Development of Land-Use Suitability Assessment Criteria for South Africa

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1. Background to the Project

Land as a resource is limited in nature and its use is not only determined by the user but also by the capability of that land to sustain productive activities. Land capability in turn is governed by the different land attributes such as the type of soil, underlying geology, topography and hydrology. These attributes define the extent to which land can be put to competing purposes in order to optimize its return. Currently a criteria or a scientific basis for the selection of the most appropriate and sustainable use of land for a particular area does not exist in South Africa. For example, agriculture, commercial development, creation of conservation areas and urban development are crucial for the growth of South Africa's economy, but when confronted with competing potential uses, it is currently not clear how the choices are to be made in an objective, transparent and consistent manner. It is evident that currently, certain land activities are practiced on unsuitable lands and this problem is likely to persist in future if not addressed. Little has been done to model and project land performance for various competing uses going into the future.

It is against this backdrop that the Department of Rural Development and Land Reform (DRDLR) commissioned a project to develop Land Use Suitability Assessment Criteria (LUSAC) for South Africa. LUSAC is an important tool in bringing to effect the provisions of the recently enacted Spatial Planning and Land Use Management Act (SPLUMA, 2013). SPLUMA seeks to promote consistency and uniformity in procedures and decision-making processes related to spatial planning and land use management. Among the key changes brought by SPLUMA is the confirmation of municipalities as authorities of first instance in matters of land development and land use management. The broad principle is that the vast majority of land use and spatial planning decisions are to be taken at municipal level. Section 20 of SPLUMA requires a municipality to prepare a Spatial Development Framework (SDF) one of whose functions is to guide development and the identification of land that is suitable for various types of developments.

In order to achieve the above, it is necessary that land suitability assessments are carried out on land before any developments are implemented. The tool would also assist municipalities in preparing land use schemes and SDFs as they would have the knowledge of what is more suitable and viable before undertaking the process. The content of Municipal SDF is comprehensively described in Part E Section 21 of SPLUMA. Elements of the SDF require that assessment practices towards future land use demarcation or identification be introduced. The requirements that are relevant to Land Use Assessment criteria and that must be in the SDF include:

- A written and spatial representation of a five-year spatial development plan for the spatial form of the municipality.

- A longer term spatial development vision statement for the municipal area which indicates a desired spatial growth and development pattern for the next 10 to 20 years.
- Estimates of the demand for housing units across different socioeconomic categories and the planned location and density of future housing developments.
- Identify, quantify and provide location requirements of engineering infrastructure and services provision for existing and future development needs for the next five years.
- Identification and designation of areas where a national or provincial inclusionary housing policy may be applicable.
- A strategic assessment of the environmental pressures and opportunities within the municipal area, including the spatial location of environmental sensitivities, high potential agricultural land and coastal access strips, where applicable, and
- Determination of the purpose, desired impact and structure of the land use management scheme to apply in that municipal area.

Equipping municipalities with the tools necessary to undertake these assessments would go a long way in supporting efficiency and effectiveness of the preparation and implementation of land use schemes and SDFs. When applied, the criteria would help rank various potential land uses where the land is capable of being used for multiple purposes. Embedded within the criteria will be clear procedures and processes to be followed to enable the generation of optimal land-use models or a mix of land-uses that yield the *"highest" overall cumulative suitability*.

It is however appropriate to mention here that regardless of the quality and performance of the proposed tool, the final decisions on how land uses are allocated will be based on consultations, and the integrity of the decisions by those vested with the responsibility of making such decisions. This implies that issues of governance, efficient and sustainable use, are among other key underpins of Land Use Suitability Assessment Criteria (LUSAC).

2. The Concept of a Land Use Suitability Assessment

Broadly defined, land-use suitability analysis aims at identifying the most appropriate spatial pattern for future land-uses according to specific requirements, preferences, or predictors of some activities. It relates to land performance when used for a specified purpose, based on an evaluation of the land form, soils type, vegetation, geology, topography and other features in order to resolve competing potential uses within a framework of the applicable proposed developments

Every portion of the Earth's landscape is characterized by a different set of features that render it more suitable for certain uses than others. Land Use Suitability Criteria consist of three main elements:

- ***The Land*** – ground or soil of a specified situation, nature, or quality
- ***Suitability*** – adapted to a use or purpose, and
- ***Analysis*** – the process of separating of the whole into its component parts, and therefore allowing structured decision making.

Based on the above 3 components, land suitability analysis is the separation of the nature or quality of land into its component parts based on the land's ability to serve a particular use or purpose. ***"High land suitability"*** means the land has relatively high numbers of the component parts in favour of its use for a particular purpose, while ***"low***

land suitability" means the land has relatively low numbers of the component parts it needs to serve a particular use or purpose.

Land suitability assessment has two sides to it. It involves classification of characteristics according to their suitability for a particular activity, that is to say, identification of which land use is to apply in some given circumstances. The second element of the analysis defines where the best site to apply a particular type of land use is located given a set of potential alternative sites. The explicit site search analysis determines not only the site's suitability but also its spatial characteristics such as its shape, contiguity, and/or compactness by aggregating the basic units of observations according to some criteria.

The value of land quality is the function of the assessment and grouping of land types into orders and classes in the framework of their suitability – generally categorized as suitable (S) and not suitable (N). These suitability classes can then be further sub-divided, as required. In practice, three classes (S1, S2 and S3) are often used to distinguish land that is ***highly suitable, moderately suitable and marginally suitable*** for a particular use. Two classes of 'not suitable' can usefully distinguish land that is unsuitable for a particular use at present but which might be useable in future (N1), from land that offers no prospect of being so used (N2).

The procedure for optimizing land use allocation will depend on whether the land uses are compatible or conflicting. When the land uses are compatible, technically there is no pressure to allocate land for alternative uses, hence the allocation is based on a descending measure of overall or cumulative suitability for the compatible land uses. However, the optimal land use allocation procedure is a bit more complicated when the objectives are conflicting. In this case, allocations are exclusionary, that is land units can only be allocated to one use only. Mendoza (1997) advised a prioritized allocation to solve this problem that is the land uses are compared in terms of priority. Allocation is done to the land use rated as the highest priority. Then allocation of remaining land units is done for the lower priority land uses.

Land Use Suitability Assessment can be a powerful tool in support of Land Use Planning. It involves all kinds of urban and rural land use such as agriculture, forestry, wildlife conservation, tourism, transportation, water resources and industries among others. It is an important part of forward planning as it provides a predictive framework on the suitability of the land for different demands and the consequences of such demand on the environment. Land suitability inventory provides feasibility information to developers and investors on the possible location of various investments and the limitations therein.

3. Multi-Criteria Decision Analysis as an Underpinning Principle

In our daily lives, we usually use multiple-criteria analysis to implicitly make regular decisions such as what to buy, where to live and what to eat. We are often comfortable with the consequences of such decisions even when they are made based on our mental frame or intuition.

On the other hand, when stakes and the costs of consequences are high, it is important to properly structure the problem into various options and explicitly use a multiple criteria analysis to determine the attendant trade-offs between the choices. In making the decision of whether to build a nuclear power plant or not, and where to build it, there are not only very complex issues involving multiple criteria analysis, but also multiple parties who are deeply affected from the consequences. Structuring complex problems well, and considering multiple criteria explicitly, may lead to more informed and better decisions.

Land use suitability assessment is inherently a multi-criteria issue, that is to say, it is a decision making problem process that involves consideration of a variety of factors to identify the use that leads to the best possible range of outcome for society. The principal problem of land suitability analysis is to measure both the individual and cumulative effects of the different factors on land.

Multi-Criteria Decision Analysis, or MCDA, is a valuable tool that we can apply to many complex decisions. It is most applicable to solving problems that are characterized as a choice among alternatives. It has all the characteristics of a useful decision support tool. It helps in focusing on what is important, is logical and consistent, and is easy to use. At its core, MCDA is useful for:

- Dividing the decision into smaller, more understandable parts
- Analysing each part, and
- Integrating the parts to produce a meaningful solution.

3.1 GIS and Multi-Decision Analysis Criteria

Use of GIS is the centrepiece of the recommended methodological approach. The strength of a GIS environment is that it allows for the development of integrated GIS-based multi-criteria approaches and model(s) which combine the spatial capabilities of GIS with multi-criteria analytical capabilities. Fundamentally, integrated GIS-based multi-criteria approaches to site (land-use) suitability take into consideration the different factors (i.e. both the socio-economic and biophysical land parameters) affecting suitability of the site/land, as well as specific land uses. The factors include (but are not limited to) natural system constraints, compatibility with existing land-uses and development patterns, existing land-use policies, and the availability of community facilities. The map analysis techniques in GIS-based site (land) suitability assessments include (but are not limited to):

- Retrieval and reclassification
- Measuring distance and connectivity
- Characterizing and summarizing neighbourhoods, and
- Overlay (combination of various datasets) techniques.

Within a GIS environment, an MCDA framework is developed for both *site (land-use) suitability analysis* and *land allocation*. Although, one is distinct from the other, the former serves as a basis for the later. The MCDA framework captures the multi-criteria nature of land-suitability assessment/evaluation/analysis, and simultaneously allocates land by maximizing overall suitability of a land area.

GIS is an enabler of site (land-use) suitability analysis as well as the intricately linked land-use allocation. This, it does, by integrating the various elements needed for this entire assessment process (refer to Figure 1). GIS creates a convenient and powerful platform which integrates cross-sectional datasets (i.e. vector and/or raster) and Multi-Criteria Evaluation (MCE) and allocation methods (approaches and indices) all within a MCDM framework. Having linked all these facets, GIS goes on to enable spatial analysis, through both quantitative and qualitative techniques (e.g. reclassification, measuring distance and connectivity, buffering, overlay, etc.). The outcomes of this integrated GIS-based process include: decision making tools/products such as land-use models/scenarios, and optimal land-use mixes (which optimize cumulative suitability).

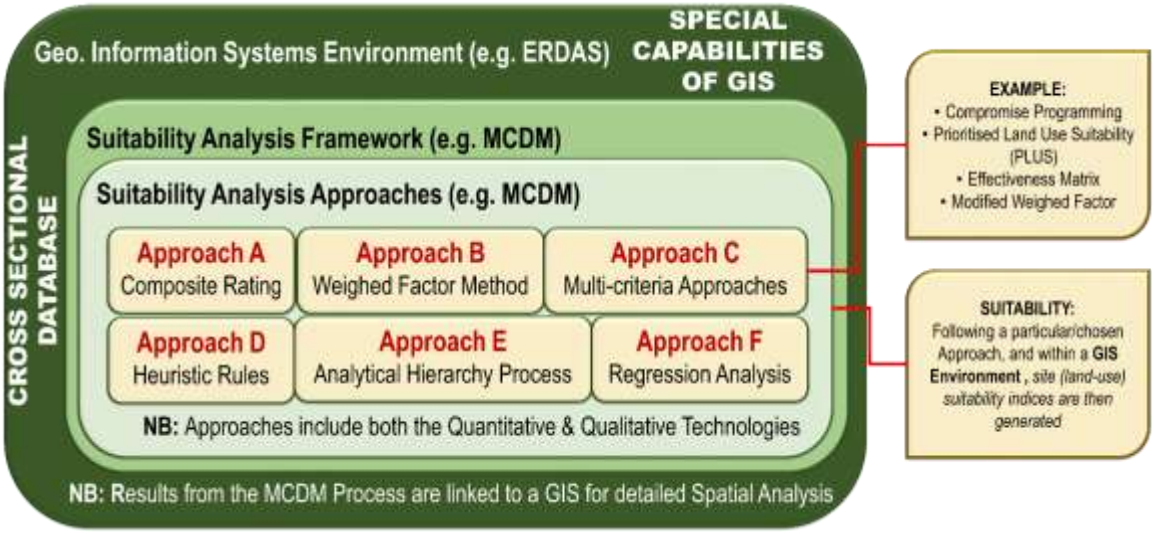


Figure 1: Land Suitability Analysis, MCDM and GIS interface

It should be noted that GIS has been used extensively to develop decision-making tools (particularly maps) to enable the evaluation of site suitability and the assignment of various measures or attributes of suitability to specific sites or geographic areas. Presented in the following sections are a select few exemplar cases from South Africa and elsewhere (international), respectively.

4. The Proposed Tool: A Two-Pronged Sustainability Approach

The proposed and use suitability model consists of two major sub-models. The first is a ***Developability index*** and the second a ***Desirability index*** (refer to Figure 2 below).

Figure 2: The two components of the criteria

4.1 The Developability Index

Developability includes criteria which are in most cases non-negotiable (e.g. very steep slopes). The Developability criteria are mostly natural and policy constraints which makes development impossible or very costly. A non-negotiable criteria item may cause certain areas to be “no-go” areas for development and are removed very early in the process.

4.2 The Desirability Index

Desirability criteria are mostly qualitative in nature. In most cases all the areas are developable, but the degree of desirability differs (e.g. it is more desirable in terms of

travel cost to live close to employment centres than far from them). Most desirability criteria are negotiable and different values (weights) can be given to each. A low value (weight) given to an area does not mean it is a "no-go" area.

4.3 The Main Information Pillars of the Model

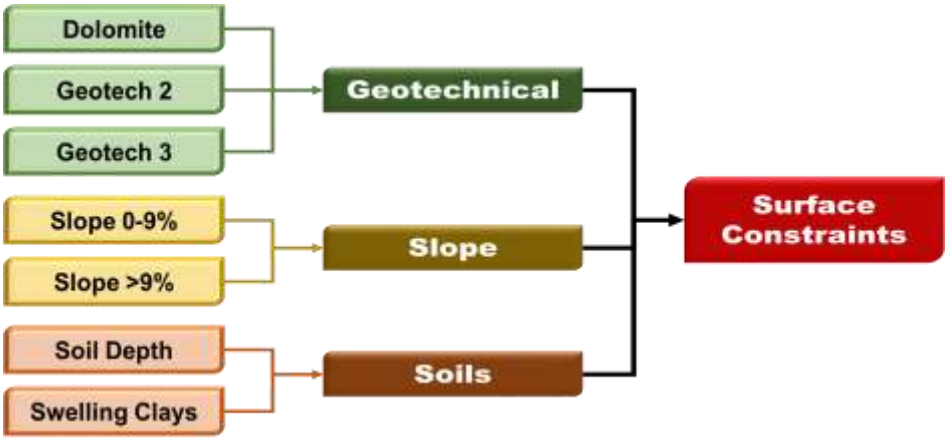
The second level of the proposed land suitability tool is based on major information pillars. The developability and desirability sub-models get informed by various relevant information topics. The following paragraphs describe each of these topics.

4.3.1 Developability

Figure 3: Sub-components of developability index

4.3.1.1 Surface Constraints

Surface constraints includes slope, geo-technical conditions and soils (refer to Figure 4 below) that are in some cases regarded as no-go areas and in other cases may be very costly to develop on.



- ***Geotechnical constrains*** includes no-go areas such as dolomite as well as other geological conditions that either is unsafe or costly to develop
- ***Slope*** has a cost impact on development and un-developability at steeper slopes
- ***Soil*** has a cost impact on development and may also impact on development timeframes

4.3.2 Desirability

As noted previously, desirability criteria are mostly qualitative in nature. They involve value judgments of what is desirable or ideal and even when an area scores low on desirability for a certain development, it does not totally disqualify it. The desirability index consists of the following 4 sub-models as shown in Figure 3 below:

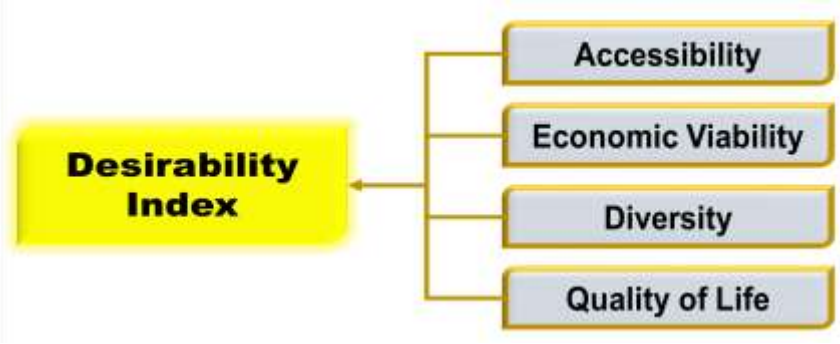


Figure 3: Sub-models of the Desirability Index

4.3.2.1 Economic Viability

Figure 4 below shows that economic viability is underpinned by the assumption that areas with demonstrated economic potential provide greater livelihood and income protection because of a greater diversity of income sources.

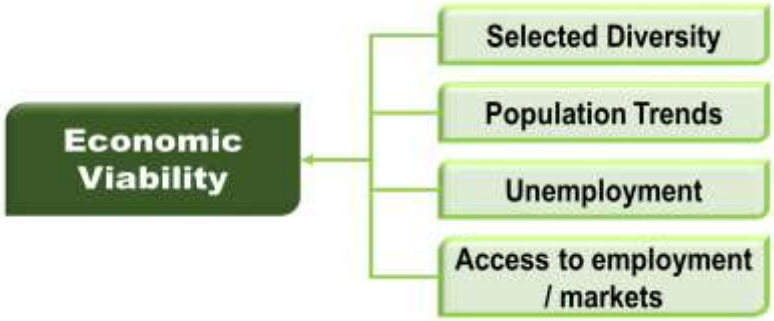


Figure 4: Economic viability considerations

- ***Sectoral diversity*** is a characteristic of a healthy economy. Single sector economies should be highlighted before large scale community developments are planned.
- ***Population trends*** refer to areas of growth and decline.
- ***High unemployment clusters*** should be avoided. More inclusive development without large scale "poverty traps" is preferred, and
- ***Access to employment/markets*** secures greater diversity of income sources and will always be preferable for development.Accessibility.

4.4 The Full Model at a Glance

While the foregoing sections have unpacked in relatively more detail the various criteria relating to the Land Suitability Multi-Criteria Model, Figure 5 below provides an overview of the model as a whole.

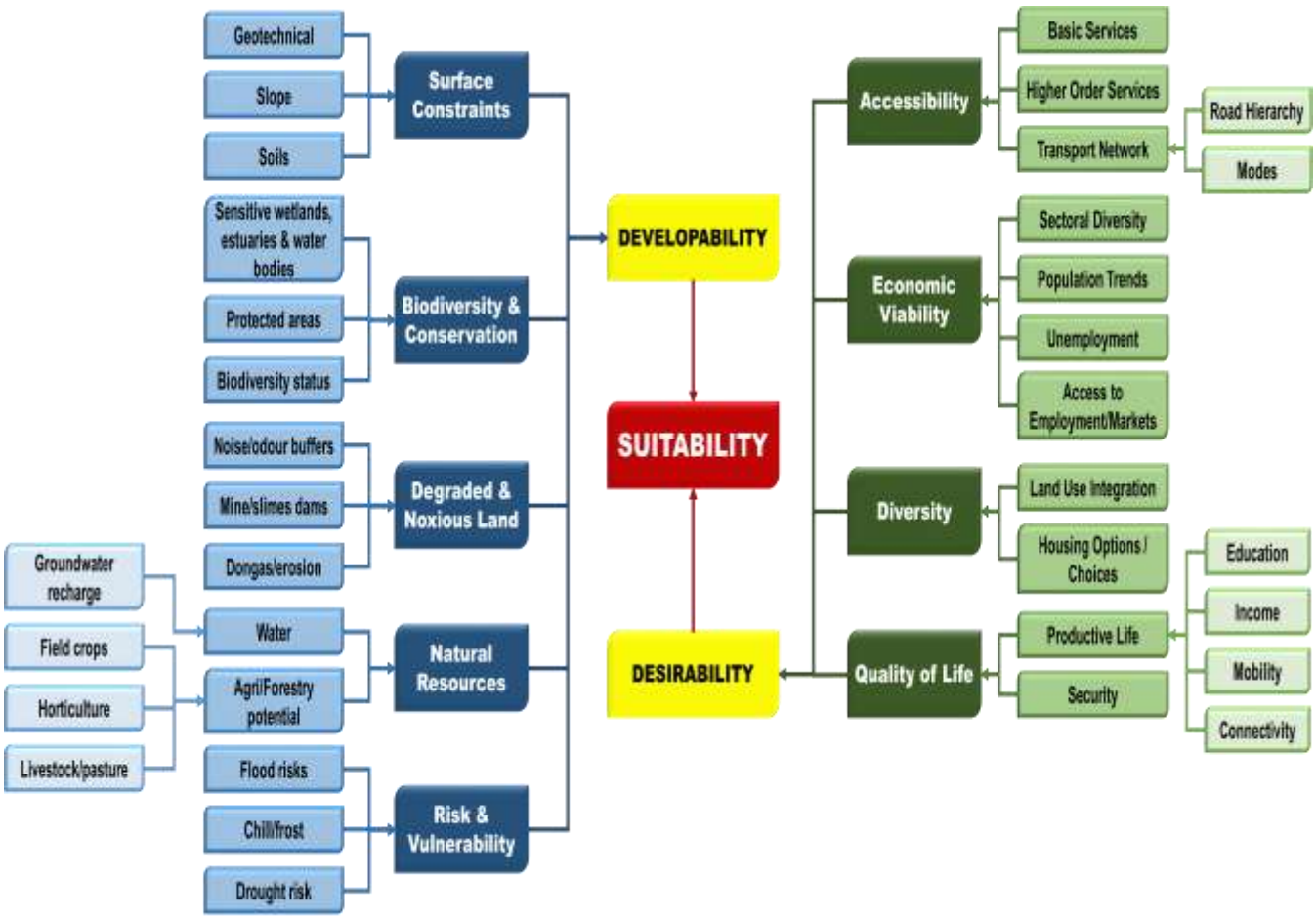


Figure 5: Integrated LUSAC Model

4.5 Interpreting the Results of the Model

As explained in the beginning of the document, the multi-criteria decision-making process is carried out on the basis of creating indices, with the final suitability result expressed as an index. The index can be from 1 to 10 or from 1 to 100. This normally depends on the amount of detail required to make a final decision. The following example is based on suitability assessment for densification in Gauteng. The index is from 1 to 10 with a score of 1 the lowest and a score of 10 the highest level of suitability.

Figure 6 below is a Gauteng example depicting a densification assessment.

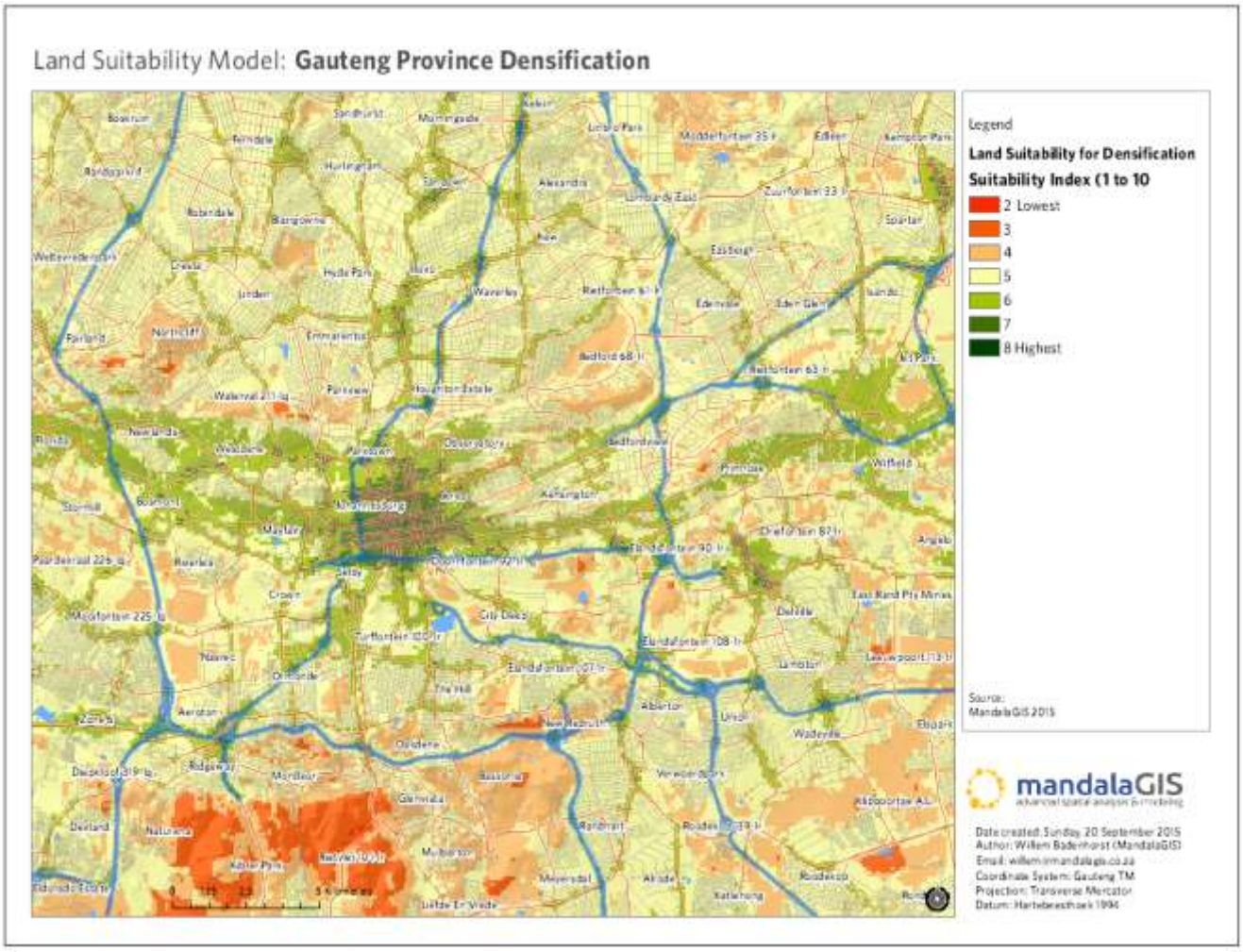


Figure 6: Example of Densification Assessment in Gauteng

Figure 7 below represents a typical result for a proposed development study area.

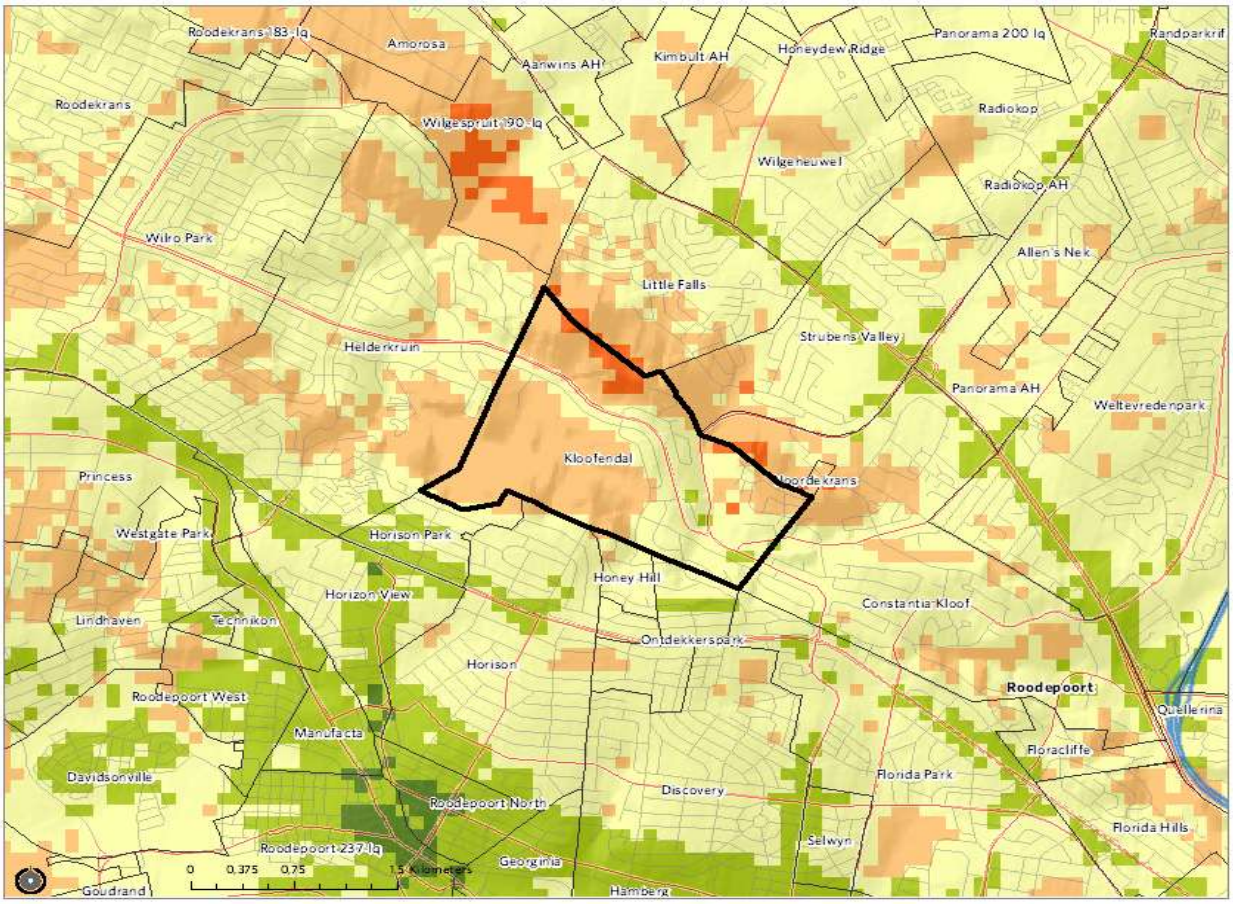


Figure 7: Typical assessment of proposed development

Land Suitability for Densification

Suitability Index (1 to 10)

- 2 Lowest
- 3
- 4
- 5
- 6
- 7
- 8 Highest

In the above example, the interpretation of the suitability result is that the study area, or proposed development, does not comply with the desired conditions for densification. The reason can then be found in one of the input criteria layers (e.g. a lack of public transport infrastructure).

4.6 Contextualising the Results

It is always be important to remember that the result of the suitability model is only a guideline and should be interpreted with the local context in consideration. A suitability model for use across the whole of South Africa, will not be able to take in consideration all the local nuances and characteristics that differ from place to place. However, the suitability model

should very clearly indicate any unsuitable areas that fall in the non-negotiable class (e.g. protected nature areas).

4.7 Software and Skills Challenges

The nature of multi-criteria decision modelling requires two very important sets of conditions. The first is availability and cost of appropriate GIS software packages, and the second, is the appropriate GIS skills and knowledge to interpret the input information.

5. Way Forward and Conclusions

The proposals presented are tailor-made for a simply constructed tool that is easy to use bearing in mind that the capacity for collection and analysis of complex data sets is a bottleneck for most municipalities in South Africa. It has been noted that LUSAC relies on multi-criteria decision modelling which requires two very important sets of conditions. The first is availability and cost of appropriate GIS software packages, and the second, is the appropriate GIS skills and knowledge to interpret the input and output information.

The issue of availability of appropriate GIS skills and knowledge across the country has been highlighted. Multi-criteria analysis as the basis for LUSAC relies on a very rich data environment. Although this is very advantageous, it also requires that the users of the tool should have a very good knowledge of the input information and how to interpret it. Local municipalities with lower skills level may have difficulty in interpreting the input information as well as the output results. This may imply that the "depth" levels of the models may need to be varied to suit the knowledge and capability levels of the users in different organizations.

To address the question of capacity, two scenarios of application have been provided. Municipalities or other entities with high levels of GIS skills may be able to use the full model with all its multiple layers. In the case of lesser knowledge and skills levels, the depth of the model may be offered on a lesser scale with some of the sub-models being pre-processed by sectoral experts. In this case, the organization will only use the First Level of the model to contextualize and make decisions.

References:

1. MENDOZA, G.A. (1997) ***A GIS-based Multi-criteria Approach to Land Use Suitability Assessment and Allocation,*** Proceedings of the 7th Symposium on Systems Analysis in Forest Resources, Traverse City, Michigan, USA, 28-31 May 1997.
2. Associating a combination of factors and their various impacts with respect to potential land-uses [Mendoza, 1997].
3. The actual process of designing an optimal mix of land-uses based on their estimated suitability and perceived management objective [Mendoza, 1997].