A Spatial Multiple Criteria approach for poverty eradication planning

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Abstract

Poverty eradication as a policy issue has received significant attention since the promulgation of the South African National Development Plan (NDP). The NDP envisages that by 2030 income poverty should be eradicated. To do this government must accurately target their interventions ensuring that the intended population benefits from the actual poverty eradication intervention. With the evolution of systems and processes in the Science and Technology industry over the past two decades, the integration of GIS and MCDM techniques has achieved encouraging results within different planning domains. This research paper presents a vector – based GIS – MCDM methodology that combines Principal Component Analysis (PCA) and Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS). This integration is facilitated through the use of loose coupling within the ArcGIS 10.2 environment.

A case study in the City of Cape Town is used to demonstrate the use of the methodology and how it can be applied to conduct an evaluation study to rank each of the communities based on poverty measures. The results of the GIS – MCDM analysis show that a significant cluster of high levels of poverty existing in the southern part of the City of Cape Town: Khayelitsha, Philippi, Gugulethu, Nyanga ect. Moreover the prominence of apartheid led spatial planning and the resulting socio – economic segregation across the City of Cape Town is still spatially evident across two decades after democracy. Thus the above map can be used by planners and decision makers to inform better decision making by ensuring that the fiscal budgets are targeted at the correct communities thus ensuring that the intended benefit population actually benefit.

1. Introduction

In June 2011, the first Diagnostic Report for South Africa was drafted by the National Planning Commission (NPC) (NPC, 2011). This report noted that since 1994 this country has made significant economic and political strides. Yet with these achievements millions of South Africans are still unemployed, illiterate and are living with monthly incomes too close to the poverty line (NPC, 2011). The NPC has therefore set out the new developmental agenda for South Africa through the promulgation of the National Development Plan (NDP). The main objective of the NDP is to redress the high levels of poverty and inequality by 2030. For this redress to happen, new and dynamic processes and procedures must be introduced into the policy and decision making environments. One such procedure is the integration of Geographical Information Systems (GIS) and Multiple Criteria Decision Making (MCDM) techniques to evaluate the spatial distribution of the of poverty across the City of Cape Town. With the evolution of systems and processes in the Science and Technology industry over the past two decades, the integration of GIS and MCDM techniques has achieved encouraging results within different planning domains. Thus a GIS – MCDM tool has been developed to identify and rank alternatives (communities) using multiple conflicting criteria associated with each community sourced from the latest Census 2011 data. Based on these assessments government is able to determine the extent of the socio–economic policy interventions required to eradicate poverty and reduce inequality by 2030. The following section defines the problem statement and the challenges with using a one-dimensional approach for measuring and assessing the extent of poverty in a region.

2. Problem Statement

The NDP aims at eradicating the proportion of households living with a monthly income of less than R419 per person, through the enhancements of critical capabilities such as education and skills, and access to work opportunities (NPD, 2011). This outcome indicator fundamentally translates into income being considered as the primary manifestation of citizens 'living valued lives'. From a policy planning and decision maker's perspective, this means that the conceptualisation of community based policy and programme interventions developed to redress capability issues will be driven solely from a conventional monetary perspective.

The use of this traditional one-dimensional approach for measuring poverty has shown to have resulted in significant losses of critical information. This approach removes the nuances and complexities that exist between the poor and non–poor; thus many countries have begun to steer away from using this one–dimensional approach for assessing poverty (Belhadj and Limam, 2011). The loss of information results in the skewed distribution of government resources, resulting in most of the intended programme benefits being received by the

unintended population. The consequences of this type of inadequate programme targeting are seen in figure 1 which shows that while government has made strides in reducing income poverty the progress has been to slow.

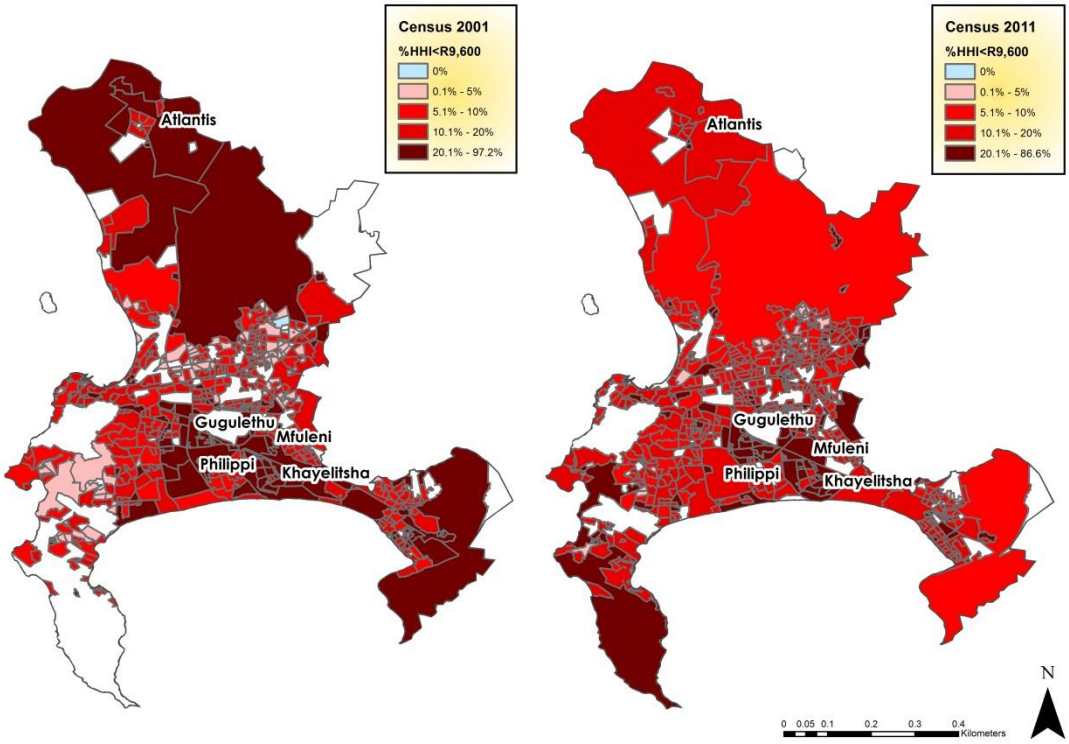

Figure 1: Comparisons between 2001 and 2011 of household earning less than R 9 600 per annum

3. Methodology

In 1988, a well–known GIS researcher concluded that "….GIS is best defined as a decision support system involving the integration of spatially referenced data in a problem solving environment" (Cowen, 1988: 1554). This definition was later disputed by others citing that the abilities of GIS fell well short of providing decision makers with the necessary decision tools needed to make informed decisions (Densham and Goodchild, 1989). Today, the decision making abilities of GIS has been enhanced significantly through the coupling of GIS with MCDM tools thereby supplying accurate, reliable and relevant information to decision makers allowing them to make more robust evidence–based decisions (Malczewski, 2006). The eradication of poverty and the reduction of inequality levels, both pervasive and unrelenting human rights issues, require that government programmes and interventions be informed by accurate, reliable and relevant information. This will ensure that these programmes are accurately targeted at poorer communities to ensure the benefits of these community specific programmes reach the intended population. For this to happen, communities must be evaluated over its potential, limitations and constraints to determine the levels of poverty which exists in each community. This poverty analysis process will involve

the integration of multiple potentially conflicting criteria ranging from unemployment to piped water access and various decision makers and content experts decision preferences. These criteria and decision preference occur within a specific spatial context and will vary from community to community hence the relevance of GIS and MCDM integration (Chen and Khan, 2010).

The proposed decision making process has been decomposed into four general activities as proposed by Keeney (1982). These activities include:

- structuring the decision making problem;
- assessing the possible impact of each evaluation alternative;
- determining the preferences of each decision maker; and
- assessing and comparing each alternative.

These four activities are subsumed into the proposed seven phase theoretical decision making methodology used for evaluating one of the main goals of the NDP which is to eradicate poverty by 2030. The six phases are:

1. Defining the decision making problem;
2. Identification of stakeholders;
3. Identification of alternatives;
4. Identification of decision criteria;
5. Calculating the criteria weights; and
6. Evaluation of the alternatives.

Figure 2 represents the GIS - MCDM framework which will be used to provide a methodical sustenance to a complex multiple criteria decision making problem such as poverty eradication. The MCDM process commences when the decision maker formulates the decision making problem thereby defining the main objectives of the multicriteria decision making problem.

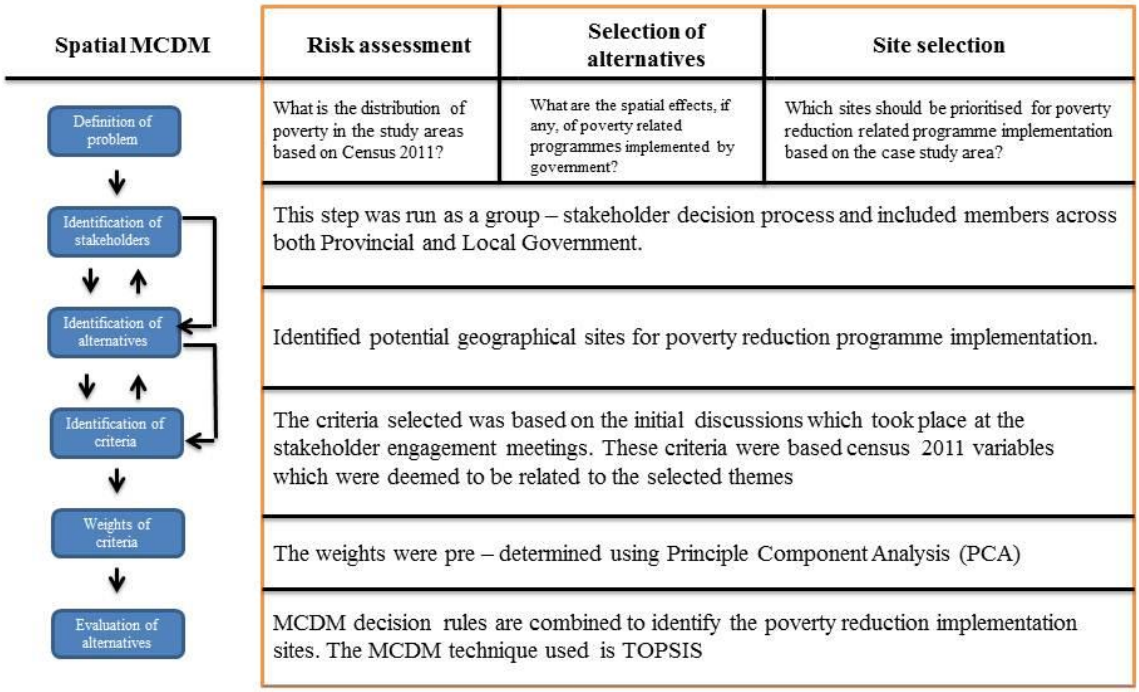

Figure 2: GIS - MCDM methodology used in research study

Once the decision making problem has been formulated the following phases are implemented:

- The first phase contextualizes the decision making problem by identifying the objectives, outcomes, scope and limitations;
- The second phase includes the identification of all relevant internal and external stakeholders like content experts, planners and decision makers;
- Phase three and four incorporates: identifying all possible decision alternatives; and defining all relevant evaluation criteria used in assessing each of the decision alternatives. This is done through a consultative process which various experts and is based on available data sources;
- For phase five, the decision criteria weights are calculated using Principal Component Analysis (PCA) for each of the evaluation criteria.
- Phase six includes the amalgamation of all decision criteria with relevant weighting schemas using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) resulting in a composite poverty index for each decision alternative.

4. Identification of stakeholders

On the 21st of October 2012, the Western Cape Government held a Socio – Economic Index development workgroup session to develop a methodology for constructing a multi – dimensional index used to inform policy planning and decision making. To do this, a comprehensive quantitative and qualitative knowledge base was developed in the context of poverty eradication planning. To populate this knowledge base, multiple experts with relevant expertise and experience in multiple socio – economic domains were invited from the City of Cape and Western Cape Government.

5. Development of decision alternatives

The purpose of this study is to evaluation a number of alternatives using GIS – MCDM. This evaluation will be done based on pre–defined sets of potentially conflicting evaluation criteria sourced from census 2011. These criteria are then amalgamated together to form an overall poverty index. Based on this index, each of the alternatives (sub–places) will be ranked accordingly, identifying which alternative requires government intervention. In this study area there are exactly 705 alternatives, derived from Statistics South Africa's Census 2011 sub – place boundaries, identified for possible poverty eradication intervention.

Study

Figure 3: Study area alternatives

The 705 alternatives were derived using the following census criteria:

- an alternative has an enumeration area type of formal, informal and traditional residential; and
- the alternative must have a total dwelling count of more than 100 dwelling units.

Figure 4: Study area

Table 1: Theoretical structure for objectives and criteria

Criteria theme	NDP objectives	Derived evaluation criteria
Household services	Providing basic services that enable people to develop capabilities to take advantage of opportunities	No electricity for lighting
		Access to piped water in dwelling or yard
		No refuse removal by local authorities
		Sanitation access (no bucket system)
Education	Improve the quality of education in underperforming schools and further education and training colleges	Functionally illiterate (15 – 64yrs)
		Employed with matric and more (15 -64yrs)
Economic	Introduce active labour market policies and incentives to grow employment, particularly for young people and in sectors employing relatively low-skilled people	Official unemployment rate (15 – 64yrs)
		Individual income less than R800 per month
		Employed in the formal sector
Housing	Promote mixed housing strategies and more compact urban development	Informal dwelling type
		Household size more than 6
		Tenure status

6. Identification of decision criteria

The evaluation criteria were conceptualised and development based on both:

- the review of national and international national literature relating to conceptualizing and measuring poverty (National Planning Commission, 2011), M. Noble et al. (2006), A. Sen (2000) and M. Nussbaum; and

- Western Cape Government workgroup discussions with both internal and external stakeholders, policy and decision makers and other project related team members on deriving a census–based index for measuring poverty.

It was agreed upon in the workgroup, that four main criteria themes would be used for assessing poverty. These themes are: household services, housing, economic, and education. While the objectives for each of these criteria themes were not defined in the workgroup sessions, the NDP provides detailed objectives for each of the criteria themes. Based on these NDP objectives, census related criteria were then derived and used to develop a poverty index. Table 1 presents the criteria theme, the objectives as defined in the NDP and the criteria derived for each theme.

7. Analysis and Results

7.1 Development of decision criteria weighting schema

The estimation of criteria weight schemas is considered as the most important phase in the MCDM process. These schema estimations are used unambiguously to assign criteria importance in the MCDM model. If you were to ask a group of decision makers who are all leading experts in their field, which of the following dimension: household services; education; housing; and economy, would carry more weight in a poverty eradication decision making model, you would get a mixed bag of complex biased results. Some experts would argue that the provision of appropriate housing structures is a fundamental dimension to poverty reduction and should therefore be heavily weighted in a decision making matrix while other developmental experts would debate that decent education should be the primary dimension and should therefore take priority.

This type of bias behavior in decision making is well document in different literature relating to behavioral decision making. One type of such decision bias is called anchoring and adjustment. It often occurs when a decision maker anchors his/her opinion about a criterion weight and then later often fails to adequately re–adjust the anchor (Buchanan and Corner, 1997). The anchoring of criteria weights result in decision making models generating skewed decision results. These skewed results have a negative effect in the way government apportions its resources causing smaller percentages of the poor being reached with a given fiscal budget. Therefore in order to negate any bias in the results, Principle Component Analysis (PCA) is used to assign importance to each of the evaluation criteria.

Table 2: Principal component (eigenvector) results

CRITERIA	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9
Income	0.4161	0.0870	0.0467	-0.1324	0.0737	-0.3983	0.7524	-0.0084	-0.2631
Formal	-0.2870	0.1118	0.1089	0.8801	0.0145	-0.1936	0.2302	0.1255	0.1110
Unemploy	0.4352	0.2234	-0.0031	0.0177	-0.0942	-0.1182	-0.2472	0.8041	0.1728
Hhsize	0.2307	0.6514	0.0373	0.2055	-0.0761	0.3391	-0.1714	-0.2071	-0.5345
Tenure	0.0587	-0.1288	0.9719	-0.0542	0.0280	0.1739	0.0044	0.0379	0.0057
Illiterate	0.4310	0.2655	0.0135	0.0844	0.1647	0.0469	0.0001	-0.4369	0.7185
Lighting	0.3139	-0.3640	-0.0600	0.2413	0.7431	-0.0630	-0.2840	-0.0271	-0.2637
Refuse	0.3114	-0.4195	-0.1834	0.2296	-0.2338	0.6853	0.3222	0.1102	0.0206
Toilets	-0.3423	0.3318	-0.0514	-0.2108	0.5872	0.4109	0.3254	0.2991	0.1289

PCA is a useful multivariate statistical method used to classify and extract patterns in large datasets and also underlines the relationships and variances in these datasets. The application of PCA also allows for datasets to be compressed by minimizing the number of interrelated criteria with minimal loss of information, although this is not critical to the proposed application of PCA to MCDM. This mathematical method is most valuable because of its ability to create new sets of uncorrelated linear weighted components from an initial decision matrix which comprises of highly correlated variables. PCA will be applied on a set of decision criteria relating to household services, economic, education and housing for the all sub-places in the City of Cape Town. The initial principal component was calculated using STATA 12 software and was applied as weightings in the poverty rank index.

Before the initial principal components (weights) are calculated, correlation and multi-collinearity testing was conducted to determine criteria exclusion from the final MCDM rank index model. For the correlation testing, a correlation matrix consisting of 66 Pearson's correlation coefficients were developed and tested at a 0.05 significance level. The results showed that 95.5% (63 of the 66) of the coefficients were statistically significant at a 95%

confidence level which revealed the presence of multi-collinearity. This was tested using the *vif* (variance inflation factor) commands in STATA. The results generated showed a presence of multi-collinearity in three criteria; access to piped water in dwelling or yard, employed with matric and more (15-64yrs), and persons living in informal dwelling types. Based on these results the three evaluation criteria were removed from the initial criteria set of 12 to reduce the standard errors and width of the confidence interval for the evaluation criteria. The remaining nine criteria were used to generate the relevant eigenvectors (Principal Components) used in the decision making model.

Table 2 presents the ranking of the principal components in order of their importance (determined based on variability) and is denoted by its associated eigenvector for each PCA. In this research paper, the PC scores associated with each of the criterion of poverty are conceptualized as poverty indices. By retaining only the eigenvectors associated with PC1, which accounts for most of the variability in the data, smaller independent indices of poverty is created (Abson *et al*., 2012). The load factor of the original poverty related criteria on the retained PC highlights the spatial pattern of poverty across the City of Cape Town.

Before factor loading can occur, the eigenvectors relating to PC1 is normalised $(\frac{PC1_{ij}}{\sum_j^1 PC1_1})$ and applied as the weighting schema for the MCDM model to determine the rank of each alternative.

7.2 Evaluation of decision alternatives

The evaluation methodology used will assist decision makers and planners with identifying and assessing the spatial distribution of poverty and inequality through the aggregation of multiple conflicting criteria such as; employment status; illiteracy; etc. These evaluation criteria were aggregated into an overall rank index using a MCDM technique called Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) which is used to rank each of the alternatives therefore identifying the areas of need.

The TOPSIS technique was developed by Hwang and Yoon in 1981. This decision making technique ranks alternatives that simultaneously have the shortest distance from the positive ideal solution and furthest distance from the negative ideal solution (Behzadian *et al*., 2012). A literature survey on TOPSIS application compiled by Behzadian *et al*., (2012) found that the application areas varied significantly but could be divided into nine areas: Supply chain management; Design and Engineering; Business management; Health, Safety and Environment management, Resources management and other topics such as Educaton, Agriculture and Governance (Behzadian *et al*., 2012). While no research has been conducted on the application of TOPSIS in a poverty context, this techniques ability to generate credible ranking results based on multiple conflicting criteria makes the TOPSIS technique most

appropriate for this study. When the TOPSIS technique is applied to solve a multi–criteria decision making problem within a spatial environment this method is referred to as Spatial TOPSIS. The procedure for the TOPSIS method can be described in the following five steps listed below.

- Step 1: A normalised decision matrix is constructed to ensure that the original consequence data is transformed into actual values to be consumed. The result of this step is used as part of the input into MCDM process

$$\mathbf{x_{ij}} = \frac{\mathbf{x_{ij} - x_{min}}}{\mathbf{x_{max} - x_{min}}} \quad [1]$$

- Step 2: The eigenvectors relating to PC1 is applied as the weighting schema for the normalised decision matrix

$$\boldsymbol{\omega_{ij}} = \boldsymbol{\varphi_j x_{ij}} \quad [2]$$

- Step 3: Determine the separation measures for each alternative

$$\boldsymbol{S_i^+} = \sum_{j=1}^{k} \boldsymbol{\omega_{ij}} \textbf{ for positive alternatives} \quad [3]$$

$$\boldsymbol{S_i^-} = \sum_{j=k+1}^{k} \boldsymbol{\omega_{ij}} \text{ for negative alternatives} \quad [4]$$

Vector $\boldsymbol{S_i^+}$ comprises of maximum values of each benefit criterion and the minimum value for each cost criterion while vector $\boldsymbol{S_i^-}$ holds the minimum value of each benefit criterion and the maximum value for each cost criterion. Thus the positive and negative alternative provides the best and worst criteria solution for each alternative provide for in the decision matrix (Berger, 2006).

- Step 4: Determine the significance of each decision alternative

The importance (Q_i) of each alternative is determined using the following equations:

$$\boldsymbol{Q_i} = \boldsymbol{S_i^+} + \frac{\sum_{i=1}^{m} \mathbf{s_i^-}}{\mathbf{s_i^-} \sum_{i=1}^{m} \frac{1}{\mathbf{s_i^-}}} \quad [5]$$

- Step 5: Calculate the performance index of each alternative

In the next step the performance index is calculated to determine the complete ranking of all decision alternatives.

$$\boldsymbol{P_i} = \frac{\boldsymbol{Q_i}}{\boldsymbol{Q_{max}}} \times 100 \quad [6]$$

Once the performance index was been calculated the following equation is applied to determine the poverty index for each of the decision alternatives. This index is then used to rank each of the alternatives according to government priority.

$$\mathbf{Poverty_{index}} = \mathbf{1} - \mathbf{P_i} \quad [7]$$

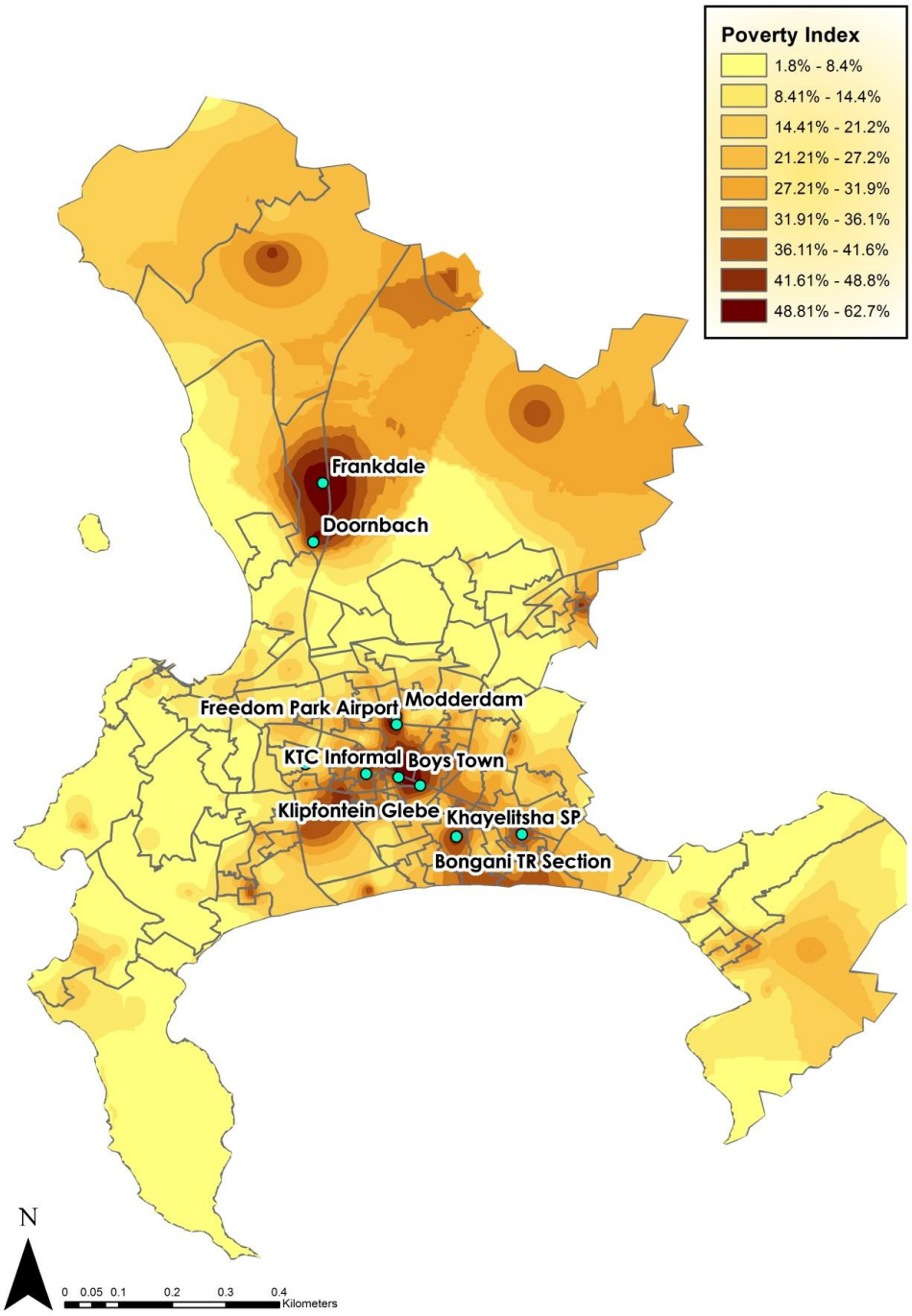

Figure 5: Output of MCDM model

The map in Figure 5 displays the results of the GIS - MCDM process. The map shows the spatial distribution of poverty across the City of Cape Town and identifies a significant cluster of high levels of poverty existing in the southern part of the City of Cape Town, Khayelitsha, Philippi, Gugulethu, Nyanga ect. Figure 5 also shows the prominence of apartheid led spatial planning and the resulting socio – economic segregation across the City of Cape Town. Thus the above map can be used by planners and decision makers to inform

better decision making by ensuring that the fiscal budgets are targeted at the correct communities thus ensuring that the intended benefit population actually benefit.

7.3 Discussion

The major challenge with eradicating poverty is ensuring that the intended programme and project investment is effectively reaching the intended population (poor) thereby reducing any fiscal 'leakages' and under-coverage rates. To address this issue, governments should move away from a non–evidence based approach to an evidence–based approach for decision making. The approach incorporates geographical targeting of poverty eradication programmes at community level using multiple conflicting criteria to identify communities in need. This type of targeting may help to redress the past policy biases that had led to difference in quality of basic services as an example.

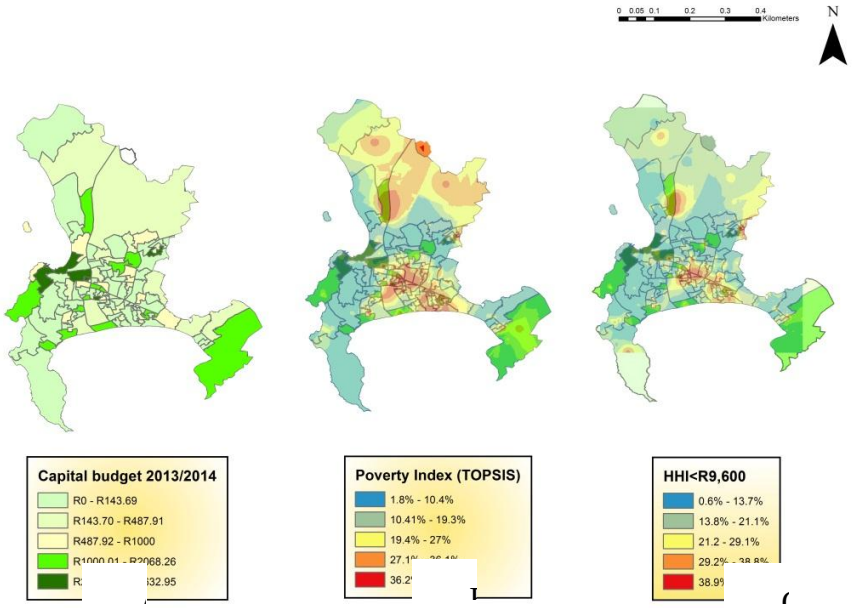

Figure 6: Multidimensional measures versus single dimensional measures

Note: Map A is a capital budget density map for the City of Cape Town, Map B is the Poverty Index developed using TOPSIS and, Map C is the Income Poverty Index derived from census 2011.

Map 4A shows the spatial distribution of the capital budget 2013/2014 spent per person for each ward in the City of Cape Town. Map 4B and 4C shows spatial distribution of poverty using a multiple criteria approach (4B) and a single criteria (income) approach (4C) overlaid with the capital budget spent per person. These results show; firstly, that the City of Cape Town has made significant inroads in terms of targeting areas of need but fiscal 'leakages' still exist; and secondly that planning using a single dimensional approach can

significantly skew any needed community–based policy intervention as shown in map 4C; and lastly the results from map 4B shows that GIS – MCDM methodology can assist policy and decision makers to conduct more robust evidence decision analysis which incorporates multiple often conflicting criteria thereby reducing fiscal 'leakages'.

8. References

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