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Site suitability and the analytic hierarchy process: How GIS analysis can improve the competitive advantage of the Jamaican coffee industry

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ABSTRACT

This paper presents a site suitability model for growing coffee in the island of Jamaica and how it can be used to assist the development of the Jamaican coffee industry as it seeks to regain the presence it once had in the specialty coffee market. Home to the Jamaica Blue Mountain coffee – one of the world's most exotic and expensive coffees, the industry has struggled in face of increased competition in the specialty coffee market and increasing costs of production. This decline in competitive advantage has forced stakeholders to seek innovative means to remain viable. This suitability model integrated the perspectives of local coffee stakeholders using the analytic hierarchy process to determine the weights for the biophysical and infrastructure criteria used in the suitability analysis. The results indicated that the most suitable locations for growing coffee in the island were in the mountainous core of central and eastern Jamaica, especially in and around the Jamaica Blue Mountain coffee region and the hills of south-central Jamaica. The results also highlighted areas with limited coffee production potential across the island. This model lays the groundwork for potential applications of the model such as its use in policy making decisions and scenario planning as the industry contemplates the possible impacts of climate change on coffee growing regions across the island. This suitability model promises to be a stepping stone in the creation of novel applications of geospatial technology in agriculture within small islands.

Introduction

The specialty coffee market is big business, especially in coffee consuming countries. For example, in 2012 the retail value of the U.S. coffee market was estimated at $30–32 billion dollars, with specialty comprising approximately a 37% volume share but nearly 50% value share (Specialty Coffee Association of America 2012). The rise in prominence of geographic origin, emphasizing single-origin coffees has bode well for countries that can market themselves in that light (Daviron & Ponte, 2005; Pierrot, Giovannucci & Kasterine 2010; Wilson, Conley, Harris and Lafone 2012) and has been one of the most successful responses to the global decline in coffee prices (Bacon, 2005; International Coffee Organization 2013; Kilian, Jones, Pratt, & Villalobos, 2006; Roseberry, 1996). However, the volume of coffee moved through specialty, organic, and Fair Trade commodity chains remain relatively small and must be set within the context of changing global coffee markets (Bacon, 2005). Because of its success, the number of stakeholders in the specialty coffee sector has grown rapidly and is quite possibly the most profitable sector in the international coffee industry (Pierrot et al., 2010; Wilson et al. 2012). In order to thrive in this profitable yet volatile market, one needs to have some sort of competitive advantage (CA). The pioneer of this concept, Michael Porter stated that "competitive advantage is at the heart of a firm's competition in competitive markets" and that it "grows fundamentally out of the value a firm is able to create for its buyers (in the form of) prices lower than its competitors for equivalent benefits or the provision of unique benefits that more than offset by a premium price" (Porter, 1985).

The island of Jamaica is home to one of the world's most exotic and expensive coffees – the Jamaica Blue Mountain (JBM) coffee. Though recognized as being in the highest echelons of specialty coffees for decades, the rapid growth of the specialty coffee industry over the last 30 years and increasing costs of production, have eroded the CA of the JBM brand. Stakeholders have had to work hard to retain its traditional customer base and like many other producers around the world have sought ways to increase

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their efficiency (Bacon, 2005; Eakin, Bojorquez-Tapia, Diaz, Castellanos, & Hagger, 2011; Rueda & Lambin 2012). But even large stakeholders are relatively small in the global context and producers, especially smallholder coffee producers are the most vulnerable due to their lack of access to resources in both the financial and technical realms. Fortunately, progress in computing sciences, including remote sensing, Geographical Information Systems (GIS) and Multi Criteria Decision Analysis (MCDA) can assist in handling this complexity (Joerin, Thériault & Musy, 2001). Geospatial tools have helped solve wide-ranging issues such as assessing the impact of policy adoptions on land cover change (Chávez, Broadbent, & Zambrano, 2014; Schmitt-Harsh, 2013), population resettlement (Shibru, Suryabhagavan, Mekuria, & Hameed, 2014), agricultural policy and future greenhouse gas emissions (Förster et al. 2008), drivers of deforestation in agroecosystems (Tadesse, Zavaleta, Shennan, & FitzSimmons, 2014) and assessing potential expansion of many agricultural enterprises (Gallant, Euliss & Browning 2014; Nzeyimana, Hartemink & Geissen 2014).

This paper presents a site suitability model for coffee production in Jamaica. Based on an MCDA approach, this paper used the analytic hierarchical process (AHP) devised by Saaty (1990) to create a suitability model considering several biophysical (and one infrastructural) factors. With a nascent geospatial sector in Jamaica, this body of work sought to highlight how GIS-based MCDA can be used to enhance competitive advantage, not just in coffee but all agricultural enterprises where spatial location is crucial for success. Thus, the major objective of this paper was to identify the most suitable locations for growing coffee in Jamaica. The results indicated that the most suitable locations for growing coffee in the island were in the mountainous core of central and eastern Jamaica, especially in and around the Jamaica Blue Mountain coffee region and the hills of south-central Jamaica. This model also laid the groundwork for future applications of the model such as its use in policy making decisions and scenario planning within the coffee industry as stakeholders sought to regain the presence they once had in the ever competitive specialty coffee market.

Theory

According to Porter (1985) sustainable competitive advantage is based in either cost advantage (having lower costs compared to rivals) or differentiation (of a product, delivery system or some other factor). These in turn stem from industry structure. In exploring these characteristics, Porter developed the Five Forces Model as a means of determining industry profitability. One of these five forces is the bargaining power of suppliers (Magretta, 2012; Porter, 2008). Supplier power is based on several factors including the presence of substitute products, the intensity of competition among rivals and the role of production costs. Porter argues that technologically based assessments such as the MCDA approach has its place in CA as it can lead to superior performance by boosting an industry's profit potential.

Multicriteria decision analysis can be thought of as a process that combines and transforms spatial and aspatial data (input) into a resultant decision (output). In order to incorporate both data and value judgments, multicriteria decision making (MCDM) methods can be incorporated with GIS. The MCDM procedures (or decision rules) define a relationship between the input and output layers/maps. These procedures involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules (Malczewski, 2004). In a survey of the literature on GIS-MCDA approaches, Malczewski (2006) showed that the largest proportion of papers was concerned with land suitability analysis. Additionally, papers focused on agriculture were most concerned with resource allocation and site selection in addition to land suitability analysis.

A number of multicriteria decision rules have been implemented in the GIS environment. These tend to be either multiobjective approaches (using mathematical programming model-oriented methods) or multi-attribute approaches (data oriented). Multi-attribute techniques (such as those used in this research paper) are also referred to as the discrete methods because they assume that the number of alternatives (plans) is given explicitly (Malczewski, 2004). According to (Malczewski (2006, 717):

> The major advantage of incorporating MCDA techniques into GIS-based procedures is that the decision-makers can insert value judgments (their preferences with respect to evaluation criteria and/or alternatives) into GIS-based decision-making procedures, and receive feedback on their implications for policy evaluation. Such feedback can enhance the decision-maker's confidence in the results, consistent with general findings in the decision support system literature on the importance of feedback. MCDA provides mechanisms for revealing decision-makers' preferences, and for identifying and exploring compromise alternatives. It can help users understand the results of GIS-based decision-making procedures, including tradeoffs among policy objectives, and use those results in a systematic, defensible way to develop policy recommendations.

A major reason for the popularity of the weighted summation and related methods is that the approaches are very easy to implement within the GIS environment using map algebra operations and cartographic modeling. The methods are also easy-to-understand and intuitively appealing to decision-makers. Thus, the implementation of such MCDA approaches is well documented in the literature. Walke, Obi Reddy, Maji, and Thayalan (2011) used a multi-criteria overlay analysis to evaluate the suitability of cultivating cotton in the Nagpur district of Maharashtra, India. They used weighted overlay analysis to inventory various soil properties of their study site and calculate the overall suitability cumulative value. Combining analysis of landforms, characterization of physico–chemical properties of soils, geospatial database generation, and evaluation-based multicriteria overlay analysis techniques in GIS, they were able to delineate suitability classes for cotton. Bandyopadhyay, Jaiswal, Hegde, and Jayaraman (2009) focused on categorizing the potential of a watershed region in south-west India to support rain-fed agriculture. Using a weighted overlay analysis similar to that of Walke et al. (2011), they created their agricultural suitability map for the study site. With this in place they could make suggestions for an action plan for the study area incorporating soil and water conservation measures, ideal crops to cultivate and water management plans. Nzeyimana et al., 2014 also utilized weighted overlays in assessing potential coffee yields for suitable sites in Rwanda. In addition to creating a qualitative scale to define coffee productivity, they contrasted predicted yields with actual yields at various sample sites to validate their model.

A site suitability assessment is inherently a multi-criteria problem (Mendoza, 2000). That is, land suitability analysis is an evaluation/decision problem involving several factors. Therefore a robust assessment of the criteria is required in order to make accurate and informed decision making. To this end, this paper uses Thomas Saaty's AHP. Developed in 1980, it has been considered one of the most significant contributions to the sub-field of multicriteria decision making with the core function being the determining of weights for the criteria being used in the MCDM process through expert opinion and pairwise comparison. This approach was selected over an equal weighting approach in order to incorporate the experience and knowledge of those intimately involved in coffee cultivation in Jamaica and result in a more realistic output. According to Saaty (2008):

> To make a decision we need to know the problem, the need and purpose of the decision, the criteria of the decision, their sub-criteria, stakeholders and groups affected and the alternative actions to take. We then try to determine the best alternative, or in the case of resource allocation, we need priorities for the alternatives to allocate their appropriate share of the resources.

The AHP method has been used in two distinctive ways within the GIS environment. First, it can be employed to derive the weights associated with attribute map layers. Then, the weights can be combined with the attribute map layers in a way similar to the weighted additive combination methods. This approach is of particular importance for problems involving a large number of alternatives, when it is impossible to perform a pairwise comparison of the alternatives or when a simple 9 point relative rating scale is sufficient (Eastman, Toledano, Jin, & Kyem, 1993). Second, the AHP principle can be used to aggregate the priority for all level of the hierarchy structure including the level representing alternatives. In this case, a relatively small number of alternatives can be evaluated when taking the multi-attribute decision making aspect of MCDM (Jankowski, 1995). Authors such as Weerakoon (2002), Carr and Zwick (2005), and Feizizadeh and Blaschke (2013) highlight the power of combining AHP as part of GIS analyses in land use planning. Weerakoon (2002) used AHP to derive weights for his urban land evaluation in suburban Colombo, Sri Lanka; Carr and Zwick (2005) used the AHP in their efforts to identify future land use conflicts in North–Central Florida, USA; and Feizizadeh and Blaschke (2013) also performed a GIS-based MCDM land suitability analysis which incorporated the use of AHP to derive weights in their agricultural land suitability evaluation in Tabriz County, Iran.

The study area

The Jamaican coffee industry (JCI) produces an Arabica varietal cherished as a mild, smooth coffee with hints of chocolate (Espresso & Coffee Guide 2011) and has a longstanding reputation as being among the best coffee in the world (Hoy, 1938 describes this early recognition). Though the island has transitioned from an agriculture-based economy to one heavily dependent on the service industry (especially tourism), the niche market that Jamaican coffee commanded has made it a valuable segment of the local agricultural sector. Employing several thousand people, the industry remains one of the island's largest sources of agricultural foreign exchange – earning US$17.9 million (over J$1.5 billion) in 2012 according to the Bank of Jamaica (2014).

Coffee is typically grown in several regions across the island of Jamaica (Fig. 1). Located either in the JBM or non-Blue Mountain (NBM) region, most coffee farms are located above 300 m on soils rich in organic material. The famous JBM coffee is grown in the Blue Mountains located in eastern Jamaica. With a maximum height of 2256 m, the range covers over 750 km^2. JBM coffee is grown at elevations ranging from a low of 550 m up to 1600 m, with the best beans growing between 1100 and 1600 m. At these elevations, the higher quality *Coffea arabica* thrives; the berries mature more slowly, and produce a drink with more delicate flavors than those grown at lower elevations. According to production data obtained from the Coffee Industry Board of Jamaica (CIB), over 80% of Jamaica's coffee production has been derived from the JBM region for the past decade (214,525 60 lb. boxes from the JBM region vs. 42,115 60 lb. boxes in the NBM region in the 2012–2013 crop year). Although these mountains possess some of the most important conditions for coffee cultivation, the suitability analysis will assess the suitability of the entire island due to scope of the JCI.

Materials and methods

Broadly speaking, decision problems can be categorized into decisions under certainty and decisions under uncertainty. This is dependent on the amount of information (knowledge) about the decision situation that is available to the decision-maker/analyst. If the decision-maker has perfect knowledge of the decision environment, then the decision is made under conditions of certainty (deterministic decision-making). Many real-world decisions involve some aspects that are unknown or very difficult to predict. This type of decision-making is referred to as decisions under conditions of uncertainty. It should be recognized, however, that uncertainty may come from various sources. Many analysts deliberately choose to model spatial decisions as occurring under a condition of certainty because of insufficient data or because the uncertainty is so remote that it can be disregarded as a factor (Malczewski, 2006, 713). This paper also assumes decisions under certainty.

The primary objective of the paper can be restated as this: based on bio-physical and infrastructural factors, where are the most ideal locations to grow coffee in Jamaica? This paper uses both a nine point scale for data reclassification as well as a simplified scale of three sub-categories in the results and discussions section: 1.0–3.0 being unacceptable for coffee production, 3.01–6.0 being acceptable for coffee production, and 6.01–9.0 being ideal for coffee production.

According to the literature on coffee production, there are several factors that must be considered when one decides on a location to grow coffee. These include precipitation (rainfall), temperature, elevation, slope, access to infrastructure (such as roads, urban areas and farm co-operatives), underlying geology and soil type (Mickle, 2009; Nzeyimana et al., 2014; Wrigley, 1988). Consultation with personnel in the CIB reinforced the importance of temperature and elevation and also included relative humidity, solar insolation, average wind speed and cloud cover. Among these factors, several could be readily identified as feasible for inclusion in a suitability model while others such as relative humidity and percentage cloud cover were not considered due to the absence of available datasets The following criteria were obtained for the study area: soil type, geology type, elevation, slope, precipitation, temperature, major roads, major waterways (rivers), protected areas, forest reserves and water bodies. All the GIS data collected were managed and analyzed using ArcMap and ArcCatalog versions 10.0–10.2 in the ArcGIS for Desktop software suite.

Advocating the importance of relative judgments, Saaty (2008) outlines the AHP as having four steps:

1. Defining the problem to be addressed.
2. Creating a decision hierarchy.
3. Constructing a set of pairwise comparison matrices for the criteria related to the research problem.
4. Weighting the criteria under comparison using the priorities derived from the previous steps.

A fundamental scale from 1 to 9 is used in the AHP with 1 representing two activities or criteria of equal importance and 9 indicating the strongest order of difference between two criteria/activities under assessment. Although it can be modified in certain circumstances, this scale has been the default for most applications of AHP, including this research paper.

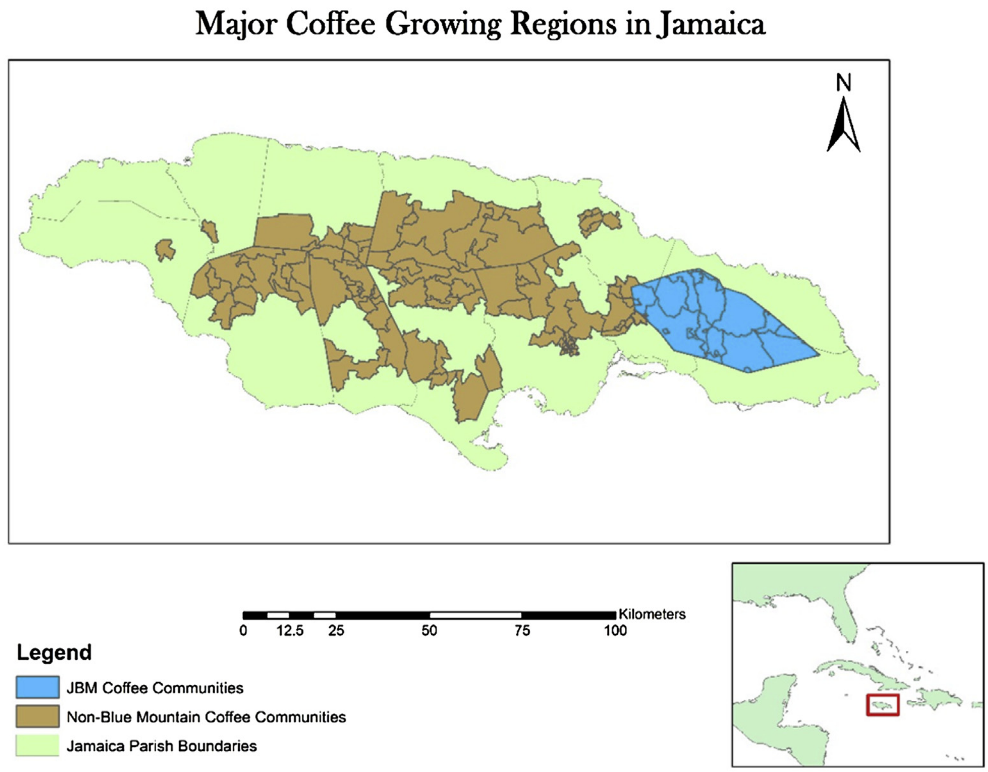

Fig. 1. Major coffee growing regions in Jamaica. The Jamaica Blue Mountain (JBM) coffee region is highlighted in blue and the Non-Blue Mountain (NBM) coffee regions are shown in brown. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Data collection and preparation

The data used in this suitability analysis was acquired from three sources. A 3 arc-second (90 m) resolution Digital Elevation Model (DEM) was downloaded for the region including Jamaica from the Unites States Geological Survey (USGS) Hydrosheds database (http://hydrosheds.cr.usgs.gov/). Mean temperature data was acquired from the WorldClim website (http://www.worldclim.org/current) as a 30 arc-second (1 km) resolution grid. Both datasets were clipped to the extent to the extent of the study area – Jamaica, using a country boundary shapefile obtained from the third source described below. Additionally, because the temperature data obtained divided the mean temperature by month, mean annual temperature was obtained by adding the 12 monthly mean temperature rasters and dividing by 12 using the Map Algebra Function in ArcToolbox. The remaining datasets used in the suitability analysis were obtained from the Mona GeoInformatics Institute (MGI) (http://www2.monagis.com/) located in Kingston, Jamaica. These datasets included country boundaries, soil type, geology, forest reserves and protected areas, waterways, roads and land use information. With this data in hand, a decision hierarchy could be constructed for AHP (Fig. 2). According to Saaty (2008), structuring the problem as a hierarchy enables clarification of outcomes by comparing the relative importance of the various criteria used in the decision making process.

Suitability data reclassification

With a decision hierarchy in place, each criterion in the suitability analysis was then reclassified based on their suitability for coffee production. It was decided that a scale of 1–9 would be used where 1 = lowest suitability and 9 = highest suitability (details shown in Table 1). According to Carr and Zwick (2005), nine suitability values are not only workable but ideal. More than nine values are difficult for humans to visually comprehend and fewer than nine values decrease the sensitivity of the (suitability) process.

Wrigley (1988) and Mickle (2009) state that the best soils for coffee are deep, well drained loamy soil, slightly acidic, rich in

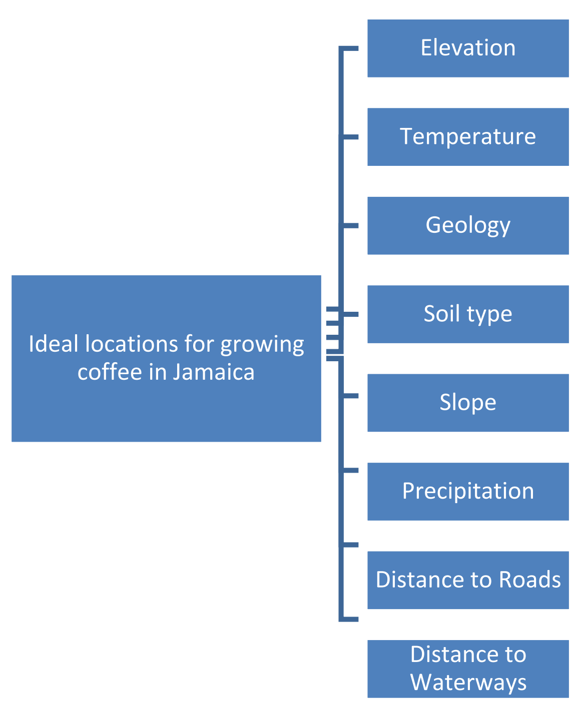

Fig. 2. Decision hierarchy for coffee suitability analysis.

Table 1
Suitability rankings according to Carr and Zwick (2005).

Rank	Meaning
1	Lowest suitability
2	Very low suitability
3	Low suitability
4	Moderately low suitability
5	Moderate suitability
6	Moderately high suitability
7	High suitability
8	Very high suitability
9	Highest suitability

humus and bases (especially potassium and phosphorous). Volcanic soils, latosols/podsols and lateritic clays/loams were also good soils. Saline or marshy soil, hard pan (in heavy loam soils), gravel and those near high water tables were the worst soils to grow coffee. Additionally soil pH should be between slightly acidic (5.5–6 or 7) and moderately to well drained.

The soils shapefile obtained from the MGI categorized 27 soil types in Jamaica based on several characteristics including mineralogy, erosion potential and texture. However, the texture field was used as it contained the most complete descriptions of the soil types. A list of the various soil textures and their reclassification rankings can be found in the online supplementary material. The geology shapefile classified 20 geology types by name. There was only one descriptive field, and this was used reclassify the geologies into the 9 suitability classes as shown in Fig. 3 and in the online supplementary material. Descriptions of geology types in coffee areas such Southeast Brazil (James, 1932) and Wrigley (1998) who states that volcanic materials are considered to be the best base for coffee plants and that the pH of soils should be between 5.5 and 6 (slightly acidic) lend support to the derived ranking. After reclassification, the soils and geology datasets were converted to raster format to be used in the final suitability analysis.

Unlike the soil and geology information with its discrete classes contained in polygons, the elevation, slope, precipitation and temperature datasets were represented as a continuous variable within rasters. This facilitated a more straightforward reclassification based on guidelines provided by the CIB, Wrigley (1988), Mickle (2009) and Nzeyimana et al. (2014). A detailed breakdown of the reclassification details for these datasets can be found in the online supplementary materials.

Arabica coffee thrives best in more temperate climates, where the annual average temperature is between 17 and 25 °C (Devi & Kumar, 2008; James, 1932; Wrigley, 1988). In tropical countries, these temperatures are obtained at higher elevations. The CIB uses three elevation classifications for high quality coffee based on their different production profiles – low (350–600 m), mid (600–900 m) and high (900–1500 m). Additionally, the government of Jamaica has designated altitudes over 1666.67 m (5500 feet) as forest reserves so no coffee cultivation should occur above these elevations. With these considerations in mind, the DEM was reclassified to covered nine suitability classes. Areas below sea level and above the forest reserve limit were given a suitability of 1, areas below 350 m were classified between 2 and 4 and areas between 350 and 1666.67 m were classified between 5 and 9 (see Fig. 4 for an illustration).

The slope tool in the ArcGIS ArcToolbox was used to calculate the slope for the island's landscape. This reclassification was challenging as what is considered ideal varies with each country. The most desirable slopes are extensive, flat surfaces at high elevations but these are not found in Jamaica. A middle ground of 3.1–5% slope was chosen as the most ideal slope – a compromise between the flat lands at low elevations and steep slopes at high elevations. It should be noted that the lowest suitability for this dataset was 3 instead of 1 due to the limited range of slope values to classify into meaningful groups.

Coffee should receive between 1500 and 2500 mm of rainfall with 2000–2500 mm being the ideal rainfall regime (Devi & Kumar, 2008; Wrigley, 1988). The distribution of this precipitation is also important – it is needed most in the first few months of the coffee year and least during the harvest. The precipitation dataset was reclassified into the nine suitabilities in 500 mm increments with the lowest rankings given to areas with excessive rainfall and too little rainfall. The highest suitabilities were given to areas receiving between 1500 and 3000 mm of rainfall with lower suitability values assigned to areas with more and less precipitation. As noted above, the ideal temperature range for coffee is between 17 and 25 °C. Jamaica's temperature range of 14.97–26.7 °C was divided into 1 °C increments with the highest suitability going to the 18–21 °C range and decreases as temperatures get warmer or cooler from this range.

Finally in the absence of standardized guidelines for infrastructure suitability with regards to suitability, the distance from the major roads and major waterways was reclassified using distances derived from zonal statistics. In order to assign a suitability rank to road distances the Euclidean Distance tool was run to obtain distances of major towns away from the major roads dataset (obtained from the MGI). The mean road distance away from these towns as well as the standard deviation were then calculated using the Zonal Statistics as Table tool. After this was obtained, the Reclassify tool was used to assign a suitability of 9 to all areas that were within the mean distance value while the remaining suitabilities were assigned using ½ standard deviation increments in order to cover the complete range of distances in the desired number of categories. This process was repeated on the major rivers dataset, with the main difference being that the suitabilities from 8 to 1 were assigned at ¾ standard deviation increments. See the online supplementary information for complete details of each reclassification.

Pairwise comparison matrix and criterion weighting

After the datasets were reclassified, the next step in the AHP was to create a pairwise comparison matrix which allowed each criterion to be compared against the others. Following the recommendation of Saaty (2008), a nine point scale was used where 1 denotes equal importance of the compared criteria and a 9 indicates extreme importance of one criterion over another. A matrix of pairwise comparisons was created (see online supplementary material) and sent to various coffee stakeholders in the JCI. By the end of the data collection period, responses were obtained from four persons – two from the CIB and two from private coffee companies. These responses were used in the construction of the weights (see online supplementary material). Following the methods outlined in Saaty (1990, 2008), the values from the matrix of each respondent were entered in the comparison matrix and a set of weights were determined. The consistency ratio (CR) was calculated to be 0.051 – well below the 0.1 (or 10%) threshold level of inconsistency. The calculated weights could therefore be safely accepted. Table 2 details the final weights calculated for each of the criteria of interest.

Putting it all together – the weighted suitability model

While most of the island has some form of suitability with respect to each of the criteria being considered, some areas needed to be excluded from the final analysis – built up urban areas, water

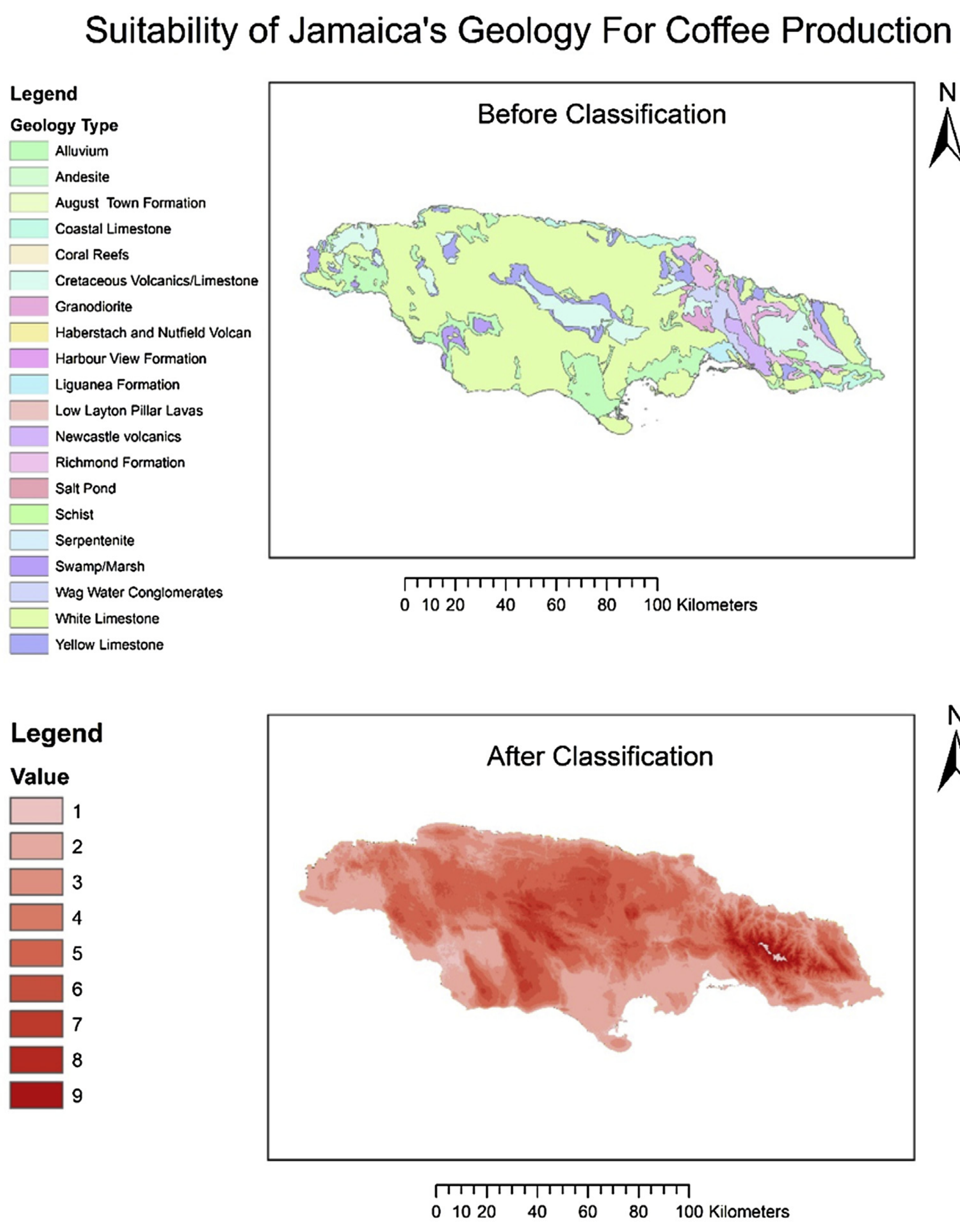

Fig. 3. Jamaica geology dataset before and after reclassification. Darker red areas indicate greater suitability for coffee production. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

bodies and protected lands. In order to account for these areas an exclusion mask was created to unite these areas.

The layers used to build the exclusion mask were a land use layer for Jamaica for 1998[1], a protected areas layer which listed the various protected areas across the island and a forest reserves layer that identified the various forest reserves across the island – all datasets were acquired from the MGI. These data layers were combined using the Merge tool and converted to raster format. This new layer was modified using the IsNull tool to give all areas falling in the exclusion mask a value of "No Data" while retaining the remaining areas (assigned a value of 1).

Each weight shown in Table 2 was assigned to its respective criterion and the layers were then combined together using the Weighted Sum tool to obtain a suitability layer for the entire island. This output was then combined with the exclusion mask using the Times tool to obtain the final suitability layer to give the final suitability layer. The model used to achieve this can be seen in Fig. 5 while the final suitability layer can be seen in Fig. 6.

Results and discussion

Wrigley (1988) and Mickle (2009) identified many of the above characteristics as being important considerations for coffee production. Table 2 showed that temperature, precipitation and soil type would have the most significant influence on suitable locations for coffee in Jamaica. It was a surprise to see the relatively low emphasis placed on elevation by the coffee experts since many literature sources (such as Devi & Kumar, 2008; Wrigley, 1988) often list it as a primary consideration. Upon further investigation

[1] Although old, it was the most up-to-date dataset available.

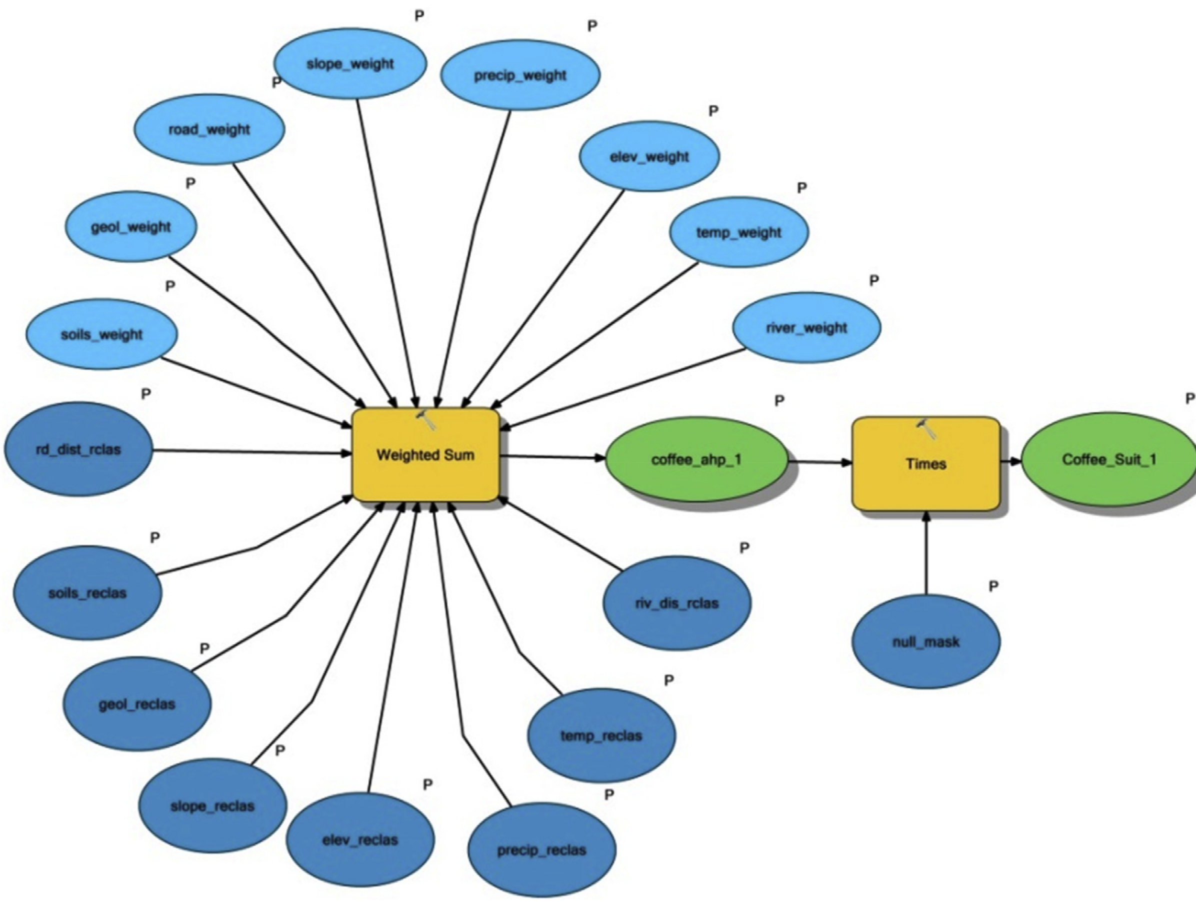

Fig. 4. AHP Suitability Model – the weights shown in Table 2 were assigned to each of the reclassified criteria layers. The output layer was combined with the exclusion mask to obtain the final suitability layer.

of the reclassified datasets, it was observed that the most ideal soils and temperature ranges tended to be located at higher elevations, which may explain the order of the criterion weights.

An example of the data reclassification is shown in Fig. 3. According to many geologists, most of the Caribbean islands started out as the upper portions of under-sea mountain chains. In Jamaica, the oldest portions of the island are located in the Blue Mountains and is composed of volcanic rock while the rest of the island is composed mainly of older yellow and newer white limestone sediments. Consequently the most ideal geology types seen in Fig. 3 reflect the island's origin.

The output in Fig. 5 highlights that the most suitable areas for growing coffee were to be found in the mountainous core of central and eastern Jamaica. This conformed to the pattern of the suitability of several of the input criteria. It was also observed that the least suitable areas were to be found on the southern and north-western coastal plains of the island. Most of the large plains across the island were also shown to have low suitability scores. The two most extensive areas of high suitability regions were in and around the JBM coffee region and the hills of south-central Jamaica. The average suitability for the island was calculated to be 5.07 (acceptable for coffee production as shown in Fig. 6), with a minimum of 1.92 and a maximum value of 8.78. The JBM coffee area had higher suitability values: a mean of 6.18 (ideal for coffee production), minimum of 3.09 and a maximum suitability value of 8.78. These higher values provide empirical support for the continued focus of coffee production in the JBM region.

Table 2
Final weight calculation for suitability layers. The weights were obtained using the AHP pairwise comparison matrix.

Suitability criterion	Final weight
Temperature	0.224
Precipitation	0.176
Soil type	0.155
Geology	0.142
Distance to road	0.093
Distance to waterways	0.079
Elevation	0.066
Slope	0.065

The creation of this suitability model allows us to ask the question – how can this model be applied as the JCI seeks to remain competitive in the global specialty market? A major application would be providing stakeholders within the JCI with objective-GIS based reference for making decisions related to coffee production. Much of the spatial decision making in the CIB involved working with more generalized maps of advisory areas. While this is adequate for the general management of coffee areas, more detailed information is needed when making more specific decisions. Examples include resolving land use conflict, management of the current farmer population, and developing a policy to encourage coffee infrastructure development.

The evaluation of a detailed map as shown in Figs. 5 and 6 enables farmers, processors, dealers and regulators to make more informed decisions about the potential of an area with relation to coffee. Prospective farmers can look at a certain region and

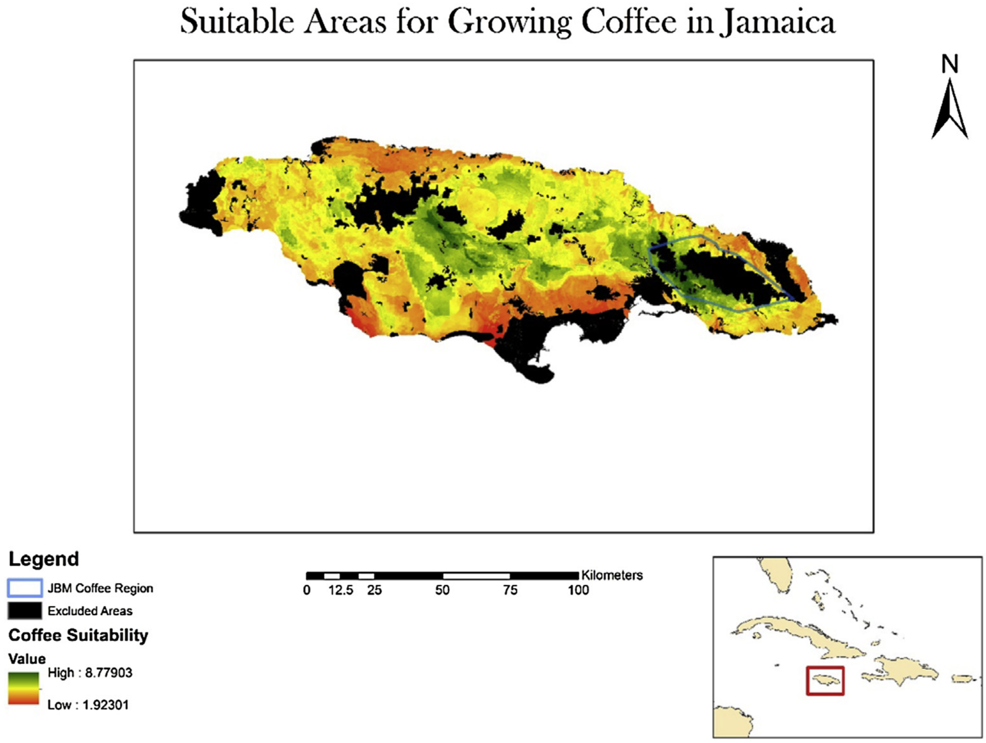

Fig. 5. Final coffee suitability layer. Greener areas are more suitable for coffee production while redder areas are least suitable for coffee production. Excluded areas are shown in black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

determine its potential for coffee and how much investment may be required to ensure profitability. Regulators can use this information in addition to their considerable knowledge of the local and global market to guide various aspects of policy development such as where to provide incentives for production. The development of this model also facilitates scenario planning (e.g. the assessment of the possible impacts of climate change on precipitation and temperature patterns and how those changes may affect coffee growing

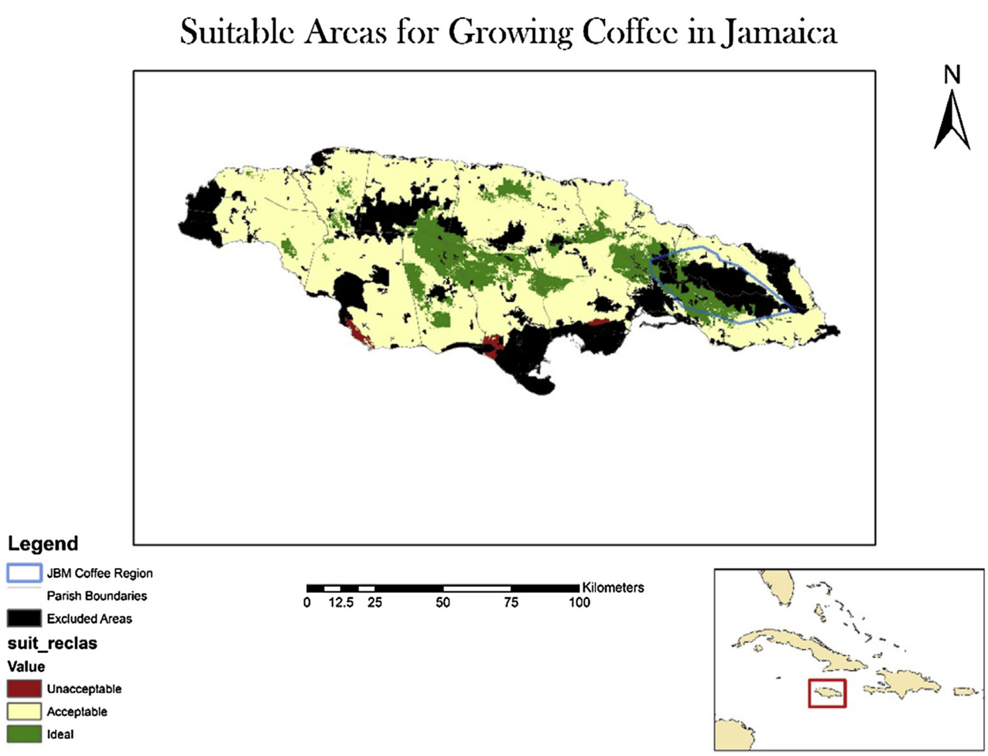

Fig. 6. Reclassified coffee suitability map. Green areas are ideal for coffee production, yellow areas are acceptable and red areas are unacceptable for coffee production. Excluded areas are shown in black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

regions in the island). Devi and Kumar (2008) note that sustainable land management has to address the environmental and ecological concerns of society while ensuring the production of sufficient food and fiber to maintain basic quality of life. In this regard, this model can also serve as part of the toolset to generate and update the natural resources information in spatial format at frequent intervals, thus enabling proper monitoring of natural resources (including and beyond coffee).

The CA of the JCI had always focused on product differentiation. Since the most recent shifts in the global coffee market have seen the bargaining power of suppliers weaken in a number of areas, utilizing this suitability model provide stakeholders with the opportunity to reduce (or at least stabilize) rising production costs relative to its competitors in the specialty coffee market – the other arm of CA. By focusing on the most suitable lands for current management and future development, stakeholder could potentially make smarter, more efficient business decisions – starting at the foundations of production, i.e. land suitability assessment. In addition, this suitability model may serve as a stepping stone in pioneering novel applications of geospatial technology, not just to coffee but to other agricultural enterprise in Jamaica and in other small islands.

Conclusions

Bojórquez-Tapia, Diaz-Mondragón and Ezcurra (2001, 148) notes that information generated at a regional scale is of limited use for decision making at the local level and that more complex models are needed to sanction projects at that level. Nevertheless, the worth of a land suitability assessment as a strategic planning tool at the regional level must be evaluated in light of the accuracy of the model and its potential utility for the stakeholders in the JCI. In this regard, this suitability analysis provides a valuable first step in integrating geospatial technologies in policy decision making. Future iterations of this model seek to incorporate a wider range of more recent and detailed datasets and include more socio-economic and infrastructural criteria as the data becomes available.

As stakeholders develop a more objective and targeted plan for competing in the global specialty coffee market, this model lays the groundwork for future applications of the model and highlight how GIS-based MCDA could be used to enhance competitive advantage, not just in coffee but all agricultural enterprises where spatial location is crucial for success.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2015.01.010.

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