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Degree of site suitability measurement in a GIS: The effect of various standardization methods

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Abstract. Suitability analysis is performed to identify sites (usually grid cells or pixels) suitable for a specific purpose so that management decisions can be made in a site-specific manner. However, sites identified as suitable are rarely equally suitable in the real world. Measurement of the degree of site suitability (DoSS) is therefore crucial to be able to manage sites in a truly site-specific manner. Conventionally, site suitability analysis is performed using weighted linear combination (WLC) of standardized input factors within Geographic Information Systems (GIS). Input factors used in such analysis can be standardized in a number of different ways. The method of standardization used in the analysis could have varying effects on the DoSS measurement. However, it is yet to be assessed and quantified. Therefore, the objective of this study was to quantify the effect of various standardization methods on the DoSS measurement. In this study, the DoSS of agricultural field was measured for site-specific application of animal waste as fertilizer.

Seven input factors were used in the analysis. They were standardized using a) Boolean logic, b) discrete classification, and c) continuous rescaling methods. The Boolean logic method of standardization classified factor attributes as either ‘suitable (with class weight of 100)’ or ‘unsuitable (with a class weight of zero)’. The discrete classification method of standardization grouped attributes in up to five classes of approximately equal class size. These classes were weighted with equally-incremented class weights that added up to 100. The continuous rescaling method of standardization rescaled the range of attributes in a suitability value of 0 to 100. Standardized input factors were combined respectively using a WLC model to produce composite suitability maps. The DoSS of the composite maps were assessed using weighted average (WA), coefficient of variation (CV), and value range (VR) parameters.

Standardization using Boolean logic method was of no consequence since it did not produce different degrees of site suitability. All suitable grid cells were equally suitable (i.e. WA= 700, CV=0 and VR=0). The discrete classification method of standardization produced diverse suitability values with weighted average ranging between 221.9 (CV=6.3 & VR=100) and 700 (CV=0 & VR=0) depending on the number of classes. This has highlighted the measurement inconsistencies of this method of standardization. Further investigation is therefore essential to quantify the effect of discrete classification method of standardization on the DoSS measurement. The continuous rescaling method produced a DoSS map with a WA of 419.05 (CV=8.04 & VR=332). This method of standardization is more consistent in the DoSS measurement and hence potentially useful for future DoSS assessment. However, there is a need to further assess the effect of rescaling using different attribute endpoint values on the DoSS measurement.

Keywords: degree of site suitability, input factors, standardization, weighted linear combination model

1. Introduction

Site suitability analyses are performed frequently (e.g. (Dobson, 1979; Banai-Kashani, 1989; Hendrix and Buckley, 1992; Jain *et al.*, 1995; Basnet, 2002; Buitrago *et al.*, 2005; Al-Shalabi *et al.*, 2006) to identify sites suitable for specific purposes. In such analyses, several input factors are used to delineate suitable sites. Each input factor imposes constraints through its attributes. These constraints may have effect on both magnitude and degree (or level) of site suitability (Basnet *et al.*, 2001). Logically, input factors with greater proportion of unsuitable attributes would reduce the magnitude of suitable area whereas the input factor with higher proportion of less suitable area may only lower the degree of site suitability (Basnet and Apan, 2007). Since most input factors have attributes varying widely in their level of suitability, the outcome of different degree of site suitability (DoSS) is a real possibility.

The DoSS is a parameter of interest because suitable sites are not usually discrete (i.e., suitable or unsuitable) in nature. Instead, they express varying degrees of fuzziness or set membership (Jiang and Eastman, 2000). The DoSS measurement is therefore an approach of practical significance to make management decisions in a truly site-specific manner. However, this measurement has received very little attention in the past despite the fact that the site suitability scoring technique was first introduced in early seventies (Hopkins, 1977) and used for power plant selection in Maryland a few years later (Dobson, 1979). This is largely because the DoSS measurement is an outcome of a complex relationship between the number of input factors included in the analysis, the differential weighting of input factors, and the method of factor attributes standardisation adopted in the process (Basnet, 2002).

The spatial variation of attributes within each input factor is not uncommon because most dataset come with inherent natural variability. Standardization becomes necessary to make these datasets commensurable for a suitability analysis. Standardization is a data reduction process that simplifies the data structure (Burrough *et al.*, 1992). Input factors may be standardised using a Boolean logic, a discrete classification, or a continuous rescaling method. The Boolean logic method of standardization is typically used for crisp spatial mapping in which areas are designated as either belonging (i.e., true or suitable) or not belonging (i.e., false or unsuitable). This crisp spatial mapping method ignores the important aspects of fuzziness or inexactness by dividing the undividable continua (Eastman, 2000) to produce significantly different results for the same area (Burrough, 1996). Therefore, the Boolean outcome produced by this method of site suitability analysis limits the way we think about the real world (Burrough, 1996).

Many dataset used in a site suitability analyses are inherently categorical (e.g., land use) or recorded in a categorical format (e.g., soils). These datasets are conveniently standardised using discrete classification method. In this method of standardization, the factors are brought to a common numeric range by classifying their attributes into discrete classes (Banai-Kashani, 1989; Jain *et al.*, 1995). These classes are then weighted or scored (Banai-Kashani, 1989; Hendrix and Buckley, 1992; Siddiqui *et al.*, 1996) appropriately for site suitability analysis. Discrete classification can also be applied to standardize non-categorical data such as distance and elevation. Most modern GIS have in-built function to perform this task. The assumption that all changes between classes takes place at the class boundaries is the severe limitation of the application of discrete classification method on continuous data (Burrough, 1989).

Continuous data have attributes varying naturally and gradually from one location to another (e.g., slope and proximity). Such datasets are more conveniently standardised by rescaling their attributes in a continuous numeric scale of a fixed suitability range (Burrough *et al.*, 1992; Eastman, 1999). Continuous data may be rescaled in a suitability range of 0 to 255 (Eastman, 1999), 0 to one (Burrough, 1989), or 0 to 100 (Eastman, 2000) depending on user's choice. This method of standardisation is explained by the rapidly growing branch of mathematics concerned with inexact reasoning called 'fuzzy set theory' (Burrough, 1989). Fuzzy sets are classes without sharp boundaries (Eastman, 1999). Fuzziness refers to imprecision in characterizing classes that do not have sharply defined boundaries (Burrough, 1989).

Each of these three methods of standardization (i.e., Boolean logic, discrete classification, and continuous rescaling) is likely to produce different DoSS outcome because spatial constraints may be applied differently. In effect, it is possible that the DoSS measurement for a site may depend on the method of standardization adopted. However, there have not been very few attempts in the past to examine the effect of factor attribute standardization methods on the DoSS measurement. Therefore, the objective of this study was to assess and quantify the effect of these three factor attribute standardisation methods on the DoSS measurement. In this study, DoSS analysis is performed to identify suitable sites and to determine their degree of suitability for site-specific application of animal waste as fertiliser in the agricultural fields.

2. Research methods

2.1. Study area

The Westbrook creek sub-catchment located in the south-east Queensland, Australia (Figure 1) was selected as the study area. The sub-catchment covering 24903ha area is drained by the Westbrook Creek system. This is a relatively flat (i.e., 90% area < 10% slope) sub-catchment with some undulating hills. Most flat areas are covered with rich fertile self-mulching Vertosols and they are used for extensive (i.e., broad acre) farming.

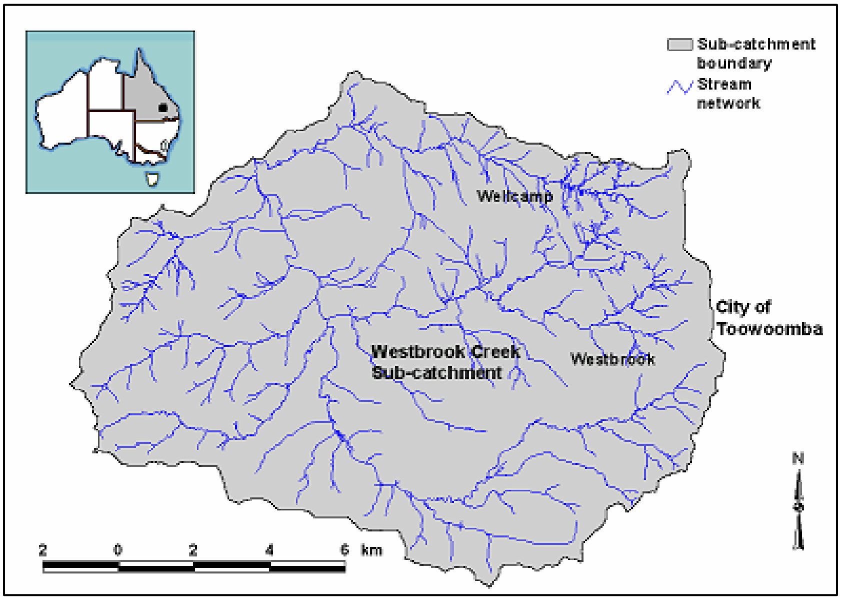

Figure 1: Westbrook creek sub-catchment, south-east Queensland, Australia

2.2. Datasets and pre-processing

Seven input factors (Table 1) that are likely to have effect on socio-economic, environmental, and/or agricultural suitability of a site for animal waste application, were selected based on literature adopted by Basnet (2002). The datasets were pre-processed within ArcInfo to create raster grids with 10m×10m cell resolutions.

Areas covering unsuitable attributes for animal waste applications (e.g., water bodies and residential areas) were assigned no-data value in each of the seven input factor. Literature based exclusionary criteria adopted by Basnet (2002) were employed to identify unsuitable attributes. The remaining attributes of each input factor were standardised using Boolean logic, discrete classification and continuous rescaling methods. The Boolean logic method of standardisation is based on binary (i.e., true/false) categorization. So, it divided factor attributes into one of the two possible sets (i.e., suitable or unsuitable). This method of standardisation left all suitable attributes in a single suitability category with a cell value of 100 (Table 1).

Table 1: Potentially suitable area within each input factor and the standardization using Boolean logic method

Input factors	**Unsuitable area (ha)**	**Unsuitable cell value**	**Suitable area (ha)**	**Number of suitable cells**	**Suitable cell value**
Catchment boundary	0	No data	24903	2490320	100
Land use	12967	No data	11936	1193696	100
Proximity to town	7516	No data	17387	1738729	100
Proximity to stream	7071	No data	17832	1783256	100
Soils	5895	No data	19008	1900857	100
Slopes	2453	No data	22450	2245068	100
Proximity to road	1787	No data	23116	2311662	100
Proximity to IAI	120	No data	24783	2478326	100

The discrete classification method of standardization involved replacing continuous (or disconnected) attributes with classes and weighting them appropriately (Burrough *et al.*, 1992). Various classification techniques (e.g., equal area, equal interval, and natural break) and numerous classification options in terms of class number, class size and class weight are available. In this study, factor attributes were classified in up to five classes of approximately equal size (Table 2a) using equal area method of classification for all but land use input factor which contained only one suitable attribute (i.e., crop/pasture) with no further details on crop or pasture type.

Table 2(a) Area in hectares under each class using equal area method of classification

Class number	**Land use**	**Proximity to**		**Soil**	**Slope**	**Proximity to**	
		Town	**Stream**			**Road**	**IAI***
	Single class						
1	10720	17387	17832	19008	22450	23116	24783
	Two classes						
1	10720	8695	8967	9502	11279	11559	12401
2	-	8692	8865	9506	11171	11557	12382
	Three classes						
1	10720	5800	5945	6389	7637	7741	8272
2	-	5796	5947	6150	7343	7675	8254
3	-	5791	5940	6469	7470	7700	8257

	Four classes						
1	10720	4373	4564	4650	5613	5919	6209
2	-	4322	4403	5331	5666	5640	6193
3	-	4353	4431	4728	5627	5785	6187
4	-	4339	4434	4299	5544	5772	6194
	Five classes						
1	10720	3500	3608	3432	4568	4644	4964
2	-	3459	3532	5331	4568	4640	4955
3	-	3482	3579	4728	4378	4613	4958
4	-	3475	3549	2775	4511	4596	4951
5	-	3471	3564	2742	4425	4623	4955

 # Suitability increasing with class number ** Intensive animal industries*

Standardized factor attribute classes were weighted using an arbitrarily selected equal increment of five (Table 3b) to distribute weights evenly (i.e., at equal interval) between classes. The highest weight was assigned to the most suitable class and the sum of the class weights was maintained to 100.

Table 2(b) Weight distribution between classes

	L/use	**Town**	**Stream**	**Soils**	**Slopes**	**Road**	**IAI**	**Weight distribution between classes**					**Sum of weight**	**Incre-ment**
								1	**2**	**3**	**4**	**5**		
No. of classes	1	1	1	1	1	1	1	100.0					100.0	-
	1	2	2	2	2	2	2	52.5	47.5				100.0	5.0
	1	3	3	3	3	3	3	38.3	33.3	28.3			100.0	5.0
	1	4	4	4	4	4	4	32.5	27.5	22.5	17.5		100.0	5.0
	1	5	5	5	5	5	5	30.0	25.0	20.0	15.0	10.0	100.0	5.0

Sum of class weight = 100.0 *Weight Increment: (38.3–33.3) = (33.3-28.3) = 5.0*

The continuous rescaling method of standardization may rescale attributes into a suitability range of, zero to one, zero to 100 or zero to 255. In this instance, a suitability range of zero to 100 was chosen to make it consistent with other methods of standardisation. Attributes of both continuous and non-continuous input factors (except land use factor) were rescaled to this range. The land use input factor contained a suitability value of 100 for all suitable cells. The endpoints of the datasets were used as the minimum and maximum values to linearly rescale continuous attributes. Input factors with discrete attributes (e.g., soils) were ranked in the order of least to most suitable prior to rescaling them. Ranking in the order of merit was considered appropriate because attributes of other continuous variables (e.g., proximities and slopes) are naturally arranged in this order.

2.3. Data processing

The standardized input factors were combined spatially using the weighted linear combination (WLC) model (Equation 1) within ArcInfo GRID. All seven input factors were weighted equally in this analysis. The weighted linear combination of input factors produced a composite suitability map through cell-wise summation of the suitability values of corresponding cells in each of the seven input factors. Consequently, the final value of a cell in the composite map represented suitability of that particular cell. Thus, a higher cell value on a composite map would mean higher degree of site suitability and a lower cell value would mean lower degree of site suitability for the application of animal waste as fertiliser. The variation of cell-values within a composite map would therefore mean various degree of site suitability.

$$S_i = \sum_{j=1}^{n} \left(f_{ji}.suit \times w_j \right) \qquad [Equation \quad 1]$$

Where,

S_i = combined output grid with suitability values at i_{th} cell locations

f_{ji}.suit = grid dot notation for factor attribute classes for j_{th} factor with class weights at i_{th} cell locations,

w_j = respective weight for factor f_j (all factors treated equally by assigning a weight of one)

While a cell value represented the level of suitability of an individual cell, the overall degree of site suitability of a composite map was determined by calculating the weighted average and the coefficient of variation of the entire suitable cells. Weighted average quantified the central tendencies of the cell values while the coefficient of variation and value range measured their dispersions. Higher weighted average implied overall increase in the suitability while the higher coefficient of variation and the wider data range indicated greater dispersion of the suitability values. Thus, the weighted average, the coefficient of variation, and the value range were used as indicators of the degree of site suitability. Separate weighted linear combination tests were performed to evaluate the effect of the three methods of factor attribute standardization. One test each was required for Boolean logic and continuous rescaling methods of standardization. However, five separate tests were necessary for discrete classification method of standardisation since input factors were standardised in up to five classes. The final results were presented in a map (geographic) and tabular formats.

3. Results and discussions

3.1. Boolean logic method of standardization

The weighted linear combination of input factors, standardised using Boolean logic method, produced a map that identified all suitable areas as equally suitable. The composite cell value of each of the suitable cell was 700. Consequently, the coefficient of variation and value range were zero (Table 3).

Table 3: Degree of site suitability measurement using Boolean logic method of standardisation

No. of input factor used	Weighted average	Standard deviation	Coefficient of variation (%)	Range of cell values
7	700.0	0.00	0.00	0

The usefulness of the Boolean logic method of standardisation for the degree of site suitability measurement was found to be limited. In real world, suitable areas vary widely in their level of suitability. So, we have the natural perception of spatial variability when we think of real world. However, the Boolean logic method of standardisation did not discriminate areas into different degree of suitability. Thus, it failed to provide true representation of the real world. This result agrees with the findings of earlier researchers including Burrough (1996) and Eastman (2000). The crisp spatial mapping, using Boolean method of standardisation, ignores the important aspects of fuzziness or inexactness by dividing the undividable continua to produce significantly different results (Eastman, 2000). Nevertheless, it is necessary to deal with concepts that are not necessarily ‘true or false’, but that operates somewhere in-between (Burrough, 1996).

The result from this analysis would have been different if unsuitable cells were assigned zero value instead of no data. In this instance, masking out of unsuitable cells from the input factor was necessary to ensure that the cells identified as ‘suitable’ were actually suitable in each of the seven input factors. However, there is a possibility of not masking out the unsuitable cells and hence creating an environment to reconsider suitability of other cells that are not identified as ‘suitable’ in all the input factors. In this way Boolean logic method of standardization could possibly be used to measure the degree of site suitability.

3.2. Discrete classification method of standardization

The weighted linear combination of input factors, standardized in up to five classes using discrete classification method of standardization, produced five separate composite maps. The suitability values of these maps were found to be different to each other. The weighted average of suitability value ranged between 221.9 and 700 depending on the number of factor attribute class used in the analysis (Table 4). The increase in class number has clearly decreased the weighted average while increasing the coefficient of variation and value range (Table 4).

Table 4: Degree of site suitability measurement using discrete classification method of standardization

No. of factors used	Attribute classes	Weighted average	Weighted standard deviation	Coefficient of variation (%)	Range of cell values
7	1	700.0	0.00	0.00	0
	2	399.5	5.31	1.33	30
	3	298.8	8.34	2.79	60
	4	250.3	11.43	4.57	80
	5	221.9	13.96	6.29	100

This result demonstrated considerable difficulty in determining degree of site suitability using discrete classification method of standardization. It has presented two serious limitations in terms of degree of site suitability measurement. Firstly, it offered unlimited choices in terms of the class number, the class size, and the weight distribution between classes (Basnet, 2002). Secondly, it assumes that all change between classes takes place at the class boundaries and little change of importance occurs within a class (Burrough, 1989). Both of these limitations have complex and substantial effect on the degree of site suitability measurement (Basnet and Apan, 2007).

For the purpose of this analysis the basic assumption of discrete classification (i.e., changes only occurs at the class boundaries and no change of importance occurs within a class) was retained and the boundary conditions (i.e., class number, class size and class weight) were set arbitrarily. So, the input factor attributes were classified in up to five classes of approximately equal class sizes using equal area method of classification. These classes were weighted to a sum of 100 using an arbitrarily assigned equal weight increment of five (5) to distribute weights evenly between classes. Therefore, the result presented in this analysis applies to the above mentioned boundary conditions only and it should not be generalised and/or extrapolated to make use in any other circumstances.

A clear trend has been emerged from this restricted analysis in the sense that the increase in the class number has caused decrease in the weighted average and an increase in the coefficient of variation and the value range. This outcome is largely due to greater fragmentation of suitability values (i.e., class weights) as the class number increased from one to five. Clearly smaller class weights would mean lower weighted average and higher dispersion as indicated by the increase in coefficient of variation and value range (Basnet and Apan, 2007). So, the outcome of this analysis is logical and obvious. At this stage, it is important to note that this result was obtained because the sum of all the class weights was kept constant (i.e., 100) for each of the input factor used in the analysis and the weight distribution was incremented by five. The outcome would have been different if these conditions were not met.

Fragmentation of class weight (or suitability values) may appear deceptive for the purpose of degree of site suitability measurement using this method of standardization. However, it should not be consider negative in all circumstances. In fact, fragmentation of class weight becomes necessary to recognise subtle differences in the level of suitability of individual classes. The practical significance of the result obtained from this analysis is that the increase in class number causes greater discrimination between suitability classes. Since the purpose of the degree of site suitability measurement is to discriminate between various suitable areas, a greater class number is desirable. However, the constraint is that there is no limit to the number of class to be used in an analysis and each option produces different outcome making comparison of results difficult. This obviously leads to the concept of many classes without sharply defined boundaries (i.e., fuzziness). This concept is being applied in the continuous rescaling method of standardisation.

3.3. Continuous rescaling method of standardization

The continuous rescaling method of standardization produced a suitability map with a wide range of suitability values. Due to wide variation in the suitability values the result required regrouping for presentation. Therefore, the suitability map presented in Figure 2 (below) is classified into low, medium and high suitability classes. The weighted average of the suitability values was found to be 419.05 with the coefficient of variation of 8.04% and a value range of 332 (Table 5).

Table 8 Degree of site suitability measurements using rescaling method of factor attribute standardisation

Number of input factors	Weighted average	Weighted standard deviation	Coefficient of variation (%)	Value range
7	419.05	33.69	8.04	332

Measurement of the degree of site suitability using continuous rescaling method of standardisation is somewhat simpler in the sense that it offers one-step process to rescale factor attribute into a suitability range of zero to 100. In this analysis, the application of this standardisation method resulted in a relatively higher weighted average (Table 5).

A relatively higher weighted average of 419.05, as compared to the previous measurement, was due to the fact that there was no requirement for the scales to be added up to 100 as it was the case with the discrete classification method of standardisation. A wider range of suitability value of 332 with higher coefficient of variation of 8.04% indicated that the continuous rescaling method of standardisation has a greater potential to discriminate suitable area into various degrees of suitability. This is largely because this method of standardisation better represents the spatial features that are gradual in the nature (Burrough, 1989). For instance, the proximity and distance input factors have attributes that vary gradually from one location to another. The continuous rescaling method of standardisation caters for such attributes by assigning numeric suitability values that ranges between zero and 100 to match to gradually changing attributes. Therefore, the use of rescaling method is appropriate to standardise continuous data for degree of site suitability measurement.

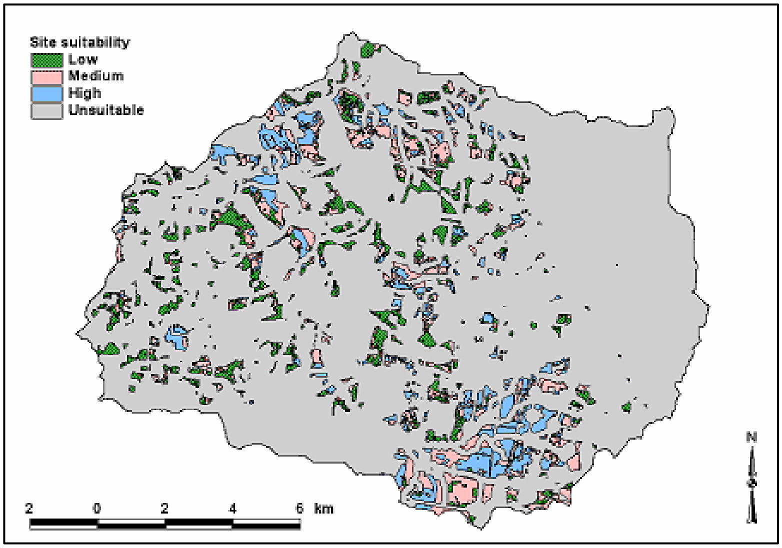

Figure 2: Degree of site suitability using rescaling method

However, not all the datasets are continuous in the nature. Rescaling of categorical data such as soils and land use is rather challenging. In this analysis, the attributes of such datasets were ranked in the order of least to most suitable, based on literature, prior to rescaling. The ranked attributes were then rescaled within a range of zero to 100. Fortunately, data capture technology is improving with time. It is expected that most non-categorical data will be captured in a continuous format in the future. Thus, the application of this method of standardisation for the degree of site suitability measurement has increasing future potential even though there are still some outstanding rescaling issues. Typically, attributes are rescaled linearly using maximum and minimum values of the datasets as endpoints. However, Eastman (1999) warned against the blind use of endpoint as minimum and maximum values without considering the inherent meaning of the values. There is no obligation to choose the endpoints as the maximum and the minimum values since rescaling can be done using membership functions (Burrough, 1998).

4. Conclusions

The objective of this study was to assess and quantify the effect of three factor attribute standardization (i.e., Boolean logic, discrete classification, and continuous rescaling) methods on the degree of site suitability measurements. In this study, systematic analyses were performed to conclude the followings.

The Boolean logic method of standardization is found to have limited use in terms of the degree of site suitability measurement since this method of standardization produces a composite map in which all suitable cells are equally suitable. So, it failed to discriminate suitable areas into different degree of suitability.

The discrete classification method of standardization is found to be complicated in terms of the degree of site suitability measurement. Results were found to be dependent on the classification option and it provided too many classification options in terms of class number, class size and weight distribution between classes. The measurements were not directly comparable to each other. Hence, this method of standardisation raised more questions than answers.

The continuous rescaling method of standardization is found to be easier to use for continuous datasets such as proximity and distance. However, the rescaling of categorized datasets remains challenging and requires further investigation. This study also identified that the selection of endpoints for the rescaling of attributes could be an issue requiring careful examination.

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