**UNIVERSITY OF NAIROBI**

**DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY**

**SCHOOL OF ENGINEERING**

# USE OF GEOGRAPHIC INFORMATION SYSTEM (G.I.S) TO IDENTIFY AGRO-CLIMATIC AND EDAPHIC CONDITIONS FOR COFFEE GROWTH, CASE STUDY: REPUBLIC OF RWANDA

**By**

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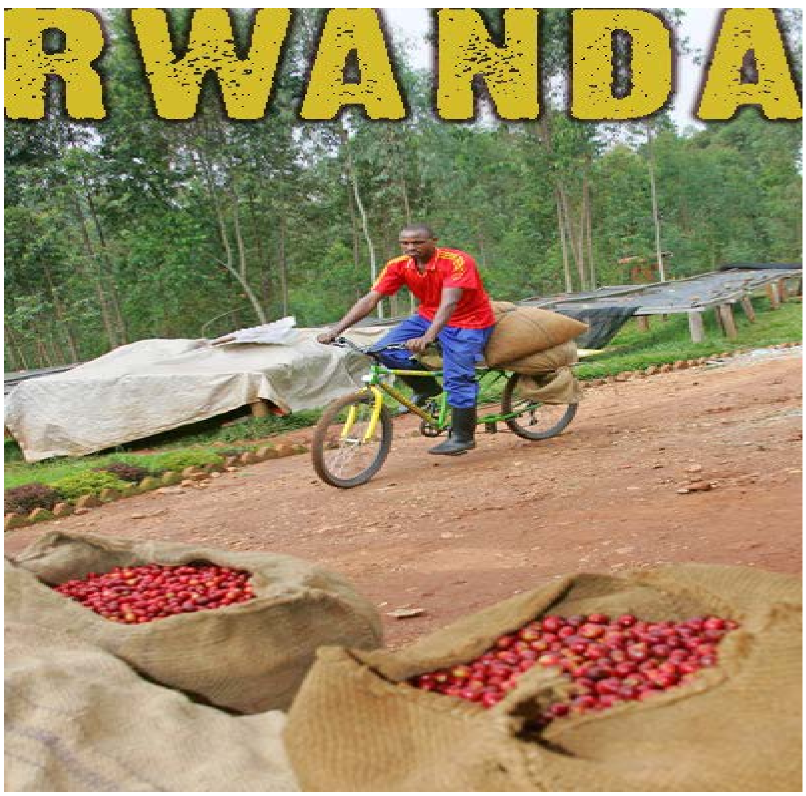
F56/79947/2012

A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF THE MASTER OF SCIENCE IN GEOGRAPHIC INFORMATION SYSTEMS, IN THE UNIVERSITY OF NAIROBI

**May, 2014**


RWANDA

# Declaration

I, Claude MIGAMBI, hereby declare that this research project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

Signature………………………………… Date.....…………………

Claude MIGAMBI

This project has been submitted for examination with my approval as university supervisor.

Signature..…………………………… Date .........……………

Mr. Peter WAKOLI

# DEDICATION

I dedicate this work to the LORD GOD almighty, my creator and giver of life.
Great is your powerful name. He covers me with his feathers and he shelters me with his wings.
His faithful promises are my armor and protection.
I dedicate it again to my family especially my wife and my two children, Michael and Shammy.

## Acknowledgements

First and foremost, i wish to thank the Almighty GOD for his love, abundant Grace and provision that enable me to study without any interruptions. I thank him for giving me the strength, Grace, Wisdom and knowledge to successfully complete my study.

My sincere gratitude goes to my supervisor Mr. Peter Wakoli for his professional guidance, valuable advice and contributions that lead me to the successful pursuit of this project. I am so much grateful for his reliability that enables me to consult with him severally to enhance the quality of this research project.

I would also record sincere gratitude to Dr-Ing.D.N.Siriba for his various contributions in one way or another to this work.

My greatest appreciation goes to my family especially my wife for the unconditional support and responsibility she has taken during my absence period.

Finally, i would like to thank my country for the technical support i got through the NUR-GIS and Remote sensing Centre.

# Abstract

The significance of geospatial technology to this project lies in the fact that agriculture is of spatial nature. Agriculture and natural resources are essentially understood by a geographic location. Spatial technology is an important lever in responding to changing market forces.

GIS is playing an increasing role in agriculture production throughout the world by helping farmers expand production, reduce costs, and manage their land more efficiently and effectively. Inconsistent practices such as coffee extension without matching the environmental conditions; and the issue of land space referring to the population size contradict the maximization of land use in Rwanda. The capability of GIS to visualize agricultural environments and workflows has proved to be very beneficial to the formulation of accurate strategies. The powerful analytical capabilities of the technology have been used to examine farm conditions, measure and monitor the impacts of environmental factors including the suitability of growing.

A thorough understanding of the potential and shortcomings about coffee growth in Rwanda has a positive significance for farmers especially those who are more interested in coffee crop investment, to clearly identify the better direction and actions.

In order to find out suitable conditions of coffee growing areas in Rwanda, my research was limited to the four most important agro-climatic and edaphic variables namely temperature, rainfall, elevation and soil ph distributed in the whole Country.

Therefore, the coffee growing areas in the republic of Rwanda was assessed through literature review, geospatial dataset such as administrative boundaries, environmental data, topographic and hydrologic data; then Strength, Weaknesses, Opportunities and Treats (SWOT) and Multi criteria decision (MCD) Analysis has been developed.

The results of the project have identified the favourate environment of Arabica Coffee in some areas of Rwanda; and therefore the policy should be established to encourage the right way of coffee plantation settlement and avoid the wrong practices cited above.

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## List of Acronyms

**NISR:** National Institute of Statistics Rwanda

**NAEB:** National Agriculture Export Board.

**RAB:** Rwanda Agriculture Board.

**ISAR**: Institut des sciences agronomiques du Rwanda (Rwanda Agricultural Research Institute)

**NUR:** National University of Rwanda.

**MINAGRI:** Ministère de l'agriculture t de l'élevage

**MINALOC**: Ministère de l'administration locale et du développement communautaire

**MINIREMA:** Ministry of Natural Resources

**GIS:** Geographic Information System.

**MCE:** Multi-Criteria Environment

**MCDM:** Multi-Criteria Decision Making

**SMCDM:** Spatial Multi-criteria Decision Making

**LUTs:** Land Use Types

**IPM:** Integrated Pest Management

**I.J.E.S.D**: International Journal of Environmental Science and Development

# Chapter 1: INTRODUCTION

## 1.1. Background

Coffee and tea constitute by far the principal export crops of the country, representing 71% of the total value of Rwanda exports. The share of the other crops (pyrethrum, quinquina, cut flowers and fresh fruits) remains marginal.

Coffee plays a major role in the economy of the country, contributing significantly to foreign exchange earnings and to the monetization of the rural economy.

Coffee-trees were first planted by German missionaries in the south western part of the country, in Mibirizi, the present district of Cyangugu, at the beginning of the $20^{th}$ century.

Thereafter, the colonial authorities pushed the crop in many parts of the country, and made it compulsory in1927.

After independence in 1962, the coffee crop extension remained a motivation for as long as 50 years. The Ministry of Agriculture established a parastatal agency, OCIR-Café, with monopolistic powers to organize the smallholder planters, purchase their crops in the form of café cherries, contract with private factories the processing of the cherries into green coffee and sell the final product on the international market. The most popular variety of coffee in Rwanda is Arabica which occupy more than 98% and Robusta with less than 2% in the whole country.

## 1.2. Problem Statement

It has been observed that most of the agricultural practices in many countries are settled randomly without considering the appropriate environmental conditions of crop growth. The fact that coffee plays a major role in the economy of the country and contributes significantly to foreign exchange earnings and to the monetization of the rural economy has motivated the coffee crop extension as long as 50 years after independence in 1962. The wide extension of coffee trees all over the country took in account the economic value rather than the suitability of growing. Therefore, coffee has been cultivated even in some regions which do not match the suitable growth conditions for that particular plant.

## 1.3. Objectives

### 1.3.1. General Objective

The overarching objective of this study is to identify the suitable areas for growing coffee in Rwanda.

### 1.3.2. Specific Objectives.

More specifically, this study aims to:

- Define key environment factors and criteria that affect directly the conditions for coffee growth,
- Collect data for quantifying the significance of each factor in various spatial locations,
- Find out the potential zones for coffee production through multi-criteria analysis,
- Carry out a comparative analysis of the spatial distribution of the current coffee production areas versus the identified high potential areas.
- Make appropriate conclusions and recommendations.

## 1.4. Justification for the Study

Actually, the extension of coffee plantation in Rwanda doesn't consider the criteria of environmental conditions (coffee census final report, 2009). The outputs of the result will expose the ideal from the existing practices. The study will allow farmers or any other people interesting on that business, to identify the appropriate zones of growing coffee in the country. This will also justify the reason of success on coffee quality production particularly for some locations in the country comparatively to others.

## 1.5. Scope of Work

The Study was focusing on Arabica variety and applied all over the country; other varieties like Robusta are not practically cultivated in Rwanda. But referring to the time and financial constraint, the research has considered only the primary environmental factors that affect directly the coffee growth such as Temperature, Rainfall, Elevation and Soil PH variables. Secondary factors such as Land slope in % and its direction, wind speed, relative humidity, natural enemies and appropriate I.P.M or control preventive, Soil nutrient (essential mineral elements) and fertilizer management shall be envisaged on the next study as well as the facilities are available.

# Chapter 2: LITERATURE REVIEW

## 2.1. Study Area Description

At 2000 kilometers to the Atlantic Ocean and 1200 kilometers to the Indian Ocean, Rwanda has a total surface of 26,338 square kilometers which includes both land and water bodies. The entire country is at a high altitude: the lowest point is the Rusizi River at 950 meters above sea level. Rwanda is also situated in Central/Eastern Africa, and is bordered by the Democratic Republic of Congo to the west, Uganda to the north, Tanzania to the east, Burundi to the south and is landlocked area. Rwanda is located between $2^{0}$45'degree latitude south of the Equator and 29 degree longitude east. The capital, Kigali situated within $1^{0}$ 57'S and $30^{0}$ 04'E latitude and longitude respectively with daily temperature range between $12^{0}$C ($54^{0}$F) and $27^{0}$ C ($81^{0}$ F), covering three districts Nyarugenge, Kicukiro and Gasabo. They are located near the centre of Rwanda. The land nature is characterized by its high elevation which has also led to the prevalence of a temperate type of climate. The average daily temperature near Lake Kivu, at an altitude of 4,800 feet (1,463 m) is 73 °F (22 °C). During the two rainy seasons spanning from February–May and September–December, a heavy downpours occur almost daily, alternating with sunny weather. Annual rainfall averages 800 mm (31.5 in) but is generally heavier in the western and northwestern mountains than in the eastern savannas. The use of land in Rwanda is largely for arable land. Rwanda borders Burundi for 290 km, the Democratic Republic of the Congo for 217 km, Tanzania for 217 km, and Uganda for 169 km. (MINALOC, 2007)

**Figure 2.1. Rwanda district map 2006**

### 2.2. Overview of the Agricultural sector and coffee production in Rwanda

Rwanda is a small, densely populated, landlocked country in Central-Eastern Africa. The country has 26, 338 sq. km of total area, of which 24, 950 sq. km (94.7 percent) is made up of land; of this, only 8, 600 sq. km (32.7 percent) are suitable for agriculture. The population is estimated at 8.4 million with an annual growth of 2.4 percent; its density is of 311 inhabitants per sq. km. When taking into account the arable area only, this density increases to 955 inhabitants per sq. km making Rwanda one of the most densely populated countries in Africa (Rwanda Development Gateway, 2005; The CIA World Fact book, 2006).

#### 2.2.1. Overview of the agricultural sector

Agriculture is practiced on all land types, including land of marginal quality and steep slopes. Agricultural systems in Rwanda are characterized by small family farms with an average size of 0.76 hectare which integrate polyculture and animal production systems. They are highly labour intensive since the cultivation techniques are purely manual. However, the household’s arable land is becoming smaller due to the high population density combined with soil erosion. About 97 percent Rwandan agriculture depends on rainfall. According to FAO (2005), only 8.9 percent of the arable area is irrigated. The suitability of most land in Rwanda for irrigation, given her terrain, is a major constraint, but there could be some good pockets where irrigation could be practiced. Majority of the total food production (66 percent) is for family consumption, but surpluses are marketed. However, not all households are able to sell their agricultural produce (only 60.3 percent can do so).

#### 2.2.2. Coffee production in Rwanda

Coffee is one of the important traditional cash crops in the Rwandan economy. Coffee has been grown in Rwanda (Mibirizi) since its introduction by German Missionaries in 1904. The crop was mainly kept by the colonial administration to respond to the need for coffee that they cherished but also to support the economy of the country. Coffee growing was then made compulsory in 1927 by the colonial authority and the number of coffee producers grew progressively and consequently, the number of coffee trees and the plantation area considerably increased.

After independence in 1962, the coffee crop extension remained a motivation for as long as 50 years. The National Coffee Board (OCIR) was created in 1945, with monopolistic powers to organize the smallholder planters, purchase their crops in the form of café cherries, contract with private factories the processing of the cherries into green coffee and sell the final product on the international market. In 1998, coffee production occupied around 6.3 percent of the total cultivated land (OCIR, 1998). Meanwhile as production increased, private operators started setting up coffee processing factories.

Rwanda produces Arabica coffee at 98 % and Robusta at 2%. In general, the coffee tree grows well and gives a sufficient production in regions with altitude between 1400 and 1900 meters, rainfall between 1100 and 1600 mm, temperature between 15 º C and 21º C and soils with acidity levels (pH) between 4.5 and 6, which are fertile, fragile and quite permeable (MINAGRI, 2004). Even though coffee is interspersed in all parts of the country, regions of suitability to its cultivation were identified relative to the quality of coffee production (OCIR 1998). For instance the shores of Lake Kivu in the Western province of the country are suitable for coffee growing with very good productivity. The rich volcanic soils, rainfall distribution and clement yearlong Temperatures favour the slow maturation of the coffee bean which is good for the coffee taste. The productivity per hectare varies between 1100 and 1600 kg of dry coffee.

In general, the central and southern areas are moderately suitable for coffee growing with the yield varying from 600 to 1000 kg of dry coffee per hectare. The lowland region of the eastern province is also not suitable for coffee growing due to insufficient rainfall and longer dry season; the soil potential is too low for the coffee crop (OCIR, 1998 and MINAGRI, 2004).

Coffee is harvested between the months of March and July (MINAGRI, 2004). The high volume importers include European countries France, Switzerland and Belgium, USA and Asia.

Apart from productions recorded during the period in the 1980's, the country's coffee production and exports declined especially since the war started from 1990. The other main reason of coffee degradation is the Genocide consequences where many coffee growers were killed while others went into a prolonged exile; coffee plantations burned or uprooted, which resulted in a lack of follow-up and supervision to care for the crop. Research on coffee was also disrupted following the shortage of necessary means (OCIR, 1998).

After the war in 1994, the security in the country has been established by the RPF. The changes in the coffee sector began shortly after the genocide with the national Coffee Strategy that outlined a plan for capturing a larger share of the specialty coffee sector and opened the market for coffee export to increase competition. This had great effects on the ground in Rwanda. Coffee continues to generate important export revenue for the country.

While figure varies year to year, in 2008 coffee exports generated over $47 million in revenue, compared with $35 million in 2007 (MINAGRI, 2002). Higher incomes benefit farmers, their families and their communities in a variety of ways: farmers can improve their home, pay medical expenses or school fees, or better ensure food security.

### 2.2.3. Motivation for growing coffee

The interviewed farmers expressed their motivation for growing coffee. Among the given reasons are that coffee is easily marketable (farmers sell their production to the coffee washing stations (CWS) around) and generates incomes (money). The CWS owners affirm to gain more when started to export the coffee of specialty (fully washed coffee). Again coffee crop has become part of the culture, due to the compulsory nature of its cultivation inherited from the colonial period; farmers have been cultivating coffee because their fathers and grand-fathers had been doing so. Therefore, on those geographical zones which respond to its suitability, it has found that coffee is the most important source of revenue in the rural area. The other reasons mentioned for growing coffee are the advantages taken from the coffee cooperative organizations which are mostly promoted by the government policy. (Mujawamaria, 2009)

## 2.3. The role of GIS in area suitability analysis in Agriculture.

Geographic information system (GIS) is a computer-based information system for the capture, storage, retrieval, analysis and display of geographic features tied to a common geographic coordinate system (Goodchild, 1992; Clarke, 1997). Within the framework of GIS, data are logically divided into two categories: spatial (geometric) data and attribute (non-spatial) data. The range of spatial data types currently used in most GIS is largely dictated by the data models they implement, namely vector and raster (Burrough, 1986; Goodchild, 1992).

In a vector data model, cartographic representations (i.e., points, lines and polygons) are used and the relationship among different features is maintained by spatial topology in a GIS. In the raster data model, a grid-cell or pixel representation is used. Digital elevation model (DEM), and scanned aerial photographs are good examples of raster data. These conventional vector and raster representations of geographical features in GIS focus on database management, query and spatial analysis (Rhind, 1990).

Attribute data are the characteristics about the geographic features. In both vector and raster data presentations, links are established between attribute information and spatial features. In the typical vector data model, the relational database management system (RDBMS) is most favorably incorporated for manipulation of feature attribute information. Links are established by arranging unique identifiers (or Ids) for each spatial feature (or IDs) to be recorded in the key fields of the appropriate database table(s) employed to store the attribute information. Data can be retrieved and associations developed based on the identifiers. In the raster model, by contrast, the links are implicit in the way that specific attributes are assigned to individual layers, and the values specified for the pixels or cells in each layer. By allowing links between spatial and attribute databases, a series of operations such as search, overlay, and select can be performed (Rhind, 1990).

The primary software package used to implement spatial analysis is ArcView or ArcMap GIS produced by Environmental Systems Research Institute (ESRI). ArcView and ArcMap provide ready-to-use functions to display, browse and query geographically-referenced data (ESRI, 2000). The linkage between spatial and attribute databases makes it possible for decision-makers to access location and attribute data simultaneously to simulate the effects of management and policy alternatives. Today, using GIS, land managers, planners, resource managers, engineers and many others can use geographic data more efficiently than ever before to analyze management and policy issues. Agriculture is an inherently geographical practice and it is not surprising that GIS has a significant role to play in agricultural assessments. GIS techniques have been used for farm-based assessments at national and regional scales for many years (Usery et al 1995).

## 2.4. Land suitability Analysis

Determine suitable land for a particular use is a complex process involving multiple decisions that may relate to the geospatial and agro-climatic aspects. A structured and consistent approach to land suitability analysis is therefore essential. Environmental factors decide the success of a crop. Judgments regarding crop value should include the biotic and agro-economic factors that determine the profitability.

### 2.4.1. Multi-Criteria Decision Making (MCDM)

Agricultural crop suitability involves integration information from various streams of science. There are many criteria upon which land suitability depends. The suitability analysis evaluates many alternative land use types under the light of various criteria from various streams. Alternatives here are competing with one another; criteria are both qualitative and quantitative. Decisions have to be taken at various levels starting from selecting the LUTs till the allocation of the LUTs for area that suit best. So the suitability is a multiple criteria decision making process. Earlier, the multi-criteria land suitability was assessed more non spatial, assuming the homogeneity over the area under consideration. This, however, is unrealistic in cases like land suitability studies, here decisions are made using criteria which vary across in space (Malczewski 1999). To address the spatial decision making, Multi-criteria environment (MCE) and GIS can be integrated (Jankowski), MCE seems to be applicable in GIS based land suitability analysis (Pereira and Duckstein 1993) for different crops. MCDM methods deal with real world problems that are multi dimensional in nature. When it comes to environmental issue, the methods have to deal with heterogeneous criteria that are both qualitative and quantitative in nature. In order to incorporate heterogeneous information with different measurement scales, one has to bring them into a common domain of measurement. This process is called Standardization, a basic operation in MCE. Criteria should be standardized keeping in mind the goal and alternatives that are under evaluation. Standardization can change the outputs entirely if proper attention is not paid. For environmental criteria, there is a lack of valid and reliable standardization processes (Malczewski, 1999).

### 2.4.2. Spatial Multi-Criteria Decision Making (SMCDM)

The spatial multi-criteria decision making is a process where geographical data is combined and transformed into a decision. Multi-criteria decision making involves input data, the decision maker's preferences and manipulation of both information using specified decision rules. Spatial MCDM aims to achieve solutions for spatial decision problems, derived from multiple criteria. These criteria, also called attribute must be identified carefully to arrive at the objectives and final goal. The performance of an objective is measured with the help of the attributes. These objectives and underlying attributes form a hierarchical structure of evaluation criteria for a particular decision problem. These evaluation criteria should be comprehensible and measurable. In hierarchy, a set of criteria should be decomposable, non redundant, complete, minimal and computational. Further, a map layer in the GIS represents each criterion in the hierarchy. Most creative task in the decision making is deciding what factors to include in the hierarchy structure. The principal notion behind the hierarchical structuring of a decision problem is that the elements being compared should be homogeneous. One should be aware that the hierarchy does not need to be complete, ie. An element in a given level does not have to function as criteria for all the elements in the level below. As mentioned above, hierarchy gives an opportunity to distinguish a criterion of greater importance from that of less importance: the criterion of greater importance is depicted in lower branches of the hierarchy, while the criterion of less importance is situated at the top or general level.

### 2.4.3 Applying multi-criteria decision analysis (MCDA) in GIS context.

The Multi-criteria decision analysis and the analytical hierarchy process have been applied; these methods are used to combine qualitative and quantitative criteria and to specify the degree and nature of the relationships between criteria in order to support spatial decision-making.

In our GIS context, MCDA are used to combine layers of spatial data representing the criteria in the model. The model specifies how the layers are combined, such as the relative weighting given to each individual criterion and how the data are combined.

For instance, the model adopted is the Weighted Linear Combination (WLC) as described by Voogd (1983). The suitability area is calculated from the sum of the weighted normalized data layers representing factors in the model in the following way:

$$S_i = \sum_{j=1}^{n} w_j \,.\, x_{i,j} \qquad \text{Where} \quad \sum_{j=1}^{n} w_j = 1$$

and $S_i$ is the suitability score for site *i*, $w_j$ is the weight of criterion *j*, $x_{i,j}$ is the value of site *i* under criterion *j*, and *n* is the total number of criteria. A good description of MCDA can be found in Malczewski (2006).

For analytical hierarchy process (AHP), the relationship among the objectives and attributes has a hierarchical structure; at the highest level, the objectives can be defined, and at lower levels, the attributes can be decomposed. Local experts from MINAGRI have played an important role in making pair wise comparisons between criteria at each level of the hierarchy and to develop relative weights. The AHP process involves the following steps:

• Criteria or factors contributing to the set of coffee suitable areas are identified;

• The relative importance of each factor relative to each other factor. This is usually done by domain experts;

• The consistency of the overall set of comparisons is assessed using its consistency Ratio (CR);

The CR determines the internal consistency of the weights relative to the overall solution.

After ordering in term of importance, factors have been internally classified refers to highly, moderately and slightly score of suitability as shown in table 3.1.

**Table 2.0**: An example comparisons scale (Pearl, 2002 & MINAGRI, 1998)

| Factors/Criteria | Criteria Standard weight (Order of importance in Crop growth) | Sub-classes | relative suitability categories ($S_1$, $S_2$, $S_3$) |
|---|---|---|---|
| 1.Elevation | 0.402 | 1400-1700m | $S_1$ or Highly suitable |
| | | >1700-1800m | $S_2$ or Moderately suitable |
| | | >1800-1900m | $S_3$ or Slightly suitable |
| 2.Temperature | 0.403 | >18-20$^0$C | $S_1$ or Highly suitable |
| | | 15-18$^0$C | $S_2$ or Moderately suitable |
| | | >20-21$^0$C | $S_3$ or Slightly suitable |
| 3.Rainfall | 0.597 | 1100-1200mm | $S_1$ or Highly suitable |
| | | >1200-1400mm | $S_2$ or Moderately suitable |
| | | >1400-1600mm | $S_3$ or Slightly suitable |
| 4.pH Soil | 0.655 | Equal Importance | Same Consistency Ratio |
| | | Equal Importance | Same Consistency Ratio |
| | | Equal Importance | Same Consistency Ratio |

The hierarchy gives an opportunity to distinguish criteria of greater importance from that of less importance and the criterion of greater importance is depicted in lower branches of the hierarchy, while the criterion of less importance is overlaid at the top or general level.

### 2.4.4 Weighting Factors

According to the local expert's judgment, pH soil is the most sensitive criterion in the suitability importance for coffee growth in the study area. Therefore, the local experts allocated large weight to pH soil criterion than to other factors (Rainfall, Temperature and Elevation); the internal consistence rate of pH soil has been taken as equal score and there is no subdivision of classes on the areas which respond to the suitability of coffee growth in the whole country.
For other factors, the internal suitability score has been calculated using the above formula and the average of values under criterion based on the values of different samples of production corresponding to the sub-classes (attributes) and the high production obtained under controlled conditions in that particular area (weight of criterion), (Pearl, 2002, MINAGRI, 2003, 2006).
The suitability classes have been obtained using the above formula and Xij is the value obtained by the average of the quotient of the values of coffee productions taken as samples in different sites of a class of attributes and the top coffee production obtained under controlled environment of a given variable (Conditions where variables are regulated and monitored).
The overall suitability is calculated from the sum of the weighted normalized data layers representing factors shown above.
Example of calculation of class score suitability in those criteria except pH Soil.

$$S_1 = 1 \times \left( \frac{\frac{Q_{s1}}{Q_{max}} + \frac{Q_{s2}}{Q_{max}} + \cdots + \frac{Q_{si}}{Q_{max}}}{\text{Nbr of samples}} \right)$$

Remember 1 represents $\sum_{j=1}^{n} w_j = 1$

and the whole equation is $\sum_{j=1}^{n} w_j \cdot x_{i,j}$

### 2.5. Environment (site selection)

Rwanda's natural attributes (Soil and Elevation) were recognized as most favorable to growing high quality Coffee Arabica. The Precipitation and Temperature conditions available at a favorable altitude are respectively considered in defining potential coffee yield (MINAGRI, 1998). Therefore, to grow and produce high quantity and quality coffee, the following important environmental factors should respectively be taken into account.

These include:

- Elevation
- Temperature;
- Rainfall;
- Soil.

#### 2.5.1. Elevation

Elevation influences a number of these factors and must be considered along with temperature, rainfall and water supply, soil, slope and aspect when determining where to plant coffee. An elevation between 1,400 to 1900 m above sea level is required for Arabica coffee. Low elevation Arabica coffee does not possess the quality required by the world markets. High elevation improves the quality of the bean and potential cupping quality. Due to a delay in ripening brought about by cooler weather associated with higher altitudes, the inherent characteristics of acidity, aroma and bold bean can develop fully. (Bold bean is classified as being the size between a large and a medium sized bean, with its width/ length ratio bigger than that of a large bean). (ISAR, 1990); (MINAGRI, 1998)

#### 2.5.2. Temperature

Arabica coffee prefers a cool temperature with an optimum daily temperature of between 15° to 21°C. Temperatures greater than 21°C cause plant stress leading to a cessation of photosynthesis. Mean temperatures of less than 15°C limit plant growth and are considered sub-optimal. Arabica coffee is frost susceptible. Use of shade trees will reduce the incidence of frost (ISAR, 1990); (MINAGRI, 2004)

### 2.5.3. Rainfall.

Ideal rainfall for Arabica coffee is greater than 1100 to 1600 mm per year. Both the total amount and the distribution pattern are important. Rain should to be uniformly distributed over seven to nine months of the year. At lower elevations, the dry season is often too pronounced. Lack of rainfall in either amount or timing can be compensated for by using irrigation. Coffee needs a dry, stress period with little or no rain to induce a uniform flowering. Without a stress period, flowering may extend over many months making harvesting more difficult. (ISAR, 1990)

### 2.5.4. Soil type

For successful production, a free draining soil with a minimum depth of one meter is required. Coffee will not tolerate water logging or 'wet feet'. Coffee can be grown on many different soil types, but the ideal is a fertile, volcanic red earth or a deep, sandy loam. Yellow-brown, high silt soils are less preferred. Avoid heavy clay or poor-draining soils.

Coffee prefers a soil with pH of 4.5 to 6. Many cultivated soils (less than pH 4.5) need lime or dolomite. Few soil test results exist, but indicator plants point to a pH less than 4.5 with low available phosphorus and thus shortages of many other nutrients. Low pH will limit crop performance by upsetting the availability of key nutrients to coffee plants. Good management and applications of dolomite or lime can alter and improve soil pH and fertility (ISAR, 1990).

## 2.6. DISTRIBUTION OF COFFEE TREES BY ADMINISTRATIVE ENTITY

### 2.6.1. Distribution of coffee trees, plantations, average trees per plantation and area occupied at the provincial level

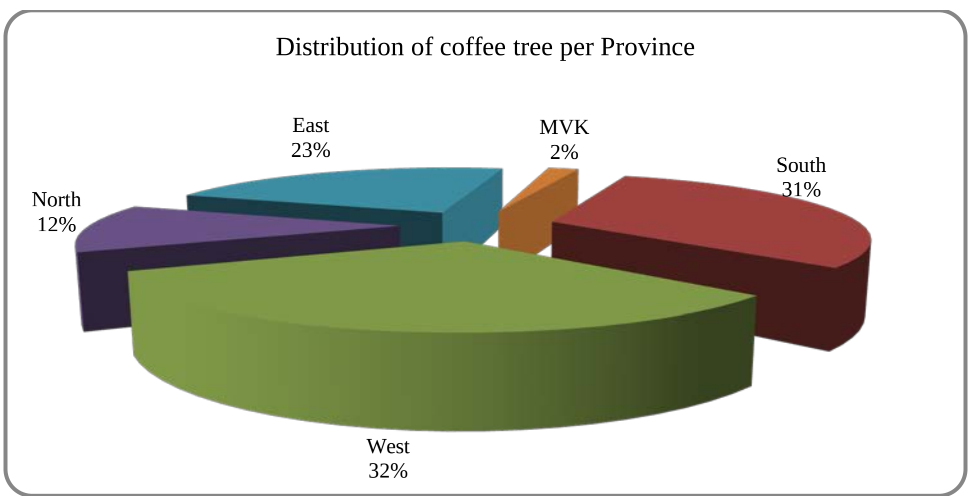
At the national level, table 1 shows a total of 394,207 coffee plantations and 72,063,912 trees, at an average of 183 trees and 28,826 ha covered per plantation.

**Table 2.1: Coffee trees distribution per Province**

| Province | Total number of coffee trees | Number of coffee plantations | Average of coffee trees per plantation | Planted surface area (2500 trees/ha) |
|---|---|---|---|---|
| East | 16,390.327 | 51.141 | 320 | 6,556 |
| North | 8,846.393 | 58.858 | 150 | 3,539 |
| West | 23,073.520 | 143.150 | 161 | 9,229 |
| South | 22,425.292 | 133.781 | 168 | 8,970 |
| MVK | 1,328.380 | 7.277 | 183 | 531 |
| | 72,063.912 | 394.207 | 183 | 28,826 |

The distribution of coffee plantations by Province is shown by Fig 2. The Western Province comes in first place with 32% of plantations, followed by the South with 31%. The Eastern Province comes in third place with 23%, the Northern Province with 12% of the plantations and lastly Kigali City with 2%. This distribution can be explained by three important factors: the availability of land favourable to coffee farming, the density of farmers, and the tradition of coffee growing in the area.

**Figure 2.2: Distribution of coffee trees per Province**




Source: National Coffee Census 2011

The distribution of the number of coffee trees by Province is slightly different from that of the number of plantations. The Eastern Province which had the third place comes with the fourth while the Northern Province occupies the third place instead of fourth.

The number of coffee farms and number of trees per plantation show that coffee farming in Rwanda remains dominated by small scale farms.

The Eastern Province has the most trees per plantation at an average of 320, followed by Kigali City with 183, the Southern Province with 168, the Western Province with 161, and the Northern Province with 150. This suggests that the Eastern Province has a higher proportion of larger coffee estates than the Northern Province, which is dominated by small farms. This refers to estates constituting only one plot belonging to an individual or to an association, and is unrelated to the distinction between grouped and ungrouped plantations, which can have both small and large plantations in one estate.

**Table 2.2: Coffee Shrubs in individual and grouped plantations**

| Province | Total number of coffee trees | Coffee trees in individual plantations | % | Coffee trees in grouped plantations | % |
|---|---|---|---|---|---|
| East | 16,390,327 | 12,112,594 | 74 | 4,277,733 | 26 |
| North | 8,846,393 | 5,346,093 | 60 | 3,500,300 | 40 |
| West | 23,073,520 | 14,428,940 | 63 | 8,644,580 | 37 |
| South | 22,425,292 | 17,141,162 | 76 | 5,284,130 | 24 |
| MVK | 1,328,380 | 788,473 | 59 | 539,907 | 41 |
| | 72,063,912 | 49,817,262 | 69 | 22,246,650 | 31 |

Source: National Coffee Census 2012

Table 2 shows that 69% of coffee trees plantations own to individuals and 31% are grouped farms. Kigali City has a high percentage of grouped plantations, but its impact is not significant due to the very low number of coffee trees in this administrative entity. Kigali City is followed by the Northern, Western, Southern and Eastern Provinces respectively.

**Table 2. 3: Age of coffee trees at national and Province level**

| Province | Number of coffee trees | Trees from 6 months to 3 years | % | Productive coffee trees < 30 years | % | Coffee trees > 30 years | % |
|---|---|---|---|---|---|---|---|
| East | 16,390,327 | 5,913,087 | 36% | 7,561,268 | 46% | 2,915,972 | 18% |
| North | 8,846,393 | 2,934,977 | 33% | 3,512,176 | 40% | 2,399,240 | 27% |
| West | 23,073,520 | 4,418,737 | 19% | 15,024,848 | 65% | 3,629,935 | 16% |
| South | 22,425,292 | 3,764,641 | 17% | 10,717,194 | 48% | 7,943,469 | 35% |
| MVK | 1,328,380 | 472,479 | 35.5% | 488,430 | 36.8% | 367,471 | 27.7% |
| Total | 72,063,912 | 17,503,921 | 24% | 37,303,916 | 52% | 17,256,087 | 24% |

Source: National Coffee Census 2009

Table 2.3 shows that 52% of coffee trees are between ages 3 and 30 years. The highest rate of productive trees is found in the Western Province (65%), followed by the South (48%), the North (40%), the East (40%) and Kigali City (36.8%). It also appears that 40.2% of coffee trees which have been reached the maturity age are found in the Western Province, 28.7% in the Southern Province, 20.2% in the Eastern Province, 9.4% in the north and 1.3% in Kigali City.

The Western and Southern Provinces alone represent 69% of all coffee trees in maturity age. Young coffee plants (6 months to 3 years) represent 24% of all coffee trees. The highest rate of young coffee trees is observed in the Eastern Province (36%), followed by Kigali City (35.5%), North (33%), West (19%) and South (16%). From the total of trees within 6 months and 3 years, the Eastern Province has 33.8% followed by the West (25.2%), the South (21.5%), the North (16.8%) and Kigali City (2.7%). This percentage shows that the Eastern Province has made the greatest recent effort to plant new coffee plantations.

From the total of 17,256,087 old trees, the Southern Province has 46%, followed by the West (21%), East (17%), the North (14%) and Kigali City (2%). From the District data analysis, it has been observed that the border of Mayaga region possess a higher percentage of old trees.

**Summary statistics of coffee farming in Rwanda are listed below:**

| | | |
|---|---|---|
| (i) | Total number of coffee trees | 72.063.912 |
| (ii) | % Productive trees (330years) | 52% |
| (iii) | % Young coffee trees (6 months 3years) | 24% |
| (iv) | % Old coffee trees (>30 years) | 24% |
| (v) | Total number of coffee plantations (coffee farmers) | 394.207 |
| (vi) | % Scatted plantations | 70% |
| (vii) | % Grouped plantations | 30% |
| (viii) | Total planted area (in ha) | 28.826 |
| (ix) | Average coffee trees per plantation | 183 |
| (x) | % of male farmers | 69% |
| (xi) | % of females | 30% |
| (xii) | % of schools, cooperatives etc. | 1% |
| (xiii) | Coffee farmers non members of cooperatives | 80% |
| (xiv) | Coffee farmers members of cooperatives | 20% |
| (xv) | Mineral fertilizers utilized (Qty in Kg) | 5,695,267 |
| (xvi) | Manure utilized (Qty in Kg) | 151,542,320 |
| (xvii) | Number of coffee trees sprayed with pesticides | 37,695,628 |
| (xviii) | Number of coffee trees mulched | 37,984,181 |
| (xix) | Number of coffee trees regenerated | 23,287,261 |

### 2.6.2. Distribution of coffee trees, plantations, average trees per plantation and area occupied per District

The data collected at the District level allows us to have a general view of coffee farming in Rwanda. The relative tables and graphs identify coffee status from one administrative entity to another.

#### 2.6.2.1. Number of coffee trees.

Based on the number of coffee trees, some classifications have been done at the national level. First, six Districts possess 4 to 8 million trees: Nyamasheke (8,379,115), Rusizi (6,121,002), Gakenke (5,166,853), Kamonyi (4,292,794), Ngoma (4,292,396) and Rutsiro (4,115,004). The above Districts represent 45% of the total number of coffee trees nationwide. Nyamasheke District from the Western Province has the highest number of coffee trees and coffee plantantions, followed by Rusizi District still from the Western Province, Gakenke District situated to the northern province, Kamonyi District located to the Southern Province, Ngoma District located to the Eastern Province and Rutsiro in the Western province. But respectively, all of them possess the top number of coffee trees in their province except Rusizi which occupies the second position after Nyamasheke

Secondly, eleven districts possess 2 to 4 million trees. Those are respectively Huye (3,692,521), Kirehe (3,415,268), Nyamagabe (2,971,689), Nyanza (2,931,745), Karongi (2,644,401), Rwamagana (2,629,910), Ruhango (2,524,718), Gatsibo (2,331,949), Bugesera (2,305,268),Gisagara (2,097,825) and Nyaruguru (2,062,329). The group represents 41% of the total number of coffee trees. Among them, 6 districts are located in the Southern Province; that justifies the second place after the western province. Furthermore, the Southern Province still has the highest number of old coffee trees.

Thirdly, four districts count 1 to 2 million coffee trees: Rulindo (1,829,316), Muhanga (1,851,671), Gicumbi (1,661,633) and Kayonza (1,071,432). They represent 9% of the total number of coffee trees.

Finally, nine Districts make up the last group with the number of coffee trees varying between 100,000 and 1 million. These are the Districts of Ngororero (960,388), Gasabo (902,557), Rubavu (531,355), Nyagatare (344,104), Nyabihu (322,255), Nyarugenge (254,622), Kicukiro (171,201), Musanze (136,169) and Burera (52,422). Their total number of coffee trees represents only 5% of the total number at the national level.

**Figure 2.3**: **Distribution of coffee trees per District**

**Table 2.4: Coffee trees, plantations and average per District**

| District | Number of coffee trees | % Coffee trees at national | Number of plantations | % Plantations at national level | Average of coffee trees/plantation | Planted surface area (2500 trees/Ha) |
|---|---|---|---|---|---|---|
| Bugesera | 2,305,268 | 3.2 | 8,982 | 2.3 | 257 | 922 |
| Gatsibo | 2,331,949 | 3.2 | 8,857 | 2.2 | 263 | 933 |
| Kayonza | 1,071,432 | 1.5 | 3,763 | 1.0 | 285 | 429 |
| Kirehe | 3,415,268 | 4.7 | 6,667 | 1.7 | 512 | 1,366 |
| Ngoma | 4,292,396 | 6.0 | 12,941 | 3.3 | 332 | 1,717 |
| Nyagatare | 344,104 | 0.5 | 1,121 | 0.3 | 307 | 138 |
| Rwamagana | 2,629,910 | 3.6 | 8,810 | 2.2 | 299 | 1,052 |
| Sub-Total | 16,390,327 | 22.7 | 51,141 | 13.0 | 320 | 6,556 |
| Burera | 52,422 | 0.1 | 682 | 0.2 | 77 | 21 |
| Gakenke | 5,166,853 | 7.2 | 31,113 | 7.9 | 166 | 2,067 |
| Gicumbi | 1,661,633 | 2.3 | 14,784 | 3.8 | 112 | 665 |
| Musanze | 136,169 | 0.2 | 1,196 | 0.3 | 114 | 54 |
| Rulindo | 1,829,316 | 2.5 | 11,083 | 2.8 | 165 | 732 |
| Sub-Total | 8,846,393 | 12.3 | 58,858 | 14.9 | 150 | 3,539 |
| Karongi | 2,644,401 | 3.7 | 16,732 | 4.2 | 158 | 1,058 |
| Ngororero | 960,388 | 1.3 | 5,635 | 1.4 | 170 | 384 |
| Nyabihu | 322,255 | 0.4 | 2,645 | 0.7 | 122 | 129 |
| Nyamasheke | 8,379,115 | 11.6 | 47,612 | 12.1 | 176 | 3,352 |
| Rubavu | 531,355 | 0.7 | 3,375 | 0.9 | 157 | 213 |
| Rusizi | 6,121,002 | 8.5 | 27,578 | 7.0 | 222 | 2,448 |
| Rutsiro | 4,115,004 | 5.7 | 39,573 | 10.0 | 104 | 1,646 |
| Sub-Total | 23,073,520 | 32.0 | 143,150 | 36.3 | 161 | 9229 |
| Gisagara | 2,097,825 | 2.9 | 13,791 | 3.5 | 152 | 839 |
| Huye | 3,692,521 | 5.1 | 18,442 | 4.7 | 200 | 1477 |
| Kamonyi | 4,292,794 | 6.0 | 28,831 | 7.3 | 149 | 17171 |
| Muhanga | 1,851,671 | 2.6 | 12,851 | 3.3 | 144 | 741 |
| Nyamagabe | 2,971,689 | 4.1 | 11,315 | 2.9 | 263 | 1189 |
| Nyanza | 2,931,745 | 2.9 | 20,961 | 5.3 | 140 | 1173 |
| Nyaruguru | 2,062,329 | 3.5 | 13,912 | 3.5 | 148 | 825 |
| Ruhango | 2,524,718 | 31.1 | 13,678 | 3.5 | 185 | 1010 |
| Sub-Total | 22,425,292 | 1.3 | 133,781 | 33.9 | 168 | 8970 |
| Gasabo | 902,557 | 0.2 | 5,836 | 1.5 | 155 | 361 |
| Kicukiro | 171,201 | 0.4 | 641 | 0.2 | 267 | 68 |
| Nyarugenge | 254,622 | 1.8 | 800 | 0.2 | 318 | 102 |
| Sub-Total | 1,328,380 | 100.0 | 7,277 | 1.8 | 183 | 531 |
| Total | 72,063,912 | | 394,207 | 100 | **183** | **28,826** |

Source : National Coffee Census 2011

Table 4 shows the total number of coffee trees, number of plantation, average trees per plantation, plant surface area and the percentages by district. Among 10 districts with the top number of coffee trees, 7 belong to the Western and southern provinces, that confirms their position as areas with high coffee production.

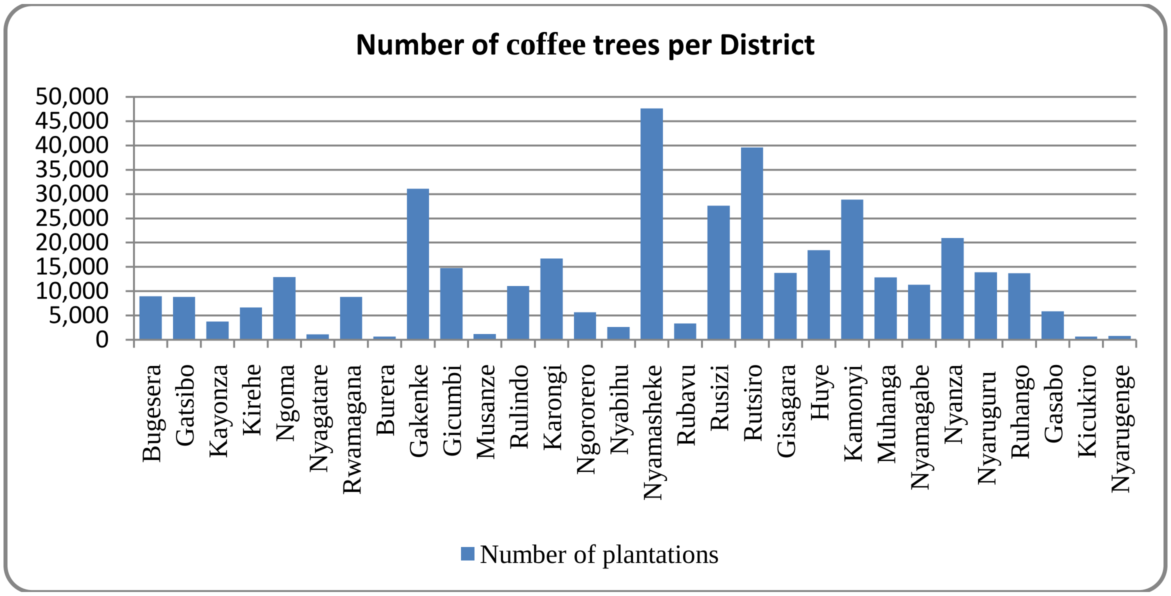
**Table 2.5: Districts ranking according to the number of coffee trees**

| Rank | District | Total number of coffee trees | Relative % of total number of coffee trees |
|---|---|---|---|
| 1 | Nyamasheke | 8,379,115 | 11.6 |
| 2 | Rusizi | 6,121,002 | 8.5 |
| 3 | Gakenke | 5,166,853 | 7.2 |
| 4 | Ngoma | 4,292,396 | 6.0 |
| 5 | Kamonyi | 4,292,794 | 6.0 |
| 6 | Rutsiro | 4,115,004 | 5.7 |
| 7 | Huye | 3,692,521 | 5.1 |
| 8 | Kirehe | 3,415,268 | 4.7 |
| 9 | Nyamagabe | 2,971,689 | 4.1 |
| 10 | Nyanza | 2,931,745 | 4.1 |
| 11 | Karongi | 2,644,401 | 3.7 |
| 12 | Rwamagana | 2,629,910 | 3.6 |
| 13 | Ruhango | 2,524,718 | 3.5 |
| 14 | Bugesera | 2,305,268 | 3.2 |
| 15 | Gatsibo | 2,331,949 | 3.2 |
| 16 | Gisagara | 2,097,825 | 2.9 |
| 17 | Nyaruguru | 2,062,329 | 2.9 |
| 18 | Muhanga | 1,851,671 | 2.6 |
| 19 | Rurindo | 1,829,316 | 2.5 |
| 20 | Gicumbi | 1,661,633 | 2.3 |
| 21 | Kayonza | 1,071,432 | 1.5 |
| 22 | Ngororero | 960,388 | 1.3 |
| 23 | Gasabo | 902,557 | 1.3 |
| 24 | Rubavu | 531,355 | 0.7 |
| 25 | Nyagatare | 344,104 | 0.5 |
| 26 | Nyabihu | 322,255 | 0.4 |
| 27 | Nyarugenge | 254,622 | 0.4 |
| 28 | Musanze | 136,169 | 0.2 |
| 29 | Kicukiro | 171,201 | 0.2 |
| 30 | Burera | 52,422 | 0.1 |

Source: National Coffee Census 2011

This ranking would be more meaningful if we could compare the number of coffee trees with the volume of production at the level of each district. However, as we shall see far ahead, data regarding production are not reliable.

**Figure 2.4: Distribution of coffee trees per District**




Source: National Coffee Census 2011

### 2.6.2.2. Plantations and average trees per plantation.

The distribution of coffee plantations and the average number of trees per plantation at the District level mirror the national trend of scatted plantations owned by many farmers.

Table 4, Fig 4 and 5 give more clarification about this paragraph.

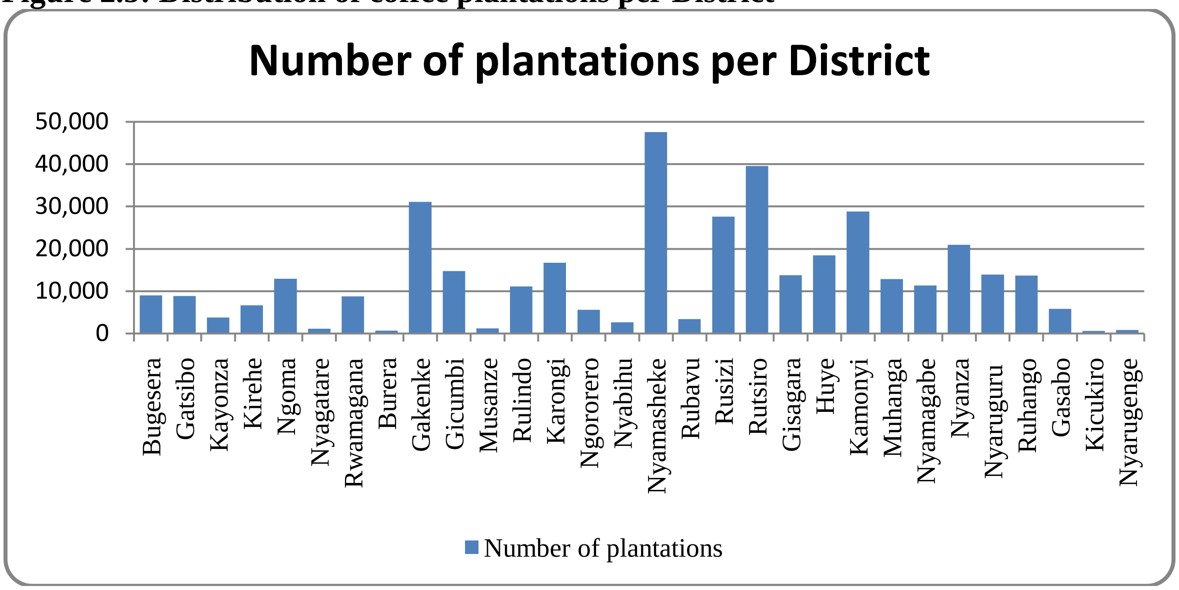
In terms of number of plantations, the following 6 Districts have between 20,000 and 48,000 plantations: Nyamasheke (47,612 ), Rutsiro (39,573), Gakenke (31,113), Kamonyi (28,831), Rusizi (27,578) and Nyanza (20,961). Three of them are in the Western Province; two are in the Southern Province and one in the Northern Province. These Districts account 50% of all coffee plantations in Rwanda.

In the second group, 10 Districts have between 10,000 and 20,000 plantations: Huye (18,442), Karongi (16,732), Gicumbi (14,781), Gisagara (13791), Nyaruguru (13,912), Ruhango (13,678), Ngoma (12941), Muhanga (12,851), Nyamagabe (11,315) and Rulindo (11,083). Six of them are in the Southern Province, one in the Western Province, two in the Northern Province and one the Eastern Province. This group represents 35% of the total number of coffee plantations.

The third group which possess between 5 000 and 10,000 plantations consists of 6 Districts: Bugesera (8,982), Gatsibo (8,857), Rwamagana (8,810), Kirehe (6,667), Gasabo (5,836) and Ngororero (5,635). This group represents 11% of the total number of plantations in Rwanda. All are in the Eastern Province Except Gasabo and Ngororero which belong respectively to the Kigali-City and the northern province.

The fourth group brings together 8 Districts with between 800 and 4000 plantations and it represents 4% of the total plantations. The largest number of plantation is found in the Districts with traditional coffee farming, around Lake Kivu, in central plateau and in Mayaga.

**Figure 2.5: Distribution of coffee plantations per District**




Source : National Coffee Census 2011

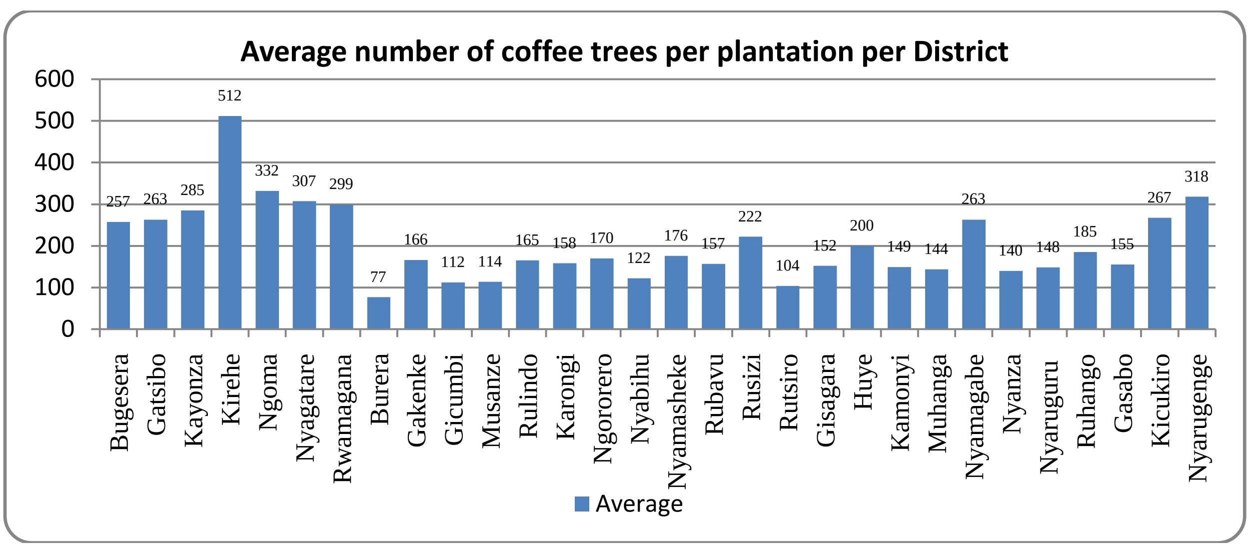
If we consider the average number of trees per plantation, we find an unusual situation. Table2.6 and Fig 2.6 show that only 12 Districts have an average number of trees per plantation above the national average of 183: Kirehe, Ngoma, Nyarugenge, Nyagatare, Rwamagana, Kicukiro, Gatsibo, Nyamagabe, Bugesera, Rusizi, Huye and Ruhango. Their average number of trees per plantation ranged from 200 to 330 coffee trees, except Kirehe that averaged 512 trees. With the exception of Rusizi District, this list does not include any Districts which are in the top group in term of number of coffee trees and number of plantations. In the remaining 18 Districts, the average number of coffee trees varies between 100 and 185 trees per plantation except Burera District with an average of 77 coffee trees, far below the average of 100. In this category, Nyamasheke, Gakenke, Rutsiro and Kamonyi have the most coffee trees.

**Table 2.6: Districts ranking according to coffee plantations and average of trees per plantation**

| Ordre | District | Plantation | % total | Rank | District | Average |
|---|---|---|---|---|---|---|
| 1 | Nyamasheke | 47,612 | 12.10 | 1 | Kirehe | 512 |
| 2 | Rutsiro | 39,573 | 10.00 | 2 | Ngoma | 332 |
| 3 | Gakenke | 31,113 | 7.90 | 3 | Nyarugenge | 318 |
| 4 | Kamonyi | 28,831 | 7.30 | 4 | Nyagatare | 307 |
| 5 | Rusizi | 27,578 | 7.00 | 5 | Rwamagana | 299 |
| 6 | Nyanza | 20,961 | 5.30 | 6 | Kayonza | 285 |
| 7 | Huye | 18,442 | 4.70 | 7 | Kicukiro | 267 |
| 8 | Karongi | 16,732 | 4.20 | 8 | Gatsibo | 263 |
| 9 | Gicumbi | 14,784 | 3.80 | 9 | Nyamagabe | 263 |
| 10 | Gisagara | 13,791 | 3.50 | 10 | Bugesera | 257 |
| 11 | Nyaruguru | 13,912 | 3.50 | 11 | Rusizi | 222 |
| 12 | Ruhango | 13,678 | 3.50 | 12 | Huye | 200 |
| 13 | Ngoma | 12,941 | 3.30 | 13 | Ruhango | 185 |
| 14 | Muhanga | 12,851 | 3.30 | 14 | Nyamasheke | 176 |
| 15 | Nyamagabe | 11,315 | 2.90 | 15 | Ngororero | 170 |
| 16 | Rulindo | 11,063 | 2.80 | 16 | Gakenke | 166 |
| 17 | Bugesera | 8,982 | 2.30 | 17 | Rulindo | 165 |
| 18 | Gatsibo | 8,857 | 2.20 | 18 | Karongi | 158 |
| 19 | Rwamagana | 8,810 | 2.20 | 19 | Rubavu | 157 |
| 20 | Kirehe | 6,667 | 1.70 | 20 | Gasabo | 155 |
| 21 | Gasabo | 5,836 | 1.50 | 21 | Gisagara | 152 |
| 22 | Ngororero | 5,635 | 1.40 | 22 | Kamonyi | 149 |
| 23 | Kayonza | 3,763 | 1.00 | 23 | Nyaruguru | 148 |
| 24 | Rubavu | 3,375 | 0.90 | 24 | Muhanga | 144 |
| 25 | Nyabihu | 2,645 | 0.70 | 25 | Nyanza | 140 |
| 26 | Musanze | 1,196 | 0.30 | 26 | Nyabihu | 122 |
| 27 | Nyagatare | 1,121 | 0.30 | 27 | Musanze | 114 |
| 28 | Nyarugenge | 800 | 0.20 | 28 | Gicumbi | 112 |
| 29 | Burera | 682 | 0.20 | 29 | Rutsiro | 104 |
| 30 | Kicukiro | 641 | 0.20 | 30 | Burera | 77 |

Source : National Coffee Census 2011

**Figure 2.6: Average number of coffee trees per plantation per District**




**Source**: National Coffee Census 2011

From the number of plantations and average number of trees per plantation, we can note that:
(i) The distribution of coffee trees and average number of trees per plantation at the District level reflects the situation at the national level, where there are a lot scattered plots and small scale coffee farmers.
(ii) Small scale farming is predominant in the traditional areas of coffee growing areas such as the Western and Southern Province and the Gakenke District
(iii) A small average of trees per plantation is observed in those Districts where still practice the traditional coffee farming except Rusizi District.
(iv) In districts with relatively more free land where coffee growing is expanding, such as in the Eastern Province, the average number of trees per plantation is above the national average.

**2.6.2.3. Grouping of plantations into coffee estates**

The tables 7 and 8 and Figure 7 show the status of grouped plantations into coffee estates.
It is important to remember that the idea of grouping plantations is different from the size of plantations which refers to the number of trees per plantation.
As mentioned above, 20% of coffee plantations are grouped, meaning that 80% are scattered plots on different hills. Rubavu and Rutsiro Districts come in first place with rates of grouped plantations of 72% and 64% respectively. It is important to note that Rutsiro is a District with high concentration of coffee (5% of the whole country).
The second group is composed of 6 Districts with a percentage ranging from 41% to 49%. They are Rulindo, Ngororero, Nyabihu, Bugesera, Gasabo and Gakenke. The percentage of 41% from Gakenke is significant in this group because Gakenke represents 7.2% of the total number of plantations nationwide.
The third group consists of Gatsibo, Nyarugenge, Karongi, Gisagara, Huye and Kamonyi with rates of grouped plantations above the national average of 31%. The rates for these Districts varied between 32% and 36%. It is important to note that the highest rate of grouped plantations are found in the districts Kamonyi, Huye and Karongi with respectively (6%),(5.1%) and (3.7%).
The last group comprises 16 Districts with rates below the national average. They vary between 7% and 30%. Therefore, the Districts with the high rate of grouped plots are Nyamasheke, Rusizi, Kirehe and Gicumbi, which had between 28% and 30%.

## Table 2.7: Coffee trees in isolated plantations and grouped plantations per District

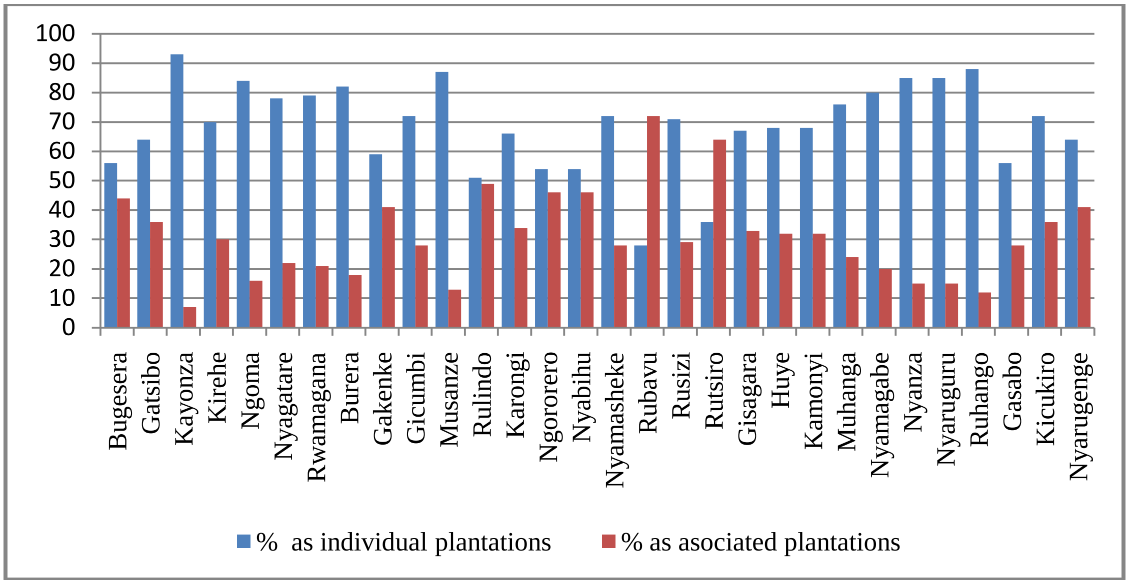
| Province | District | Total number of trees | Coffee trees in individual plantations | % | Coffee trees in grouped plantations | % |
|---|---|---|---|---|---|---|
| East | Bugesera | 2,305,268 | 1,284,625 | 56 | 1,020,643 | 44 |
| | Gatsibo | 2,331,949 | 1,502,321 | 64 | 829,628 | 36 |
| | Kayonza | 1,071,432 | 998,314 | 93 | 73,118 | 7 |
| | Kirehe | 3,415,268 | 2,381,838 | 70 | 1,033,430 | 30 |
| | Ngoma | 4,292,396 | 3,612,008 | 84 | 680,388 | 16 |
| | Nyagatare | 344,104 | 268,964 | 78 | 75,140 | 22 |
| | Rwamagana | 2,629,910 | 2,064,524 | 79 | 565,386 | 21 |
| North | Burera | 52,422 | 43,088 | 82 | 9,334 | 18 |
| | Gakenke | 5,166,853 | 3,046,960 | 59 | 2,119,893 | 41 |
| | Gicumbi | 1,661,633 | 1,201,833 | 72 | 459,800 | 28 |
| | Musanze | 136,169 | 117,960 | 87 | 18,209 | 13 |
| | Rulindo | 1,829,316 | 936,252 | 51 | 893,064 | 49 |
| West | Karongi | 2,644,401 | 1,743,945 | 66 | 900,456 | 34 |
| | Ngororero | 960,388 | 518,412 | 54 | 441,976 | 46 |
| | Nyabihu | 322,255 | 173,773 | 54 | 148,482 | 46 |
| | Nyamasheke | 8,379,115 | 6,000,516 | 72 | 2,378,599 | 28 |
| | Rubavu | 531,355 | 147,465 | 28 | 383,890 | 72 |
| | Rusizi | 6,121,002 | 4,375,240 | 71 | 1,745,762 | 29 |
| | Rutsiro | 4,115,004 | 1,469,589 | 36 | 2,645,415 | 64 |
| South | Gisagara | 2,097,825 | 1,414,021 | 67 | 683,804 | 33 |
| | Huye | 3,692,521 | 2,525,716 | 68 | 683,804 | 32 |
| | Kamonyi | 4,292,794 | 2,922,658 | 68 | 1,370,136 | 32 |
| | Muhanga | 1,851,671 | 1,415,333 | 76 | 436,338 | 24 |
| | Nyamagabe | 2,971,689 | 2,389,408 | 80 | 582,281 | 20 |
| | Nyanza | 2,931,745 | 2,482,743 | 85 | 449,002 | 15 |
| | Nyaruguru | 2,062,329 | 1,761,447 | 85 | 300,882 | 15 |
| | Ruhango | 2,524,718 | 2,229,836 | 88 | 294,882 | 12 |
| Kigali Ville | Gasabo | 902,557 | 503,312 | 56 | 399,245 | 28 |
| | Kicukiro | 171,201 | 123,093 | 72 | 48,108 | 36 |
| | Nyarugenge | 254,622 | 162,068 | 64 | 92,554 | 41 |
| Total | | | | | | |

Source: National Coffee Census 2011

## Table 2.8: Districts ranking according to % of grouped coffee trees

| Rank | District | % | Ran17k | District | % |
|---|---|---|---|---|---|
| 1 | Rubavu | 72 | 16 | Rusizi | 29 |
| 2 | Rutsiro | 64 | 17 | Gicumbi | 28 |
| 3 | Rulindo | 49 | 18 | Nyamasheke | 28 |
| 4 | Ngororero | 46 | 19 | Kicukiro | 28 |
| 5 | Nyabihu | 46 | 20 | Muhanga | 24 |
| 6 | Bugesera | 44 | 21 | Nyagatare | 22 |
| 7 | Gasabo | 44 | 22 | Rwamagana | 21 |
| 8 | Gakenke | 41 | 23 | Nyamagabe | 20 |
| 9 | Gatsibo | 36 | 24 | Burera | 18 |
| 10 | Nyarugenge | 36 | 25 | Ngoma | 16 |
| 11 | Karongi | 34 | 26 | Nyanza | 15 |
| 12 | Gisagara | 33 | 27 | Nyaruguru | 15 |
| 13 | Huye | 32 | 28 | Musanze | 13 |
| 14 | Kamonyi | 32 | 29 | Ruhango | 12 |
| 15 | Kirehe | 30 | 30 | Kayonza | 7 |

**Figure 2.7: Distribution of individual plantations and associated plantations per District**




Source: National Coffee Census 2011

### 2.6.2.4. Distribution of coffee trees by category of age

In this section, our reflections will be based on the proportion of old plantations in order to avoid repetition. Through table 9, Fig 8, and the three of age considered, we observe that aging trees are more prevalent in the Districts of the Southern Province, except Nyaruguru and Muhanga Districts which have the rates of 22% and 21% respectively. The other Districts have rate varying between 32% and 49%. The rate of ageing coffee trees is very in the areas of Mayaga. We recall that this area has many grouped plantations which mean that coffee intensification has been motivated. It has been observed that the rejuvenating program implemented few years ago has not performed well in that place. The Northern Districts has a rate of ageing trees ranging from 24% to 31%, except Musanze, where 61% of coffee trees are between 6 months and 3 years, and only 12% are above 30 years. However, this District did not do well in terms of coffee production. The District with the highest rate of ageing trees is Gicumbi with 31% of old trees versus 26% young trees.

The highest proportion of aging trees is found in the Eastern Province in Rwamagana District with 28% old trees and 25% young trees. The fewer rate was recorded in Kirehe with 8%.
This figure is of importance because Kirehe is the second highest coffee grower in the Eastern Province after Ngoma District with 21% old coffee trees and 30% young trees.

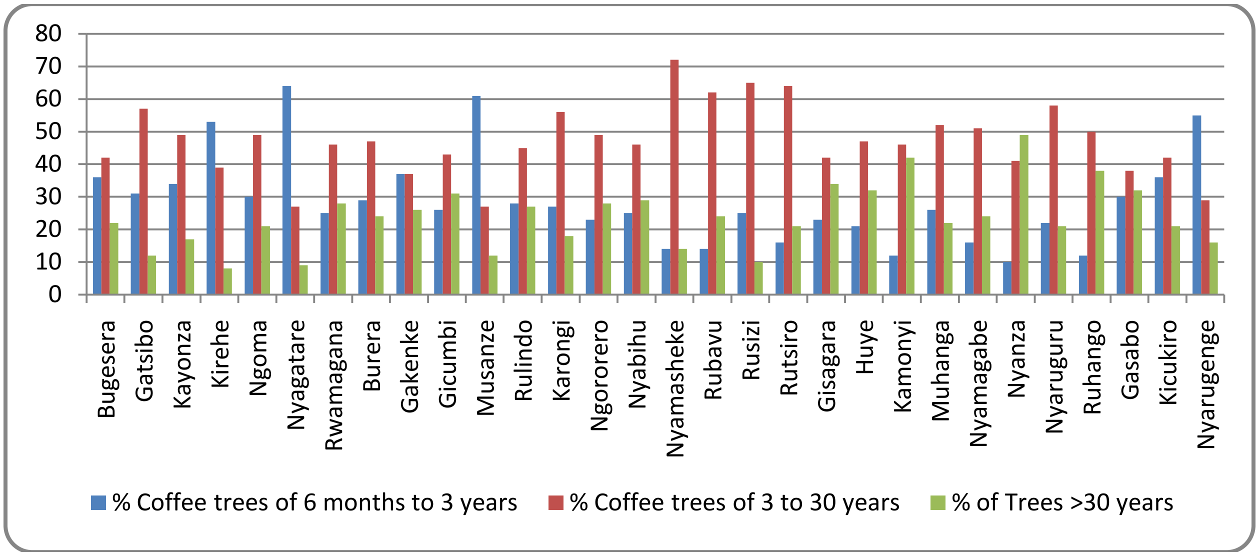
The Districts of the Western Province play a big role in coffee production in Rwanda. Thus any unfavorable factor in these sectors has a negative influence on the perfomance at national level. Considering rate of ageing coffee trees, the districts of Ngororero and Nyabihu have rates above the national average but the effect is very small based on their small number of trees.

The two biggest producers of coffee in the whole country are Nyamasheke and Rusizi and have rates of old trees respectively 14% and 10%. In this western Province, the average of productive coffee trees is 65% compared to 52% for the national level. Note that the districts with high rates of productive trees are Nyamasheke 72%, Rusizi 65% and Rutsiro 62%.

**Table 2.9: Coffee trees per age per District**

| Province | District | Total coffee trees | Coffee trees of 6 months to 3 years | Relative % | Coffee trees of 3 to 30 years | Relative % | Trees >30 years | Relative % |
|---|---|---|---|---|---|---|---|---|
| East | Bugesera | 2,305,268 | 836,596 | 36 | 962,146 | 42 | 506,526 | 22 |
| | Gatsibo | 2,331,949 | 732,639 | 31 | 1,324,761 | 57 | 274,549 | 12 |
| | Kayonza | 1,071,432 | 368,297 | 34 | 525,958 | 49 | 177,177 | 17 |
| | Kirehe | 3,415,268 | 1,821,856 | 53 | 1,328,308 | 39 | 265,104 | 8 |
| | Ngoma | 4,292,396 | 1,267,758 | 30 | 2,112,467 | 49 | 912,171 | 21 |
| | Nyagatare | 344,104 | 220,967 | 64 | 91,425 | 27 | 31,712 | 9 |
| | Rwamagana | 2,629,910 | 664,974 | 25 | 1,216,203 | 46 | 748,733 | 28 |
| North | Burera | 52,422 | 15,151 | 29 | 24,552 | 47 | 12,719 | 24 |
| | Gakenke | 5,166,853 | 1,888,333 | 37 | 1,913,537 | 37 | 1,364,983 | 26 |
| | Gicumbi | 1,661,633 | 431,452 | 26 | 713,322 | 43 | 516,859 | 31 |
| | Musanze | 136,169 | 83,296 | 61 | 36,492 | 27 | 16,381 | 12 |
| | Rulindo | 1,829,316 | 516,745 | 28 | 824,273 | 45 | 488,298 | 27 |
| West | Karongi | 2,644,401 | 708,114 | 27 | 1,468,695 | 56 | 467,592 | 18 |
| | Ngororero | 960,388 | 219,880 | 23 | 467,044 | 49 | 273,464 | 28 |
| | Nyabihu | 322,255 | 81,727 | 25 | 147,957 | 46 | 92,571 | 29 |
| | Nyamasheke | 8,379,115 | 1,160,479 | 14 | 6,003,809 | 72 | 1,214,827 | 14 |
| | Rubavu | 531,355 | 75,919 | 14 | 330,234 | 62 | 125,202 | 24 |
| | Rusizi | 6,121,002 | 1,523,140 | 25 | 3,991,392 | 65 | 606,470 | 10 |
| | Rutsiro | 4,115,004 | 649,478 | 16 | 2,615,717 | 64 | 849,809 | 21 |
| South | Gisagara | 2,097,825 | 490,836 | 23 | 891,253 | 42 | 715,736 | 34 |
| | Huye | 3,692,521 | 777,599 | 21 | 1,732,145 | 47 | 1,182,777 | 32 |
| | Kamonyi | 4,292,794 | 525,930 | 12 | 1,966,380 | 46 | 1,800,484 | 42 |
| | Muhanga | 1,851,671 | 473,747 | 26 | 971,251 | 52 | 406,673 | 22 |
| | Nyamagabe | 2,971,689 | 465,443 | 16 | 1,509,373 | 51 | 996,873 | 24 |
| | Nyanza | 2,931,745 | 294,717 | 10 | 1,188,215 | 41 | 1,448,825 | 49 |
| | Nyaruguru | 2,062,329 | 443,862 | 22 | 1,195,244 | 58 | 423,223 | 21 |
| | Ruhango | 2,524,718 | 292,507 | 12 | 1,263,333 | 50 | 968,878 | 38 |
| Kigali City | Gasabo | 902,557 | 269,655 | 30 | 341,719 | 38 | 291,183 | 32 |
| | Kicukiro | 171,201 | 62,261 | 36 | 72,165 | 42 | 36,775 | 21 |
| | Nyarugenge | 254,622 | 140,563 | 55 | 72,165 | 29 | 39,513 | 16 |

**Figure 2.8: Distribution of coffee trees by age per District.**




Source: National Coffee Census 20011

Considering the number of coffee trees, Nzahaha Sector in Rusizi District is the first at the national level with 1,392,171 trees followed by Macuba Sector with 1,210,539 trees and Karambi wth 1,152,085 trees both Sectors of Nyamasheke District. We can observe that the first three Sectors with high number of coffee trees are all located in the biggest coffee growing area in the Western Province. The last three sectors with small number of coffee trees at the national level are Tabagwe with 1,890 trees in Nyagatare District, Gatsata with 160 trees in Gasabo District and Kinoni with 94 trees in Burera District.

In order to understand well the above statistics, we have subdivided the 331 Sectors into five groups according to the number of coffee trees in the following ranges: > 800,000 trees, 450,000 to 800,000 trees; 250,000 to 450,000 trees; 100,000 to 250,000 trees and < 100,000 trees.

(i) The first group comprises 13 Sectors with the number of coffee trees between 804,385 and 1, 392,171. Among them, 8 are located in the Western Province in the Districts of Rusizi, Nyamasheke and Rutsiro. Two Sectors are in the Northern Province in the District of Gakenke, one in the Southern Province in the District of Huye and lastly two are in the Eastern Province in the Districts of Rwamagana and Ngoma. These 13 Sectors represent 18% of the total number of coffee trees at the national level. Those Sectors possess 65,135 plantations with an average of 200 trees per plantation occupying 5,222 hectares.

(ii) The second group comprises 33 Sectors with the number of coffee trees ranging from 455,260 to 785,931. Among them, 3 are in the Eastern Province: 1 in Gatsibo District; 2 in Kirehe district; 14 are in the Southern Province in the Districts of Kamonyi (4), Huye (2),Ruhango (2), Nyamagabe (3), Nyaruguru (1) Nyanza (1), Muhanga (1).

13 Sectors within the Western Province in 5 Districts of Nyamasheke(7), Rusizi(3), Rutsiro(1), Karongi(1), Rubavu(1). They have 27% of coffee trees countrywide accounting for 101,845 plantations with an average of 194 trees per plantation and occupying 7,888 hectares.

(iii) The third group puts together 57 Sectors having between 250,831 and 499,873 coffee trees. They are well from different Provinces of the country except Kigali City. This group has 28% of coffee trees at the national level. It has 103,533 plantations with an average of 192 trees per plantation and occupies 7,971 hectares.

(iv) The fourth group is composed of 85 Sectors with the number of coffee trees ranging from100, 509 and 249,849. This group represents 19% of the total number of coffee trees Well spread out in all Provinces. It has 80,818 plantations with an average of 167 trees per plantation and occupying 5,395 hectares.

(v) Finally the fifth group brings together 143 Sectors with the number of coffee trees between 94 and 99,965. Despite the fact that this group accounts for 43% of the total number of coffee growers, it only represented 8% of coffee trees. It accounts 42,876 plantations with an average of 137 trees per plantation and occupying 2,355 hectares.

# CHAPTER 3: MATERIALS AND METHODS

The study was conducted through all over the country. This one has 5 Provinces, 30 Districts and each with an estimated area occupied by coffee plantations.

The materials and equipment used are: Pens, Pencils, Notebooks, Digital camera and Computer (Lap-top) for data storage and treatment, flash disk for collecting data in softcopy format and current GIS Software (ArcMap 10.1).

## 3.1 Techniques of data collection

Several techniques were used to get the data required such as literature research, discussion with key informants, survey and observation. An explanation of how was performed follows below.

- **Literature research**

This technique helped in acquiring secondary data which were analyzed in order to have better insights into the agricultural situation in Rwanda, and in particular, the coffee production. The data were also used in providing background information on the study areas useful for the research. The literature was important in setting up the foundation of all other techniques that were used later. Several documents that were collected include past studies and reports considered relevant to the research problem, policy papers and development plans from different institutions.

- **Discussion with key informants**

Discussions with key informants were useful to collect as much data as possible about the key information needed in the research. The dataset collected include climatic and topographic data, administrative boundaries, agro-environmental criteria or attributes data and hydrology data.

The discussion with the informants helped:

- to define key environment factors that affect directly the condition of coffee growth,
- to quantify the significance of each factor in various spatial locations,
- to understand the theory of setting the potential zone of coffee growth through MCDA.

Informants were the staff in different institutions and ministries dealing with agriculture, environment, research and development issues. Those are Rwanda government organizations such Rwanda METEOROGY, NAEB, NISR, MINEREMA, MINALOC and RAB/ISAR/ MINAGRI.

### 3.2 Analytical approach

To identify suitable coffee growing areas in Rwanda, Multi-criteria environment (MCE) and GIS have been integrated to address the spatial multi-criteria decision making. The spatial multi-criteria decision making is a process where geographical data is combined and transformed into a decision. Multi-criteria decision making involves input data, the decision maker's preferences and manipulation of both information using specified decision rules.

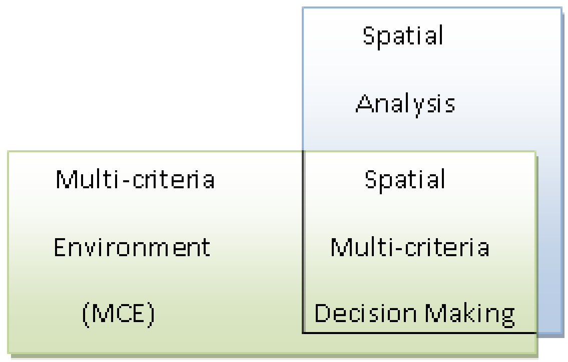



**Figure 3.1:** Integration of MCE and GIS into Spatial MCDM

**The selection and overlaying steps:**

- Identify potential coffee growing areas:

The research has considered only the primary environmental factors that affect directly the coffee growth such as Temperature, Rainfall, Elevation and Soil PH variables.

- Define potential criteria or attribute of each factor contributing to the set of coffee suitable areas in various spatial locations
    - Elevation between 1400 and 1900m
    - Temperature between 15 and 21$^0$C
    - Rainfall between 1100 and 1600mm
    - pH Soil between 4.5 and 6

**Step 1: Selection by attributes.**

From the shapefiles collected from the above institutions, illustrating the distribution of each variable among the four; we selected from the attributes table on ArcGIS windows using "Select by attribute" function. By applying with a potential attributes, we obtained the areas which respond positively to the coffee growth and this selection has been done for each factor.

**Step 2: Overlaying by intersection**

The next step was overlaying by intersection from the Arc Toolbox windows. The selected parts or the set of suitable areas of coffee growth for each variable have been overlaid consecutively with the respect of the hierarchical structure principle (The criteria of greater importance is depicted in lower branches of the hierarchy). The final result illustrates the suitable or potential areas of coffee growth in Rwanda.

**A work flow diagram illustrating the selection and overlaying procedures.**

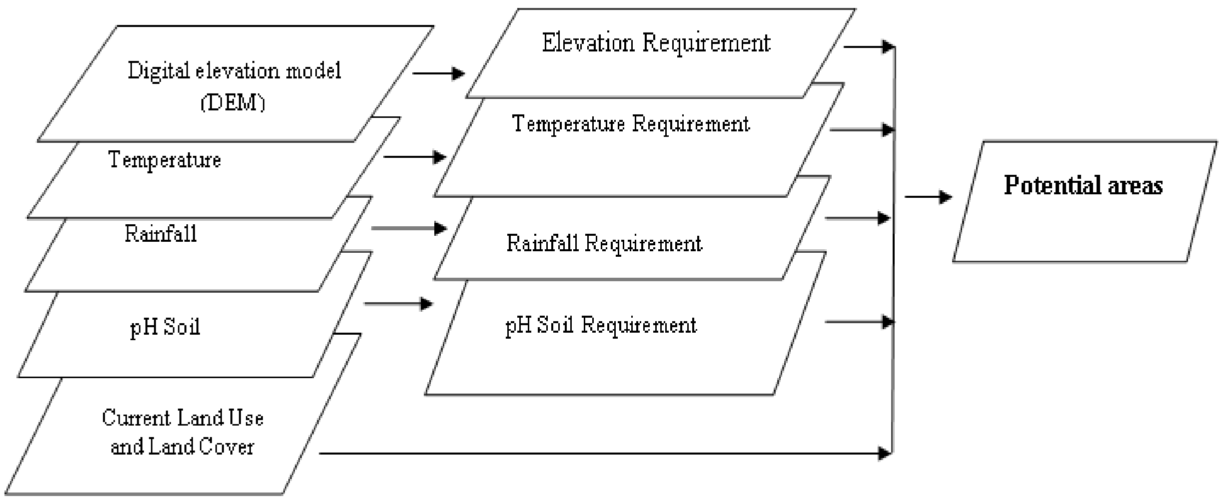



**Figure 3.2: A cartographic model of using GIS to identify potential areas for coffee**

The figure 3.2 shows different shapefiles illustrating the distribution of the defined environmental factors all over the country (First colon). The potential criteria described above have been selected by its attributes to extract suitability of area by each variable and alternatives classes have been created (colon II). Then the result obtained has been overlaid respectively and hierarchically to retrieve the areas which respond to all criteria of coffee growth enumerated above. The specific location obtained after selection and overlaying at a scale of 1:1,500,000, identifies the potential areas whereon coffee grows successfully with high production and quality.

# CHAPTER 4: RESULTS AND INTERPRETATION

The main objective of this study is to identify suitable areas for growing coffee in Rwanda; that has been achieved by choosing among many, the most important environment factors which respond greatly to the coffee production. Therefore, i have proceeded by selecting their potential attributes values then overlay the selected parts consecutively to obtain the suitable areas.

## 4.1. SELECTION BY ATTRIBUTES

### 4.1.1 Elevation and Coffee Growth

High elevation improves the quality of the bean and potential cupping quality. The altitude contributes significantly to coffee taste profile. High grown beans are hard, dense, and possess the potential for exceptional coffee flavor. The truly stunning coffee is grown between (1400-1900m. The Altitude, the weather, the amount of light, the temperature, the less amount of oxygen; all that makes the beans ripen very slowly, and that allows the flavor to concentrate and also they are harder. The following map shows the Rwanda Digital Elevation Model.

**Figure: 4.1. Rwanda Digital Elevation Model.**

As the elevation increases, a coffee's flavor profile becomes more pronounced and distinctive until the marginal position of significance. The suitability growing area is obtained by selecting the attributes defining the potential variable which respond well to the coffee growth conditions**.** The suitable area of coffee is found in the western part of Rwanda along the Kivu-lake; the central and Eastern parts are also suitable area for growing coffee by elevation.

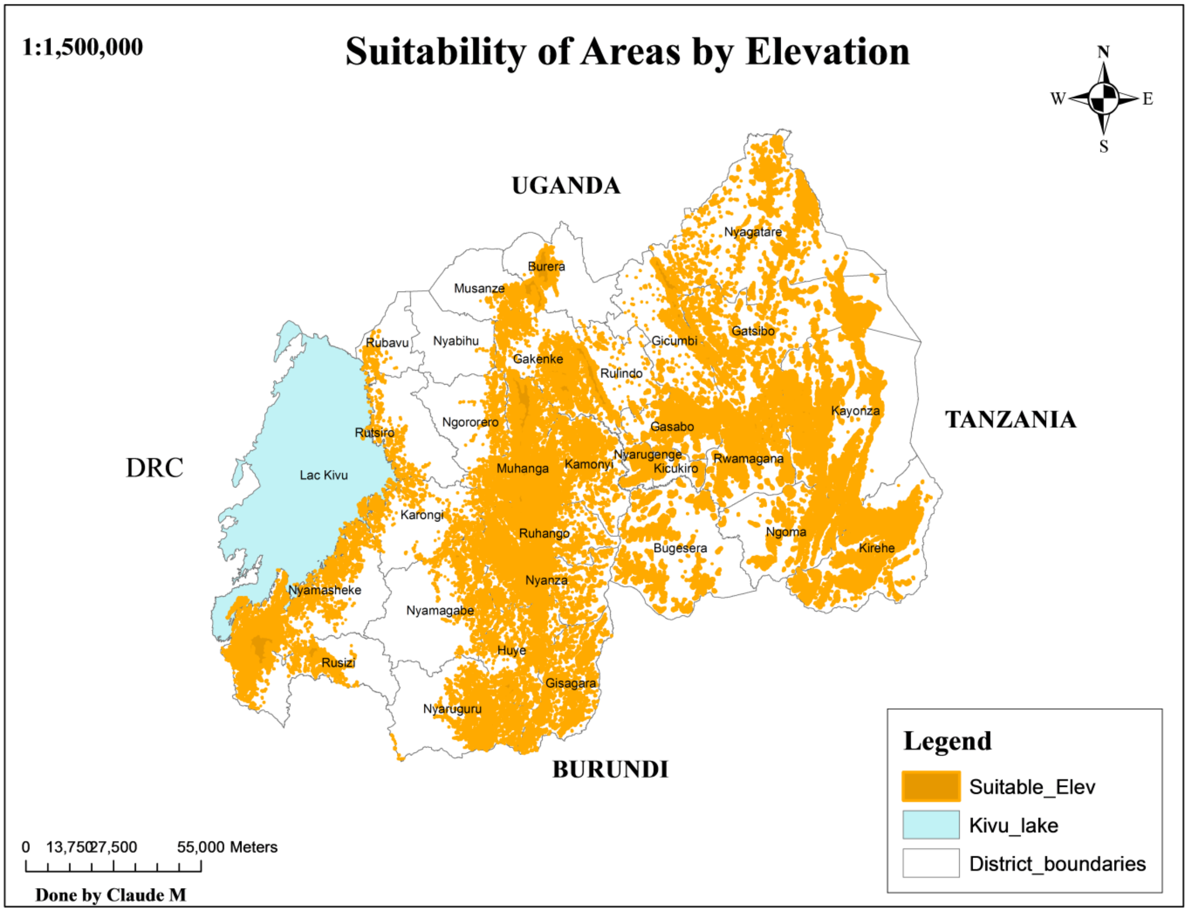



**Figure 4.2: Suitability of areas by Elevation**.

In Rwanda, the impact of distribution of elevation on coffee growth has been weighted according to the degree of suitability. It was found that the elevation between 1400m to 1700m respond highly well to the suitability of coffee growth; and based on the findings of the study, this part is allocated in the western, central and eastern part of the country.

As well as we move to the elevation between 1700m and 1800m, we are penetrating the area with moderate suitability for coffee growth allocated to the central part; then between 1800m and 1900, the suitability decreases slightly through the dispersed parts of the country.

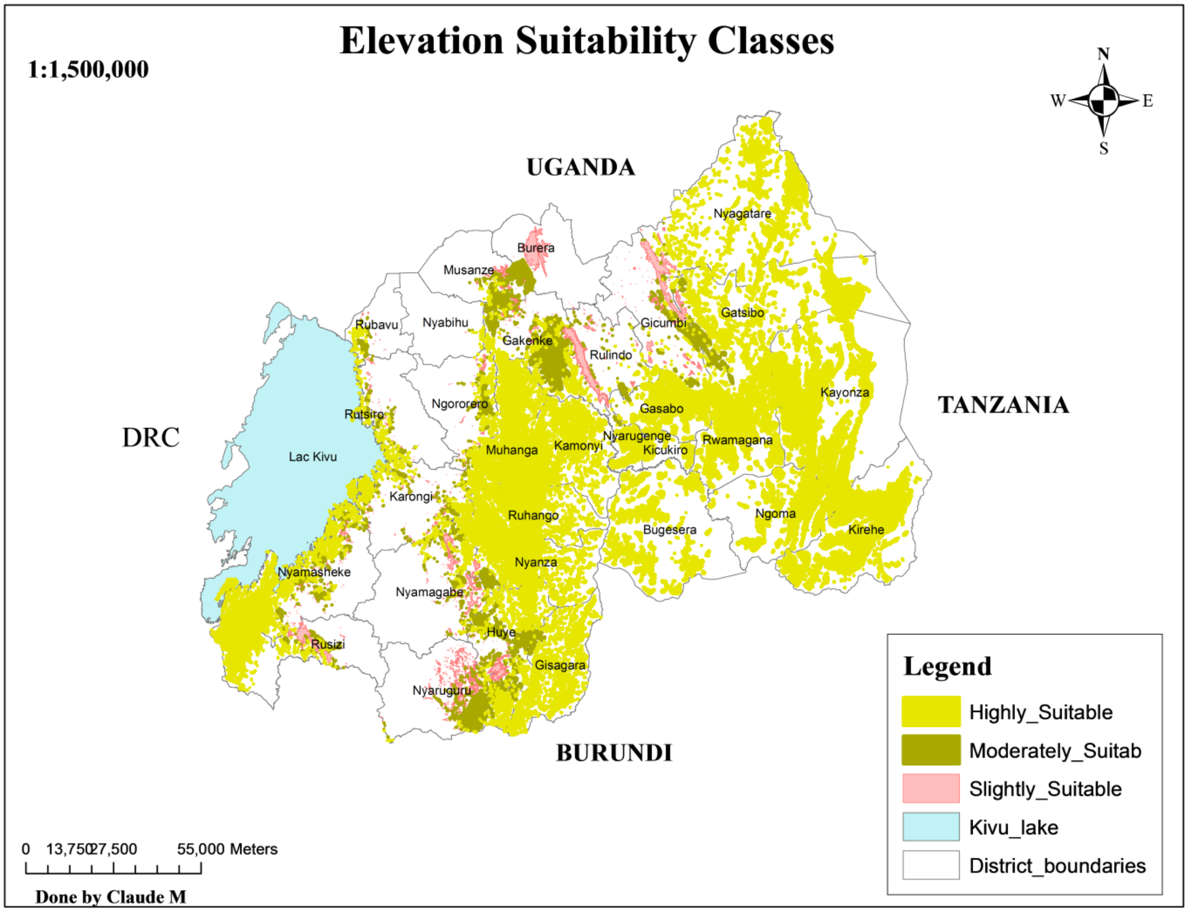



**Figure 4.3:** Suitability classes by Elevation

### 4.1.2. Temperature and coffee growth

The range in temperature of a particular region is affected by location. Like all plant, coffee will not grow optimally when temperature are either too low or too high, Ambient air temperature influence the leaf development. There is a direct relationship between extremes of day and nighttime temperatures and coffee quality. Experimental evidence has indicated that a large gap between day and nighttime temperatures is beneficial to the flavor of fruits.

Since a coffee cherry is a fruit and the seed is in contact with the fruit, these benefits will be passed onto the seed and therefore into the cup. The map in figure shows how the temperature is annually distributed in the whole country.

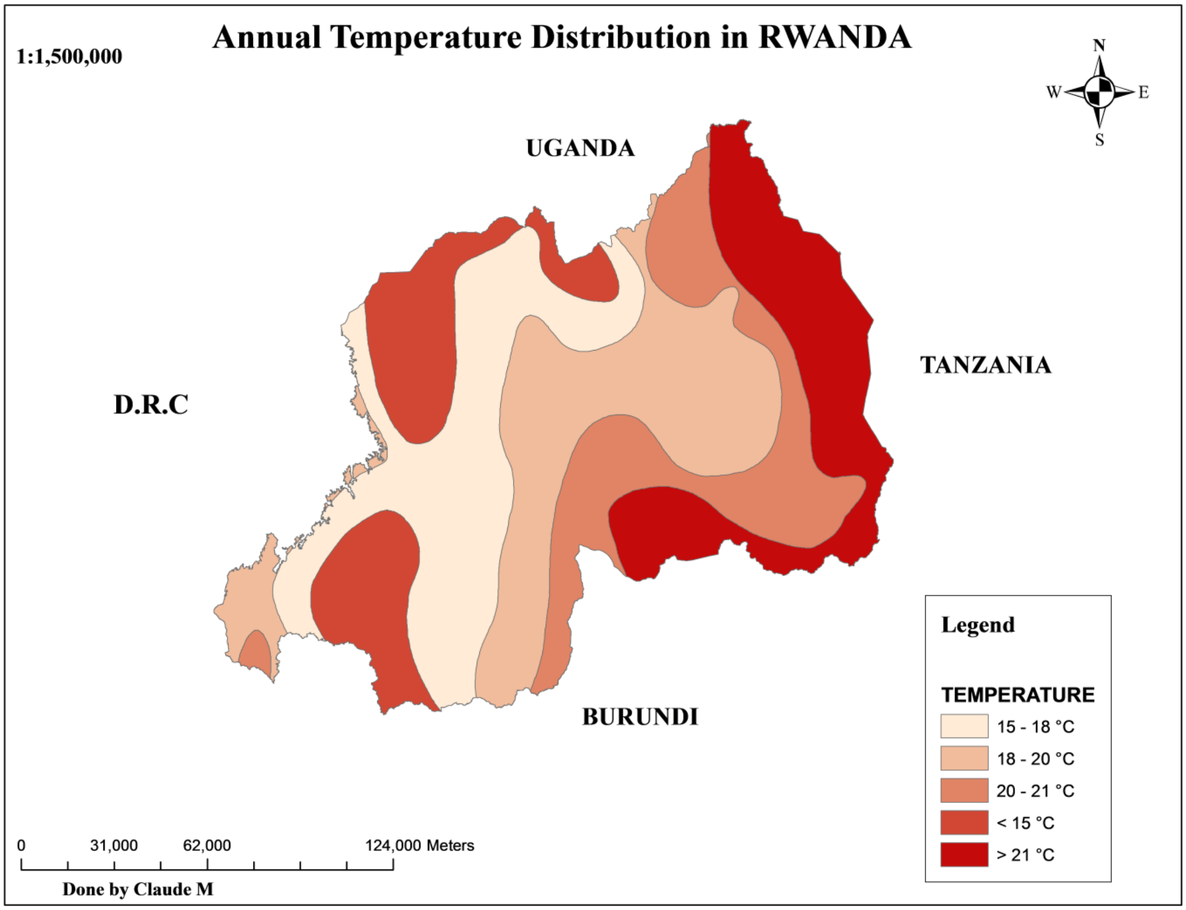



**Figure 4.4:** Rwanda annual temperature distribution

The shapefile illustrate the annual distribution of temperature all over the country. The previous published researches on vulnerability of coffee production to global climate change reported that the coffee grows well under air temperatures range of 15-21$^0$C (Waston, 1986). The temperatures greater than 30°C cause plant stress leading to a cessation of photosynthesis. Mean temperatures of less than 15°C limit plant growth and are considered sub-optimal.

From the Rwandan annual temperature distribution Shapefile; the land suitability of coffee growth has been identified based on the potential variable range of temperature which varies between $15^{o}$ to $21^{0}$C. The selected part on the map below represents the location which responds positively to the coffee growth by temperature in the country.

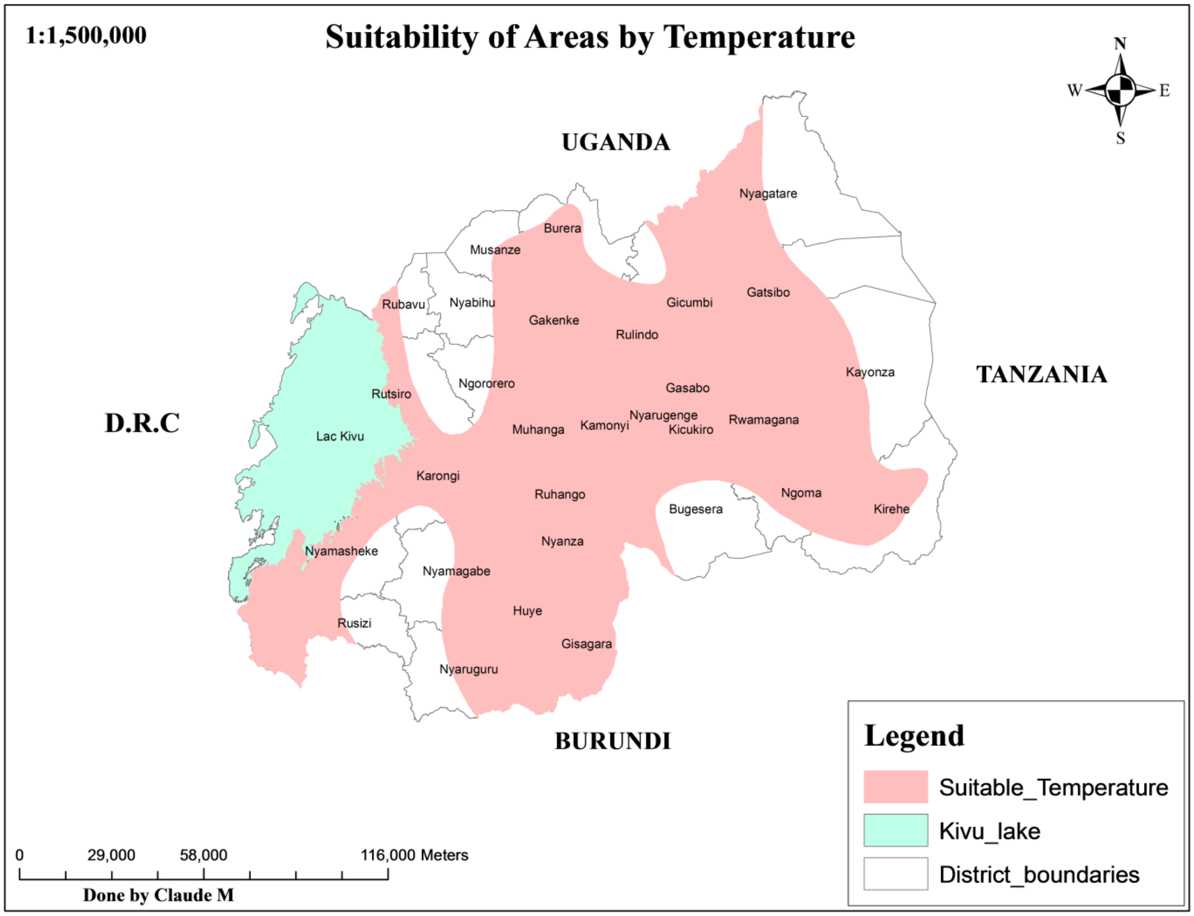



**Figure: 4.5.** Suitability of area by Temperature

The suitable areas of coffee growth are found in the west part and the centre-eastern part of Rwanda. Based on the suitability area by temperature, the impact of that variable on coffee growth has been weighted according to the degree of suitability. It has observed that the temperature beyond $18^{0}$ to $20^{0}$ respond highly well to the suitability of coffee growth; and the temperature between 15 to $18^{0}$ enclose the area with moderate suitability; As well as we move up to the temperature above $20^{0}$ to $21^{0}$, , the suitability decreases slightly to coffee growth.

The classification identifies different level of the consistence ratio of suitability to the coffee growth by temperature.

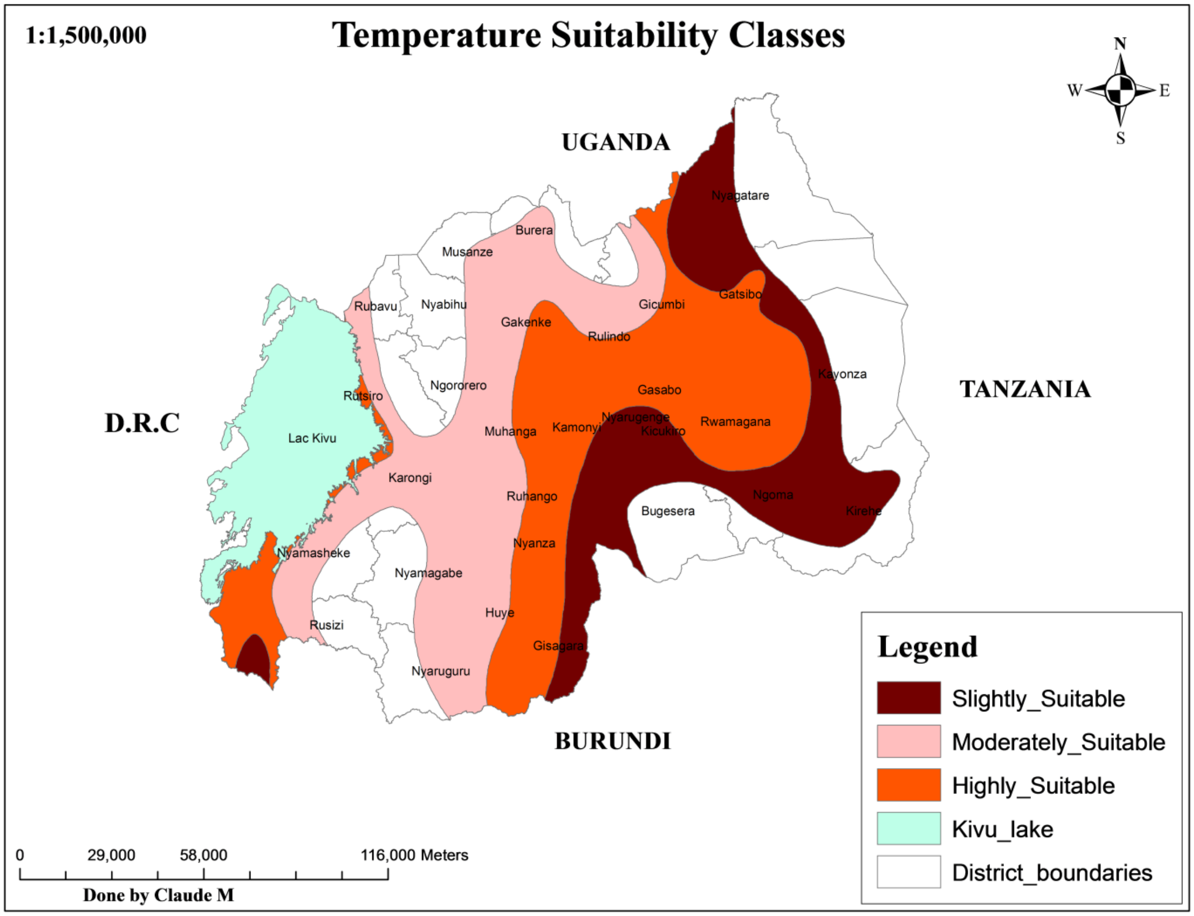



**Figure 4.6:** Suitability classes by Temperature

The western part along the lake-Kivu and central part are the highest suitable area followed by the middle of those two parts in light green color; the third class of suitability by temperature is the eastern part in yellow color.

## 4.1.3. Rainfall and Coffee Growth

In general, coffee needs an annual rainfall of 1,100 to 1,600 mm. The pattern of rainy and dry periods is important for growth, budding and flowering. Rainfall requirements depend on the retention properties of the soil, atmospheric humidity and cloud cover, as well as cultivation practices.

The shapefile below illustrates the annual distribution of rain in Rwanda. Both the total amount and the distribution pattern are important. Unless regular rain is received, young trees should be irrigated to ensure establishment of the newly planted trees.

Rain should to be uniformly distributed over seven to nine months of the year, as is the case especially at higher elevations. Coffee requires adequate water during the growing and cropping period; however it also requires a dry stress period followed by sufficient rain or irrigation to promote uniform flowering and a good fruit set.

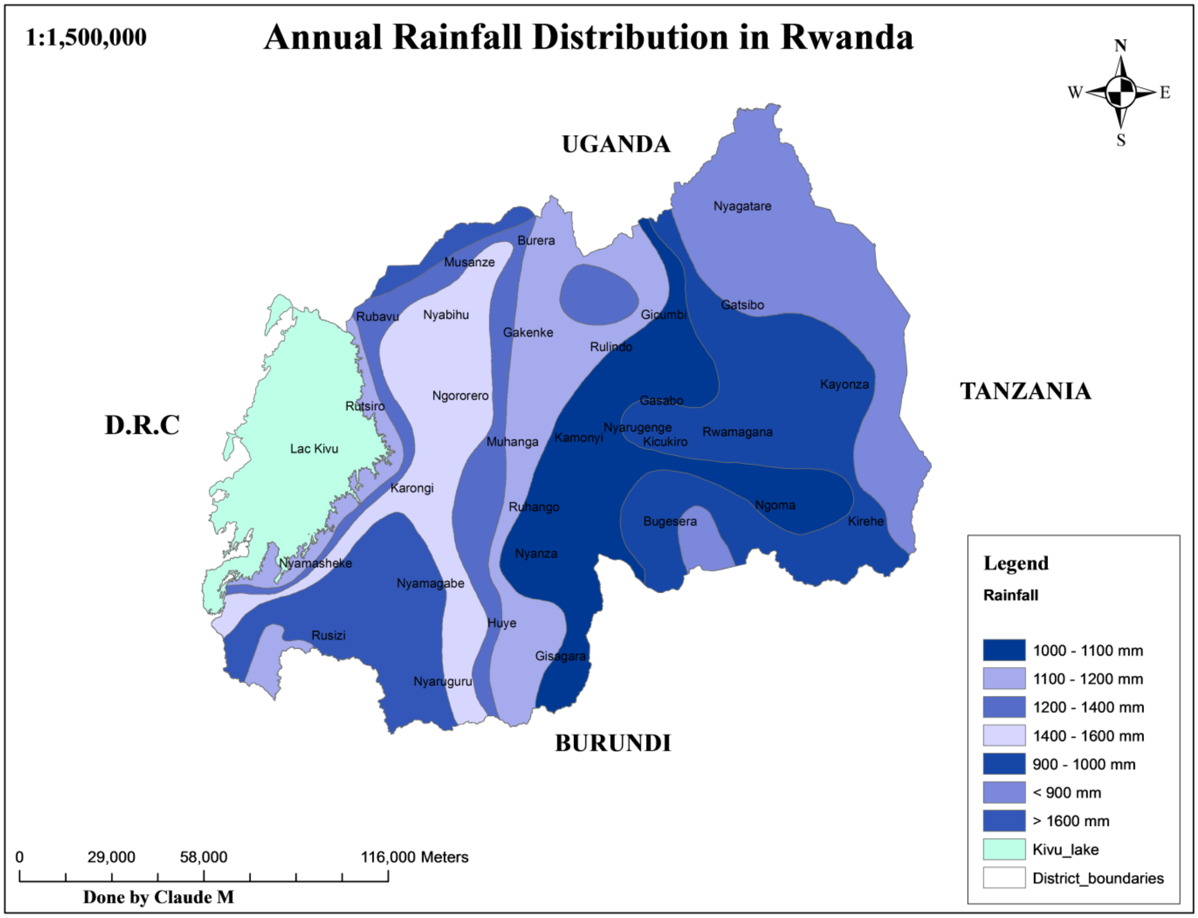



**Figure 4.7:** Rwanda Rainfall distribution

The ideal rainfall for Arabica coffee is greater than 1100 to 1600 mm per year. If heavy rain continues for several days during the coffee flowering period, flowers will rot and the crop will be small.

The extracted part on the map illustrates the area on which coffee has suitable rainfall for the growth in Rwanda. The zones which respond to the suitability areas by rainfall are the western and the central part of Rwanda.

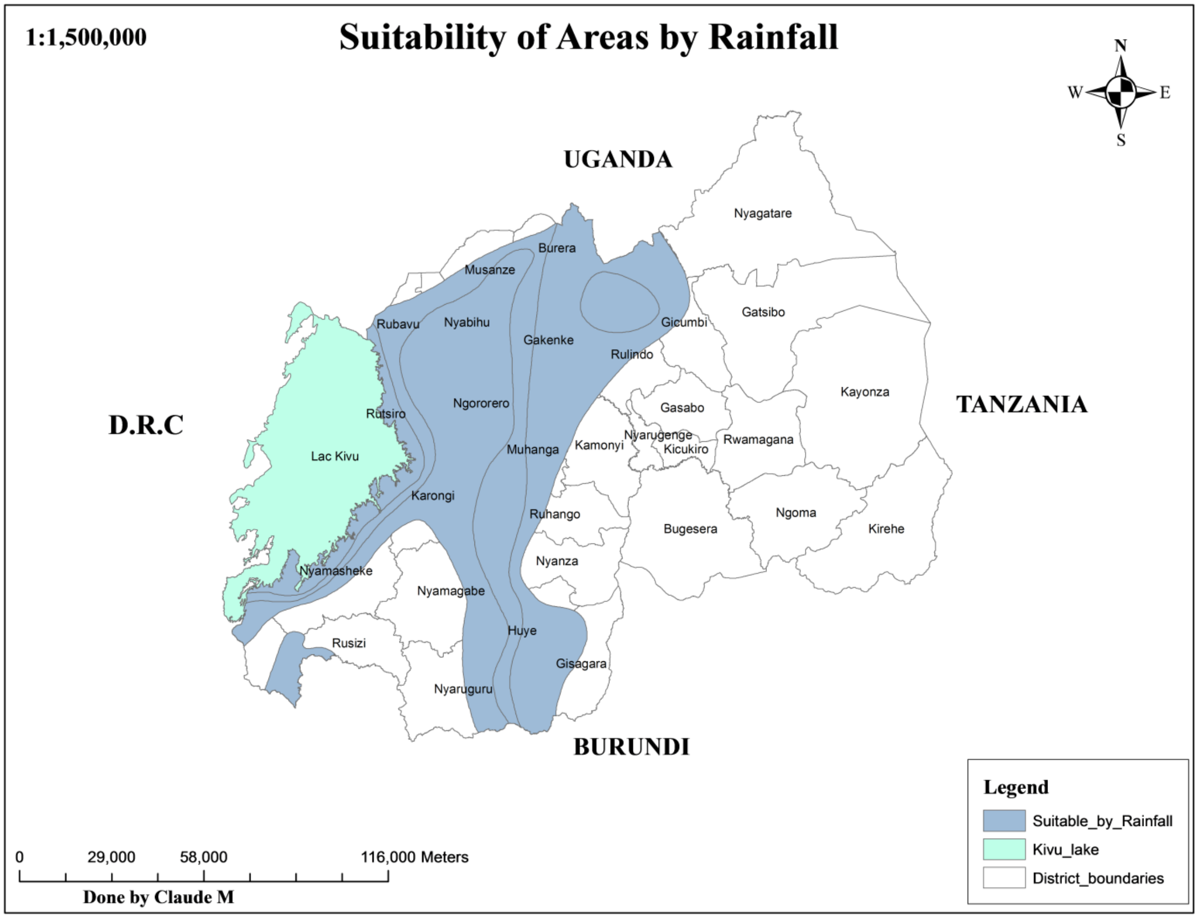



**Figure 4.8:** Suitability of area by Rainfall

It has been observed that the Rainfall between 1100 to 1200mm respond highly well to the suitability of coffee growth; and the Rainfall above 1200 to 1400mm correspond to the area with moderate suitability on coffee growth; As well as we move up to the temperature beyond 1400 to 1600mm, the suitability decreases slightly to the coffee growth.

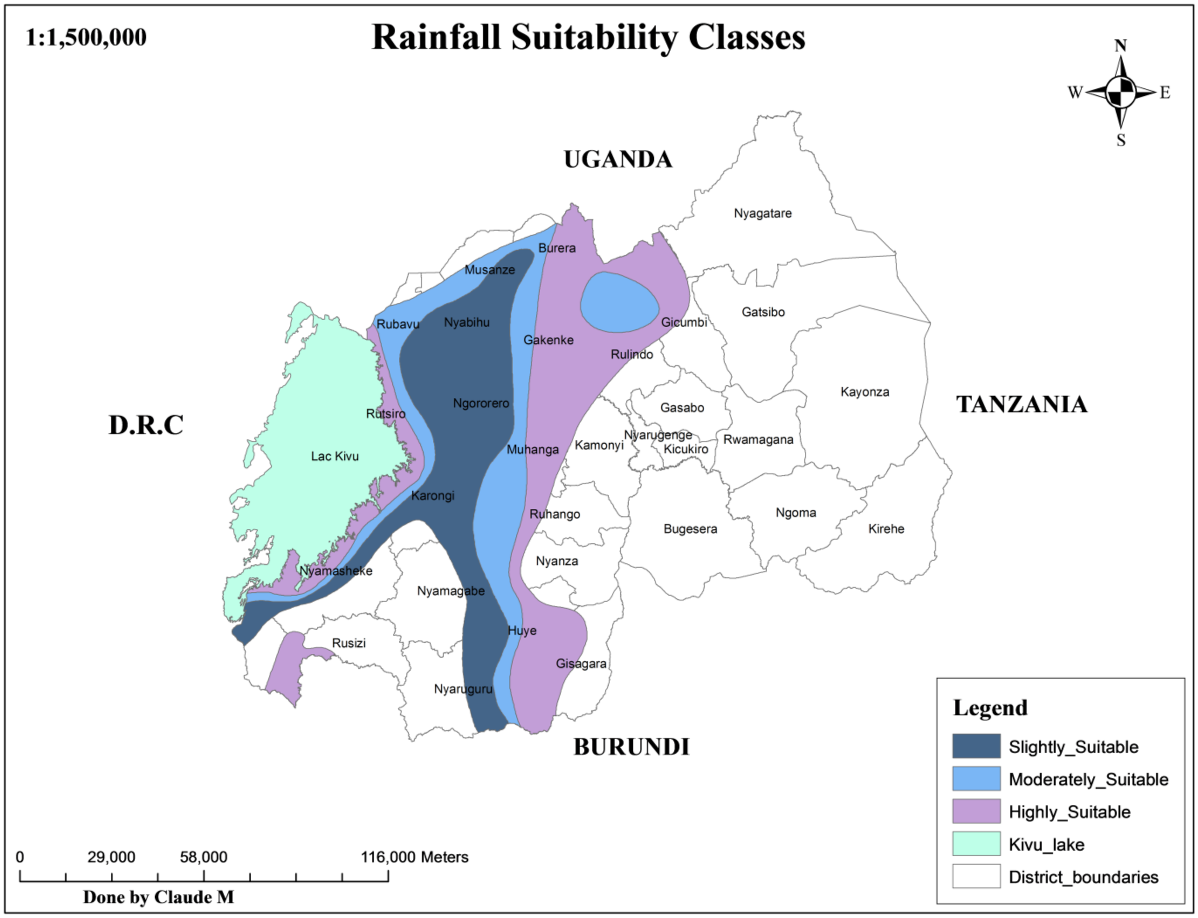



**Figure 4.9**: Suitability classes by Rainfall

The western part along the lake-Kivu and central part are still the highest suitable area followed by the middle of those two parts in light green color as you can see on the Map and the Legend.

## 4.1.4. pH Soil and Coffee Growth

The shapefile below shows the pH soil distribution in Rwanda. Coffee grows best on deep, porous, well drained soils, especially those of volcanic origin. Soils with excessively leached topsoil, impervious subsoil layers, or solid rock close to the surface will not support healthy coffee trees. Coffee will not do well and can die on heavy soils if drainage is a problem or if the soil is kept continually waterlogged below the surface. The map on the next page illustrates the pH Soil distribution all over the country.

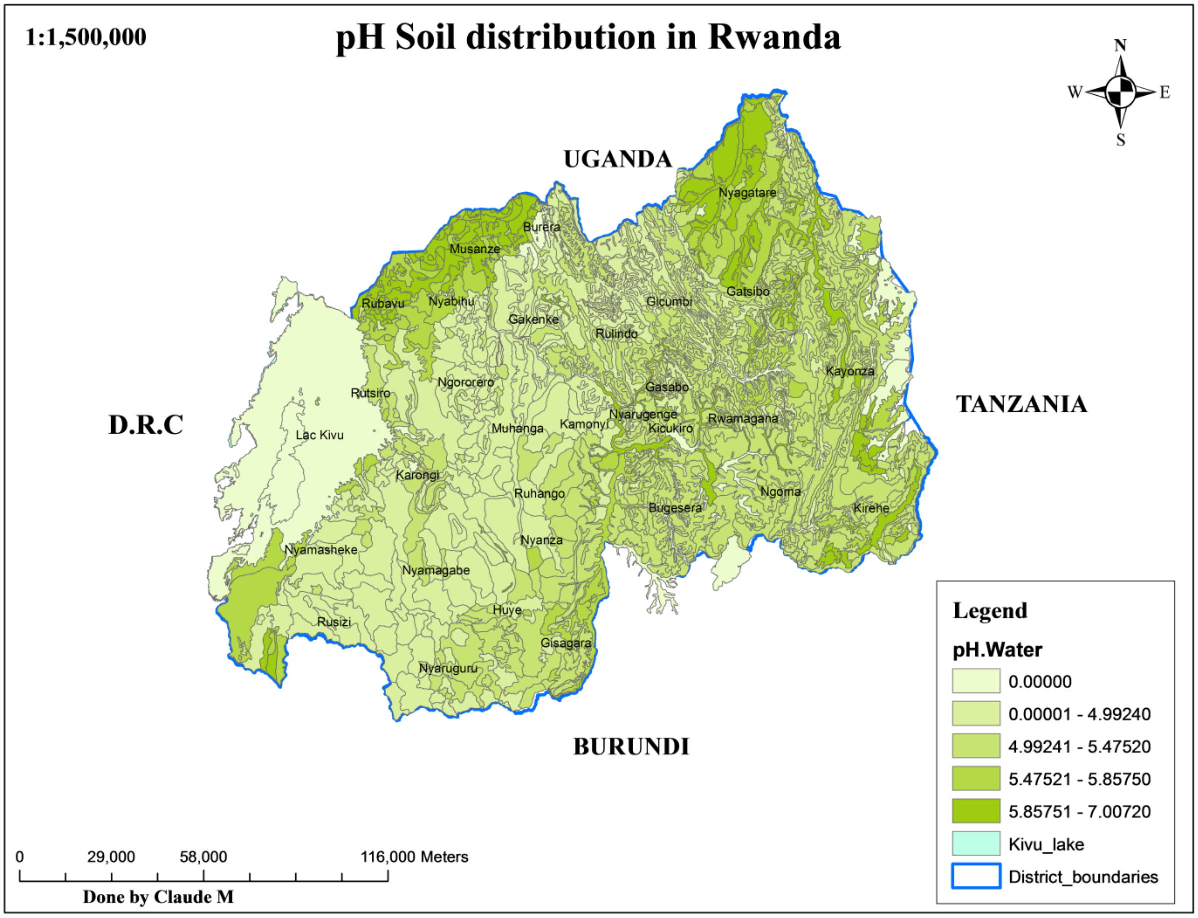



**Figure 4.10:** Rwanda pH Soil distribution

Coffee prefers a soil with PH of 4.5 to 6. Acid less than 4.5 need lime or dolomite. Soil pH is important because of the many effects it has on biological and chemical activity of the soil, which affects the metabolism of the plants.

Low PH Soil will limit crop performance by upsetting the availability of key nutrients to coffee plants. The following map shows the suitability of area by pH Soil according to the preferences described above.

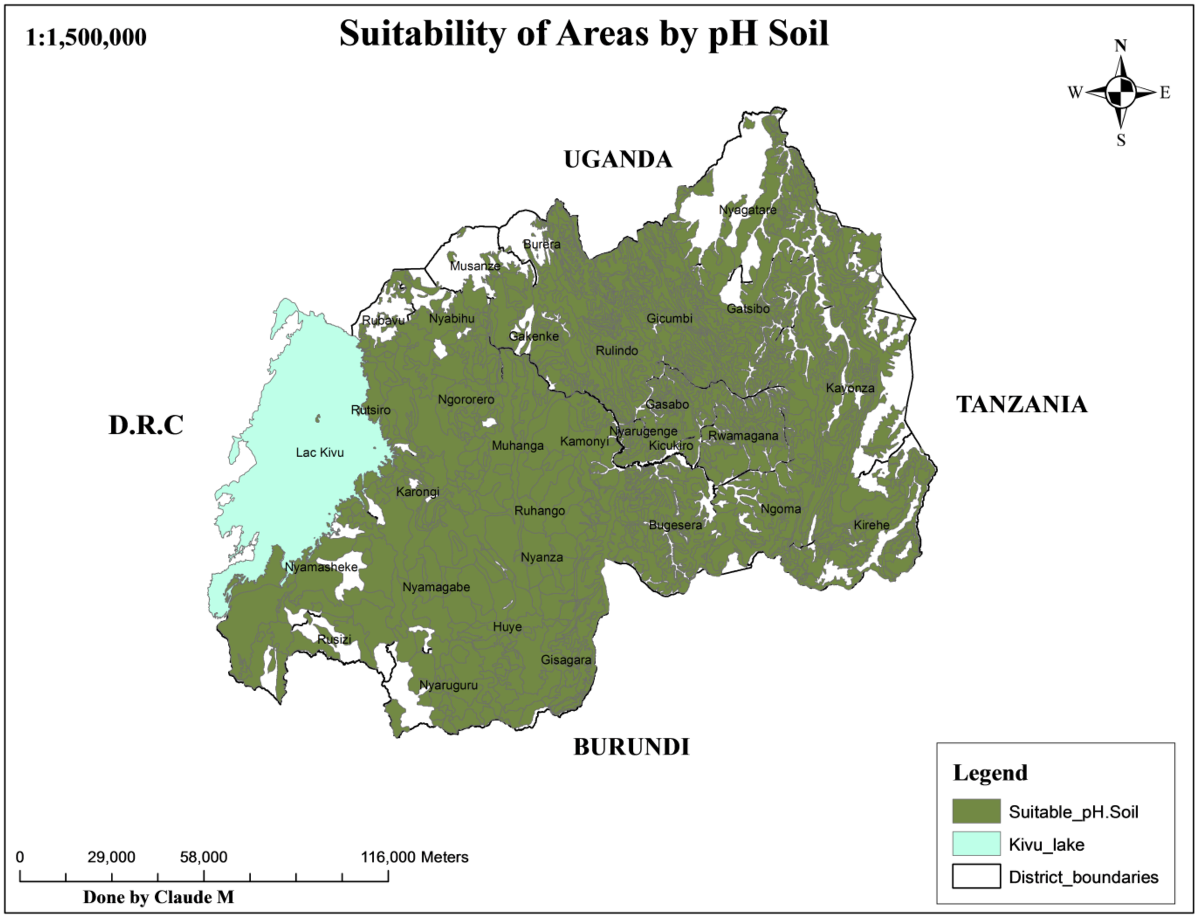



**Figure 4.11:** Suitability of area by pH Soil.

The suitability of areas by pH soil are found almost all over the country. Referring to the degree of suitability, the impact of that variable on coffee growth has been weighted and the internal consistence rate of pH soil has been taken as equal score and there is no subdivision of classes based on the suitability area of coffee growth in the whole country.

## 4.2 . OVERLAYING FEATURES BY INTERSECTION.

The following step is to overlay (intersect) respectively the results obtained from different criteria in the selection by attributes; and retrieve finally the overall solution which correspond to the land suitability for a particular location. The areas that respond to all criteria give the well conditions of coffee growth. The level of suitability for each site was measured by the overlaid lands based on the score of suitability from one criterion to the other using the same formula. The CR determines the internal consistency of the weights relative to the overall solution.

### 4.2.1. Elevation and Temperature

Elevation and Temperature conditions are important factors in defining potential coffee yield. The elevation of prevailing temperatures has an important effect in modifying transpiration losses. The Arabica coffee plant responds sensitively to increasing temperatures, specifically during blossoming and fructification. The two variables have been overlaid first to respect the hierarchical structure principle. The results attribute the potential of coffee growth to the west and centre eastern part of the country.

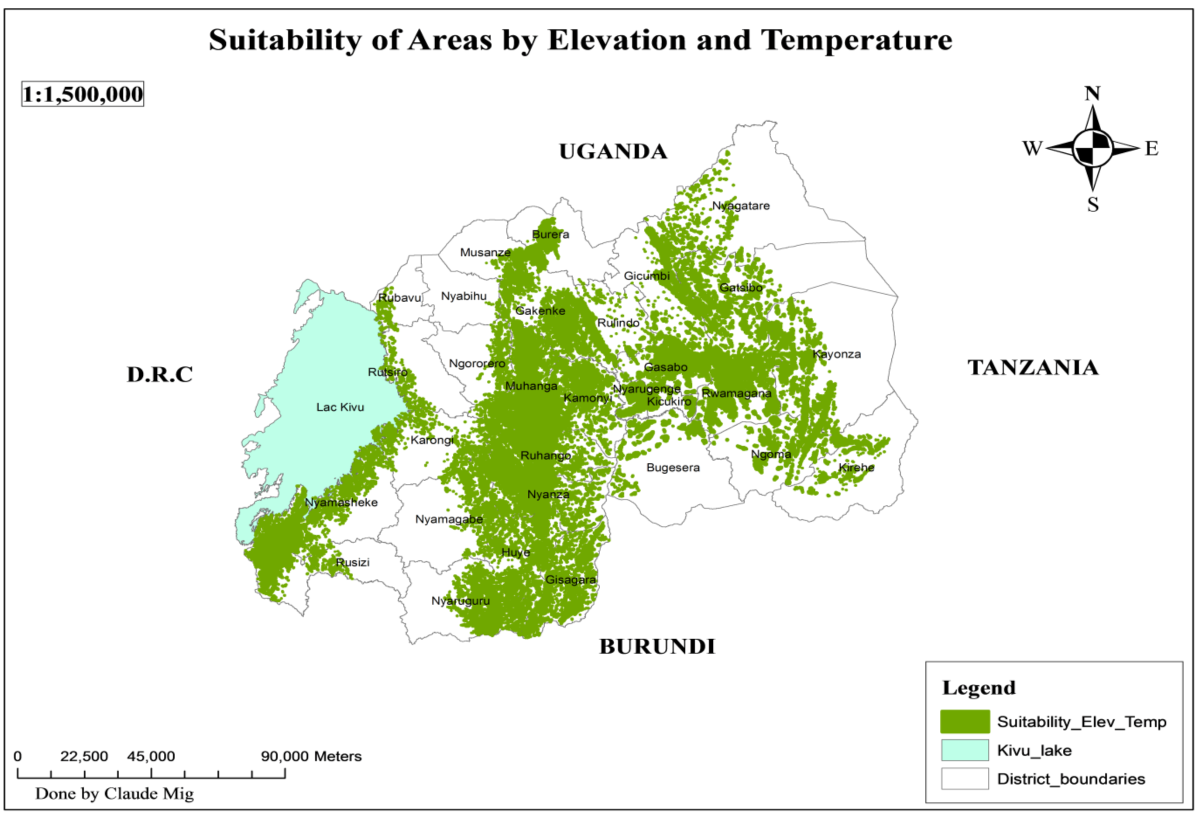



**Figure 4.12:** Suitability of area by Elevation and Temperature

## 4.2.2. Elevation, Temperature and Rainfall.

The map below illustrates the zone on which environment responds positively to the coffee growth by Temperature, Rainfall and elevation.

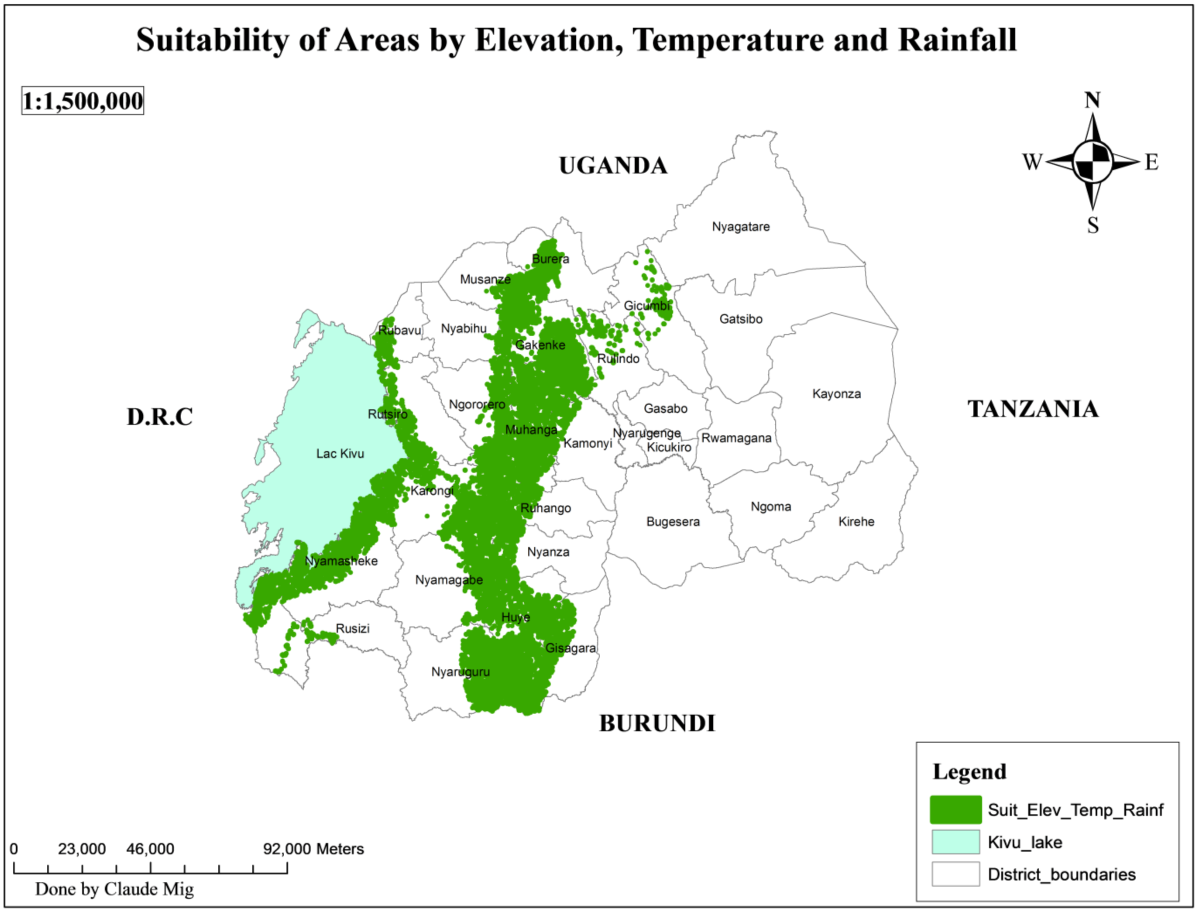



**Figure 4.13:** Suitability of area by Elevation, Temperature and Rainfall

The study findings illustrate that the suitability of areas by the tree variables or attribute give the potential of coffee growth on the western and the central part of the country.

A period of moisture stress (rain after a dry spell) helps cause a homogenous flowering and therefore promotes a clearly defined harvesting season. Coffee producing by countries with more than one wet and dry season will have more than one harvesting season. A period of moisture stress (rain after a dry spell) cause a homogenous flowering and therefore promotes a clearly defined harvesting season. The suitable coffee growing requirement above recommends the temperature between 15 and 21$^{0}$C then the Rainfall between 1100 and1600 mm.

### 4.2.3. Elevation, Temperature, Rainfall and pH Soil

The selected part on the map below shows the suitable area of coffee growth in Rwanda. The zone is covering the border of the Lake Kivu respectively in the district of Rubavu, Rutsiro, Karongi, Nyamasheke and Rusizi. The south province of the country responds also to the suitability of coffee growth especially in the district of Muhanga, a part of Ruhango and Nyanza; still in the southern province, the Huye district, part of Nyamagabe, Nyaruguru and Gisagara district have been found out as a suitable coffee growing area. In the North province, Gakenke district gives potential to coffee growth and a part of Rulindo, Gicumbi, Musanze and Burera district.

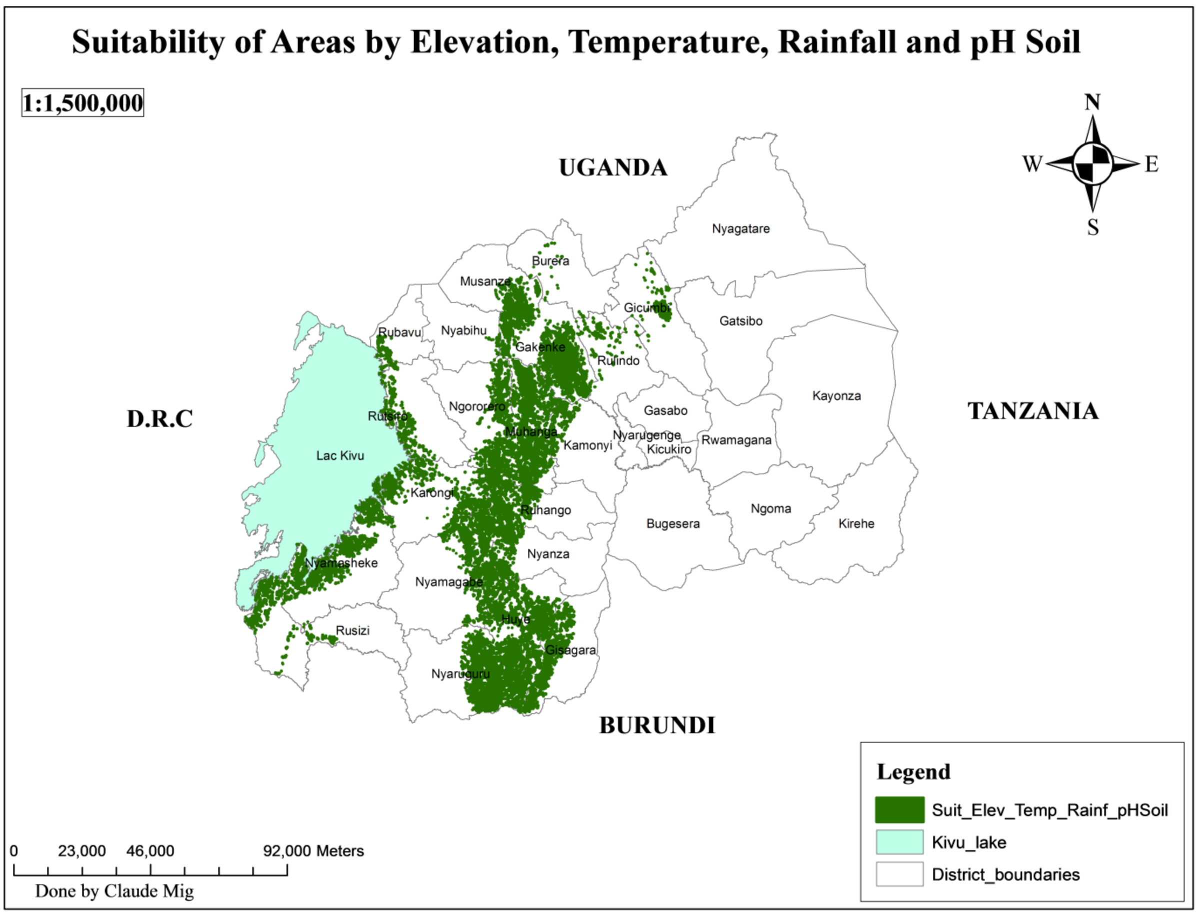



**Figure 4.14:** Suitability area by Temperature, Rainfall, Elevation and pH Soil

# CHAPITRE 5: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS.

## 5.1. DISCUSSION

Generally, environment factors have a great impact on the suitability coffee growing area in Rwanda. Temperature, rainfall, elevation and soils are all important, but requirements vary according to the varieties grown. Unfavorable climate could affect Arabica coffee production directly and indirectly; and diseases directly because climate affects the flowering stage of coffee by flower abortion and the bean filling stage by causing premature ripening of the beans, and indirectly due to the appearance or increasing incidence of certain pests. The unpredicted rains will cause coffee to flower at various times throughout the year, causing the farmers to harvest small quantities continuously.

The zone of Mibirizi, the actual districts of Nyamasheke and Rusizi, constitute a greater potential areas of coffee growth in Rwanda based on suitability classification; it coincides with the event of planting the first coffee tree by German missionaries at the beginning of the 20$^{th}$ century in that southern zone along the Lake-Kivu. The north prolongs bordering the lake-Kivu in the districts Karongi, Rutsiro and Rubavu have also a wonderful environment of coffee growth.

This evidence confirms the three first winning lots from that zone, scoring between 89 to 91points recently in 2013 Rwanda Cup of Excellence Competition. Furthermore, this zone is the highest in number of coffee trees in the whole country with 8,379,115 and 6,121,002 respectively in district of Nyamasheke and Rusizi, previously known Mibilizi.

The central part of Rwanda from the north to the southern province, respectively in the south east of Musamze district, in eastern part of Nyabihu, Ngororero, Karongi, Nyamagabe and Nyaruguru districts; the whole districts of Gakeneke, Muhanga and Huye then the oustern part of Rulindo, Muhanga, Ruhango, Gisagara and the east of Gicumbi are both suitable to coffee growth.

Some evidences are confirming the findings of the study such as the Gakenke district which came on the third position in the competition with 5,166,853 coffee trees and the Kamonyi district which occupies the fifth position in quality with 4,292,396 coffee trees in the whole country.

In between the western and central suitable parts cited above, we find unsuitable areas of coffee growth covering the west Musanze, Nyabihu, Ngororero, Nyamagabe, Nyaruguru, south of Karongi and the east of Rubavu, Rutsiro, Nyamasheke and Rusizi districts.

All the remaining part of the country which are the eastern province constituted by the Nyamagabe, Gatsibo, Kayonza, Rwamagana, Bugesera, Ngoma and Kirehe districts including the Kigali-city are both unsuitable areas of coffee growth.

Inconsistent practices have been recognized such as coffee intensification and extension in those districts which do not match the environment of coffee growth; such Ngoma and Kirehe district coming on the top ten districts in statistics with 4,292,396 and 3,415,268 coffee trees respectively. An extension of coffee settlement on wide land with an average more than 257 trees per plot; that is mainly found in the eastern province where there is still available space of agriculture land in the district Kirehe which occupying the first position with average of 512 trees per plot, Ngoma district is coming on the second position with average of 332 trees per plot, the same to Nyagatare, Gatsibo, Rwamagana, Kayonza, and Bugesera districts but do not respond to the suitability areas of coffee.

Adaptation strategies have to consider the resource constraints and risk adverse behavior of coffee smallholders. Planting shade trees can be an adaptation strategy to unsuitable climate. Fruit trees can at once provide shade, increase food security while timber tree provide wood for use in building and carpentry. Intercrops like banana can also be used as they provide cash and food from the same piece of land and offer shade.

Whereas the adaptation practices require investments (Labor, planting material, nutrients, pesticides), only a small number of farmers actually re-invest part of their revenue back into their coffee field at present. This is because the income from coffee has to be spent on more urgent priority like school fees, food products, and medical expenses.

It has been observed that farmers located in the potential environment areas of coffee growth are motivated and invest a lot on coffee business, case study of district Nyamasheke, Rusizi, Huye. The case study in eastern province, on the other hand, farmers with deficient of coffee environmental potential are discouraged by the low production after spending a lot of efforts. Consequently, some of them have given up their coffee plantations or do not replace the old ones.

Those problems will be solved by allocating the Arabica coffee or other crops in the zone where environmental factors in place responds to the needs of growth for a given plant. And the only way to achieve the good results is to associate geospatial information system and Agriculture activities.

## 5.2. CONCLUSIONS

The role of geospatial technology in agriculture is here to stay. The strong responsibilities of agriculture in the global economy in terms of being a source of sustainable development, reducing poverty and addressing the food requirements of the significantly increasing population, coupled with depleting natural resources, can only be met with generous contribution from modern technologies. With the demand for farmlands and farm produce continuing to grow while the land resources remain limited, GIS has a key role to play in allocating resources and maximize productivity and output.

The study findings indicate that the suitable areas of coffee growing is located on specific zones of the country such as the west part of Rwanda along the lake kivu respectively in district Rusizi, Nyamasheke, and Rubavu; another area which gives potential of coffee growth is finding in central of Rwanda, from the north province in district Gicumbi, Rulindo, towards the south province in district Kamonyi, Muhanga, Ruhango, Nyanza, the whole of Huye, Gisagara, Nyaruguru and Nyamagabe.

The remaining zones are identified as unsuitable areas of coffee growth such as the eastern province of Rwanda in districts Nyagatare, Gatsibo, Rwamagana, Kayonza, Bugesera, Ngoma and Kirehe include the Kigali-city in district Gasabo, Nyarugenge and Kicukiro.

However, Rwanda is suffering the issue of land space comparatively to the population size. The maximization of land use is the most important strategy that can lead our agricultural production to the great result; and that can be greatly achieved by enhancing the relation between crops and its favourite environmental areas which respond to the suitability of growth.

GIS is found to be a technique that provides greater flexibility and accuracy for handling digital spatial data. The combination of AHP method with GIS in our experiment proves that this technology is a powerful combination to apply for land-use suitability analysis.

## 5.3. RECOMMENDATIONS

Rwanda is a small country and our land resource is also limited in term of size. As long as the population grows and the arable land unaltered, we should adopt a policy of maximizing the productivity and output of agriculture activities. That shall be achieved by involving GIS which is one of the important technologies in allocating agriculture activities on an appropriate area of potential.

The study has identified some realistic and wrong practices of coffee plantations settlement. The western volcanic mountain zones along the lake-kivu and the central part of the country which offer the high suitability conditions are on the right place and should be hold for coffee growth. Unfortunately, the eastern province and the Kigali-city with the low suitability potential should not be intended for any extension of Arabica coffee plantation because the region does not respond favourably to that particular crop.

For sustaining development, the theory of crop regionalization all over the country using agro-geospatial information should be taken into consideration. This principle combining with the land use consolidation and fertilize practices will play a major role to achieve successfully the high production and quality in agriculture.

Therefore the country should encourage and promote the policy for allocating Agricultural resources on appropriate environmental conditions to exploit our land more efficiently and effectively; and manage an unavoidable coming issue of food security to the unlimited growing population.

Further research should be envisaged on the ulterior study as well as the facilities are available; and consider secondary environmental factors which also affect coffee growth such as Land slope in %, wind speed and its direction, relative humidity, natural enemies and appropriate I.P.M or control preventive, Soil nutrient (essential mineral elements) and fertilizer management.

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