends at different scales allows for a “big picture” understanding of various factors (such as vulnerability across the whole informal settlement), together with a finer understanding at an individual level (such as the feasibility of specific crèche locations).

This study has confirmed that useful analysis can be achieved through interaction between GIS professionals and communities. The knowledge and participation of communities could be used to produce sophisticated mapping and analysis, and ultimately could assist in the upgrading of the community.

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