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Cultivation Potential in Hambantota District, Sri Lanka

A Minor Field Study

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Abstract

The importance of less developed countries to increase the agricultural production, in order to improve food supplies and generate employment and income, requires the removal of resources constraints by improving agricultural practices and identifying land suitable for different agricultural activities. This Minor Field Study (MFS) is made within the present Sida/SAREC-financed research project "Regional Development in an Open Economy – a comparative study of Hambantota and Gampaha districts, Sri Lanka". The purpose is to investigate, by the means of both the qualitative measures of interviews and the quantitative measures of a land suitability classification, the cultivation potential in the study area. The study area is located within Hambantota district in the dry south-eastern part of Sri Lanka. Twenty-six interviews of farmers and administrative personnel were performed, and the interview analysis shows that, even if it is impossible to extend the cultivated area, it seems possible to increase the crop yield, to change between crops and especially between wet paddy (rice plant) and banana. A point system was used in the land suitability classification with respect to the physical and chemical requirements of wet paddy and banana, and the classification includes the parameters of soil fertility, drainage, texture, depth and pH. The results shows that three of the five great soil groups present in the study area to a certain extent are suitable for paddy cultivation and that two of the five great soil groups to a certain extent are suitable for banana cultivation. As a simple test of the classification, the percentage of the total paddy area that falls within the area of suitable soils were calculated and resulted in the percentage value of 96.4 %. Even if there are limitations in the classification, it does fulfil the purpose of picturing the situation, and above all, it points at the possibility of a more accurate and elaborate fuzzy land suitability classification in the future.

Key concepts: cultivation potential, fuzzy classification, interviews, land suitability classification, point system

Sammanfattning

För att öka tillgången på mat och att generera arbeten och inkomster är det angeläget för utvecklingsländer att öka produktionen inom jordbruket. En förutsättning för detta är att eliminera produktionshinder genom att dels förbättra jordbruksmetoder, dels identifiera olika områden som är lämpliga för olika typer av jordbruk. Denna Minor Field Study (MFS) är utförd inom det befintliga Sida/SAREC-finansierade forskningsprojektet ”Regional Development in an Open Economy – a comparative study of Hambantota and Gampaha districts, Sri Lanka”. Syftet är att, utifrån både en kvalitativ analys av intervjuer och en kvantitativ lämplighetsklassificering av jordmånsgrupper, undersöka odlingspotentialen i studieområdet. Studieområdet ligger i distriktet Hambantota i den torra sydöstra delen av Sri Lanka. Tjugosex intervjuer genomfördes av både bönder och administrativ personal, och analysen tyder på att även om det är omöjligt att öka jordbruksarealen så verkar det vara möjligt att öka skörden, att växla mellan olika grödor och speciellt mellan våtris och banan. Lämplighetsklassificeringen av jordmånsgrupperna genomfördes, med hjälp av ett poängsystem, i relation till de fysikaliska och kemikaliska kraven hos våtris och banan och inkluderar följande fem jordmånsparametrar: bördighet, dräneringsförmåga, textur, djup och pH. Resultaten visar att tre av de fem stora jordmånsgrupperna i området till en viss del är lämpliga för odling av våtris och att två till en viss del är lämpliga för odling av banan. Ett enkelt test av klassificeringen visar att 96.4 % av den totala våtrisarealen faller inom området med lämpliga jordmåner. Trots begränsningar ger denna klassificering en bild av hur det ligger till, och framförallt visar den att en noggrannare och mer genomarbetad framtida oskarp lämplighetsklassificering är möjlig.

Preface

This study was made within the framework of the Minor Field Study (MFS) Scholarship Programme, which is funded by the Swedish International Development Co-operation Agency (Sida). The MFS scholarship gives the student the opportunity to carry out a fieldwork in one of the developing countries supported by Sida. After the homecoming, the student is supposed to write a report for Sida. Since the extent of this report corresponds to a bachelor or master thesis, it is often written as the final thesis of the university studies.

The MFS Scholarship Programme is intended to give Swedish students the possibility to increase their knowledge about developing countries and development issues. It is also supposed to give the students, teachers and departments at Swedish universities the possibility to develop and strengthen contacts with departments, institutes and organisations in developing countries.

The Department of Social and Economic Geography at Lund University is one of the university departments that administer and mediate the MFS scholarships. Except for their internal scholarships, which are given to students studying at the department, they have a small number of external scholarships, which are given to students studying at other departments. The scholarship given for this study is external.

Acknowledgements

First of all, I will give special thanks to both of my supervisors: Associate Professor P. Pilesjö at GIS Centre, Department of Physical Geography and Ecosystems Analysis, Lund University in Lund, Sweden and Professor N. Dangalle at Sida/SAREC Research Project Office, Faculty of Social Science, University of Kelaniya in Colombo, Sri Lanka. Professor N. Dangalle is a professor at Department of Social Geography at University of Kelaniya, and I will emphasize all the help and advice I got from all the other personnel at this department. Special thanks also goes to Mr. L.M. Ariyapala who was my guide and interpreter in the study area.

Contents

1 Introduction

1.1 Outline of the text

The introduction in this first chapter is continuing with a description of the objectives of the study and a geographical and socio-economical background to Sri Lanka and the study area. In Chapter 2, the interview technique and the associated data quality are discussed, the interview material is analysed and conclusions are drawn. The analysis of the interview material is aimed at answering some of the questions of this study and to serve as a background to and an argument for the following land suitability classification. Chapter 3 constitute the main part of this thesis and contain the theory, material, method, results, discussion and conclusions of the land suitability classification. Finally, the study is shortly concluded in Chapter 4.

1.2 Objectives of the study

This thesis is written within the present Sida/SAREC-financed research project "Regional Development in an Open Economy – a comparative study of Hambantota and Gampaha districts, Sri Lanka", which is conducted co-operatively by Sida/SAREC Research Project Office, Faculty of Social Science, University of Kelaniya in Colombo, Sri Lanka and Department of Human and Economic Geography, Göteborg University in Göteborg, Sweden. The project was started in 1998 and is aimed at studying, with a comparative approach, the regional development experiences of Hambantota and Gampaha districts (Dangalle 2002 and Karunanayake & Närman 2002). In order to get a more complete picture, both qualitative and quantitative methods are used in the project, and Geographical Information System (GIS) is brought in as an illustration and analysis tool (Karunanayake & Närman 2002 and Pilesjö 2002).

Skidmore (2000) points out the importance of less developed countries to increase agricultural production in order to improve food supplies and generate employment and income. Increasing agricultural production requires the removal of resources constraints by supplying adequate amount of water, developing high-yielding crop varieties, improving agricultural practices and "*...identifying land suitable for different agricultural activities...*" This study, which is based on the qualitative measures of interviews and the quantitative measures of a land suitability classification, is an investigation of the cultivation potential in the study area located within Hambantota district. Over and above providing a general picture of agriculture, the specific objectives of this study is to answer the following five questions:

- Is it possible to increase the crop yield?
- Is it possible to extend the cultivated area?
- Is it possible to change crops?
- Is it possible to change from wet paddy to banana?
- Where is it possible to cultivate wet paddy and banana?

It should be emphasized that this study is concerned with *wet paddy* ("paddy" means rice plant), which is highly predominant in Sri Lanka and the study area and require much more water than *dry paddy*. During the interviews it became clear that there is an ongoing discussion of and a special interest in the question of changing from wet paddy to banana, and this is the reason why the focus will be on the last two questions and why the land suitability classification will be made with respect to wet paddy and banana.

1.3 Background

1.3.1 Study area

Sri Lanka is a tropical island located in the Indian Ocean immediately south-east of the southern tip of peninsular India (Encyclopædia Britannica 1992). In approximate values, the island stretches between 6º and 10º N latitude and 80º and 82º E longitude. The country has an area of about 65,610 km^2, and a length (north-south) and width (west-east) of about 435 km and 224 km respectively. Sri Lanka is divided into a hierarchy of administrative units: provinces, districts, divisions and the smallest so-called GN-divisions (Department of Census & Statistics 2003 and Statistical Abstract 1999). The southern province consists of Galle, Matara and Hambantota districts, and the study area is located within Hambantota district and within the lowland region in the south-eastern part of the country (Figure 1).

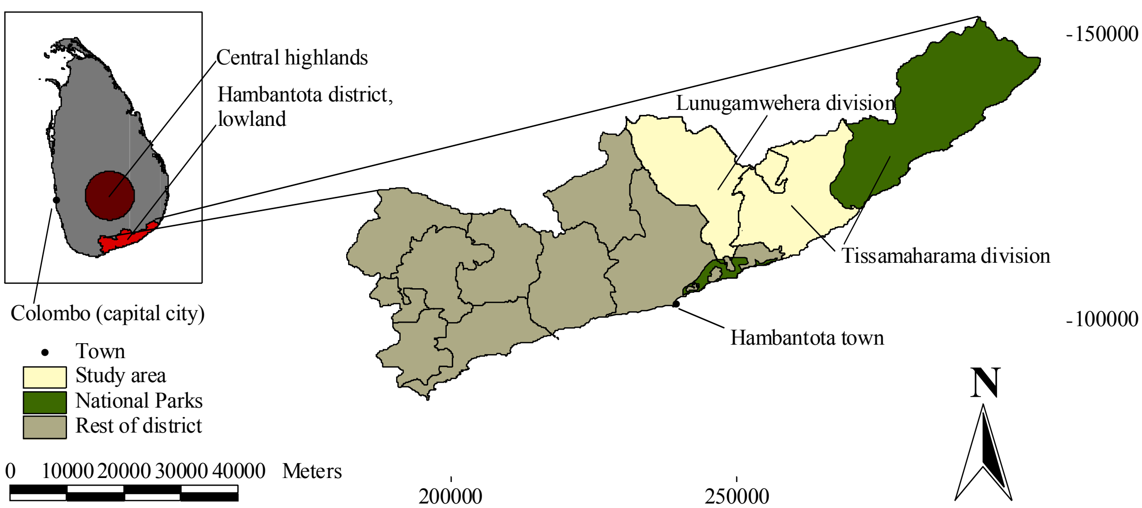

Figure 1. Map showing the study area. The coordinates are given in the local system called SL Datum 95 (see Section 3.2). Source: Topographic Information (1:50,000) 2003.

Lunugamwehera division covers the western part of the study area, and Tissamaharama division covers the eastern part. There is a small part of Bundala National Park located within Lunugamwehera and a large part of Yale National Park located within Tissamaharama. Because they are protected areas, both of these national parks are excluded from the study area, and this results in an area of about 593 km^2 and a length (west-east) and width (north-south) of about 43 km and 18 km respectively.

The Minor Field Study was introduced during the first week in Sri Lanka by the opportunity to accompany Assistant Professor Anders Närman and both of my supervisors during interviews performed by Anders Närman in Hambantota district. After this fruitful introduction, the study area was chosen mainly because it is a problematic agricultural area with severe climatic conditions (see Section 1.3.4).

1.3.2 Socio-economy

Sri Lanka attained independence from British rule in 1948, became a republic in 1972, and adopted the constitution in 1978, according to which the country is the Democratic Socialist Republic of Sri Lanka (The World Factbook 2003 and FOCUS 98 1997). The civil war between the government and Liberation Tigers of Tamil Eelam (LTTE) started with eruptions of violence between the Sinhalese majority and the Tamil separatists in 1983. After almost two decades of fighting, a ceasefire began in December 2001, with Norway as the brokering peace negotiator.

The total population was estimated to about 19.7 million in 2003, with a growth rate of 0.83 % (The World Factbook 2003). The population density was the twenty-first highest in the world in 1996, and the population is concentrated in a few areas in the south-western and central parts of the country (Arjuna's Atlas of Sri Lanka 1997). Other parts, especially the south-eastern and northern, of the country are less densely populated. In 2003, the distribution of the population among ethnic groups was: Sinhalese (74 %), Tamil (18 %), Moor (7 %) and Burgher, Malay and Vedda (1 %) (The World Factbook 2003). The distribution of the population among religions was: Buddhism (70 %), Hinduism (15 %), Christianism (8 %) and Islam (7 %). In 1998, the labour force was estimated to 6.6 million with 45 % in the service sector, 38 % in the agricultural sector and 17 % in the industrial sector.

In 1997, Hambantota district had a population of about 555,000, which means a population density of 210 inhabitants per sq. km. with 400-600 in the western part and 100-150 in the eastern part (Karunanayake & Närman 2002). Hambantota district is ethnically homogenous with 98.5 % of the population being Sinhalese. According to the Deputy Director of Agriculture and the Assistant Director of Agriculture in Hambantota district (see Section 2.2), 90 % of the population are in some way connected to agriculture.

The United Nations Development Programme (UNDP) has defined the two concepts of "human development" and "human poverty" to be used in connection with developing countries. The concept of "human development" is described as follows:

> The concept of human development is defined over three fundamental dimensions of personal well being: (i) the opportunity to lead a long and healthy life; (ii) the ability to acquire the capabilities that arise through participation in the world of knowledge and learning; and (iii) the power to access adequate resources to attain a decent standard of living. (UNDP 1998).

The Human Development Index (HDI) is developed by UNDP and captures these dimensions of opportunity, capability and welfare in a single measure (UNDP 1998). In comparison with other developing countries, Sri Lanka has achieved a level of human development well above its level of per capita income. However, the concept of "human poverty" examines actual deprivations in important social and economic dimensions of life. The Human Poverty Index (HPI) is also developed by UNDP and captures these social and economic dimensions. In 1998, the level of human poverty in Sri Lanka was estimated to be substantial and moderately high, with approximately 18 % of the population experiencing deprivations in the social and economic dimensions. Analysis also reveals wide regional disparities between provinces and districts in both human development and human poverty. There are great differences in HPI between different districts with Hambantota district on the eleventh place out of seventeen. This makes Hambantota district one of the more backward regions in the country. These two concepts are similar, but while the concept of human development focus on levels of achievement and fulfilment human poverty focus on actual deprivations and shortfalls.

Paddy is the staple food crop in Sri Lanka and involved 30 % of the labour force in 2000 and had an annual average of the cultivated area of about 870,000 ha (1 ha = 10,000 m^2) (Department of Agriculture 2000). Banana is also considered as an important crop and involved approximately 100,000 of the population in 2001 (Kudagamage et al. 2002). The cultivated area was about 48,686 ha in 1998 and has an increasing trend from 1973 to 2000.

In ancient Sinhalese kingdom times (250 B.C.-1235 A.D.) the dry areas in Sri Lanka were flourishing with wet paddy cultivation, which was irrigated with water collected in constructed reservoirs (Domrös 1974). Today, the cultivation of wet paddy is similarly based on what is called tank irrigation, where the tanks mainly are restored ancient water reservoirs. Connected to the tanks are three classes of irrigation schemes, which are ranked according to the irrigable area (Irrigation Department 2003) (Table 1).

Table 1. Three classes of irrigation schemes (1 acre ≈ 4,047 m^2). Source: Irrigation Department 2003.

Irrigation scheme	Irrigable area (acre)
Major	> 1,500
Medium	200-1,500
Minor	< 200

The important Lunugamwehera Scheme is a large major scheme with an irrigable area of about 13,250 acres, and within this scheme Lunugamwehera Reservoir also feeds five tanks in Tissamaharama division (Irrigation Department 2003). In total, there are six major irrigation schemes in Lunugamwehera and Tissamharama divisions, and Lunugamwehera Scheme is without comparison the largest of them all. Farmer organizations are connected to the major irrigation schemes, and together with the government they play a significant role in the management of the schemes (see Section 2.2) (Arjuna's Atlas of Sri Lanka 1997).

1.3.3 Geomorphology

Sri Lanka forms a continuation of peninsular India, and both peninsular India and Sri Lanka stand on the same continental shelf (Encyclopædia Britannica 1992). A southern central massif called the central highlands is formed by faulting and dominates the island (Figure 1). The central highlands are surrounded by an intermediate zone of upland ridges and valleys, which is separated from the central highlands by well-defined scarps. An outer lowland zone surrounds the intermediate zone, except in the south-west where the land meets the ocean in the form of cliffs. In other places, the coastal fringe consists of sandbars, dunes, peninsulas, lagoons and marshes.

With an altitude of 2,524 m Pidurutalagala is the highest point of the central highlands (Encyclopædia Britannica 1992). Despite the central highlands, about five-sixths of the island is below an altitude of 300 m. The southern edge of the central highlands is curving southward in the centre and consists of a rim of steep scarps, and at the so-called World's End the scarp wall drop about 1,524 m. North of the central highlands Knuckles Mountain is separated from the highlands by the valley of Mahaweli Ganga ("ganga" means river), which is the largest river in Sri Lanka. There are a number of short rivers in Sri Lanka, radiating out from the central highlands. The south-western part of the island is a continuation of the central highlands and is also mountainous with ridges, valleys and a crisscross drainage pattern. The northern lowland consists of an undulating landscape with isolated hills or inselbergs and ridges. In the farthest north, the Jaffna Peninsula is associated with a coral reef.

The eastern and south-eastern lowland also consists of an undulating landscape containing some isolated hills or inselbergs.

The study area is located within the south-eastern lowland with its undulating landscape and isolated hills or inselbergs (Topographic Information (1:50,000) 2003). As can be seen in Figure 6 in Section 1.3.6, a large part of the Kataragama Hills is located in the north-eastern part of the study area. The large water reservoir called Lunugamwehera Reservoir is located in the north-eastern part of Lunugamwehera division, and a total of seventy-four artificial water tanks fall within the study area. Beside this, there are three rivers and a number of streams and water channels in the study area (small streams and water channels are not shown in Figure 6). Lunugamwehera Reservoir, the seventy-four tanks and the water channels are all used for irrigation purposes. It should be mentioned that the number of tanks is changing over time, since they sometimes are abandoned and sometimes reclaimed (International Water Management Institute 2003). The river connected to Lunugamwehera Reservoir is called Kirindi Oya ("oya" also means river), and the other two rivers are Malala Oya and Menik Ganga. (Malala Oya and Menik Ganga are almost impossible to see in Figure 6, since they coincide with the border of the study area.)

1.3.4 Climate

The northern and eastern part of Sri Lanka is, according to Köppen's climatic classification system, classified as tropical wet and dry (Aw) (Ahrens 2000). A comparison of the climate diagram for Hambantota town, available in Domrös (1974), with the Köppen's climatic classification system, available in Ahrens (2000), show that the climate of the far south-eastern part also is best described as tropical wet and dry (Aw) (Figure 2 and Table 2).

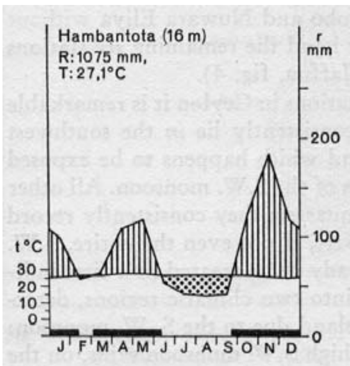

Figure 2. Climate diagram for Hambantota town. The numbers in the upper left corner show elevation above mean sea level, mean annual rainfall and mean annual temperature. Source: Domrös 1974.

Table 2. Köppen's definition of the tropical wet and dry (Aw) climate. Source: Ahrens 2000.

Symbol	Climate characteristic	Criteria
A	Humid tropical	All months have an average temperature of 18 ºC or higher
w	Tropical wet and dry	Winter or monsoon dry season. Rainfall in the driest month is less than 60 mm and less than 100-P/250, where P is mean annual rainfall in mm.

Hambantota is located outside the study area and by the sea (Figure 1), but since the whole south-eastern lowland region has a rather uniform climate and is affected by the ocean's modifying influence on the climate (Domrös 1974), the climate in Hambantota can be used to approximately represent the climate in the study area. A comparison can be made with the rainfall diagram for the meteorological station called Tissamaharama Irrigation within Tissamaharama division (Figure 3).

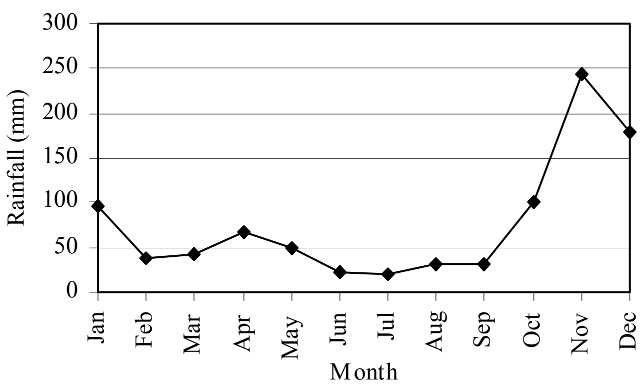

Figure 3. Rainfall diagram that shows mean monthly rainfall for Tissamaharama Irrigation calculated on rainfall data from 1990 to 2002. Source: Department of Meteorology 2003 (Rainfall statistics).

The remaining part of the country is classified as tropical wet (Af) (Ahrens 2000). The climate in Sri Lanka belongs to the South Asian monsoon climate, and the monsoon can be considered as the dominating factor influencing the climate (Domrös 1974). In the course of one year, there are two monsoon seasons, the south-west monsoon and the north-east monsoon, depending on the predominant wind direction, and two inter-monsoon seasons (Table 3).

Table 3. Monsoon and inter-monsoon seasons and their periods. Source: Domrös 1974.

Season	**Period**
First inter-monsoon season	March – mid-May
South-west monsoon season	mid-May – September
Second inter-monsoon season	October – November
North-east monsoon season	December – February

The air masses of the south-west monsoon can be classified as rather humid and the air masses of the north-east monsoon as comparatively dry (Domrös 1974). Within the two monsoon periods, there is a spatial differentiation in climate due to the central highlands which function as an orographic barrier. In addition to this, the relief in the central highlands modifies the climate both of the windward sides and the leeward sides, and this is the reason why the climatic differentiation is largest in the central highlands. By contrast, more equal conditions are to be expected over the larger part of the lowlands, because of the absence of modifying relief and the presence of the moderating and climate-balancing factor of the ocean. Even if the ocean has its influences over the entire island, the greatest effect is to be found in the lowlands.

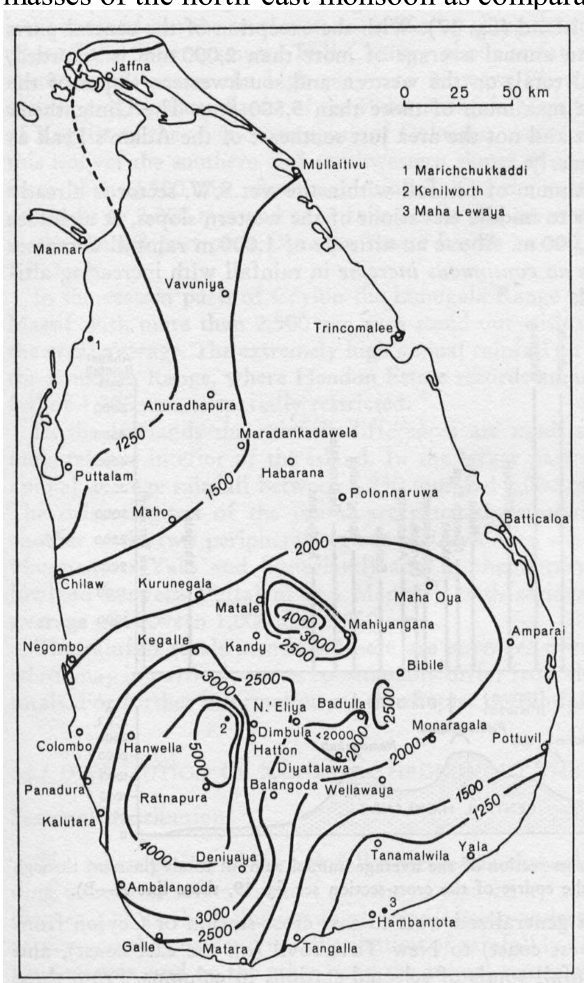

Figure 4. Illustration, by isohyets in mm, of the distribution of mean annual rainfall. Source: Domrös 1974.

The mean annual rainfall can be characterized by large differences and a clearly arranged spatial differentiation (Domrös 1974) (Figure 4). Despite the small area, mean annual rainfall varies to a large extent over the country reaching about 5,500 mm in the wettest parts and about 1,000 mm in the driest parts (Domrös 1974). The south-western part and the central highlands are the wettest parts while the north-western and south-eastern parts are the driest. Regarding mean annual temperature, there is only a slight horizontal differentiation and seasonal variation at lower latitudes, and the differences that needs to be considered are those related to altitude. A comparison of mean annual temperature shows homogeneous temperatures in the lowland and rapidly decreasing temperatures with altitude in the central highlands. In Hambantota town (at sea level), the mean annual temperature is 27.1 °C and in Nuwara Eliya (1,882 m) 15.4 ºC.

1.3.5 Soils

In general, the major factor influencing soil formation in Sri Lanka is climate followed by parent rock and topography (Arjuna's Atlas of Sri Lanka 1997). Lateritic loams, which are reddish leached iron-bearing soils of clay, silt, sand and organic matter, are the most common soils in the wet zone (Encyclopædia Britannica 1992). The same types of parent rock result in semi-lateritic and non-lateritic soils in the dry zone. In the northern sedimentary limestone areas, red lime-rich loams are common. Rich alluvial soils occur along the lower courses of the rivers and on their floodplains. Sandy soils are prevalent along the coastline. For the entire country, the soils have been classified at the level of great soil groups and subgroups, and parts of the country have been classified at a more detailed level (Sri Lanka Council for Agricultural Research Policy (publication year is missing)). In total, there are thirteen great soil groups, and five of these are present in the study area (Table 4 and Figure 5).

Table 4. The five great soil groups in the study area and their geomorphological location in the landscape. Source: Sri Lanka Council for Agricultural Research Policy.

Great soil group	Location in the landscape
Reddish Brown Earths	On the crests, upper slopes and mid-slopes in the undulating landscape.
Low Humic Gley Soils	On the lower parts of the slopes and valley floors in the undulating landscape.
Solodized Solonetz	On the lower parts of the slopes and valley floors in the undulating landscape.
Alluvial Soils	Along rivers and streams and on their floodplains.
Regosols	Along the coastline.

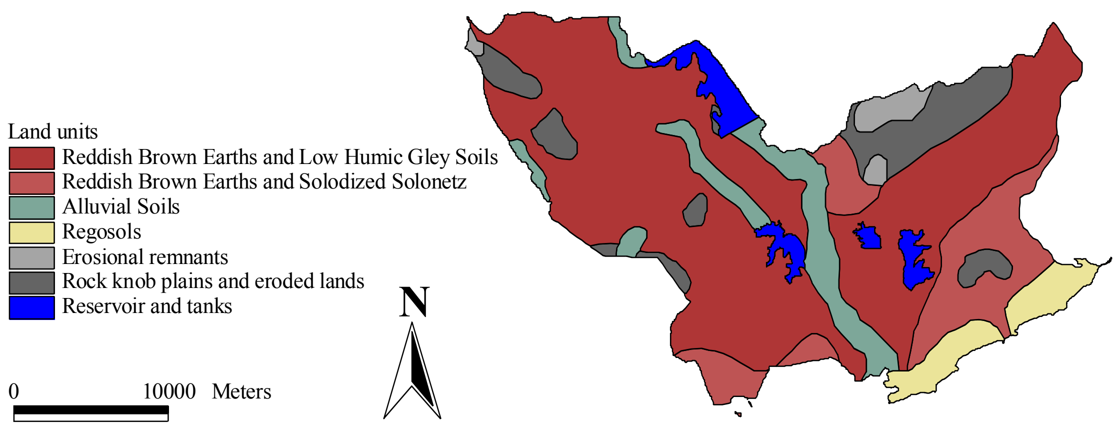

Figure 5. Map showing the distribution of the five great soil groups in the study area. Source: Soils, Survey Department 2003 and Topographic Information (1:50,000) 2003.

Reddish Brown Earths are the predominant soil group in the study area, and both Low Humic Gley Soils and Solodized Solonetz occur in association with Reddish Brown Earths in the undulating landscape (Sri Lanka Council for Agricultural Research Policy). In Figure 5, the five great soil groups are grouped into only four groups. Since Low Humic Gley Soils and Solodized Solonetz occur in association with Reddish Brown Earths, the soils are grouped accordingly in the available paper maps (see Section 3.2).

See Table 12 in Section 3.2 for a more detailed description, on soil parameter level, of the five great soil groups in the study area.

1.3.6 Agro-ecological regions

Sri Lanka has been divided into three rainfall zones and three elevation zones (Department of Agriculture (publication year is missing)) (Table 5 and 6).

Table 5. Rainfall zones. Source: Department of Agriculture.

Rainfall zone	Mean annual rainfall (mm)
Dry Zone (DZ)	< 1,500
Intermediate Zone (IZ)	1,500-2,500
Wet Zone (WZ)	> 2,500

Table 6. Elevation zones. Source: Department of Agriculture.

Elevation zone	Elevation above mean sea level (m)
Low Country (LC)	0-300
Mid Country (MC)	300-1,000
Up Country (UC)	> 1,000

The three elevation zones are effectively defining three temperature zones (Sri Lanka Council for Agricultural Research Policy). Based on these rainfall and elevation zones, the country is divided into seven Agro-Ecological Zones (AEZ) (Department of Agriculture and Sri Lanka Council for Agricultural Research Policy). Based on the amount of rainfall, temperature, soil types and landform patterns, these AEZs are subdivided into twenty-four Agro-Ecological Regions (AER). The study area is located within the AEZ called the Low Country Dry Zone (LCDC) and the AERs called the Dry Low 1 (DL1) and Dry Low 5 (DL5) (Table 7 and Figure 6).

Table 7. Distinguishing characteristics of DL1 and DL5. Source: Arjuna's Atlas of Sri Lanka 1997.

Characteristic	DL1	DL5
Annual rainfall (mm) with 75% expectancy	> 775	> 500
Terrain	Undulating	Undulating and flat
Dominating soils	Reddish Brown Earths and Low Humic Gley Soils	Reddish Brown Earths and Solodized Solonetz

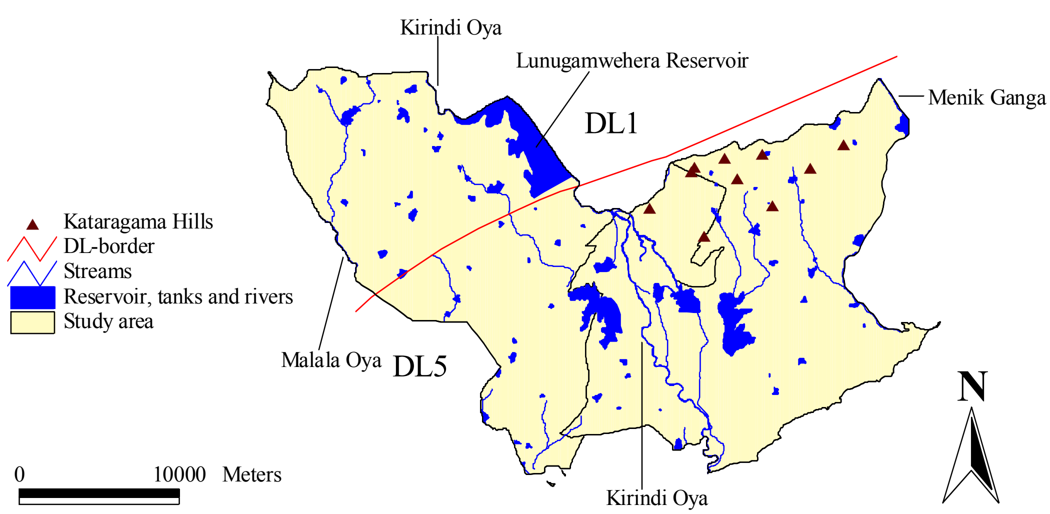

Figure 6. Map showing the two AERs of DL1 and DL5 and water bodies in the study area. Source: Sri Lanka Council for Agricultural Research Policy and Topographic Information (1:50,000) 2003.

As can be seen in Table 7, the southern DL5 is drier than the northern DL1. In Sri Lanka, there are two cultivation seasons called Yala (April-August) and Maha (October to March) (Domrös 1974). As can be seen in Figure 2 and 3 in Section 1.3.4, there are two rainfall peaks occurring during one year in the study area (April-May and October-November) (Sri Lanka Council for Agricultural Research Policy). Maha is the main rainy season in the study area and commences with the second inter-monsoon and its convectional thunderstorms (see Table 3 in Section 1.3.4) and the north-east monsoon rains that immediately follow. After that, a short dry spell is followed by the second rainy season of Yala, which commences with the first inter-monsoon with its convectional afternoon and evening thunderstorms. Yala is shorter and usually get terminated with the decline of the convectional thunderstorms. Finally, the second and longer dry period sets in.

1.3.7 Crops and vegetation

The difference between the wet and dry zones can also be seen in the distribution of the cultivated crops (Domrös 1974). In the wet zone, perennial crops are dominating with tea, rubber and coconut as the leading crops, which also are the major commercial crops in the country. However, in the irrigated dry zone, perennial crops are almost absent, and annual crops are dominating with the staple food crop paddy as the leading crop. As was mentioned in Section 1.2, wet paddy is highly predominant in Sri Lanka and the study area and requires much more water than dry paddy (in the remaining text it is understood that “paddy” means wet paddy). Outside the irrigated areas, in the dry zone, there are a number of so-called highland farmers practicing slash and burn cultivation (chena) of subsidiary crops.

Since Sri Lanka has been populated for many centuries, the natural vegetation has been altered by cultivation (Arjuna’s Atlas of Sri Lanka 1997 and Encyclopædia Britannica 1992). Despite this, nearly 50 % of the island was by the year of 1992 still covered with forest, open forest, scrubland, grassland and wasteland. The largest part of the country is treeless land. The best-developed evergreen forests are the tropical rainforests located in the south-western wet zone, while the forests in the dry zone are of poor conditions. The dry lowlands are characterized by dry monsoon forest, open forest, scrubland and wasteland. On altitudes above 1,000 m, there are sub-montane forests, and in the central highlands there are montane forests and open grassland characterize the central highlands. Along the rivers, there are some riverine forests, and along the coastline, there are some mangrove forests.

2 Interview analysis

2.1 Interview technique and data quality

Devereux & Hoddinott (1992) points out that the closer the interviewer is to the respondent the better the interviewers understanding of the interview material is. They also say that there often is a need for an interpreter, since it seldom is manageable to work entirely alone, and using an interpreter, the interviewer still have a fairly direct contact with the respondent. Another mentioned advantage of having an interpreter is the possibility of he or she providing information about the area, the culture and practical things. During the two weeks spent in the study area, the interviews were performed with the help of an interpreter who is a senior citizen and has worked as an interpreter before. The transport were carried out with a hired car and a driver, and relevant places in the area (Figure 7 and Appendix 1) were found with the help of a road map bought at the Survey Department in Colombo and also by asking people along the way.

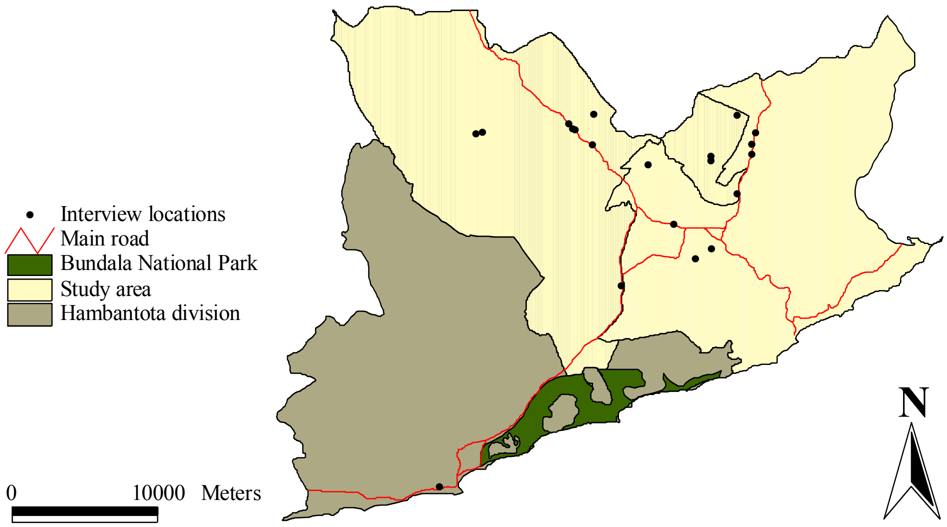

Figure 7. Map showing the interview locations in the study area. Source: GPS data, Survey Department 2003 and Topographic Information (1:50,000) 2003.

In some cases, walking around in the fields was required to get in contact with the farmers. Through using the Global Positioning System (GPS) with an error of up to 10 m the interviews were positioned in the reference system WGS 84. According to Devereux & Hoddinott (1992), a general rule of stratifying interviews is that the stratifying criteria should reflect the research interests. The twenty-six interviews performed were stratified in the following way (see Appendix 2 for a more detailed description):

- 6 interviews of administrative personnel
- 10 interviews of farmers in Lunugamwehera division
- 10 interviews of farmers in Tissamaharama division

The six interviews of the administrative personnel were further stratified according to division and administrative level, and the ten interviews in both Lunugamwehera and Tissamaharama division were further stratified according to GN-division, cultivated crop and agro-social class (the different agro-social classes are described in the analysis of the interviews). Following Halvorsen (1992), this sample of interviews is of course not statistically valid, but on the other hand it can be considered to be representative with respect to the objective of the study.

There is a distinction between the two main types of interviews called structured and unstructured interviews (Devereux & Hoddinott 1992 and Halvorsen 1992). The structured interview has a formal questionnaire while the unstructured interview does not and could be described more as a free discussion. In the unstructured interview, there is only a checklist of topics discussed in any order that seems appropriate according to the circumstances. The interviews in this study are sometimes called semi-structured interviews, which means that the interviews are performed using a list of open-ended questions to be discussed. Since the questions in a semi-structured interview are open-ended, the interview still have the character of a discussion, and one advantage of this is that the respondents usually feel more comfortable with the situation. One list of questions with a broad perspective was used for the administrative personnel and another but similar list was used for the farmers (see Appendix 3).

According to Devereux & Hodinott (1992), the basic methodological technique in most social science fieldwork is the one-to-one interview. The intention was to perform the interviews in this way, but sometimes it is impossible to prevent curious people from coming to see what is going on. In some cases, it is also hard to avoid people who want to interfere with the interview. To use some kind of force in these situations would probably be even worse with respect to the quality of the interview. In these situations, it is better trying to understand which parts of the answers that are the respondent's own opinion and not other person's. Of course, a continuous understanding and interpretation of the interviews is important. It should also be mentioned that two of the interviews of the administrative personnel were deliberately performed with more than one respondent. Another problem connected to the interview situation is the so-called interviewer effect, which means that the respondent will give answers that he or she presume is what the interviewer wishes to hear. The interviewer effect is even harder to control using an interpreter, and that is one reason why an experienced interpreter is important.

Regarding the interviews performed, the general impression is that they are reliable and that at least all of the interviewed farmers felt comfortable during the interviews. Most of the administrative personnel interviewed also seemed comfortable, except for one who was uninterested and suspicious. Still, the general impression is that there were no serious misunderstandings during the interviews.

Since there is a high uniformity both between the answers of the respondents in Lunugamwehera and Tissamaharama division and between the answers of the administrative personnel and the farmers, the interview material is treated as a whole. The analysis of the interview material is aimed at answering some of the questions of this study and also to function as a background to and argument for the following land suitability classification. Because the interviews were performed with an interpreter, the quotations in the following text cannot be considered as direct quotations of the respondents, but rather as quotations of the translations by the interpreter.

2.2 Analysis of the interview material

2.2.1 Present situation regarding agriculture

See Section 1.3.2 for a socio-economical background to the information revealed by the analysis.

Both the Deputy Director of Agriculture and the Assistant Director of Agriculture in Hambantota district pointed out that the eastern and dry part of the district, where the study area is located, has the highest production of crops, because of the large number of irrigation schemes. They also said: "*Right now there are eight major irrigation schemes in the district, and these are expanding very slowly*" and "*there are no plans to have large areas controlled by a small number of farmers.*" Of course, this is a good strategy to the extent that it keeps the population employed. In general, the interview respondents used the term "large-scale farming" to denote farming within the major irrigation schemes, and "small-scale farming" to denote farming within the minor irrigation schemes. This means that the concepts of the terms do not involve anything about the size of the cultivated area. The majority of the farmers in Hambantota district are small-scale farmers. However, a lot of farmers in Lunugamwehera division are connected to the Lunugamwehera Scheme, and they are therefore large-scale farmers. Within this major scheme every farmer is assigned three acres of land.

Two of the administrative personnel in Lunugamwehera and Tissamaharama divisions seem to be critical of the government policy. One of them said that even if the general policy is supposed to be that of the government, there is actually no such policy. The other was more specific: "*There are too many ministers and too many departments to handle these questions.*" Twenty departments are involved in agricultural matters, among which the most important are the Department of Agriculture, Department of Agrarian Services and Department of Irrigation. Moreover, some of the farmers shortly expressed their disappointment with the support from the government.

According to Karunanayake and Närman (2002), the preliminary result of 71 interviews performed in nine villages in Hambantota district show that there is mistrust against the politicians, which are said not to understand the situation of the poor people and to always break their electoral promises.

However, throughout the interviews it became evident that there is a well functioning organization aimed to handle questions related to agriculture. Major questions are discussed at the district meetings, where the division secretaries and representatives of departments, irrigation schemes, farmer organizations and banks are present. Minor questions on every aspect of agriculture are discussed at division level at the so-called Kanna meetings (cultivation meetings). The Division Secretary is the head of the Kanna meetings, which are attended by representatives of departments, farmer organizations and banks. During the Kanna meetings a timetable is prepared according to which the farmers have to perform their work. In addition to this, the Division Secretary is coordinating the work of the departments, and when the farmer needs to get in contact with a department, the farmer has to go through the Division Secretary. The Division Secretary in Lunugamwehera said: "*The system is good since there would be no control if the departments would function separately*" and "*this ensures uniformity.*" Considering the number of departments involved in agricultural questions the division secretary seems to be right about this. Agricultural instructors, representing the different departments, are available at division level and are informing the farmers about seed, fertilizers and chemicals. At the lowest administrative level, the GN-officer is working close to the population in the GN-division. The GN-officer is taking care of the daily needs of the people and also function as a link between the people and higher administrative levels. His work, like the division secretaries, concerns all kinds of subjects and is not confined to agriculture. In addition to all of this, there are some help available through different Non-Governmental Organizations (NGO) pursuing different projects in the area.

The Division Secretary in Tissamaharama pointed out that the farmer organizations, which are represented at the district meetings and the Kanna meetings, are strong organizations. This is supported by Uphoff & Wijayaratna (2000) in their study on benefits of social capital demonstrated by the farmer organizations within the Gal Oya irrigation scheme in Sri Lanka. According to Uphoff & Wijayaratna (2000), farmer organizations were first established in the early 1980s within the Gal Oya irrigation scheme, with a combination of roles, rules, norms and values that provided for mutually beneficial collective action. This could be seen in measurable improved results, and later in the 1997 dry season, even if the farmers where told that the amount of water in the reservoir was not enough to cultivate paddy, they achieved a better-than-average harvest. Uphoff & Wijayaratna (2000) points out that, today, there are 250,000 farmers participating in farmer organizations in all of the major irrigation schemes in the country.

It should be mentioned that the Kanna meetings and the decided timetable for cultivation does not apply to the highland farmers. Highland farming is non-irrigated slash-and-burn cultivation, and these farmers are the poorest of all farmers (see Section 1.3.7). Slash-and-burn cultivation is basically not allowed according to the law, but the farmers are not prohibited in practice. It is informally allowed as long as scrub jungle is cultivated, but if someone wants to cultivate within a forest area a permit has to be issued. One highland farmer in Lunugamwehera division described the situation like this: "*This is illegally occupied crown land, but the government is allowing it anyway. There is no policy for this area. No administrative unit has a policy. They only have a blind eye.*" If these farmers were not allowed to continue, then they would have no possibility to earn their living. However, one highland farmer in Tissamaharama division who got help from the NGO called CARE USA said: "*They asked him to cultivate beetroot, and it has been a complete success.*"

The economic resources are in principle restricted to private capital and loans from departments and banks. Of course, the situation is much better for those who have private capital than for those who are forced to borrow money in the beginning of every cultivation season. There are great differences between different agro-social classes. Some landowners have money to spend on every aspect of agriculture while highland farmers are beyond any kind of economic assistance. Bank loans appear to be available only for paddy and banana farmers, because paddy and banana farming is irrigated and therefore has a higher security. One highland farmer in Tissamaharama division said: "*Normally bank loans are not given for highland farming, because this kind of farming is uncertain due to the weather.*" Another agro-social class that is not qualified to loan money is the leasing cultivator. The leasing cultivator lease land either from a landowner or an under cultivator, who gets one fourth of the income and who can reclaim their land whenever they want, and is not considered as a proper cultivator. In contrast, the under cultivator, which is a similar agro-social class, is qualified to loan money. The under cultivator lease land from a landowner who gets one fourth of the income but who cannot reclaim the land. However, there is always the possibility to get a loan from a private moneylender, but then the interest will be much higher.

Of course, the scarcity of water is considered, without comparison, to be the biggest problem regarding agriculture (see Section 1.3.4). The Division Secretary in Lunugamwehera said: "*This is a dry area with little rain in both Yala and Maha. Water is the main problem.*" Both the Development Officer Planning and the Development Coordinator Planning in Lunugamwehera division describe the situation in the following way:

> The environment is ideal with a rich soil. The only drawback is a shortage of water. During parts of the year the capacity of the reservoir hardly is sufficient to meet the domestic consumption. To meet basic needs water is then distributed by means of busses. A new governmental water project has been started to meet this situation, with the purpose to fill the small tanks situated in various parts of the region. This project benefits only 2 of 36 GN-divisions within this division.

Compared to Yala, there is a higher amount of rainfall in Maha, and the GN-officer in Weerawila GN-division in Lunugamwehera division said that they want something to be done about the water problem so that they can cultivate both in Yala and Maha and not only in Maha. Some farmers answered the question about the biggest problem only with the single word "water", and after that they laughed. One paddy and banana farmer within Lunugamwehera Scheme in Lunugamwehera division gave a more elaborate answer and proposed the two possible solutions of collecting drainage water and dividing water from the river. Dividing water from the river was regarded as the better solution since it would provide a constant supply of water. It was pointed out that the politicians often give electoral promises to divide the river but only to forget about it afterwards.

In their study about agronomic strategies to increase paddy yields in Sri Lanka, Weerakoon et al. (2000) claim that the farmers often use more water than is required. The main reason is said to be the storage of water in the paddy field to even out possible irregular irrigation supplies. Another reason is said to be the practice of using standing water as a method of controlling weeds. According to Weerakoon et al. (2000), this latter practice should be discouraged, since it is a costly one, and other weed controlling methods should be used instead. Maybe some amount of water could be saved through finding other methods of controlling weeds.

Even if water is by far the biggest problem, it is not the only problem. The low market price of paddy is also considered as a very big problem. Since the price is too low, it is hard to make paddy cultivation profitable. The explanation to the situation with the low market prices is that earlier the government was supporting paddy, but not anymore. The government does not have money to support paddy, and the private companies does not pay the price that the government has recommended. One paddy and banana landowner in Tissamaharama division said that there is too much paddy available in the market. Another related problem, that was mentioned, is the high prices of synthetic fertilizers and pesticides. Earlier they used organic fertilizers, and some farmers think that introducing synthetic fertilizers and pesticides has complicated the situation even more.

Several of the respondents mentioned the effects on the soil by the use of synthetic fertilizers and pesticides and the effects on people who are working with the fertilizers and pesticides. They say that the soil is getting impoverished. When it comes to the possible environmental effects of the fertilizers and pesticides, there is a difference in opinion. Some of the respondents think there is an effect on the environment, while others think there is not. One paddy under cultivator in Tissamaharama division said:

> There are instances of leakage to streams. Invariably they use chemicals as fluent, and they necessarily have an effect. If the water goes to pasture land, then cattle are bound to suffer from various diseases. The people who spread chemicals are subject to mental and physical disorders, and he himself got unconscious and had to spend three days in hospital. The leakage cannot reach the national parks.

On the other hand, one paddy and banana landowner in Tissamaharama division explained that the proper use of synthetic fertilizers and pesticides does not have an effect on the environment. After fertilizers and pesticides are applied, some time is needed for the fertilizers and pesticides to be consumed before water is used. The opinion that the possible leakage cannot reach the national parks is agreed upon among all the respondents.

Weerakoon et al. (2000) points out that better synthetic pesticides with greater efficacy on weeds and with lesser toxicity to the paddy plant, animals, fish and the environment has been identified. Of course, such a statement implies the actual risk of environmental effects. In the study on drainage water quality Piyankarage (2002) also demonstrates environmental effects as far away as to the Bundala National Park. Effects of nitrogen and phosphorus loads can be seen in the Embilikala-Malala lagoon system within the Bundala wetlands. Moreover, slash-and-burn cultivation necessarily has an effect on the environment, but as long as scrub jungle is cultivated it is not considered a problem. It is said that the scrub jungle is recovering to its initial state in three years.

Other problems are the destruction of the cultivated fields by stray cattle, elephants and boar. In the case of elephants, they also are a direct threat to the farmers themselves, and one of the farmers was actually chased by an elephant one week before the interview. Even if it is strictly illegal, the farmers sometimes feel forced to kill an elephant, if the elephant is not possible to scare away from the field. This problem is becoming bigger and bigger with the increasing population and pressure on the land resources.

2.2.2 Possibilities to increase the yield and extend the cultivated area

The Division Secretary in Tissamaharama said that, in Tissamaharama, 9,973 acres is cultivated with paddy and 1,161 acres with banana. The general opinion of the respondents is that it is possible to increase the yield with proper water management and proper use of fertilizers and pesticides. Most of the respondents among the farmers want to use synthetic fertilizers and pesticides while there is a difference in opinion among the administrative personnel. Both the Development Officer Planning and the Development Coordinator Planning in Lunugamwehera division said: "*Most farmers resort to traditional farming, but modern techniques will increase the yield. Awareness of modern techniques, such as fertilizers and chemicals, will help.*" At the same office the Division Secretary in Lnugamwehera said:

If they use organic fertilizers and traditional farming they will do better. The soil is now impoverished and organic fertilizers will bring the soil back to normal. But the same cannot be expected from other fertilizers. Traditional methods, though not commercially attractive, would ensure a steady supply of food. Traditional farming appear to be better. An increase in yield is possible only by application of organic fertilizers.

Another way to increase the yield, that was mentioned, is to improve the varieties of the crops. Weerakoon et al. (2000) propose selection of the appropriate variety of paddy as one way to increase the yield where the selection should be based on climate, soil, availability of supplementary irrigation, cropping duration, management capabilities of the farmer and the consumer preference. According to Weerakoon et al. (2000), eighteen new paddy varieties have been released by the Department of Agriculture during the last decade. The importance of developing and implementing new varieties is confirmed by the Department of Agriculture, and it is said that varieties with a wide adaptability to diverse environmental conditions are demanded (Department of Agriculture 2000). Of course, the highland farmers were emphasizing the need of more water to increase the yield.

It appears to be impossible to extend the cultivated area within the Lunugamwehera Scheme, since all the irrigated land within the scheme is distributed with three acres per farmer. All the irrigated land within all the schemes appears to be occupied. Both the Deputy Director of Agriculture and the Assistant Director of Agriculture in Hambantota district said: "*It is not possible to extend the cultivation area unless new irrigation schemes are introduced.*" Even in areas where the land has private owners it seems impossible to extend the area, since all land is occupied, and the ownership goes from generation to generation. On the other hand, in highland farming areas it is possible to extend the cultivated area by preparing new areas in the scrub jungle.

2.2.3 Possibilities to change crops and especially from paddy to banana

Regarding the policy of cultivation in Hambantota district both the Deputy Director of Agriculture and the Assistant Director of Agriculture in Hambantota district said: "*The main policy is that the main crop should be paddy. If there is no water available, then other crops should be cultivated. They are encouraging banana instead of paddy, and* *they want to find out what areas are suitable for which crop.*" This seems to mean that changing from paddy to other crops (not banana, since banana is an irrigated crop) is recommended when there is no water available. When it comes to paddy and banana, changing from paddy to banana is recommended in some areas, provided that paddy remain the principal crop. The Division Secretary in Tissamaharama said: "*They encourage people to cultivate banana instead of paddy, and highland farmers to cultivate grapes.*" It should be noted that the Division Secretary in Lunugamwehera probably does not approve of changing from paddy to banana.

According to Weerakoon et al. (2000), the total paddy production in Sri Lanka has to increase to 3.4 million tons to feed the estimated population of about 20 million people in 2005. This number is based on the production of 2.8 million tons in 2000, projected population, increasing per capita consumption, requirements for seed and wastage in handling. It is also said that a great effort to achieve this goal should be placed on the irrigated dry zone. It follows that the main policy in Hambantota district of keeping paddy as the principal crop is well founded. The results of the study on long-term trends in the banana sector in Sri Lanka by Kudagamage et al. (2002) show that the cultivated area has an increasing trend from 1973 to 2000 but also that the profitability of the banana sector is fast decreasing. Because data on cost of cultivation were not available on variety basis only the average net income could be calculated. Since there are differences in price between different varieties of banana, the results does not contradict the general opinion that banana is worth cultivating. However, if everyone starts cultivating banana, then the market will become saturated, the market price will become lower, and the profitability will decrease.

Most of the respondents among the farmers said that paddy cultivation was profitable before, but not anymore. As was mentioned in Section 2.2.1, the low market price of paddy is considered to be the main reason for this situation. Other explanations are the high prices of labour, tractors, synthetic fertilizers and pesticides. On the other hand, a few farmers with private capital said that paddy farming is profitable and that the latest drawback was due to the drought. One paddy and banana landowner with hired labour in Tissamaharama division said: "*There are economic resources available, and they can afford to spend money on every activity related to farming. Paddy cultivation is profitable. If you can use your own money it is profitable.*" Anyway, the general opinion seems to be that it is not profitable, and one paddy farmer within Lunugamwehera Scheme in Lunugamwehera division said: "*Paddy cultivation is not significantly profitable… They will have no loss if the price of one kg paddy is 17-18 Roupies. When there is a good harvest the price goes down. If there is a guaranteed price they can be sure of a profit.*" Compared to paddy, banana is often mentioned as the more profitable crop. Even if this is true, the picture is more complicated than this, and the GN-officer in Tissamaharama GN-division in Tissamaharama division said:

It is possible to change crops, and a lot of farmers already do it. Cultivating the main crop paddy is profitable in some areas and not profitable in other areas. Banana is in general more profitable to cultivate, but it is not as secure as paddy, since it is only possible to cultivate for five years. Paddy is a socially high status crop, and this is an obstacle to change to other crops.

One paddy under cultivator in Tissamaharama division described the situation like this:

Banana is a better crop but is only possible to cultivate during five years. Thereafter one has to cultivate paddy for two to three years. Paddy is a high status crop, and even if he would loose some money on cultivating paddy he would do it. If they cultivate paddy, then they get respect.

It appears like one practical problem with banana is that after five years the soil needs to rest. Then the farmer maybe has to cultivate paddy in the same field, but this can be problematic, since it is hard to restore a banana field to a paddy field. Another obstacle, and an even more important one, is that paddy is a socially high status crop. Almost every respondent agree on this, and some of the farmers are not prepared to change from paddy to banana even if they loose money on paddy. Paddy is the traditional staple food crop in Sri Lanka, and this is one reason why paddy farming has such a high status. The Division Secretary in Tissamaharama seems disappointed about this: "*Paddy owners are supposed to be affluent persons. The high status makes it almost impossible.*" It is not hard to understand the impact of high social status, since power often is more important than money. In the study on poverty and rural livelihoods in Sri Lanka, Marzano (2002) found that people who originally come from traditional paddy regions consider limited access to paddy land as an indicator of poverty, even though it would be more profitable to use the land for cash crops (like banana). Marzano explain this partly with the security of storing paddy for future consumption but also with the high status of paddy as the most culturally valued form of cultivation. Presently this is an obstacle, but it is slowly changing, as one paddy and banana farmer within Lunugamwehera Scheme in Lunugamwehera division said: "*Paddy is a high status crop, but it is about to change, because of high costs of fertilizers and labour. The price of paddy is too low.*" However, for some farmers there is no choice to be made. One paddy under cultivator in Tissamaharama division said that for an under cultivator there is no possibility to choose between the crops, since the landowner decide what has to be cultivated.

2.3 Conclusions of the interview analysis

The general opinion is that it is possible to increase the yield with proper water management and proper use of fertilizers and pesticides. Another way to increase the yield seems to be to improve the varieties of the crops. However, it most certainly is impossible to extend the cultivated area within the Lunugamwehera Scheme, since all the irrigated land within the scheme is distributed with three acres per farmer. Even in private land areas, it appears impossible to extend the area, since all land is occupied, and the ownership goes from generation to generation. On the other hand, in highland farming areas it is possible to extend the cultivated area by preparing new areas in the scrub jungle.

In general, it is possible to change between crops and from paddy to other crops. When there is no water available it is recommended to change from paddy to other crops (not banana, since banana is an irrigated crop). In some areas it is recommended to change from paddy to banana. When it comes to the question about cultivating paddy or banana, it is clear that the socio-economical conditions for paddy and banana are both similar and different. Paddy and banana are both irrigated crops and therefore treated at the district meetings and the Kanna meetings, and assistance is also available through the agricultural instructors. For both of the crops, bank loans are available through the departments and the banks. However, there is a big difference between paddy and banana, and there are different forces pulling in opposite directions where the most important are the high social status of paddy cultivation and the higher profitability of banana cultivation. As was mentioned above, it is not hard to understand the impact of high social status, since social power often is more important than money. At the same time, when it comes to money there is always a limit to what is acceptable, and everyone always needs the smallest amount required for a descent life. Maybe it is hard to say which of paddy and banana that is the best crop to cultivate. Anyway, the main policy in Hambantota district seems to be to continue having paddy as the main crop, but at the same time there is an encouragement to cultivate banana. There also is an expressed wish to find out which areas that are suitable for paddy and banana. Because of this, it would be interesting to find out which areas that are suitable for paddy or banana and also to which extent they are suitable.

3 Land suitability classification

3.1 Theory

3.1.1 FAO framework for land evaluation

In FAOs (1976) "A Framework for Land Evaluation" it is pointed out that the presented framework for land evaluation with respect to rural land uses does not by itself constitute an evaluation system. The range of possible land uses and evaluation purposes is so wide that it is impossible for one system to cover them all. Despite this, there was a need for some degree of standardization, and the framework is a set of universally applicable principles and concepts on which local, national and regional evaluation systems can be constructed. The framework is applicable in all parts of the world and covers all kinds of rural land use, and not only agriculture. The concept "land evaluation" is defined as "*the process of assessment of land performance when used for specific purposes involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation*". It is also said that economic considerations has to be incorporated for the land evaluation to be of value in the broader perspective of land use planning. In a quantitative land evaluation, inputs and benefits should be considered to determine the suitability of the investigated land uses. The land evaluation process is comprehensive and requires a multidisciplinary approach with contributions from natural science, technology, sociology and economics.

A large part of the land evaluation process consists of a comparison of the investigated land areas with the investigated land uses in the physical land suitability classification (FAO 1976). The concept "land suitability classification" is defined as "*an appraisal and grouping, or the process of appraisal and grouping, of specific types of land in terms of* *their absolute or relative suitability for a specified kind of use*". This comparison is performed with respect to relevant diagnostic criterions, which are either land qualities or land characteristics. Land qualities are combinations of land characteristics, and land characteristics are attributes of land that can be measured or estimated, like rainfall, slope and soil texture. Because of possible interactions between land characteristics, it should be avoided to apply them directly in the land suitability classification. It is preferred to combine land characteristics into land qualities in such a way that the land qualities act independently from other land qualities. For example, erosion hazard is determined not only by slope angle but also by rainfall, soil texture and other land characteristics. However, as will be seen in the following section and in the method used in this study, the possibility to apply land qualities is often limited by the available data. In this study, the investigated land uses are cultivation of paddy and banana, and if only crop requirements in terms of land characteristics are available, then land characteristics has to be used. Separate land suitability classifications should be made for the investigated land areas with respect to each of the investigated land uses (FAO 1976). It is often recommended that three suitability classes (S1, S2 and S3) are used within the order of suitable and two suitability classes (N1 and N2) within the order of not suitable. Every diagnostic criterion has a critical value or a set of critical values, which are used in defining the suitability class limits. As will be seen in the following section and in the method used in this study, the number of suitability classes depends on the available data.

3.1.2 Land suitability classifications in general

Because of the method used in this study, the examples in the following text are in terms of land characteristics and not land qualities. Explaining how land characteristics are combined into land qualities is not within the scope of this study.

Natural scientists most often focus on the physical land suitability classification in the land evaluation process, but there is a difference between the methods used. Burrough (1989) say that classifications in general are essential data reduction processes through which complex sets of data are made understandable. Good classifications are aimed at reducing the unavoidable loss of information to a minimum, and by identifying natural groups of individuals they provide appropriate ways of transferring information. Burrough (1989) explain that traditional strict Boolean set theory applied to soils and landscape first identify the central concept of a class (a set) and then determine the class limits as sharply defined boundary values. Burrough (1989) also explain that in a Boolean classification it is assumed that almost all change between classes occurs at the defined class boundaries and that the changes within classes are negligible. Rodhe & Sigstam (1994) denote a Boolean class *A* as follows (the notation in the following text is taken from Burrough (1989), McBratney & Odeh (1997), Prawitz (1989) and Rodhe & Sigstam (1994)):

$$A = \{x \mid x \text{ has the property } P\} \qquad x \in X \qquad \text{Equation 1}$$

This means that all objects *x,* within the defined universe of objects *X,* that has the property *P* is a member of *A*. Classifications into Boolean classes allows only for binary membership functions, which means that an object is a member or not a member of a given class. One example, given by Burrough (1989), is the following Boolean membership function μ_A:

$$\mu_A(x) = \begin{cases} 0 \; for \; x < b \\ 1 \; for \; x \geq b \end{cases} \qquad x \in X \qquad \text{Equation 2}$$

This means that an object *x*, within the defined universe of objects *X*, is a member (1 = true) of class *A*, if its value is equal to or larger than the boundary condition *b* and not a member (0 = false), if it is less than *b*. One example, similar to Burrough's (1989) example of deep soils, is that if the boundary of suitability of the land characteristic of soil depth is set to *b* = 100 cm, then the membership function defines all suitable sample points (objects *x*) with respect to soil depth. Burrough (1989) points out that the most common operators of Boolean algebra are AND, OR and NOT. The AND-operator gives the intersection between two or more classes:

$$A \cap B = \{x | x \in A \wedge x \in B\} \qquad x \in X \qquad \text{Equation 3}$$

This means that the intersection of *A* and *B* ($\cap$ denotes the intersection) is equal to the class of all objects *x*, within the defined universe of objects *X*, that belongs to both *A* and *B* ($\wedge$ denotes the AND-operator). The OR-operator gives the union of two or more classes:

$$A \cup B = \{x | x \in A \vee x \in B\} \qquad x \in X \qquad \text{Equation 4}$$

This means that the union of *A* and *B* ($\cup$ denotes the union) is equal to the class of all objects *x*, within the defined universe of objects *X*, that belongs to *A* or *B* ($\vee$ denotes the OR-operator). It should be noted that the union also include those objects *x* that belongs to both *A* and *B*. The NOT-operator gives the complement to a class:

$$\overline{A} = \{x | \neg(x \in A)\} \qquad x \in X \qquad \text{Equation 5}$$

This means that the complement of *A* ($\bar{}$ denotes the complement) is equal to the class of all objects *x*, within the defined universe of objects *X*, that do not belong to *A* ($\neg$ denotes the NOT-operator). The basic operations on Boolean classes is usually illustrated with Venn diagrams (Figure 8) but can also be illustrated with grids where the already classified grid cells (area units) are the objects (Figure 9).

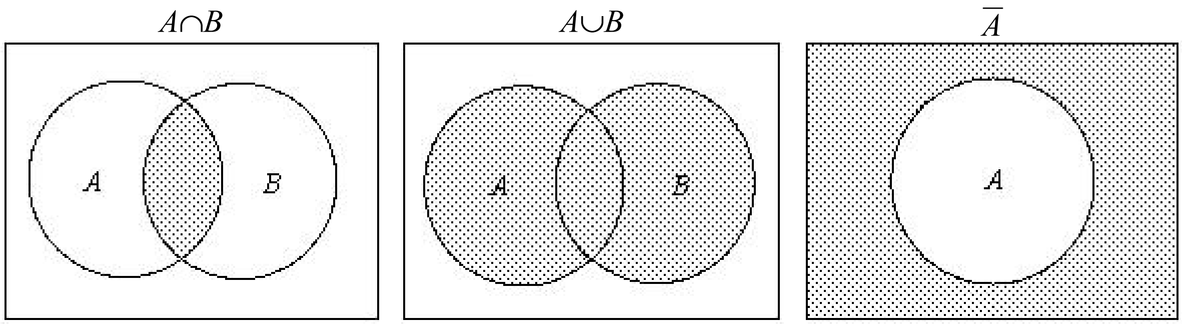

Figure 8. Illustration of the basic operations (AND, OR and NOT) on Boolean classes using Venn diagrams. Every object *x* within the rectangular frame belongs to the defined universe of objects *X*.

A

0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1

AND

B

1	1	1	1	0	0
1	1	1	1	0	0
1	1	1	1	0	0
1	1	1	1	0	0
1	1	1	1	0	0
1	1	1	1	0	0

→ $A \cap B$

0	0	1	1	0	0
0	0	1	1	0	0
0	0	1	1	0	0
0	0	1	1	0	0
0	0	1	1	0	0
0	0	1	1	0	0

A

0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1

OR

B

1	1	1	1	0	0
1	1	1	1	0	0
1	1	1	1	0	0
1	1	1	1	0	0
1	1	1	1	0	0
1	1	1	1	0	0

→ $A \cup B$

1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1

NOT

A

0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1
0	0	1	1	1	1

→ $\overline{A}$

1	1	0	0	0	0
1	1	0	0	0	0
1	1	0	0	0	0
1	1	0	0	0	0
1	1	0	0	0	0
1	1	0	0	0	0

Figure 9. Illustration of the basic operations on Boolean classes using grids. Every grid cell within the grid is an object *x* that belongs to the defined universe of objects *X*.

Following the example about soil depth, grid *A* can be said to represent all grid cells with respect to the suitability of soil depth (grid cells with the value of 1 belongs to class *A*). If grid *B* represents all grid cells with respect to the suitability of soil texture, then grid $A \cap B$ represents all grid cells with respect to the suitability of both soil depth and texture. From Figure 9 it is evident that the AND-operator gives the same result as the product of the two grids and preserves the minimum value of the corresponding grid cells, which means that the AND-operator is narrowing in its nature. On the other hand, the OR-operator preserves the maximum value of the two grids, which means that the OR-operator is widening in its nature. The NOT-operator converts all values to the opposite. Of course, the objects do not need to be grid cells, and classifications can be made on larger area units. One example on application of both a Boolean and a fuzzy land suitability classification and a comparison of their results is given later in this section.

Perera et al. (1993) and Kalogirou (2002) used, in Sri Lanka and Greece respectively, point systems in their land suitability classifications with respect to the cultivation of different crops. As will be seen in Section 3.3, this study also uses a point system, and compared to Boolean classifications, point systems are more accurate in capturing levels of suitability. In the case of using grids, a grid cell is assigned a point value depending on the suitability of the value of the represented land characteristic (Figure 10).

A

0	0	1	1	2	2
0	0	1	1	2	2
0	0	1	1	2	2
0	0	1	1	2	2
0	0	1	1	2	2
0	0	1	1	2	2

+

B

2	2	1	1	0	0
2	2	1	1	0	0
2	2	1	1	0	0
2	2	1	1	0	0
2	2	1	1	0	0
2	2	1	1	0	0

→

A+B

2	2	2	2	2	2
2	2	2	2	2	2
2	2	2	2	2	2
2	2	2	2	2	2
2	2	2	2	2	2
2	2	2	2	2	2

A

0	0	1	1	2	2
0	0	1	1	2	2
0	0	1	1	2	2
0	0	1	1	2	2
0	0	1	1	2	2
0	0	1	1	2	2

*

B

2	2	1	1	0	0
2	2	1	1	0	0
2	2	1	1	0	0
2	2	1	1	0	0
2	2	1	1	0	0
2	2	1	1	0	0

→

*A*B*

0	0	1	1	0	0
0	0	1	1	0	0
0	0	1	1	0	0
0	0	1	1	0	0
0	0	1	1	0	0
0	0	1	1	0	0

Figure 10. Illustration of operations on point values using grids.

It should be noted that the capital letters *A* and *B* in Figure 10 have the function to denote only grids and not both grids and classes as in Figure 9. However, grid *A* and *B* contain three suitability classes corresponding to the point values of 0, 1 and 2, and following FAOs (1976) framework for land evaluation, they can be named as not suitable (N), suitable (S1) and highly suitable (S2). The suitability classes are defined, for every land characteristic, in terms of appropriate value intervals of the land characteristic (see Table 13 in Section 3.3). If the suitability classes are to be applicable to the final result (like *A+B* and *A*B*), then they have to be redefined in terms of the final result (see Table 14 in Section 3.3). It is evident from Figure 10 that the sum of the point values does not necessarily discern cases where at least one land characteristic has the value of 0. If the not suitable land characteristic is decisive to the overall suitability, then there is a risk to incorrectly classify the final result as suitable. As can be seen in Figure 10, by using the product between the point values all cases with the value of 0 are discerned. Because of this, it is appropriate to consider both the sum and the product of the point values.

When using a point system, it is possible to assign different weights to different land characteristics. Depending on their relative importance to the investigated land use, the land characteristics should be weighted differently. Weights are assigned to capture the sensitivity in the performance of the investigated land use to changes in the values of the land characteristics. Ahamed et al. (2000) use an elaborate weight system in their land suitability classification with respect to different crops in India. They apply the so-called

Analytic Hierarchy Process (AHP), by which the weights assigned to the land characteristics are determined on the basis of pair-wise comparisons of the importance of the land characteristics. Experts who estimated the relative importance of the land characteristics, according to a specially designed scale, made these pair-wise comparisons. Usually, the weights are numbers between 0 and 1, which add up to unity. Perera et al. (1993) use a simpler approach and assign higher point values to rainfall compared to temperature based on how the paddy yield is affected by changes in the values of rainfall and temperature. However, it is not within the scope of this thesis to further describe the methods used to determine weights to be assigned to land characteristics.

Burrough (1989) criticise the traditional strict Boolean classification methods and speaks for the use of fuzzy mathematical classification methods. Burrough (1989) say that fuzzy classes, in contrast to Boolean classes, are appropriate to deal with ambiguity, vagueness and ambivalence, in mathematical and conceptual models of empirical phenomena. Burrough (1989) explain that fuzzy classification theory is a generalization of Boolean classification theory and define a fuzzy class as follows:

$$A = \{x, \mu_A(x)\} \qquad x \in X \qquad \text{Equation 6}$$

This means that A is the class of the ordered pairs of objects x, within the defined universe of objects X, and their degrees of membership $\mu_A(x)$ in A. Usually, $\mu_A(x)$ is a number between 0 and 1 where 0 represent non-membership of the class and 1 represent full membership. Burrough (1989) emphasize that the degree of membership is reflecting the possibility of belonging to a class and not any kind of probability. McBratney & Odeh (1997) describe the three basic forms of fuzzy membership functions called triangular, trapezoidal and Gaussian (Figure 11).

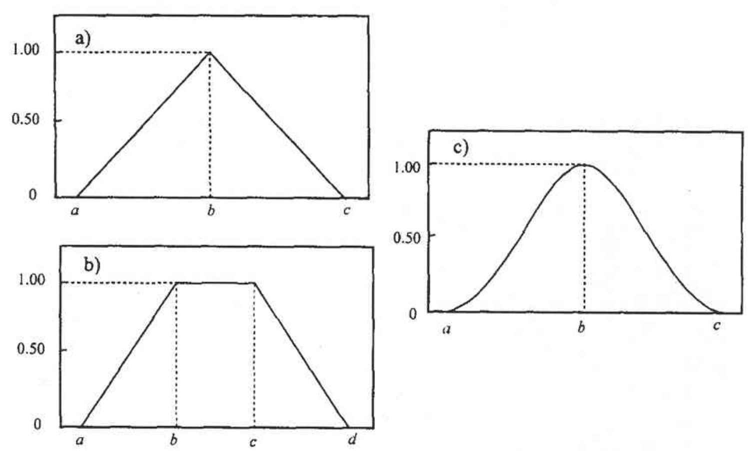

Figure 11. The three basic forms of membership functions used (*a*, *b*, *c* and *d* is on the x-axis): triangular (a), trapezoidal (b) and Gaussian (c). Source: McBratney & Odeh 1997.

The equation of the triangular and simplest form of membership function is the following:

$$\mu_A(x) = \begin{cases} 0 & x \le a \\ \dfrac{x-a}{b-a} & a < x \le b \\ \dfrac{c-x}{c-b} & b < x < c \\ 0 & x \ge c \end{cases} \qquad x \in X \qquad \text{Equation 7}$$

Burrough's (1989) most important argument against Boolean classifications is that they treat classes as internally homogenous with sharp boundaries and therefore fails to account for variations within the classes and for continuous transitions at the edges. Following the example about soil depth, the Boolean classification treats all soil depths equal to or larger than 100 cm as equally suitable (Equation 1). Probably, it would be more appropriate to describe the suitability of soil depth as a continuous transition between two values (Figure 12 and Equation 8).

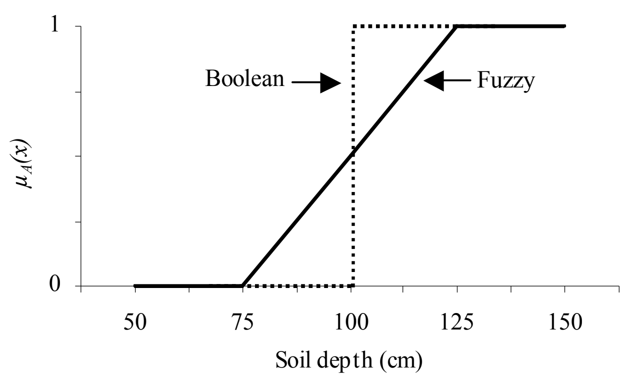

Figure 12. The continuous transition of a fuzzy membership function (soil depth is on the x-axis).

$$\mu_A(x) = \begin{cases} 0 & x \le 75 \\ \dfrac{x-75}{125-75} & 75 < x < 125 \\ 1 & x \ge 125 \end{cases} \qquad x \in X \qquad \text{Equation 8}$$

It can be seen in Figure 12 and Equation 8 that the fuzzy classification allows for variations within the class and for a continuous transition at the class edge. It can also be seen that fuzzy classifications include objects with low degrees of membership that would be excluded by Boolean classifications. Van Ranst et al. (1996) points out that fuzzy membership functions can be both symmetrical (Figure 11) and asymmetrical (Figure 12).

According to Burrough (1989), there are two possible ways of deriving fuzzy membership functions. The first approach is statistical and called the Similarity Relation

Model (SM). It is not within the scope of this thesis to describe this model. The second and simpler approach is to derive an a priori membership function and is called the Semantic Import Model (SI). The Semantic Import Model is useful when someone has a very good idea of how to classify data, but even when this is the case much effort often goes into selecting class intervals. Van Ranst et al. (1996) say that the critical values of fuzzy membership functions applied in land suitability classifications usually are difficult to determine by statistical means and are therefore based on expert judgements and experience. Burrough (1989) describe one general membership function that is commonly used when an a priori membership function is derived (Figure 13 and Equation 9).

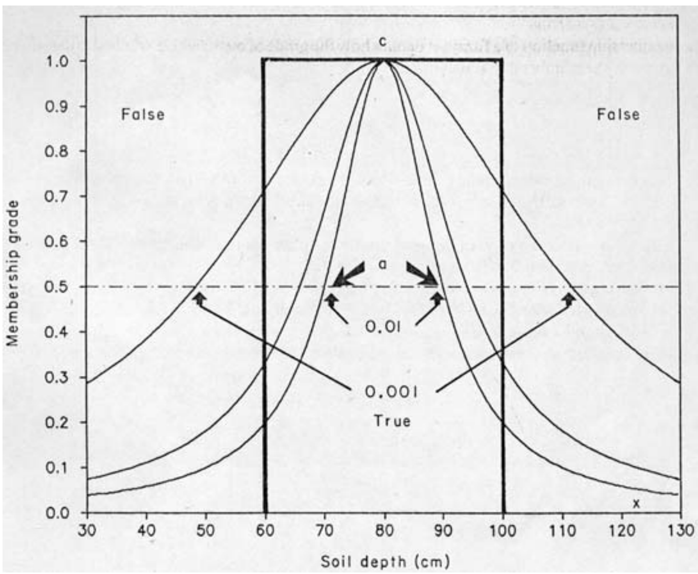

Figure 13. Graphs of equation 9 applied on soil depth with the central concept $c = 80$ cm. The graphs are showing how the shape of the membership function varies with the value of parameter a. The rectangle illustrates a Boolean membership function with boundaries at 60 cm and 100 cm. Source: Burrough 1989.

$$\mu_A(x) = \frac{1}{1 + a(x-c)^2} \qquad x \geq 0 \qquad x \in X \qquad \text{Equation 9}$$

Parameter a controls the shape of the membership function, and c defines the value of object x at the so-called central concept where $\mu_A(x) = 1$. By varying the value of a and the shape of the membership function it is possible to control the position of the so-called cross-over point where $\mu_A(x) = 0.5$. The value of the exponent can also be varied to control the dispersion as well. One example, given by Burrough (1989), is when deep soils should be distinguished from shallow and very deep soils. If the central concept of deep soils is set at $c = 100$ cm where $\mu_A(x) = 1$, then a value of $a = 0.0004$ gives the lower and upper cross-over points at 50 cm and 150 cm where $\mu_A(x) = 0.5$. Of course, this general membership function can be written in an asymmetrical version:

$$\mu_A(x) = \begin{cases} \dfrac{1}{1+a(x-c)^2} & x < c \\ 1 & x \geq c \end{cases} \qquad x \in X \qquad \text{Equation 10}$$

Burrough (1989) describes the basic operations on fuzzy classes, which are generalizations of the basic operations on Boolean classes. The intersection of two fuzzy classes is defined in the following way:

$$A \cap B = \int_X (\mu_A(x) \wedge \mu_B(x)) / x \qquad \text{Equation 11}$$

The symbol / means "with respect to", and the integral sign is not denoting a Riemann integral but is a way to express that the operation is made on all objects x within the universe of objects X. The AND-operator $\wedge$ is symbolizing "minimum", which it also does in the Boolean definition. The union of two fuzzy classes is defined in the following way:

$$A \cup B = \int_X (\mu_A(x) \vee \mu_B(x)) / x \qquad \text{Equation 12}$$

The OR-operator $\vee$ is symbolizing "maximum", which it also does in the Boolean definition. The complement of one fuzzy class is defined in the following way:

$$\overline{A} = \int_X (1 - \mu_A(x)) / x \qquad \text{Equation 13}$$

This definition corresponds to the NOT-operator in the Boolean definition. The basic operations are illustrated with grids in Figure 14 where "AND", "OR" and "NOT" should be interpreted as in the definitions above.

A

0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1

AND

B

1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0

→

$A \cap B$

0	0.2	0.4	0.4	0.2	0
0	0.2	0.4	0.4	0.2	0
0	0.2	0.4	0.4	0.2	0
0	0.2	0.4	0.4	0.2	0
0	0.2	0.4	0.4	0.2	0
0	0.2	0.4	0.4	0.2	0

A

0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1

OR

B

1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0

→

$A \cup B$

1	0.8	0.6	0.6	0.8	1
1	0.8	0.6	0.6	0.8	1
1	0.8	0.6	0.6	0.8	1
1	0.8	0.6	0.6	0.8	1
1	0.8	0.6	0.6	0.8	1
1	0.8	0.6	0.6	0.8	1

NOT

A

0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1
0	0.2	0.4	0.6	0.8	1

→

$\overline{A}$

1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0
1	0.8	0.6	0.4	0.2	0

Figure 14. Illustration of the basic operations on fuzzy classes using grids. Every grid cell within the grid is an object *x* that belongs to the defined universe of objects *X*.

Again, following the example about soil depth, grid *A* can be said to represent all grid cells with respect to the suitability of soil depth. If grid *B* represents all grid cells with respect to the suitability of soil texture, then grid $A \cap B$ represents all grid cells with respect to the suitability of both soil depth and texture. The basic operations on fuzzy classes are parallel cases to the basic operations on Boolean classes. Since the intersection of two fuzzy classes is preserving the minimum values of the corresponding grids, it is narrowing in its nature. On the other hand, the union of two fuzzy classes preserves the maximum values and is therefore widening in its nature. The complement of a fuzzy class is the difference between 1 and the grid values, which also is the case with the complement of a Boolean class. Boolean classifications are much more exclusive than fuzzy classifications, and Figure 15 shows the apparent risk of loosing a lot of information by the intersection of two Boolean classes.

A

0	0	0	1	1	1
0	0	0	1	1	1
0	0	0	1	1	1
0	0	0	1	1	1
0	0	0	1	1	1
0	0	0	1	1	1

AND

B

1	1	1	0	0	0
1	1	1	0	0	0
1	1	1	0	0	0
1	1	1	0	0	0
1	1	1	0	0	0
1	1	1	0	0	0

→

$A \cap B$

0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Figure 15. Illustration of a special case of two Boolean classes combined with the AND-operator. Every grid cell within the grid is an object *x* that belongs to the defined universe of objects *X*.

It can be seen in Figure 14 that the parallel case of the intersection of two fuzzy classes preserves much more information. Burrough (1989) also describe the so-called convex combination of fuzzy classes, which has shown to be useful in fuzzy land suitability classifications:

$$\mu_A(x) = \sum_{j=1}^{k} w_j \mu_{Aj}(x) \qquad x \in X \qquad \text{Equation 14}$$

where

$$\sum_{j=1}^{k} w_j = 1 \qquad w_j > 0$$

This means that if $A_1, \ldots A_k$ are fuzzy subclasses of the defined universe of objects X and $w_1, \ldots w_k$ are non-negative weights summing up to unity, then the convex combination of $A_1, \ldots A_k$ is a fuzzy class A whose membership function is the weighted sum.

Burrough (1989) compares the results of a Boolean and a fuzzy land suitability classification to show that fuzzy classifications are superior to Boolean classifications. Data on eleven soil parameters (land characteristics) were used to find out the suitable areas for cultivation of maize on a 45 ha farm in Túren in Venezuela. The resulting grid of the Boolean classification was produced as the intersection of eleven grids representing the eleven soil parameters. The resulting grid shows that the eleven input grids cancel each other out (as in Figure 15) and that the soil conditions in the field are unsuitable for the cultivation of maize. Since experience had shown that the soil conditions in the field actually are suitable, it was concluded that the Boolean classification was inappropriate. Instead, a fuzzy classification was performed using the fuzzy membership function in Equation 9, the convex combination in Equation 14 and approximately equal weights for each of the eleven soil parameters. The resulting grid shows that more than one third of the field has a fuzzy membership value above 0.66, which is two thirds of the ideal value of fully meeting the crop requirements.

It is possible to divide the resulting fuzzy membership values between 0 and 1 into suitability classes. Some authors use more complicated methods with the purpose of a fuzzy classification into suitability classes. Van Ranst et al. (1996) do not derive only one fuzzy membership function for every land quality (the study is made on land qualities and not land characteristics). Instead, four fuzzy membership functions, matching the four suitability classes, with different values at the central concept (where $\mu_A(x) = 1$), are derived for every land quality (Figure 16).

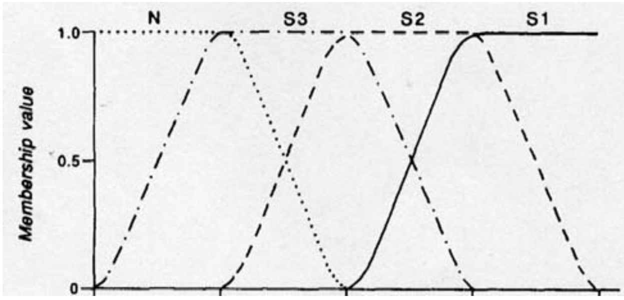

Figure 16. Graph showing the four fuzzy membership functions, matching the four suitability classes, for a land quality (the x-axis is left undefined). Source: Van Ranst et al. 1996.

For every suitability class, Van Ranst et al. (1996) combine the fuzzy membership values of all the land qualities. This means that one area unit finally is classified into more than one suitability class and that the dominant suitability class is the one with the highest membership value.

3.2 Material

The material used in the land suitability classification is the following:

Transformation parameters for transformation between WGS 84 and Everest Adjusted 1937 and between Everest Adjusted 1937 and SL Datum 95, where SL Datum 95 is the local system in Sri Lanka (Survey Department 2003 and International Water Management Institute 2003) (see Appendix 4).

GIS-data including ArcView layers (shape-files) containing administrative borders, places, roads, water bodies and land use within and around Hambantota district and ArcInfo layers (coverage files) containing administrative borders and water bodies within entire Sri Lanka (Topographic Information (1:50,000) 2003). This data was originally interpreted from aerial photographs and digitized from 1:50,000 paper maps. Since the maps in this thesis were made in ArcView, the coverage files were converted to shape-files. The original ArcView layers correspond to different original map sheets, and because of this they were merged into single layers covering the entire study area. It should be noticed that different individuals made the digitizing of the different original map sheets. This has resulted in that some administrative borders do not exactly match between the different ArcView layers. Regarding water bodies it should be noticed that small streams and irrigation channels are missing. The merged layer containing the total of administrative borders had to be complemented with some screen digitizing since the north-eastern part of Hambantota district was missing. For this purpose, an old layer containing the administrative border of Hambantota district was used as a target layer. The water bodies in the merged ArcView layer and the ArcInfo layer complement each other and were therefore combined into a single ArcView layer. This required some detailed work since there was an overlap between the hydrological features, which at the same time did not exactly coincide. In these situations, one of the overlapping features was chosen and the other deleted. This was done by comparing both of the overlapping features with five different 1:50,000 paper maps (Sri Lanka 1:50,000 1985, Sri Lanka

1:50,000 1999 and Sri Lanka 1:50,000 2000). Moreover, some of the information in the attribute tables of the ArcView layers has been complemented with additional information.

Three 1:50,000 paper maps showing the topography in the study area (Sri Lanka 1:50,000 1985, Sri Lanka 1:50,000 1999 and Sri Lanka 1:50,000 2000).

Three 1:1,000,000 paper maps showing irrigation development potential, mean annual rainfall and the distribution of the great soil groups in Sri Lanka (Irrigation Development Potential 1983, Rainfall and Soils (publication years are missing)). These paper maps were scanned and saved as raster pictures in TIFF-format. The raster pictures showing irrigation development potential and the distribution of the great soil groups were transformed and resampled in ArcGIS by using control points connecting the pictures with an already georeferenced ArcView layer used as a target layer. Affine second order transformations were used with 25 and 30 control points respectively, and the RMS-values are about 671 m and 678 m respectively. ArcView layers containing the potentially irrigated area and the five great soil groups in the study area were created by screen digitizing the scanned and resampled maps.

Buffer distances for water bodies (International Water Management Institute 2003) (Table 8).

Table 8. Buffer distances (in feet) for water bodies. Source: International Water Management Institute 2003.

Feature	Buffer (ft)
Tank	100
Main irrigation channel	33
Irrigation channel	33
River	100
Large stream	66
Small stream	33

Daily maximum and mean monthly maximum temperature statistics for Hambantota town (Department of Meteorology 2003). The daily maximum temperature statistics stretches from January to December in 2002, and the mean monthly maximum temperature statistics stretches from 1990 to 2002.

Mean monthly rainfall statistics collected at 20 meteorological stations between 1990 and 2002 (Department of Meteorology 2003). The mean monthly rainfall values were used to calculate the mean annual rainfall for all of the stations (Table 9).

Table 9. Rounded values of mean annual rainfall calculated on mean monthly rainfall values that stretches from 1990 to 2002. Latitude and longitude are given in decimal degrees in Everest Adjusted 1937 (see above). Source: Department of Meteorology 2003.

Meteorological station	Latitude (°)	Longitude (°)	Number of years	Rainfall (mm)
Ambalantota Govt. Farm	6.12	81.02	13	935
Angunakolapelessa	6.17	80.89	13	1,147
Badagiriya Tank	6.23	81.15	11	746
Bataata	6.10	80.92	12	929
Bundala Lewaya	6.20	81.25	10	963
Embilipitiya Coconut Nur	---	---	10	1,121
Hambantota	6.12	81.13	13	1,000
Kataragama	6.42	81.33	13	1,103
Kirama	6.22	80.67	8	1,874
Kuttigala Chandrikawewa	6.25	80.90	12	1,175
Liyangahatota	6.23	80.93	9	1,000
Lunugamwehera	6.33	81.20	11	1,080
Mahalewaya (Hambantota)	6.13	81.13	10	872
Mamadola	6.15	80.98	11	931
Palatupana Saltern	6.25	81.38	13	938
Ridiyagama Irrigation	6.22	80.98	4	871
Suriyawewa	6.32	81.00	11	1,143
Tangalla	6.02	80.80	5	899
Tissamaharama Irrigation	6.28	81.30	9	922
Yala	6.37	81.53	11	986

An ArcView point layer containing the position of the meteorological stations and the mean annual rainfall values were created. The position of Embilipitiya Coconut Nur (missing values) was digitized with the ArcView layer containing places as a target layer. The resulting shape-file was then projected to the local reference system called SL Datum 95 in ArcGIS (see above). As can be seen in Table 9, some of the meteorological stations have missing data for a number of years.

Physical and chemical requirements of paddy and banana taken from the FAO database called ECOCROP and complemented with some information available in the literature (ECOCROP 2003, Acland 1971 and Landon 1991) (Table 10 and 11).

Table 10. Physical and chemical requirements of paddy (*Oryza Sativa*). Source: ECOCROP 2003, Acland 1971 and Landon 1991.

Parameter	Optimal interval	Range interval
Latitude (°)	0-36	0-55
Climate zone	Tropical wet & dry (Aw), tropical wet (Ar), subtropical humid (Cf), subtropical dry summer (Cs), subtropical dry winter (Cw)	
Temperature (°C) during growing season	20-30	10-36
Annual rainfall (mm)	1,500-2,000	1,000-4,000
Soil fertility	High	Moderate
Soil drainage	Poor	
Soil texture	Wide; *fine-coarse; clay-sand*	
Soil depth (m)	> 0.5 and ≤ 1.5	0.2-0.5
Soil pH	5.5-7.0	4.5-9.0

Table 11. Physical and chemical requirements of banana (*Musa Sp.*). Source: ECOCROP 2003, Acland 1971 and Landon 1991.

Parameter	Optimal interval	Range interval
Latitude (°)	0-20	0-35
Climate zone	Tropical wet & dry (Aw), tropical wet (Ar)	
Temperature (°C) during growing season	22-32	13-38
Annual rainfall (mm)	2,400-2,700	2,000-3,500
Soil fertility	High	Moderate
Soil drainage	Well	
Soil texture	Medium; *moderately fine-coarse; coarse silt-sand*	
Soil depth (m)	> 1.5	0.5-1.5
Soil pH	5.0-7.0	4.5-7.5

The soil texture intervals in ECOCROP (2003) are given as "wide" for paddy and "medium" for banana (Table 10 and 11). After comparison with information available in Acland (1971) and Landon (1991) the soil texture intervals could be refined to the value intervals written in italics. The rest of the information is taken from ECOCROP (2003).

Physical and chemical characteristics of the five great soil groups available in the study area (Sri Lanka Council for Agricultural Research Policy) (Table 12).

Table 12. Physical and chemical characteristics of the five great soil groups available in the study area. Source: Sri Lanka Council for Agricultural Research Policy.

Parameter	Reddish Brown Earths	Low Humic Gley Soils	Alluvial Soils	Solodized Solonetz	Regosols
Soil fertility	Moderate	Moderate	Moderate	Low	Low
Soil drainage	Moderate-excessive	Very poor-poor	Very poor-well	Very poor-poor	Excessive
Soil texture	Moderately fine	Fine-moderately fine	Fine-coarse	Moderately fine-Moderately coarse	Coarse
Soil depth (m)	1.0-1.5	1.2-1.8	1.5-2.4	1.2-1.8	3.0-9.0
Soil pH	6.0-7.0	6.5-8.0	5.5-8.0	5.5	7.0

According to a soil expert at the Grain Legume and Oil Crops Research Centre in Angunakolapelessa, these parameters generally can be considered as normally distributed in the study area (Grain Legume and Oil Crops Research Centre 2003).

3.3 Method

Compared to Table 12, there are four more parameters in Table 10 and 11 and also compared to what is used in this land suitability classification. The parameters are latitude, climate, temperature during growing season and mean annual rainfall, and they are all left out from the classification as such. Latitude and climate does not make any difference, since they are fulfilled throughout the entire study area. Temperature is left out since there are no spatially differentiated temperature statistics available for the study area, and mean annual rainfall is left out since the mean annual rainfall is below the limit, throughout the entire study area, to cultivate paddy and banana without irrigation. Anyway, temperature and rainfall will be discussed in more detail.

It was mentioned in Section 1.3.4 that the climate is rather uniform in the south-eastern lowland region. Because of this, the available temperature statistics for Hambantota town can be said to approximately represent the entire study area. In the Status Review Report, written by Sri Lanka Council for Agricultural Research Policy, it is stated that the temperature distribution in the study area is uniform and remains high enough not to cause any limitation for cultivation. Generally, there is no doubt that the daytime temperature always is above the lower limit of the optimal interval and below the higher limit of the range interval for both paddy and banana (compare the mean annual temperature of 27.1 ºC in Hambantota town with Table 10 and 11). The only question is if the daytime temperature always is below the higher limit of the optimal interval for both paddy (30 ºC) and banana (32 ºC). The available daily maximum and mean monthly maximum temperature statistics for Hambantota town is analysed to give an answer to this question.

In Section 1.3.4, it became clear that the mean annual rainfall is scarce throughout the entire study area. There are spatial differences in mean annual rainfall but everywhere it is below the limit to cultivate paddy and banana without irrigation. However, as can be seen by comparing Table 10 in Section 3.2 and Figure 18 in Section 3.4, the mean annual rainfall in parts of the study area reaches the lower limit of the range interval for paddy, which is given in the ECOCROP (2003) database. This is not in agreement with the interviews, the frequency of major and minor irrigation schemes in the study area and what is written in the literature about paddy and banana cultivation in this region. Domrös (1974) have a possible explanation of this apparent contradiction:

> Since the possibilities of wet rice cultivation, and in particular the yields, depend on the water supply chiefly by irrigation, rainfall cannot be taken as a standard indicator of conditions favourable or unfavourable to wet rice cultivation, although its quantity and seasonal distribution may serve as a basis for the growing of *dry upland* rice. Domrös (1974).

It is possible that the lower limit given in the ECOCROP (2003) database has its explanation in the physical and chemical requirements of *dry paddy*, but it was emphasized in Section 1.2 that this land suitability classification is made only for the predominant *wet paddy*. Anyway, the point layer with the mean annual rainfall values in Table 9 was interpolated in ArcView using the Inversed Distance Weighted Method. The twelve nearest point values and a power of 2 (controlling the influence of distance) were used in the calculation of the grid cell values. The resulting continuous surface was compared with the scanned 1:1,000,000 paper map showing mean annual rainfall (Irrigation Development Potential 1983). Since this was made only with the purpose to see if there are any significant differences and to support that mean annual rainfall is left out from the analysis, the choice of interpolation method is not very elaborate.

The applied point system in this land suitability classification is a consequence of the quality of the data material, and the use of a more advanced system would have been inappropriate (the theory about fuzzy land suitability classifications will be used in Section 3.5). Firstly, the availability only of value intervals of the soil parameters for the five great soil groups in the study area makes it impossible to classify land suitability on grid cell level (Table 12). Secondly, it is only possible to extract three suitability classes from the value intervals of the physical and chemical requirements of paddy and banana in the ECOCROP (2003) database (Table 10 and 11). Since there is only an optimal interval and a range interval for both of the crops, the three possible suitability classes are one within the optimal interval, one within the range interval and one outside the range interval. Thirdly, since three of the five soil parameters only have values on ordinal scale level, it is most appropriate to apply a point system. Fourthly, since it has not been possible to estimate weights assigned to the soil parameters, the method does not incorporate the sensitivity of the crops to changes in the values of the soil parameters (see Section 3.1.2).

For each of the five great soil groups in the study area, the value intervals of the five soil parameters are compared with the value intervals of the physical and chemical requirements given in ECOCROP (2003) (Table 10, 11 and 12). Following the FAO (1976) framework for land evaluation, three suitability classes are based on the ECOCROP (2003) database (Table 13).

Table 13. Definitions of the suitability classes and their corresponding point values. The selection of the suitability classes N, S1 and S2 follow FAOs (1976) framework for land evaluation. Source: ECOCROP 2003 and FAO 1976.

Suitability class	In words	Meaning	Point
N	Not suitable	Value is outside the range interval	0
S1	Suitable	Value is inside the range interval and outside the optimal interval	1
S2	Highly suitable	Value is inside the optimal interval	2

For every great soil group, the value intervals of every soil parameter are compared with the value intervals of the physical and chemical requirements of either paddy or banana. Depending on how a value interval of a soil parameter is related to the value interval of the physical and chemical requirement of the crop, one or more point values are assigned to the soil parameter. The point values of the five soil parameters are then summarized and multiplied to give the total point values. Finally, the five great soil groups are classified into the overall suitability classes according to the definitions in Table 14.

Table 14. Definitions of the overall suitability classes. The selection of the suitability classes N, S1 and S2 follow FAOs (1976) framework for land evaluation. Source: ECOCROP 2003 and FAO 1976.

Suitability class	In words	Meaning
N	Not suitable	At least one value outside the range interval
S1	Suitable	At least one value outside the optimal interval and no value outside the range interval
S2	Highly suitable	All values inside the optimal interval

The final classifications are made with the help of some complementing information provided by a soil expert at the Grain Legume and Oil Crops Research Centre in Angunakolapelessa (Grain Legume and Oil Crops Research Centre 2003). For both paddy and banana, the total point values and the overall suitability classes are compared between the great soil groups.

Buffer areas around roads and water bodies were calculated on the ArcView layers in ArcView (see Section 3.2). During the fieldwork an approximate average road width of 26 feet (≈ 8 m) was estimated, and this value was used to calculate the buffer areas around the linear features of roads. Buffer areas around polygon features of tanks and rivers and linear features of large streams were calculated according to Table 8. An approximate average width of 34 ft (≈ 10 m) of large streams was added to the buffer areas around the linear features of large streams. Since no small streams, main irrigation channels and irrigation channels are represented in the ArcView layers, it was not possible to include them in the calculation. This is also the case with towns and villages, which are represented only as points without spatial extension. Anyway, the calculated buffer areas were deleted from the digitized soil map (Figure 5), and the resulting area values were calculated. In the digitized soil map, the five great soil groups are regrouped into only four groups where either of Low Humic Gley Soils and Solodized Solonetz is combined with Reddish Brown Earths. This means that the calculated areas are confined to these four groups. Despite this drawback, those of the four groups that can be considered classified as suitable were used to calculate the total area of the suitable soils. Moreover, the areas of the four groups and the suitable soils located within the potentially irrigated area were calculated by using the digitized map showing the irrigation development potential. The proportions of the areas of the four groups and the suitable soils to the study area and the potentially irrigated area were calculated as percentage values.

Furthermore, from the ArcView layer containing land use, the areas cultivated with paddy were extracted (areas cultivated with banana is not available). The buffer areas were then deleted from these areas, and the total area cultivated with paddy was calculated. To illustrate that most of the paddy cultivation is cultivation of wet paddy (see Section 1.2), the total paddy area and the percentage within the potentially irrigated area were calculated. Finally, if the land suitability classification is correct, then the paddy area should be located within the area of suitable soils. As a simple test of the land suitability classification, the total paddy area and the percentage within the area of suitable soils were calculated.

3.4 Results

Table 15 and Figure 17 contain the necessary information to answer the question if the daytime temperature in Hambantota town always is below the higher limit of the optimal interval for both paddy and banana (see Appendix 5 for temperature diagrams for the years from 1990 to 2001).

Table 15. Maximum temperature statistics calculated on daily maximum temperatures in Hambantota town in 2002. Source: Department of Meteorology 2003.

Month	Mean (ºC)	Minimum (ºC)	Maximum (ºC)	Range (ºC)	Standard-deviation	Days when t ≤ 30 ºC	Days when 30 < t ≤ 32 ºC	Days when t > 32 ºC
Jan	31.2	29.5	33.2	3.7	0.86	2	24	5
Feb	32.0	29.9	33.7	3.8	0.98	1	13	14
Mar	32.6	30.5	33.8	3.3	0.65	0	6	25
Apr	31.8	28.7	33.3	4.6	0.95	1	17	12
May	30.9	27.3	33.7	6.4	1.38	6	20	5
Jun	32.5	27.4	35.1	7.7	1.97	4	7	19
Jul	31.4	27.8	34.9	7.1	2.09	10	8	13
Aug	30.7	27.7	33.4	5.7	1.40	10	15	6
Sep	31.1	30.2	34.6	4.4	0.96	0	27	3
Oct	31.0	28.1	35.2	7.1	1.53	5	22	4
Nov	30.2	27.9	31.7	3.8	0.91	9	21	0
Dec	29.8	25.1	31.9	6.8	1.67	14	17	0

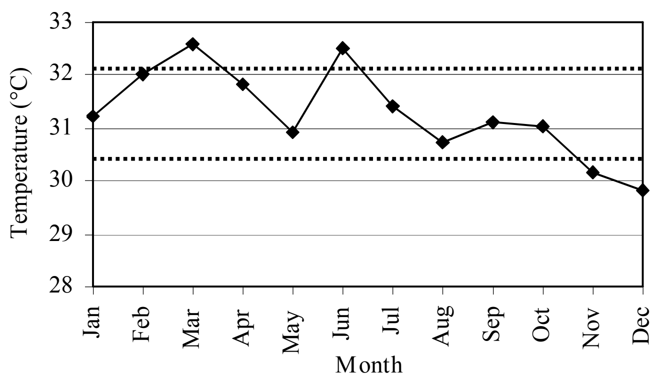

Figure 17. Temperature diagram that shows mean monthly maximum temperatures and standard deviation of the means calculated on daily maximum temperatures in Hambantota town in 2002. Source: Department of Meteorology 2003.

Except for March and June, all the mean monthly maximum temperatures are below the higher limit of 32 ºC for banana while only the value in December is below the higher limit of 30 ºC for paddy (Table 15 and Figure 17). However, except for November and December, all the maximum values of the daily maximum temperatures are above the higher limit for banana (Table 15). The mean values together with the range values and the standard deviations and the number of days above 32 ºC show that it is not uncommon with values above the higher limit for banana. In total, 106 days are above the higher limit for banana. However, 197 days are below the higher limit for banana, and 62 days are below the higher limit for paddy. All this show that the temperature conditions in Hambantota town seems to be more favourable to banana than to paddy.

The interpolation of the point layer containing the values of mean annual rainfall resulted in a continuous surface shown with two classes in Figure 18.

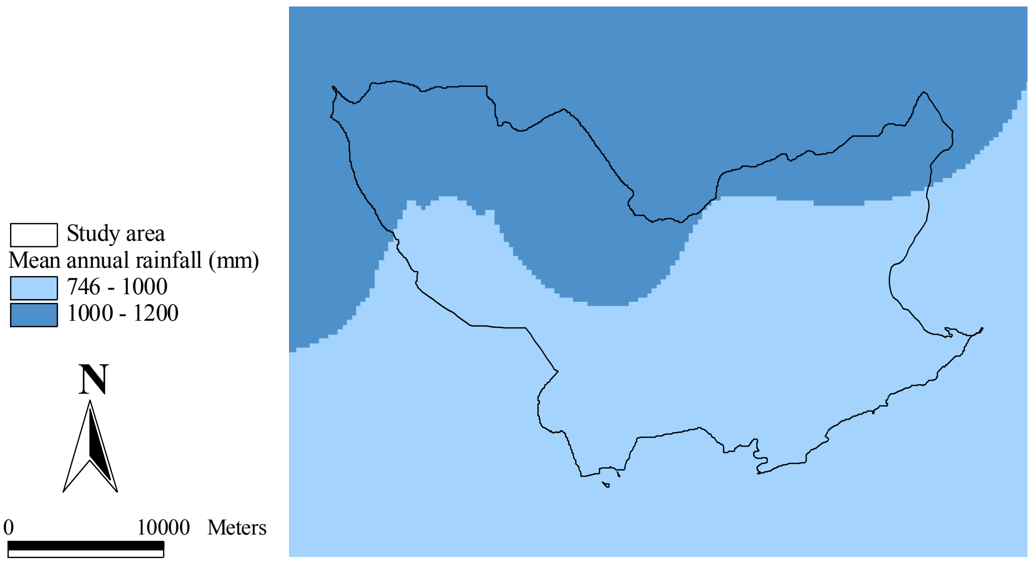

Figure 18. Interpolated mean annual rainfall in the study area. Source: Department of Meteorology 2003 and Survey Department 2003.

Considering the range of the amount of rainfall and that it is drier in the southern part of the study area, the interpolated map is similar to the scanned 1:1,000,000 paper map, which is also showing the mean annual rainfall (the scanned 1:1,000,000 paper map is not illustrated in this text) (Rainfall). The main difference is that the 750-1,000 mm interval of mean annual rainfall, shown in the scanned paper map, is confined to a smaller area in the south-eastern part of the study area. However, this means that the interpolated continuous surface does not contradict the conclusion that the amount of mean annual rainfall is below the limit, throughout the entire study area, to cultivate paddy and banana without irrigation.

For each of the five great soil groups and for both paddy and banana, the resulting point values are presented together with the value intervals of every soil parameter in Table 16 and 17.

Table 16. Point values of the five great soil groups with respect to cultivation of paddy. The sum and product are calculated for all the possible combinations. Source: Sri Lanka Council for Agricultural Research Policy.

Parameter	Reddish Brown Earths	Low Humic Gley Soils	Alluvial Soils	Solodized Solonetz	Regosols
Soil fertility	Moderate: 1	Moderate: 1	Moderate: 1	Low: 0	Low: 0
Soil drainage	Moderate-excessive: 0	Very poor-poor: 0 or 2	Very poor-well: 0 or 2	Very poor-poor: 0 or 2	Excessive: 0
Soil texture	Moderately fine: 2	Fine-moderately fine: 2	Fine-coarse: 2	Moderately fine-moderately coarse: 2	Coarse: 2
Soil depth (m)	1.0-1.5: 2	1.2-1.8: 0 or 2	1.5-2.4: 0 or 2	1.2-1.8: 0 or 2	3.0-9.0: 0
Soil pH	6.0-7.0: 2	6.5-8.0: 1 or 2	5.5-8.0: 1 or 2	5.5: 2	7.0: 2
Sum	7	4, 5, 6, 7, 8 or 9	4, 5, 6, 7, 8 or 9	4, 6 or 8	4
Product	0	0, 8 or 16	0, 8 or 16	0	0

Table 17. Point values of the five great soil groups with respect to banana cultivation. The sum and product are calculated for all the possible combinations. Source: Sri Lanka Council for Agricultural Research Policy.

Parameter	Reddish Brown Earths	Low Humic Gley Soils	Alluvial Soils	Solodized Solonetz	Regosols
Soil fertility	Moderate: 1	Moderate: 1	Moderate: 1	Low: 0	Low: 0
Soil drainage	Moderate- excessive: 0 or 2	Very poor-poor: 0	Very poor-well: 0 or 2	Very poor-poor: 0	Excessive: 0
Soil texture	Moderately fine: 2	Fine-moderately fine: 0 or 2	Fine-coarse: 0 or 2	Moderately fine-moderately coarse: 2	Coarse: 2
Soil depth (m)	1.0-1.5: 1	1.2-1.8: 1 or 2	1.5-2.4: 1 or 2	1.2-1.8: 1 or 2	3.0-9.0: 2
Soil pH	6.0-7.0: 2	6.5-8.0: 0, 1 or 2	5.5-8.0: 0, 1 or 2	5.5: 2	7.0: 2
Sum	6 or 8	2, 3, 4, 5, 6 or 7	2, 3, 4, 5, 6, 7, 8 or 9	5 or 6	6
Product	0 or 8	0	0, 4, 8 or 16	0	0

Reddish Brown Earths and paddy cultivation: In the case of paddy, the group of Reddish Brown Earths has suitable or highly suitable point values of every soil parameter except of soil drainage (Table 16). Poorly drained soils are suitable and highly suitable while the group of Reddish Brown Earths has moderate to excessive drainage (compare Table 10 and 12). However, the discussion with a soil expert at the Grain Legume and Oil Crops Research Centre in Angunakolapelessa provided complementing information (Grain Legume and Oil Crops Research Centre 2003). If enough water is available, then the moderately drained portion is suitable and in some cases even the well drained portion. The soils are impounded with water so that poor drainage conditions are created temporarily. In addition to this, when paddy cultivation is started, a hard pan of compact soil layer builds up about 40 cm below the surface. Keeping in mind that the value intervals of the soil parameters can be considered normally distributed in the study area (see Section 3.2), this means that a fair-sized portion of the group of Reddish Brown Earths (moderately drained and some of the well drained out of the moderately to excessively drained) can be classified as suitable for paddy cultivation.

Reddish Brown Earths and banana cultivation: In the case of banana, the group of Reddish Brown Earths has suitable or highly suitable point values of every soil parameter except partly for soil drainage (Table 17). Well drained soils are suitable and highly suitable while the group of Reddish Brown Earths has moderate to excessive drainage (compare Table 11 and 12). The discussion with the soil expert provided the complementing information that the moderately drained and the well drained portions are suitable (Grain Legume and Oil Crops Research Centre 2003). This means that a large portion of the group of Reddish Brown Earths can be classified as suitable for banana cultivation.

Low Humic Gley Soils and paddy cultivation: In the case of paddy, the group of Low Humic Gley Soils has suitable or highly suitable point values of every soil parameter except partly for soil drainage and soil depth (Table 16). Poorly drained soils are suitable and highly suitable, soil depths from 0.2 m to 0.5 m are suitable and soil depths from more than 0.5 m to 1.5 m are highly suitable while the group of Low Humic Gley Soils has very poor to poor drainage and soil depths from 1.2 m to 1.8 m (compare Table 10 and 12). If it is assumed that a suitable and highly suitable value of soil drainage does not exclude a highly suitable value of soil depth, and vice versa, then at least a portion of the group of Low Humic Gley Soils can be classified as suitable for paddy cultivation.

Low Humic Gley Soils and banana cultivation: In the case of banana, the group of Low Humic Gley Soils has suitable or highly suitable point values of soil fertility and soil depth but only partly suitable/highly suitable values of soil texture and soil pH and a not suitable value of soil drainage (Table 17). Since soil drainage is very poor to poor, the group of Low Humic Gley Soils can be classified as not suitable for banana cultivation (compare Table 11 and 12).

Alluvial Soils and paddy cultivation: In the case of paddy, the group of Alluvial Soils has suitable or highly suitable point values of every soil parameter except partly for soil drainage and soil depth (Table 16). Poorly drained soils are suitable and highly suitable, soil depths from 0.2 m to 0.5 m are suitable and soil depths from more than 0.5 m to 1.5 m are highly suitable while the group of Alluvial Soils are very poorly to well drained and has soil depths from 1.5 m to 2.4 m (compare Table 10 and 12). Once again, the discussion with the soil expert provided complementing information (Grain Legume and Oil Crops Research Centre 2003). As in the case with the group of Reddish Brown Earths, if enough water is available, then the moderately drained portion is suitable and in some cases even the well drained portion. It was also said that the group of alluvial soils are the most productive paddy soils in the area. Taking this into account and even if the soil depth intervals do mismatch, a considerable portion of the group of Alluvial Soils is classified as suitable.

Alluvial Soils and banana cultivation: In the case of banana, the group of Alluvial Soils has suitable or highly suitable point values of soil fertility and soil depth but only partly suitable/highly suitable values of soil drainage, soil texture and soil pH (Table 17). Well drained soils are suitable and highly suitable, soil textures from moderately fine to coarse are suitable and highly suitable, soil pH from 4.5 to 7.5 are suitable and soil pH from 5.0 to 7.0 are highly suitable while the group of Alluvial Soils are very poorly to well drained, has soil textures from fine to coarse and soil pH from 5.5 to 8.0 (compare Table 11 and 12). If it is assumed that a suitable/highly suitable value of one of these three parameters does not exclude a suitable/highly suitable value of one of the other two parameters, then at least a portion of the group of Alluvial Soils can be classified as suitable for banana cultivation.

Solodized Solonetz and paddy cultivation: In the case of paddy, the group of Solodized Solonetz has highly suitable point values of soil texture and soil pH but only partly highly suitable values of soil drainage and soil depth and a not suitable value of soil fertility (Table 16). Since soil fertility is low, the group of Solodized Solonetz can be classified as not suitable for paddy cultivation (compare Table 10 and 12).

Solodized Solonetz and banana cultivation: In the case of banana, the group of Solodized Solonetz has highly suitable point values of soil texture and soil pH and suitable and highly suitable values of soil depth but not suitable values of soil fertility and soil drainage (Table 17). Since soil fertility is low and soil drainage is very poor to poor, the group of Solodized Solonetz can be classified as not suitable for banana cultivation (compare Table 11 and 12).

Regosols and paddy cultivation: In the case of paddy, the group of Regosols has highly suitable point values of soil texture and soil pH but not suitable values of soil fertility, soil drainage and soil depth (Table 16). Since soil fertility is low, soil drainage is excessive and the soil depths is ranging from 3.0 m to 9.0 m, the group of Regosols can be classified as not suitable for paddy cultivation (compare Table 10 and 12).

Regosols and banana cultivation: In the case of banana, the group of Regosols has highly suitable point values of soil texture, soil depth and soil pH but not suitable values of soil fertility and soil drainage (Table 17). Since soil fertility is low and soil drainage is excessive, the group of Regosols can be classified as not suitable for banana cultivation (compare Table 11 and 12).

The overall land suitability classification is summarized in Table 18 and 19.

Table 18. The sums and products of all the possible combinations of point values and the overall suitability classes (resulting from the arguments above) of the five great soil groups with respect to paddy cultivation.

Sum, product and overall suitability class	Reddish Brown Earths	Low Humic Gley Soils	Alluvial Soils	Solodized Solonetz	Regosols
Sum	7	4, 5, 6, 7, 8 or 9	4, 5, 6, 7, 8 or 9	4, 6 or 8	4
Product	0	0, 8 or 16	0, 8 or 16	0	0
Overall suitability class	Fair-sized portion suitable	At least a portion suitable	Considerable portion suitable	Not suitable	Not suitable

Table 19. The sums and products of all the possible combinations of point values and the overall suitability classes (resulting from the arguments above) of the five great soil groups with respect to banana cultivation.

Sum, product and overall suitability class	Reddish Brown Earths	Low Humic Gley Soils	Alluvial Soils	Solodized Solonetz	Regosols
Sum	6 or 8	2, 3, 4, 5, 6 or 7	2, 3, 4, 5, 6, 7, 8 or 9	5 or 6	6
Product	0 or 8	0	0, 4, 8 or 16	0	0
Overall suitability class	Large portion suitable	Not suitable	At least a portion suitable	Not suitable	Not suitable

It should be noticed that the number of possible sums and products does not mean that all combinations exist in reality. Reddish Brown Earths, Low Humic Gley Soils and Alluvial Soils are all to a certain extent suitable for paddy cultivation, and Reddish Brown Earths and Alluvial Soils are both to a certain extent suitable for banana cultivation (Table 18 and 19). Low Humic Gley Soils are not suitable for banana cultivation, and both Solodized Solonetz and Regosols are not suitable for cultivation of any of the crops.

Among the four groups, where either of Low Humic Gley Soils or Solodized Solonetz is combined with Reddish Brown Earths, the groups of Reddish Brown Earths and Low Humic Gley Soils, Reddish Brown Earths and Solodized Solonetz and Alluvial Soils are considered suitable (but in reality only to a certain extent) in the following text. The areas of the four groups and the total area of the suitable soils within both the study area and the potentially irrigated area and the percentages of both the study area and the potentially irrigated area are given in Table 20 and illustrated in Figure 19.

Table 20. The areas of the four groups and the total area of the suitable soils within the study area and the potentially irrigated area and the percentages of the study area and the potentially irrigated area. The study area is 592,784,001 m^2, and the potentially irrigated area is 372,058,578 m^2.

Areas and percentages	Reddish Brown Earths and Low Humic Gley Soils	Reddish Brown Earths and Solodized Solonetz	Alluvial Soils	Regosols	Suitable soils
Area within the study area (m^2)	327,513,784	72,528,611	44,769,708	28,419,345	444,812,103
Percentage of the study area (%)	55.3	12.2	7.6	4.8	75.1
Area within the potentially irrigated area (m^2)	207,271,572	75,953,729	37,204,554	28,419,345	320,429,855
Percentage of the potentially irrigated area (%)	55.7	20.4	10.0	7.6	86.1

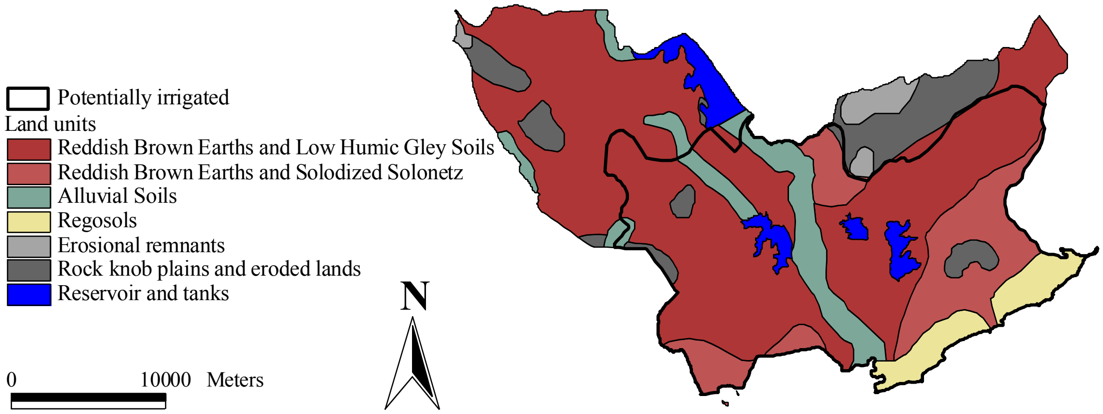

Figure 19. Map showing the distribution of the five great soil groups and the potentially irrigated area. Source: Irrigation Development Potential 1983, Soils, Survey Department 2003 and Topographic Information (1:50,000) 2003.

For both the study area and the potentially irrigated area, it is clear that the group of Reddish Brown Earths and Low Humic Gley Soils is the largest of the four groups (Table 20 and Figure 19). The group of Reddish Brown Earths and Solodized Solonetz is the second, Alluvial Soils is the third and Regosols is the fourth and smallest of the four groups. The areas and percentages of suitable soils are calculated on all groups except for Regosols, which means that the areas and percentages include the not suitable group of Solodized Solonetz. However, the calculated areas and percentages of the suitable soils can be considered useful in picturing the situation.

The total paddy area within the study area and the total paddy areas and percentages within the potentially irrigated area and the area of the suitable soils are given in Table 21 and illustrated in Figure 20 and 21.

Table 21. The total paddy area within the study area and the total paddy areas and percentages within the potentially irrigated area and the area of the suitable soils.

Areas and percentages	Paddy cultivation
Area within the study area (m^2)	106,371,548
Area within the potentially irrigated area (m^2)	100,170,807
Percentage within the potentially irrigated area (%)	94.2
Area within the area of suitable soils (m^2)	102,557,692
Percentage within the area of suitable soils (%)	96.4

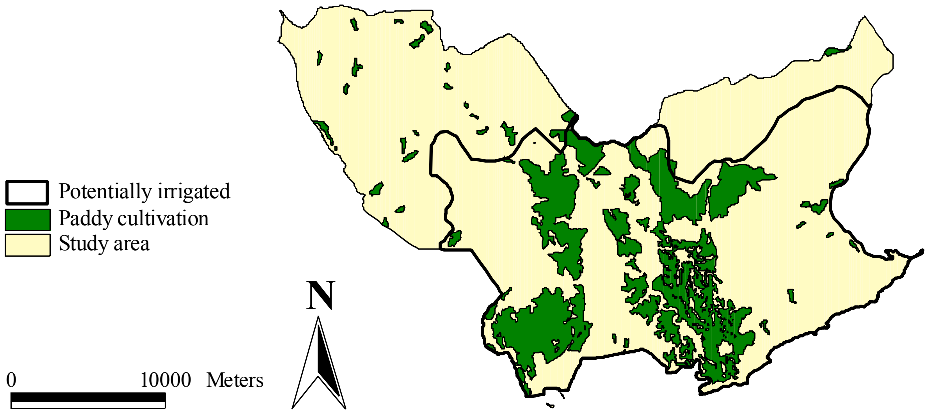

Figure 20. Map showing the paddy cultivation areas and the potentially irrigated area. Source: Irrigation Development Potential 1983, Survey Department 2003 and Topographic Information (1:50,000) 2003.

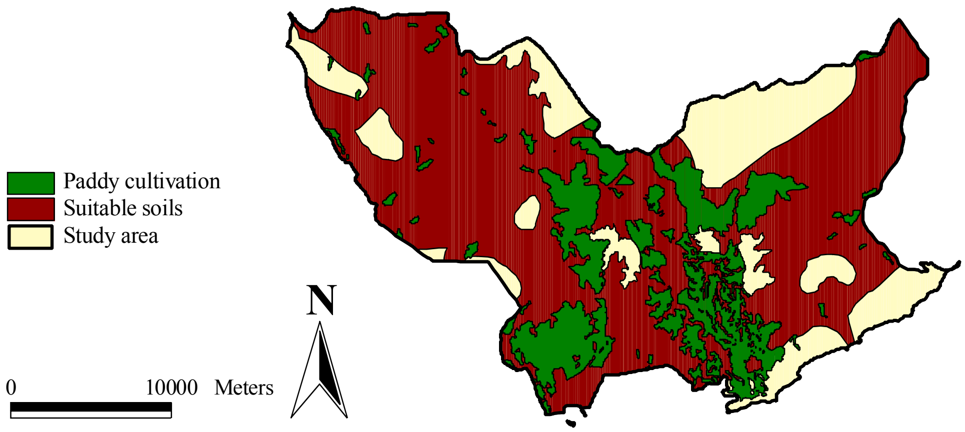

Figure 21. Map showing the paddy cultivation areas and the area of the suitable soils. Source: Soils, Survey Department 2003 and Topographic Information (1:50,000) 2003.

The main part of the total paddy area is located within the potentially irrigated area and the area of the suitable soils (Table 21 and Figure 20 and 21). This illustrate that most of the paddy cultivation is cultivation of wet paddy and corroborate that the land suitability classification is correct.

3.5 Discussion and conclusions

3.5.1 Sources of error in the material

It was mentioned in Section 3.2 that the GIS-data originally was interpreted from aerial photographs and digitized from 1:50,000 paper maps by different individuals and that this has resulted in some inconsistencies and missing data (Topographic Information (1:50,000) 2003). The GIS-data is only reliable to this extent, to the extent that the revisions made in this study are correct and to the extent that the material is up-to-date. Of course, this has affected the area calculations. This is also the case with the scanned and digitized 1:1,000,000 paper maps (Irrigation Development Potential 1983 and Soils). These paper maps are small-scale maps, and the process of scanning and digitizing does not make it better. Another factor influencing the area calculations are the buffer distances estimated during the fieldwork. The buffer distances collected at International Water Management Institute can be considered correct (International Water Management Institute 2003) but the fieldwork estimations of road width and the width of large streams are only crude approximations.

One limitation of the temperature and rainfall statistics is the availability of data only for the short period between 1990 and 2002 (Department of Meteorology 2003). Moreover, in this material, there is some missing rainfall data for some of the years. The small number of meteorological stations is also a problem, and this is especially the case with the temperature data (only one station). These limitations are one reason why the parameters of rainfall and temperature were not included in the land suitability classification. However, the rainfall and temperature statistics can be considered reliable.

There are a few things to say about the reliability of the physical and chemical requirements of paddy and banana and the physical and chemical characteristics of the five great soil groups (ECOCROP 2003, Acland 1971, Landon 1991 and Sri Lanka Council for Agricultural Research Policy). Regarding the physical and chemical requirements of paddy and banana, the requirements most probably differ between different parts of the world and also between different varieties of the crops. The value intervals used are only reliable to the extent that they are applicable in Sri Lanka and the study area and to the varieties used in the study area. However, the same data sources have been used in the land evaluation study made by Cools et al. (2003) in Syria. More important, the soil expert at the Grain Legume and Oil Crops Research Station in Angunakolapelessa confirmed the applicability of the value intervals (Grain Legume and Oil Crops Research Centre 2003). Regarding the value intervals of the physical and chemical characteristics of the five great soil groups, the reliability depend on the number of soil samples on which they are calculated on.

Moreover, there is no guarantee that the ordinal scales used for the physical and chemical requirements of the crops do entirely match the ordinal scales used for the physical and chemical characteristics of the five great soil groups. For example, it is impossible to exactly know the meaning of “moderate” in either of the scales. This is a problem that most probably has affected the results of the land suitability classification.

3.5.2 The land suitability classification

It was mentioned in Section 3.3 that the applied point system in the land suitability classification is a consequence of the quality of the data material, and that the use of a more advanced system would have been inappropriate. Firstly, because of the availability only of value intervals of the soil parameters for the five great soil groups, it was impossible to classify land suitability on grid cell level. Secondly, it was only possible to extract three suitability classes from the value intervals available in ECOCROP (2003). Thirdly, since three out of five soil parameters are on ordinal scale level, it was most appropriate to apply a point system. Fourthly, it was not possible to estimate weights assigned to the soil parameters, and therefore the sensitivity of the crops to changes in the soil parameter values was not incorporated (see Section 3.1.2). Moreover, in the overall classification, complementing soil expert information was introduced, and twice it was assumed that a suitable or highly suitable value of one parameter does not exclude a suitable or highly suitable value of another parameter. All this means that the land suitability classification is actually made on a rather crude level, and also that the results only have answered the question of where it is possible to cultivate paddy and banana at an approximate level. Of course, the simple test of the classification is also made on a crude level.

The results of this land suitability classification are connected both to the soil parameters used and the choice of the classification method. Other soil parameters might give different results, and another classification method might give results of different quality. It should also be mentioned that, in an important way, the point values and the suitability classes are only comparable between the five great soil groups and not between paddy and banana. This means that, within the same soil group area, it is not possible to decide which of paddy and banana that is the best crop to cultivate. Banana could still be the most profitable crop, even if banana was classified only as suitable and paddy was classified as highly suitable (this is not a result of this study). To decide which of the crops that is best to cultivate, economic considerations has to be incorporated in a comprehensive land evaluation (see Section 3.1.1 and 3.5.4).

However, the land suitability classification does fulfil the purpose of picturing the situation, and above all, it points at the possibility of a more accurate and elaborate alternative. An application of a fuzzy land suitability classification on grid cell level does not only ask for continuous values on grid cell level but also for expert knowledge on appropriate membership functions and weights (see Section 3.1.2). Even if the fuzzy membership function in Equation 9 and the convex combination in Equation 14 are applied, the values of the parameters have to be estimated. To estimate the weights, the Analytic Hierarchy Process (AHP) can be used, but it requires pair-wise comparisons of the importance of the parameters used. Moreover, a large number of land characteristics are desirable. For example, it would be much better to split the soil parameter of soil fertility into its components and to include other land characteristics such as rainfall, temperature, slope and soil salinity. Furthermore, the use of land qualities, which are appropriate combinations of land characteristics, would be even more adequate. Such a land suitability classification would incorporate most of the possible soil conditions and other conditions in the study area.

3.5.3 An illustrative MATLAB implementation

Of course, it would have been much better if continuous values of land qualities or land characteristics were available on grid cell level. If expert knowledge also were available, then fuzzy membership functions and weights assigned to the land qualities or the land characteristics could be established. In such an advantageous situation, the calculations are very extensive and therefore best implemented in a computer program. Based on Pärt

Enander & Sjöberg (2003) and only for illustration purposes, a simple calculation sequence on values of two land characteristics available in grids was implemented in a MATLAB program. In this calculation sequence, the fuzzy membership functions in Equation 9 and 10 and the convex combination in Equation 14 are applied. The program code and the flow chart in Appendix 6 illustrate the calculation sequence of the MATLAB program. The program was successfully tested with two simple 2x2 grids, where the saved fuzzy membership values were compared with manually calculated values.

3.5.4 Extending the land suitability classification to a land evaluation

In their land suitability classification in north-western Syria, Cools et al. (2003) successfully applied a participatory approach to integrate the knowledge of both farmers and land resource experts. The farmers' knowledge provided an understanding of the impact of microclimatic variations. Cools et al. (2003) point out that this knowledge is an important advantage since detailed climatic data rarely is available in rural communities. It is evident from this study in Sri Lanka that detailed data is hard to find, and beside additional soil samples and new measurements of other land characteristics or land qualities, a participatory approach would certainly be fruitful.

It was mentioned in Section 3.1.1 that economic considerations has to be incorporated for the land evaluation to be of value in the broader perspective of land use planning. By using the result of the physical land suitability classification together with economic considerations, it is possible to estimate the potential yield and economic income of a specific crop. In this way, suitable land areas will be identified, and by comparing the potential yield and income it is possible to make rational choices between the investigated crops.

If these final steps are taken, then the land suitability classification has been extended to the comprehensive process of a land evaluation that requires a multidisciplinary approach with contributions from natural science, technology, sociology and economics (see Section 3.1.1).

4 Conclusion

In order to get a more complete picture, both qualitative and quantitative methods are used in the present Sida/SAREC-financed research project within which this study has been made. By the qualitative measures of the interviews and the quantitative measures of the land suitability classification, this study has successfully provided a general picture of the agricultural situation in the study area and successfully met the objectives of this study. The analysis of the interviews has answered four of the five questions and functioned as a background to the land suitability classification. To a certain extent, the land suitability classification has answered the last of the five questions, and even if there are limitations, it points at the possibility of a more accurate and elaborate alternative in the future.

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Survey Department, 2003: Colombo, Sri Lanka.

Appendix 1

List of interviews

Table A1. List of the interviews. The GN-division number for Hambantota is missing.

Interview	Profession	Agro-social class	Division	GN-Division
1 - 30/9 2003	Paddy farmer	Within Lunugamwehera Scheme	Lunugamwehera	57 Seenamunna
2 - 1/10 2003	Division Secretary, Development Officer Planning and Development Coordinator Planning	---	Lunugamwehera	19 Lunugamwehera
3 - 1/10 2003	Paddy and banana farmer	Within Lunugamwehera Scheme	Lunugamwehera	57 Seenamunna
4 - 1/10 2003	Highland crops farmer	Highland cultivator	Lunugamwehera	48 Mattala
5 - 1/10 2003	Paddy and banana farmer	Within Lunugamwehera Scheme	Lunugamwehera	19 Lunugamwehera
6 - 2/10 2003	Division Secretary	---	Tissamaharama	33 Mahindapura
7 - 6/10 2003	Highland crops farmer	Highland cultivator	Lunugamwehera	48 Mattala
8 - 6/10 2003	Paddy and banana farmer	Landowner with hired labour	Tissamaharama	32 Ellagala
9 - 6/10 2003	Division Secretary	---	Lunugamwehera	19 Lunugamwehera
10 - 6/10 2003	Paddy and banana farmer	Within Lunugamwehera Scheme	Lunugamwehera	19 Lunugamwehera
11 - 7/10 2003	GN-officer	---	Lunugamwehera	19 Lunugamwehera
12 - 7/10 2003	Paddy farmer	Within Lunugamwehera Scheme	Lunugamwehera	66 Weerawila
13 - 7/10 2003	Paddy farmer	Within Lunugamwehera Scheme	Lunugamwehera	66 Weerawila
14 - 7/10 2003	Banana farmer	Within Lunugamwehera Scheme	Lunugamwehera	77 Saliyapura
15 - 7/10 2003	Banana farmer	Within Lunugamwehera Scheme	Lunugamwehera	77 Saliyapura
16 - 8/10 2003	Deputy Director of Agriculture and Assistant Director of Agriculture	---	Hambantota	x Hambantota
17 - 8/10 2003	GN-officer	---	Tissamaharama	11 Mahasenpura
18 - 8/10 2003	Paddy and banana farmer	Landowner with hired labour	Tissamaharama	1 Tissamaharama
19 - 8/10 2003	Paddy and banana farmer	Within Lunugamwehera Scheme and leasing cultivator	Tissamaharama	43 Joolpallama
20 - 8/10 2003	Banana farmer	Within Lunugamwehera Scheme	Tissamaharama	43 Joolpallama
21 - 9/10 2003	Highland crops farmer	Highland cultivator	Tissamaharama	42 Kavantissapura
22 - 9/10 2003	Highland crops farmer	Highland cultivator	Tissamaharama	42 Kavantissapura
23 - 9/10 2003	Paddy farmer	Under cultivator	Tissamaharama	11 Mahasenpura
24 - 9/10 2003	Paddy farmer	Under cultivator	Tissamaharama	11 Mahasenpura
25 - 9/10 2003	Paddy farmer	Leasing cultivator	Tissamaharama	5 Rohanapura
26 - 9/10 2003	Paddy and banana farmer	Leasing cultivator	Tissamaharama	7 Rabarwatta

Appendix 2

Stratification of the interviews

1 Stratification of the twenty-six interviews

- 6 interviews of administrative personnel at three administrative levels
- 10 interviews of farmers in Lunugamwehera division
- 10 interviews of farmers in Tissamaharama division

1.1 Stratification of the interviews of the administrative personnel

- 1 interview, at the office in Hambantota town, simultaneously of the Deputy Director of Agriculture and the Assistant Director of Agriculture in Hambantota province
- 2 interviews, at the office in Lunugamwehera town, of the Division Secretary, Officer Planning and Development Coordinator Planning in Lunugamwehera division
- 1 interview, at the office in Debarawewa town, of the Division Secretary in Tissamaharama division
- 1 interview, at the Division Secretaries office in Lunugamwehera town, of the GN-officer in Weerawila GN-division
- 1 interview, in the home, of the GN-officer in Tissamaharama GN-division

1.2 Stratification of the ten interviews of farmers in Lunugamwehera division

1.2.1 Stratification with respect to GN-division

- 2 interviews, in the field or in the homes, in every of 5 different GN-divisions

1.2.2 Stratification with respect to cultivated crop

- 3 interviews of paddy farmers (the goal was to find 4 pure banana farmers)
- 2 interviews of banana farmers (the goal was to find 4 pure banana farmers)
- 3 interviews of paddy and banana farmers (because it was hard to find pure paddy and banana farmers)
- 2 interviews of highland farmers

1.2.3 Stratification with respect to agro-social class

- 8 interviews of farmers within the Lunugamwehera Scheme
- 2 interviews of highland farmers

1.3 Stratification of the ten interviews of farmers in Tissamaharama division

1.3.1 Stratification with respect to GN-division

- 2 interviews, in the field or in the homes, in every of 5 different GN-divisions (except for two interviews divided between Ellagala and Tissamaharama)

1.3.2 Stratification with respect to cultivated crop

- 3 interviews of paddy farmers (the goal was to find 4 pure banana farmers)
- 1 interview of a banana farmer (the goal was to find 4 pure banana farmers)
- 4 interviews of paddy and banana farmers (because it was hard to find pure paddy and banana farmers)
- 2 interviews of highland farmers

1.3.3 Stratification with respect to agro-social class

- 2 interviews of landowners with hired labour
- 1 interview of a farmer within the Lunugamwehera Scheme
- 1 interview of a farmer within the Lunugamwehera Scheme and who at the same time is a leasing cultivator (the goal was to find a pure leasing cultivator)
- 2 interviews of leasing cultivators
- 2 interviews of under cultivators
- 2 interviews of highland farmers

Appendix 3

Interview questions

Interview questions for the administrative personnel

1. Maybe you could say something in general about this division/GN-division? (Population and employment?)

2. What is the present policy of agriculture in this division/GN-division?

3. Maybe you could say something about the present policy of agriculture at higher administrative levels? (Large-scale farming or small-scale farming?)

4. Are there any economic resources available for developing agriculture in this division/GN-division? (Is paddy cultivation profitable or not profitable?)

5. Do you think it is possible to increase the yield in this division/GN-division? (Extend the cultivated area? Will tourism affect or be affected by a possible increase in the yield?)

6. Do you think it would be possible to change crops in this division/GN-division? (Profitable or not profitable? Social obstacles? High status crops?)

7. What do you think the biggest problem regarding agriculture in this division/GN-division is? (Environmental effects?)

8. Is there anything that you think that I have forgotten to question about?

Interview questions for the farmers

1. Maybe you could say something in general about this area? (Population and employment?)

2. What do you think the present policy of agriculture for this area is? (Large-scale farming or small-scale farming?)

3. Do you think there are any economic resources available for developing agriculture in this area? (Is paddy cultivation profitable or not profitable?)

4. Do you think it is possible for you to increase the yield? (Extend the cultivated area?)

5. Do you think it would be possible to change crops? (Profitable or not profitable? Social obstacles? High status crops?)

6. What do you think the biggest problem regarding agriculture is? (Environmental effects?)

7. Is there anything that you think that I have forgotten to question about?

Transformation parameters

Between WGS 84 and Everest Adjusted 1937 (three-dimensional seven parameter transformation)

Translation	Rotation	Scale factor
X = 2.0553	X = 0.198003 sec.	1.0000315
Y = -763.5581	Y = 1.706361 sec.	
Z = -87.6682	Z = 3.466120 sec.	

Between Everest Adjusted 1937 and SL Datum 95 (Transverse Mercator projection)

False easting: 200,000 m
False northing: 200,000 m
Central meridian: 80º 46’ 18.16’’ E
Central parallel: 7º 00’ 1.729’’ N
Scale factor: 0.9999238418

Temperature diagrams for Hambantota town

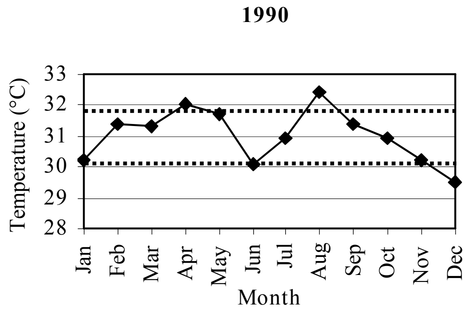

Figure A1a

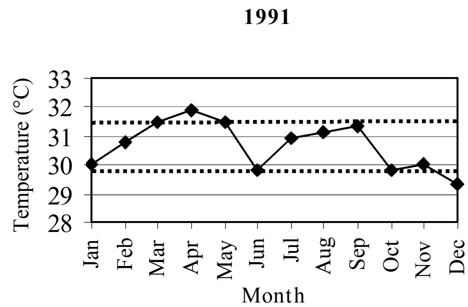

Figure A1b

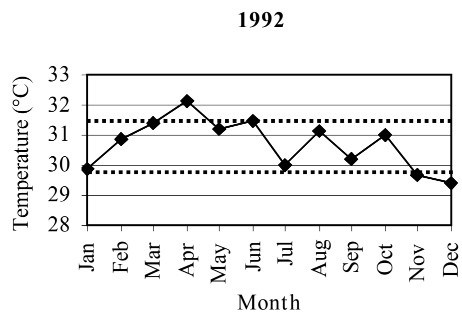

Figure A1c

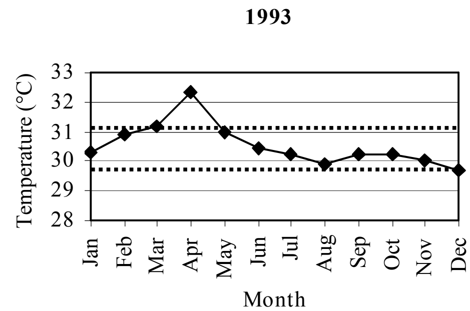

Figure A1d

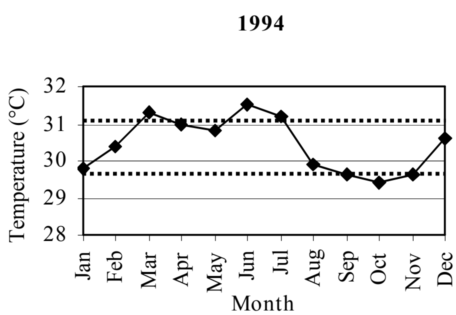

Figure A1e

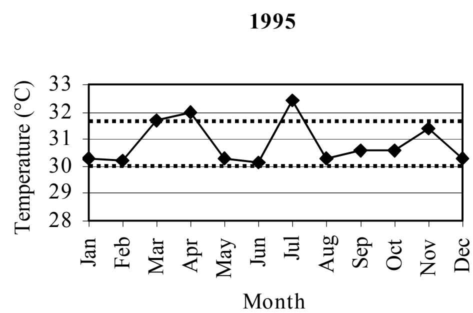

Figure A1f

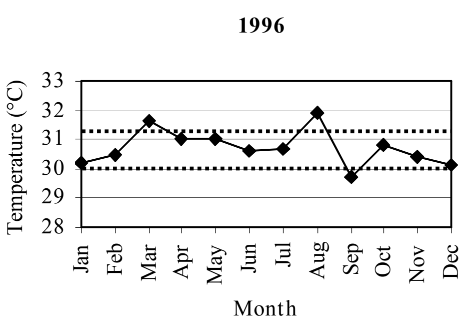

Figure A1g

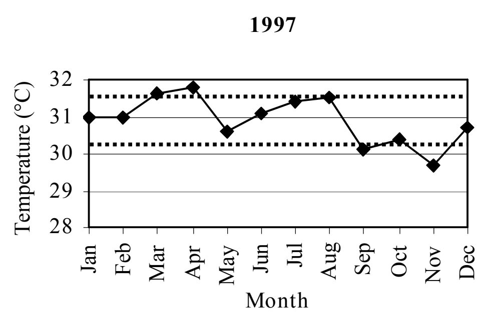

Figure A1h

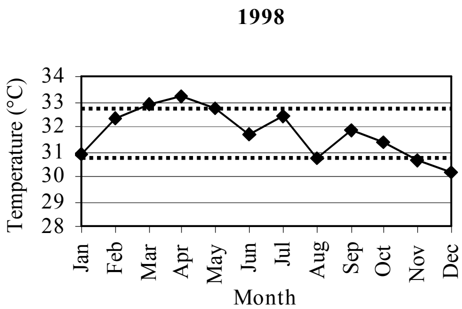

Figure A1i

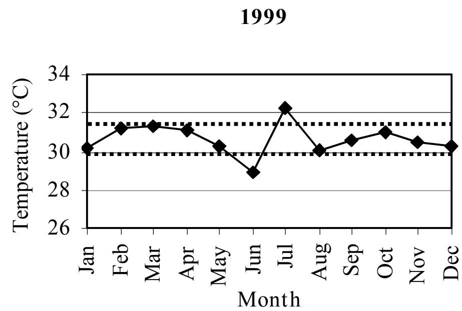

Figure A1j

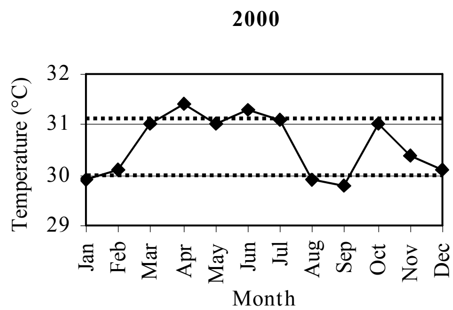

Figure A1k

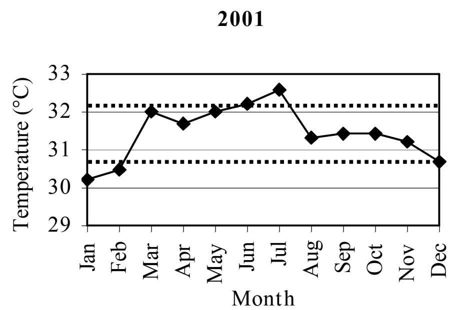

Figure A1l

Figure A1a-l. Temperature diagrams that show mean monthly maximum temperatures and standard deviation of the means calculated on daily maximum temperatures in Hambantota town for every year from 1990 to 2002.

Appendix 6

MATLAB program

Program code

```
%An illustrative example of calculation of fuzzy membership values using the fuzzy
membership functions in Equation 9 and 10 and the convex combination in Equation 14.

%Author: Per Schubert
%Date: 1 May 2004

clear,clc

%Questioning about the values of the parameters in Equation 9 and 10 and the weights
assigned to the two land characteristics:

a1=input('What is the value of parameter a for the land characteristic of grid1: ');
a2=input('What is the value of parameter a for the land characteristic of grid2: ');
c1=input('What is the value of parameter c for the land characteristic of grid1: ');
c2=input('What is the value of parameter c for the land characteristic of grid2: ');
w1=input('What is the estimated weight assigned to the land characteristic of grid1: ');
w2=input('What is the estimated weight assigned to the land characteristic of grid2: ');

%Loading the two grids in ascii-format containing the values of the two land
characteristics:

load grid1.asc
load grid2.asc

%Establishing the size of the grids:

size=size(grid1);

%Creating three empty grids where every cell is given the value of -999:

for row=1:size(1)
   for col=1:size(2)
      fuzzy1(row,col)=-999;
      fuzzy2(row,col)=-999;
      fuzzy3(row,col)=-999;
   end
end
```

```
%Calculating fuzzy membership values for every grid cell in the two grids using the
fuzzy membership functions in Equation 9 and 10 and the convex combination in
Equation 14:

for row=1:size(1)
   for col=1:size(2)

      %If there is no missing value, then calculating fuzzy membership values for the
      grid cells in the two grids:

      if grid1(row,col)~=-999

         %Symmetric fuzzy membership function:

         fuzzy1(row,col)=1/(1+a1*(grid1(row,col)-c1)^2);
      end

      if grid2(row,col)~=-999

         %Asymmetric fuzzy membership function:

         if grid2(row,col)<c2
            fuzzy2(row,col)=1/(1+a2*(grid2(row,col)-c2)^2);
         else
            fuzzy2(row,col)=1;
         end
      end

      %Calculating fuzzy membership values using the convex combination:

      if grid1(row,col)~=-999 & grid2(row,col)~=-999
         fuzzy3(row,col)=w1*fuzzy1(row,col)+w2*fuzzy2(row,col);
      end
   end
end

%Saving the three resulting grids:

save fuzzy1.asc fuzzy1 -ascii
save fuzzy2.asc fuzzy2 -ascii
save fuzzy3.asc fuzzy3 –ascii
```

Flow chart

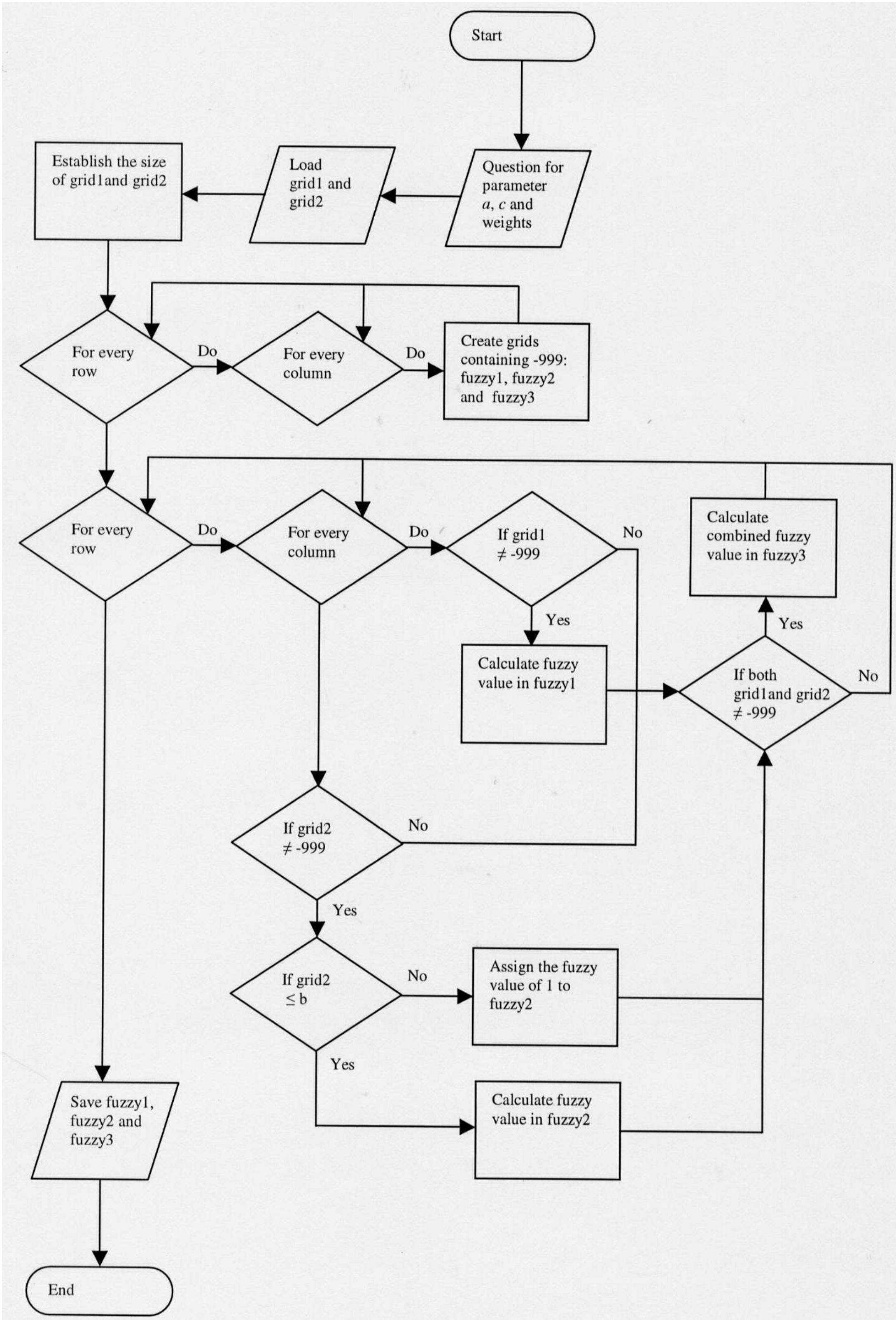

Figure A2. Flow chart showing the operation sequence of the MATLAB program.

The program starts with questioning for the values of the parameters in the fuzzy membership functions and the weights assigned to the two land characteristics. Then, the two grids in ascii-format, containing the values of the two land characteristics, are loaded. The size of the grids is established, and in the first double loop, three new grids with the same number of rows and columns are created. All the grid cells in the three new grids are given the value of -999, which represent a missing value. In the second double loop, fuzzy membership values are calculated on every grid cell in the two grids, and the calculated fuzzy membership values are put in the three new grids. Fuzzy membership values are only calculated if the grid cell values are not missing values. For one of the two land characteristics, values of a symmetric membership function are calculated, and for the other land characteristic, values of an asymmetric membership function are calculated. The combined fuzzy membership values are calculated using the convex combination. Finally, the three new grids containing fuzzy membership values are saved.

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