AN ASSESSMENT OF CURRENT AND POSSIBLE FUTURE PRODUCTION POTENTIAL OF CASSAVA FEEDSTOCK FOR BIOETHANOL PRODUCTION IN CAMBODIA

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ID: 56300700801

A THESIS SUBMITTED AS A PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL TECHNOLOGY AND MANAGEMENT

THE JOINT GRADUATE SCHOOL OF ENERGY AND ENVIRONMENT AT KING MONGKUT'S UNIVERSITY OF TECHNOLOGY THONBURI

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ABSTRACT

Cassava is one of the most important upland crops being promoted to produce bioethanol in Cambodia. However, most cassava production is used for animal feed, exports, and industrial feedstock. This study evaluates the current cassava feedstock and possible future expansion area with the estimation of future cassava production potential for bioethanol production in Cambodia. The current potential of cassava feedstock for bioethanol production was estimated based on current consumption and export. However, the land suitability assessment for cassava crop was estimated mainly based on FAO framework. In addition, the GIS application of overlay analysis technique integrated with weight and score of each factor, based on AHP approach, was subjected to identify suitable area which taken into account of mean temperature, annual rainfall, soil fertility, soil drainage, soil depth, and slope data. Furthermore, restricted area, 2002 LULC map, spatial cassava distribution map, and 2014 forest cover map were used to overlay with land suitability map for identifying the suitable area and possible future expansion area in order to come up with future possible cassava production. Preliminary results indicated that 45% of current cassava production can be fermented to bioethanol production of 520 million liters per year. Based on abundant land (forestland change to non-forestland) of each province, approximately 1.45 Mha (0.83 Mha and 0.61 Mha under S1 and S2) were found as the potential area for future expansion which can produce 26.5 million tonnes of fresh root (corresponding to 4,028 million liters per year) of possible bioethanol production. This production can fulfill the demand projection while the supply potential can be exported to the global market. These results obtained potential production and land suitability map for cassava plantation which can serve as references for cassava production planning as well as for evaluating the national potential of energy crop and bioethanol supply in Cambodia.

Keywords: Bioethanol, Cassava production, Cambodia, land suitability, zoning map

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CHAPTER 1
INTRODUCTION

1.1 Rationale/ Background

Cambodia lies entirely within the tropical between latitudes 10^o - 15^o N and longitudes 102^o - 108^o E. It is a country located in the Southern portion of the Indochinese Peninsula in Southeast Asia with a total land area of 181,035 square kilometer (97% covered by land and 3% covered by water) and 15.14 million of population in 2013 with the annual growth rate of 1.67% during 2008-2013 [1]. With experiencing rapid economic growth after half a century of civil war, the Gross Domestic Product (GDP) of Cambodia was growth double digit accounted during 2005 - 2008 and it is projected to be 6.9% until 2030 [2, 3]. To support the economic development, fulfill increasing of fuel demand, the country has imported nearly 100% of fuel oil for energy use to press national finance and sound economic development. The utilization of diesel was increased from 375 ktoe in 2005 to 578 ktoe in 2012 while the gasoline consumption was increased from 110 to 178 ktoe in transportation sector in the same period (Fig. 1.1) [4, 5]. The major industries of Cambodia are the primary industries which consist of agriculture sector that contributed 35% of total GDP [2]. Currently agriculture production is essentially share to the domestic economy growth of Cambodia. The main agricultural crops are rice, cassava, maize, soybeans, tobacco, and rubber (Fig.1.2). Agriculture sector is the main born for developing economic as it is a source of income for rural population, for their employment which employed approximately 60% of labor population with the production accounted for almost half of Cambodia's national output [2, 6].

Cambodia is endowed with huge areas of unused land that may be suitable for the growing energy feedstocks such as cassava, sugarcane, maze, Jatropha, palm oil, etc., for bioenergy development requirements. Cassava is the most important upland crops which used for human food, animal feeds, and industrial feedstock especially it is the main important candidate being promoted to produce bioethanol. Cassava can be grown without irrigation under rain-fed conditions, in area of low soil fertility, and on soils that have already been degraded and eroded [7]. In Cambodia, cassava productions in each year has varied according to market or demand condition [8]. In 2008 and 2009 during recognition as a global economic crisis, cassava production in Cambodia was decrease from 3.7 to 3.4

million tonnes (from 179,945 to 160,326 ha). However, the production has substantially increased from 4.2 million tonnes in 2010 to 7.9 million tonnes in 2013 in the average yield of 22 tonnes per ha, due to improvements yield and especially the extension of the cultivation area (from 206,226 to 421,375 ha) [9, 10]. Currently, cassava was well known both regional and global as the most effective energy feedstock for bioethanol production. Until now, the Royal Government of Cambodia (RGC) has not established any policies or initiatives for the development of energy feedstock for bioethanol production yet, thus, the clear policies related to the land use planning for energy crops are very important to secure energy feedstock in the country [11]. With land suitable condition, cassava is one of alternative feedstock for ethanol production in if compare to wheat, corn, and sugar cane. Cassava ethanol yields amount up to about 200 liters per ton [12]. Meanwhile, the RGC is planning to attract more foreign investment in the cultivation of cassava to produce bioethanol which is the main key to boost Cambodia to become a bioethanol exporter in future if the huge of unused land was used for the growing cassava [11].

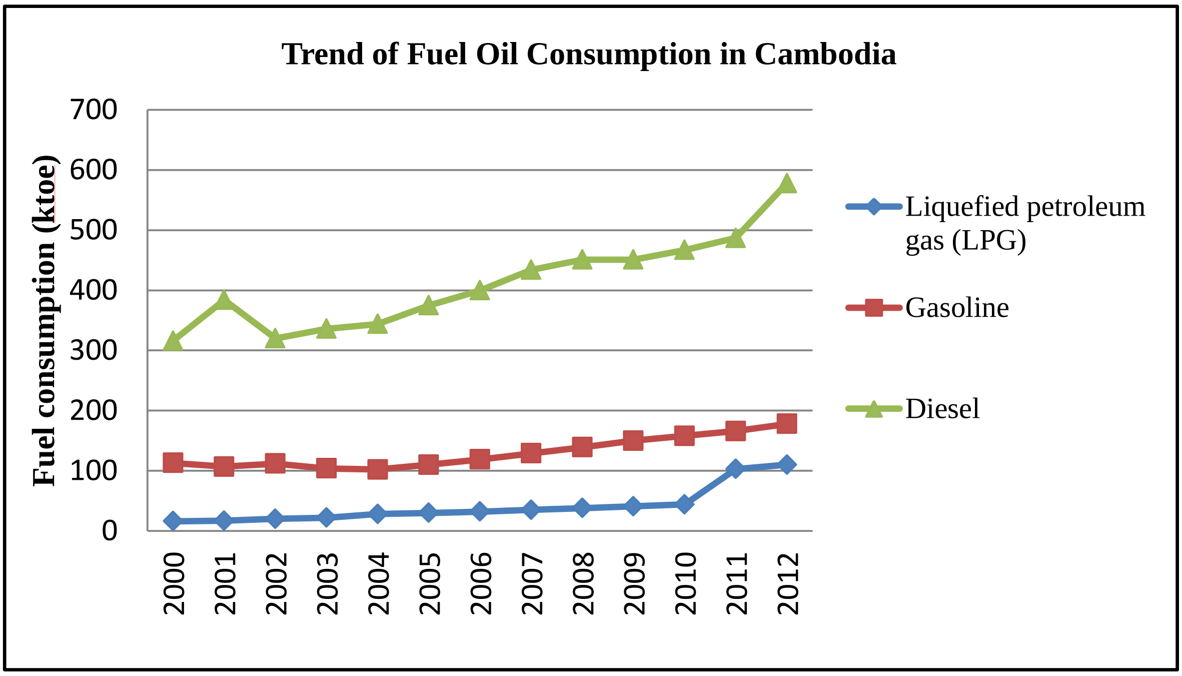
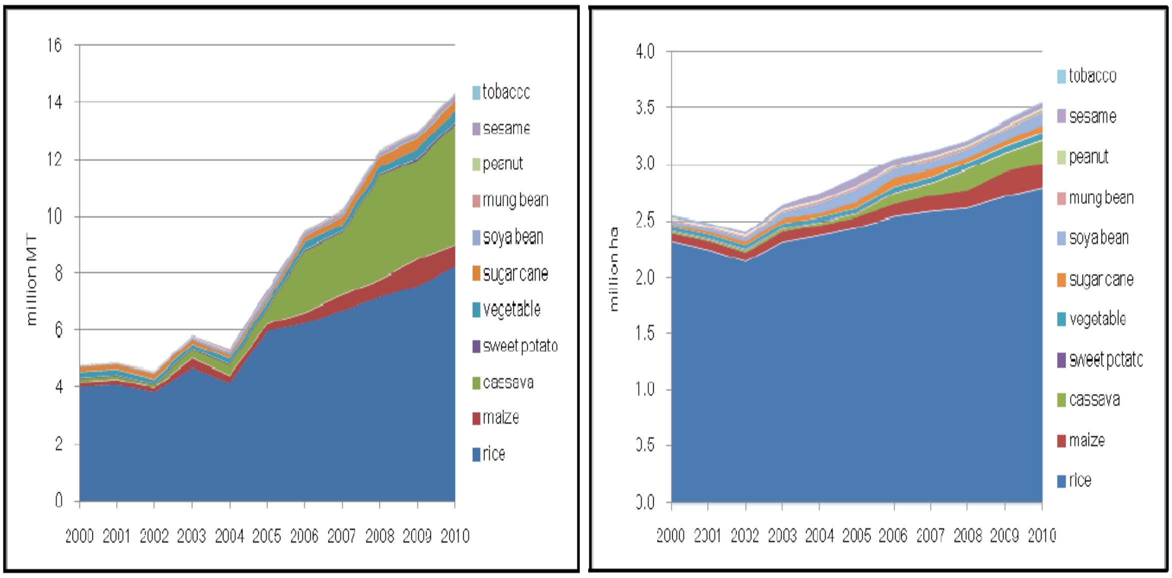


Figure 1.1 The trend of fuel oil consumption from 2000-2012 in Cambodia [5]

A number of organizations and local people are interested in suitable areas for cassava plantations in order to estimate bioenergy production. In order to comply with these principle concepts, once has to growth crops where they suit best and for which first and most requirement are to carry out land suitability analysis. To this end, a systematic and interdisciplinary approach is required to produce information on land suitability. The information can be divided into layers to model suitable area assessment [13]. Moreover, Food and Agriculture Organization (FAO) guidelines on the land evaluation 1976, 1984 and Geometric Information System (GIS) application have been widely used for land suitability evaluation which mainly based on the hand-drawn overlay technique [14, 15]. In addition, physical land evaluation methods are crucial for evaluating the potentials and constraints of land use which this system was based on matching between land characteristics and crop requirements [16-18]. Physical resources such as soil, climate, hydrology, and topography are evaluated. Recently, integrating GIS and Analytic Hierarchy Process (AHP) approach methods based on decision techniques have been widely accepted for land use suitability analysis. The AHP method is a powerful approach which used to solve complex decision problems based on an additive weighting process in which several relevant attributes are represented through their relative importance [14, 15]. In this regard, the physical land suitability for cassava plantation and possible future production potential for bioethanol production area evaluated. The results from this output can provide local policy makers, researchers, and farmers with important information for land use planning, strategic planning and investment. These outputs could also be used as a reference for cassava production planning, as well as for evaluating the national potential for this food and energy crop supply.



(A) (B)

Figure 1.2 Agricultural crops of Cambodia: (A) Crop production (million tonnes), and (B) Crop harvesting areas 2000-2010 (Mha) [2, 9]

1.2 Problem Statement

Due to the recently increasing oil prices in the world, bioenergy production has been give more attention as one of most promising source of alternative renewable energy. Currently, cassava crop is the main important energy crop being promoted and recommended to produce bioethanol in Cambodia. However, with the rapidly increasing of the production (from 4.2 million tonnes in 2010 to 7.9 million tonnes in 2013) [9, 10], it was mostly used for animal feed, foot, and exports to the neighboring country while fermented to bioethanol still limited mentioned. On the other hand, based on Bio-ethanol development plan (2007-2020), proposed by Japan Development Institute (JDI) [4], Cambodia can achieved E10 in 2015, and E20 in 2020 especially be a bioethanol producer and exporter country in the future. As consequence, the RGC is planning to attract more foreign investment in the cultivation of cassava to produce bioethanol due to the plenty of unused land were available for expansion cassava cultivation area in order to substitute with gasoline to improve and reduce environmental emission. However, due to the government policy on energy feedstock for producing bioethanol have not been published, the future possible area potential for cassava expansion and possible bioethanol production are still not mentioned in the existing potential capacity. Thus, according to these issues above, this study will provide an assessment of current and possible future production potential of cassava feedstock for bioethanol production by estimate suitable area for growing cassava based on FAO framework and estimate full capacity of Cambodia to produce bioethanol which can reduce the amount of the petroleum import (use gasohol), minimize the environmental burden, and stabilize the crop prices in the country.

1.3 Objectives

The objectives of this study are as follows:

- To estimate the current quantity of cassava feedstock for bioethanol production in Cambodia; and
- To find future possible expansion areas suitable for cassava plantations in Cambodia in order to estimate the future potential of cassava feedstock to produce bioethanol.

1.4 Scope of Research Work

In this study, the current quantity of cassava feedstock to produce bioethanol are based on national crop statistics include cassava cultivated areas, cassava production, cassava exported data, and cassava utilization in the country. On the other hand, the GIS application (overlay analysis) is used to define suitable area for cassava plantation in Cambodia. Land suitability evaluation for cassava plantation is based on the FAO Framework 1976 integrated with the weights and scores of the AHP approach, which are based on recent studies in Thailand. The GIS data which consider to estimate suitable area for cassava plantation are climatic data (mean temperature data and rainfall data), and land resources data (soil drainage data, soil fertility data, soil depth data, soil drainage data, and slope data). The suitable area for future possible expansion was analysis based on 2013 crop statistic, 2002 land use-land cover (LULC) map, spatial cassava distribution map, and 2014 forest cover map. The full capacity of Cambodia to produce bioethanol is estimated based on future potential area for the most suitable class and the most recent cassava yield of each province.

CHAPTER 2
STUDY AREA: CAMBODIA

2.1 Geographic Overview

The Kingdom of Cambodia is located in the tropical region of Southeast Asia in the part of the lower Mekong river region, with 800 km of border with Thailand in the West and North, 450 km with Lao PDR in the North, 1,250 km with Viet Nam in the East and South, and a coastline of 440 km long [19]. Cambodia was divided into 24 provinces, 167 districts, 1,621 communes, and 14,073 villages (Fig. 2.1) [2]. The physical landscape is dominated by the lowland plains around the Mekong River Delta and the Tonle Sap Lake basin. It lies completely within the tropics – its southern, most points are only slightly more than 10° above the equator. The climate is monsoonal and has marked wet and dry seasons of relatively equal length. Both temperature and humidity generally are high throughout the year [20].

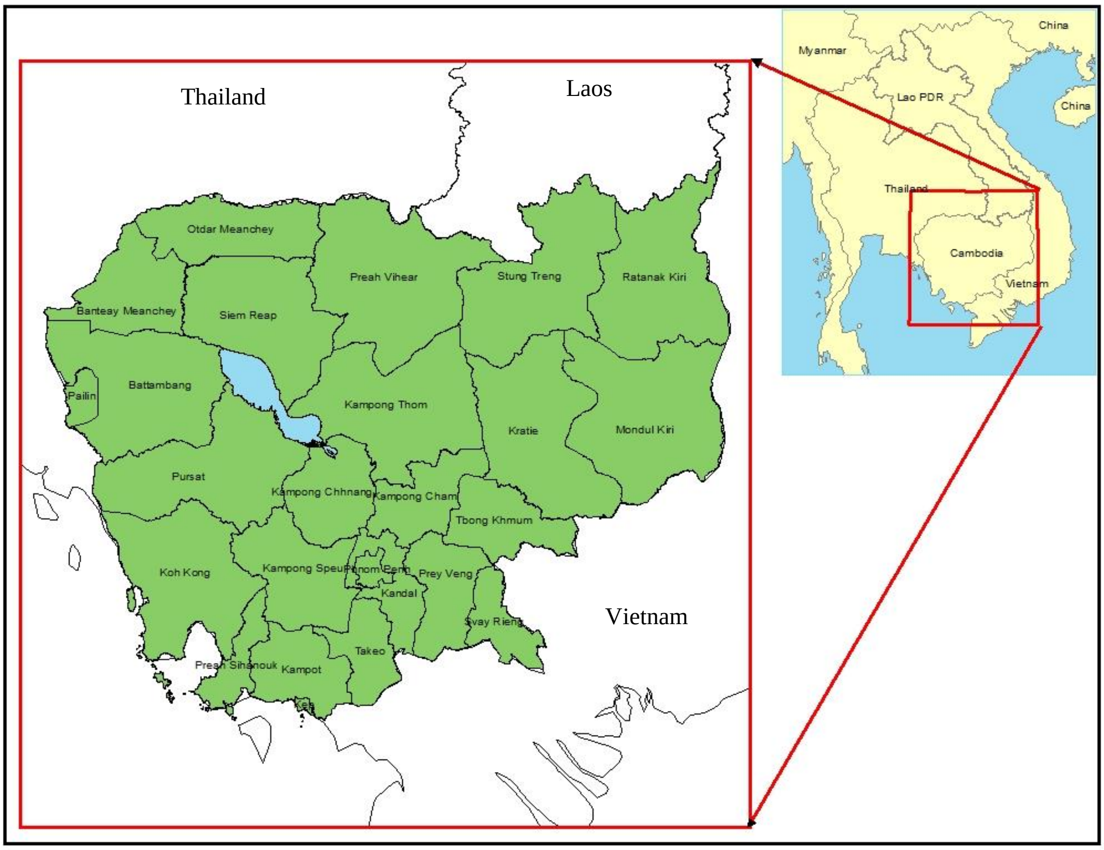


Figure 2.1 General map of Cambodia

2.2 Climate Condition

Cambodia's climate, as other Southeast Asia countries dominated by monsoons, is known as tropical wet and dries because of the distinctly marked seasonal differences. The monsoonal airflows are caused by annual alternating high pressure and low pressure over the Central Asian landmass. The climate in Cambodia is tropical and subject to both Southeast and Northwest monsoons with known as two main seasons [21]. The Southeast monsoon, which coincides with the rainy season, extends from May to October. The Northwest monsoon brings a cool but drier period from November to April. The maximum mean is about 28.0 °C while the minimum mean is 22.98 °C (Fig. 2.2) [22]. Maximum temperatures are higher than 32°C; however, it occurred before the start of the rainy season, they may rise to more than 38°C. Minimum temperatures rarely fall below 10 °C. January is the coolest month while April is the hottest month [19]. The total annual rainfall, on the other hand, is between 1,000 and 3,212 millimeters where the heaviest amounts fall in the southwest part in the mountains along the coast in the southwest, which receive from 2,500 millimeters to more than 5,000 millimeters of precipitation [23]. During the daytime in the dry season, humidity averages about 50% or slightly lower, but it may remain about 60% in the rainy period [22].

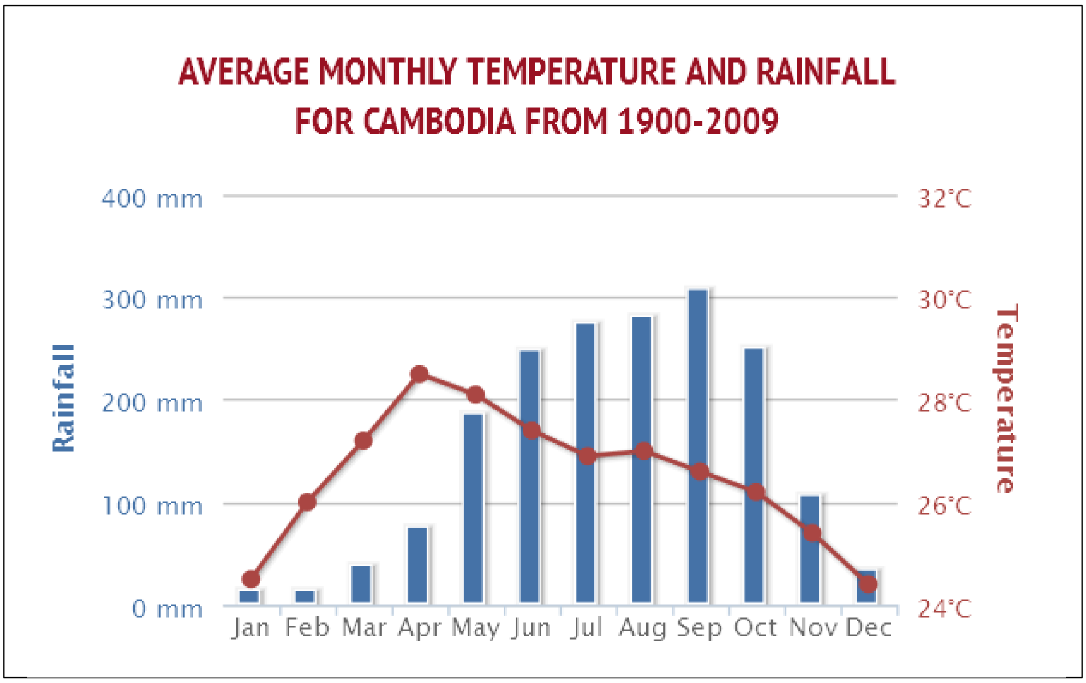


Figure 2.2 Average monthly temperature in Cambodia from 1900-2009 [22]

2.3 Topography Condition

The topography of Cambodia is mainly a lowland region, about 75%, where consists of the Tonlé Sap basin and the Mekong lowlands delta with elevations generally of less than 100 meters (Fig. 2.3). For upland region, the Cardamom mountain in the southwest, oriented generally in a northwest-southeast direction, rise to more than 1,500 meters which included the highest mountain, Phnom Aural, with 1,771 meters height located in eastern part of this range. There are mountain range running toward the south and the southeast namely Elephant and Cardamom mountains, rises to elevations of between 500 and 1,000 meters. These two ranges are bordered on the west by a narrow coastal plain that contains Kampong Saom Bay, which faces the gulf of Thailand. However, the Dangrek mountain at the northern rim of the Tonlé Sap Basin consist of a steep escarpment with an average elevation of about 500 meters, the highest points of which reach more than 700 meters. The escarpment faces southward and is the southern edge of the Korat Plateau in Thailand. The watershed along the escarpment marks the boundary between Thailand and Cambodia [20].

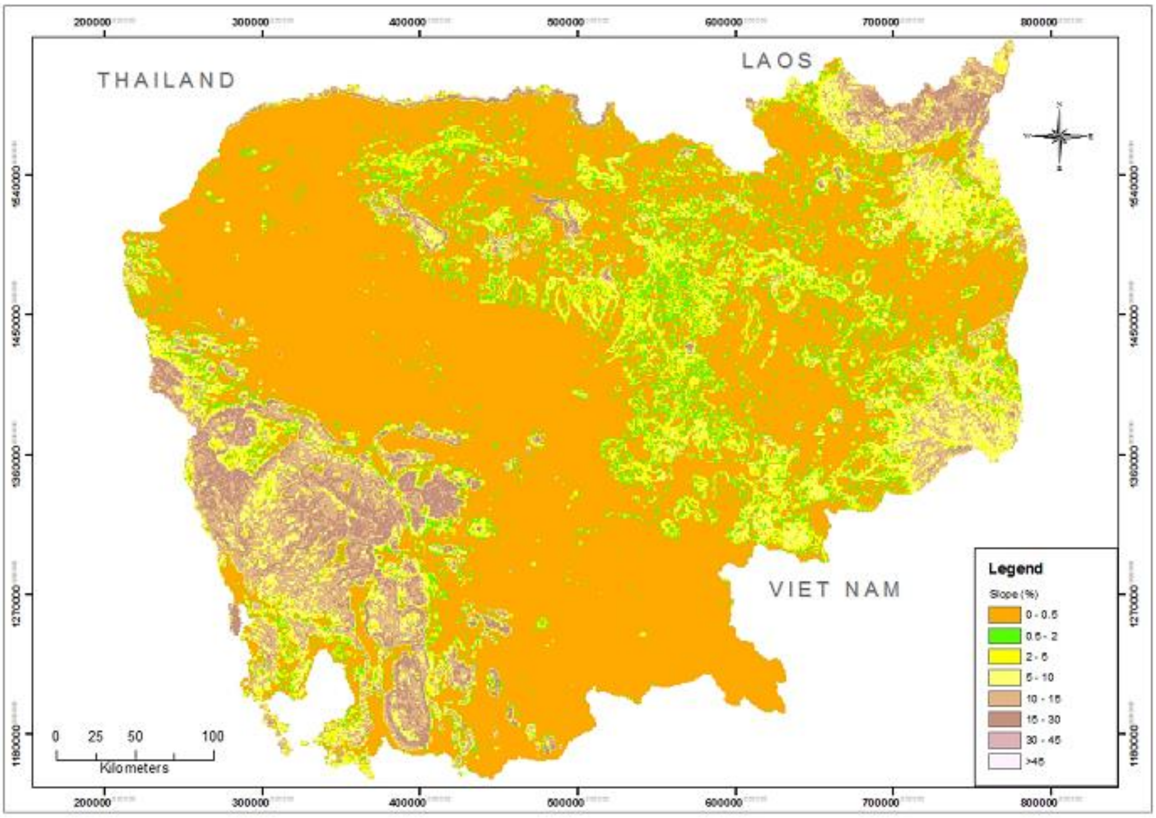


Figure 2.3 Slope map classification of Cambodia in percentage (%) [24]

2.4 Soil Classification of Cambodia

The soil in Cambodia was identified and divided into 11 great soil groups by Cambodian Agronomic Soil Classification (CASC), which was developed to complement the first comprehensive soil taxonomy classification of Crocker 1962 [25]. CASC identified 11 soil groups and 22 soil phases that mainly occur in the main rice growing areas of Cambodia. Soil groups were mapped at a scale of 1:2,500,000 (Fig. 2.4). The soil groups and phase have been widely known throughout Cambodia by researchers, agronomists, extension workers and even some farmers. Also, CASC allows correlation of these soil groups with other international classifications for comparison purposes (Table 2.1) [25].

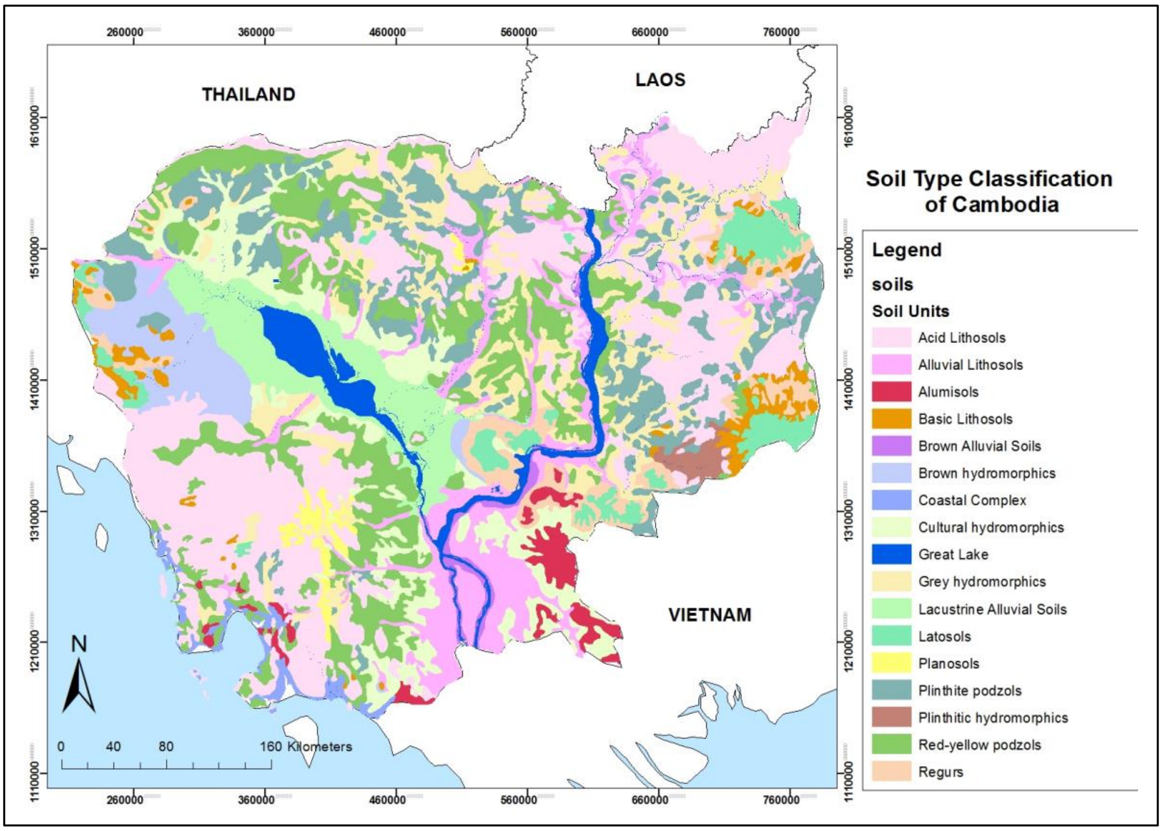


Figure 2.4 General soil type classification map of Cambodia [25]

Table 2.1 Correlation between soil groups of CASC and soil classification by FAO (1974) in Cambodia [25].

Group No	CASC* (1997)	FAO classification (1974)
1	Prey Khmer Soil	DystricFluvisols, occasionally Arenosols
2	Prateah Lang Soil	Luvisols, Acrisols, Planosols
3	Labansiek Soil	Nitisols, Ferrasols, Plinthosols
4	Orung Soil	Fluvisols
5	Krakor Soil	Fluvisol, Gleysols
6	Bakan Soil	Luvisols, sometimes Planosols or Acrisols
7	Kbal Po soil	Fluvisols, Gleysols
8	Kein Svay Soil	Fluvisol, Cambisol
9	Toul Samroung Soil	Luvisol, Vertisol
10	Koktrap Soil	Acrisols (PlinthicAcrisols, GleyicAcrisols)
11	Kompong Siem Soil	Vertisols

Note: * Only for Entisol where the sandy topsoil extends deeper than 1 m.

2.5 Land Use Land Cover (LULC) Map 2002

Agriculture includes paddy fields and upland crops, which represent approximately 24% of the country's total land area whereas about 56.36% is forest cover land (Fig. 2.5). Agricultural production is mainly concentrated in the northwestern districts bordered with Thailand, in the central plain around Tonle Sap lake and its river systems and Mekong and Basac rivers towards the Mekong delta, and in the northern and northeastern provinces of the country [25]. Based on GIS model of Figure 2.5, the total land-use area for agriculture was about 4.37 Mha. Paddy rice was the dominant crop in agriculture which comprises of nearly 80% of agricultural land which was equal to about 3.35 Mha including areas of receding and floating rice and paddy rice intersperse with village (Table 2.2). Upland crops comprised of cassava, corn, soy bean, peanut, sugarcane, rubber plantation, garden crops, orchard, and others as being slash and burn agriculture [25]. The 2002 land use-land cover (LULC 2002) [26] was classified into 8 classes namely: forestlands, paddy fields, upland crops, grass lands, shrublands, urban and built-up lands, barren land and rocks, and water bodies (Fig. 2.5) [25, 26]. The definition and characteristics of each LULC class is described as follows:

(1) Forestlands, including forest plantation, evergreen broad leaf forest, mixed forest from evergreen and deciduous species, riparian forest, bamboo and secondary forests, coniferous forest, deciduous forest, dried deciduous forest, mangrove forest, degraded mangrove forest, and riparian forest.

(2) Paddy field is an area where included rain-fed upland rice, paddy field with villages, shallow wet and dry season rice, and other floating rice field.

(3) Upland crops, including shifting agriculture, slash and burn, village garden crops, orchard, field crops, and rubber plantation.

(4) Grasslands, including grass savannah, grass with termite mound, abandoned field cover by grass, grassland (undifferentiated), flooded grassland, and marsh and swamp.

(5) Shrublands, including abandoned field covered by shrub, abandoned field covered by grass, flooded shrub, shrubland (undifferentiated), and woodland and scattered trees.

(6) Barren and rocky, including rock outcrop, sand bank, and barren land.

(7) Urban, built-up areas, including settlement, and infrastructure.

(8) Water Bodies included reservoir, lake, others (sea, bay etc.), and shrimp/fish farming and salt pan. The area of each class is presented in Table 2.2.

Table 2.2 Land use-land covers (LULC) category 2002 [25]

Land Use Land Cover Category	**Area (ha)**	**Proportion (%)**
Forestland	10,237,681	56.36
Paddy Field	3,352,256	18.46
Upland Crops	1,014,721	5.59
Grassland	1,078,484	5.94
Shrubland	1,884,103	10.37
Soils and Rocky	36,840	0.20
Urban, Built-up Area	18,071	0.10
Water Bodies	541,736	2.98
Total	**18,103,895**	**100.00**

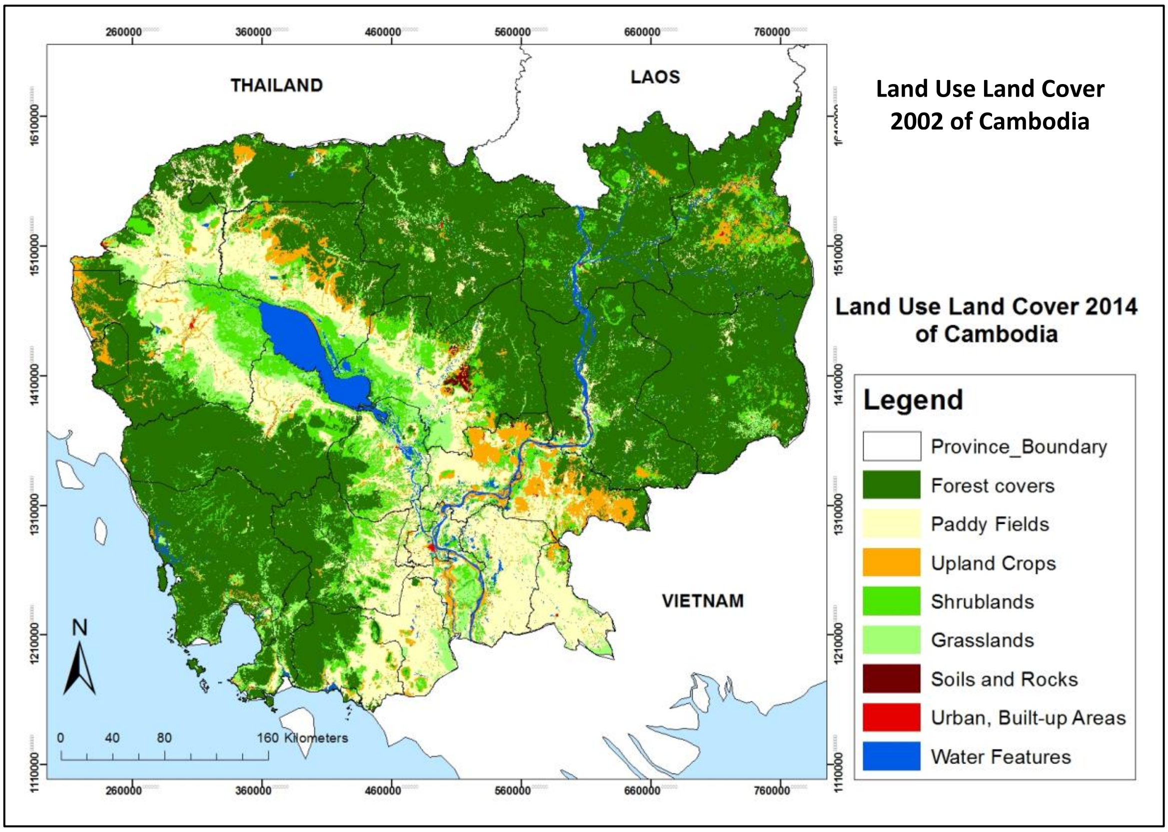


Figure 2.5 Land use-land cover (LULC) map 2002 [26]

2.6 Forest Cover Map 20014

Forest cover in Cambodia mostly found in the upland area in Southwest, North, and Northeast part of Cambodia. Total forest has decreased from approximately 73% in 1973 to 48% in 2014, while dense forests (including evergreen and semi-evergreen forests) have decreased from 42% to 16% over the same period. The level of mixed forest cover (included regrowth forest, stunted forest, mangroves, inundated or flooded forest, and bamboo, as well as forest plantations growing such as rubber, acacia, and eucalyptus or other tree crops) has stayed relatively stable over this period, being 30% in 1973 and 31% in 2014 (Fig. 2.6). Moreover, the non-forest areas which included shrubland, grassland, settlement, and agriculture land were rapidly increased due to the severely eroded as a result of widespread deforestation, illegal logging, and intensive farming [27]. The remaining forests in Cambodia are shown in Table 2.3.

Table 2.3 2014 forest cover of Cambodia [27]

Forest Category	Area (ha)	%
Forest cover	8,659,190	47.69
Non-forestland	8,787,124	48.64
Water bodies	656,576	3.67
Total	**18,103,895**	**100.00**

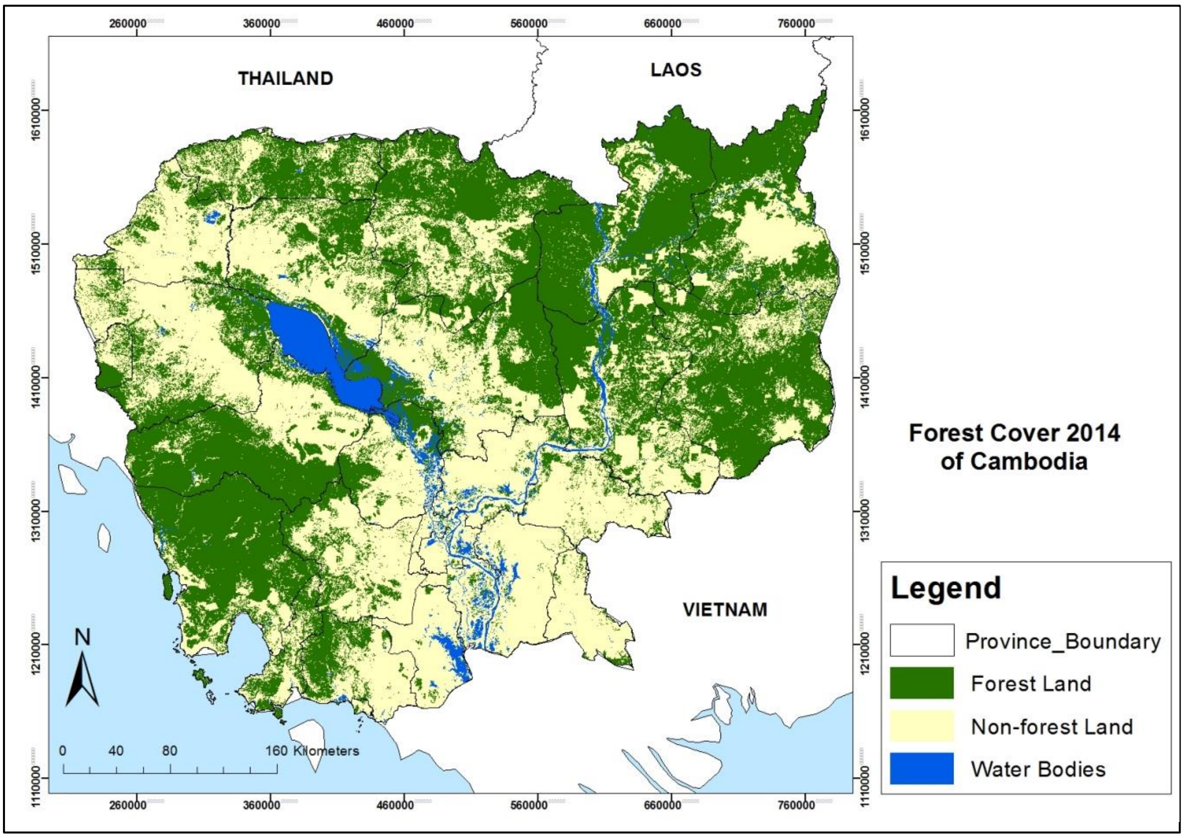


Figure 2.6 Forest cover map 2014 [27]

2.7 Cassava Production Overview in Cambodia

Being adaptable to diverse climates, cassava has been considered as a potential energy crop that can be grown in soil with low fertility. Moreover, it is planted either as a single crop or intercropped with maize, legumes, vegetables, rubber or other cover crops. It is also can be grown in sandy or mixed sandy land with organic matter not less than 1.0%. Rayong 72, however, is a cassava variety that has proposed for Cambodia since it provides high starch percentage [28].

2.7.1 Cassava Cultivation Practices in Cambodia

In Cambodia, cassava is normally planted during February–April and harvested after 8 to 12 months, depending on market price and the availability of the labor force for harvesting. Cultivation practices are usually planting in March – the earliest planting is in February and the latest in April (Fig. 2.7). The first ploughing starts in early March followed by a second ploughing and row making in the middle of March before the forecast rains come. Planting stake usually takes place in March. Most of the land ploughed twice which results in a greater yield, while about 5% get it done once due to lack of financial resources. The majority of farmers used their own cassava seeds from the previous harvest. Herbicide is usually applied at least twice to control weeds. The first application of herbicide is made in the middle of May and the second a month and a half later. A third application of herbicide might be made, depending on weed conditions and farmer's financial resources. Finally, some branches are normally cut a month or so before harvesting to admit enough sunlight for the root to grow bigger [7].

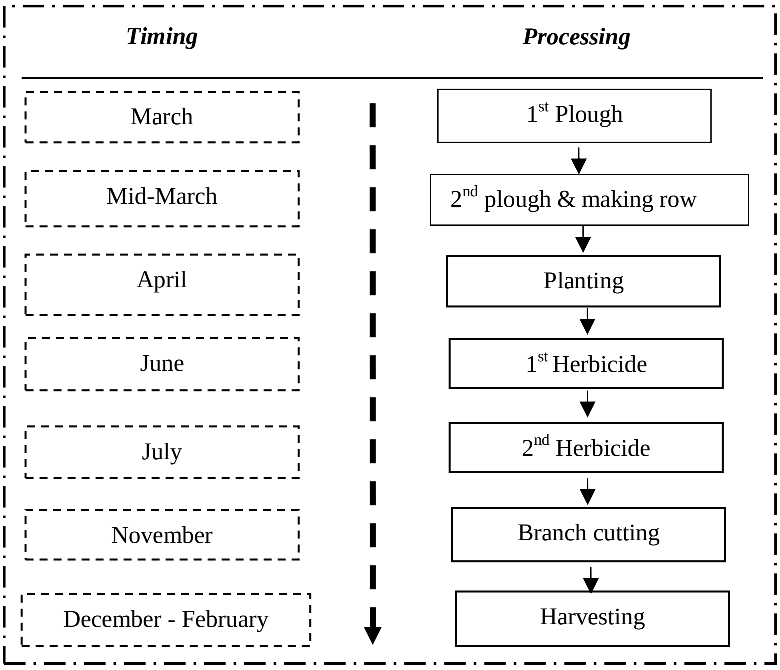


Figure 2.7 Cassava cultivation practice in Cambodia [7]

2.7.2 Cassava Production, Utilization, and Exports

In Cambodia, cassava production and cultivation areas are varied in each year according to market or demand conditions (see Appendix D.1). The main driving forces behind the dramatic increase in production recently are the rise in cassava market prices, increased export opportunities to Thailand and Vietnam and recently to China, present of new local domestic factories for producing dried chip, introduction of high yield varieties, favorable weather conditions, and smallholders growing cassava instead of other crop (Fig. 2.8) [8]. In each year, the actual harvested areas were a little bit fewer than the total planted area due to some of the planting areas being abundant in terms of economic conditions and less labor force. In 2013, cassava plantation was cultivated mostly in Kampong Cham, Battambang, Banteay Meanchey, Kratie, Kamong Thom, and Otdar Meanchey (Fig. 2-9). In addition, the high yield mostly found in Pailin, Kampong Cham, Battambang, and Banteay Meanchey (Table 2.4) [10].

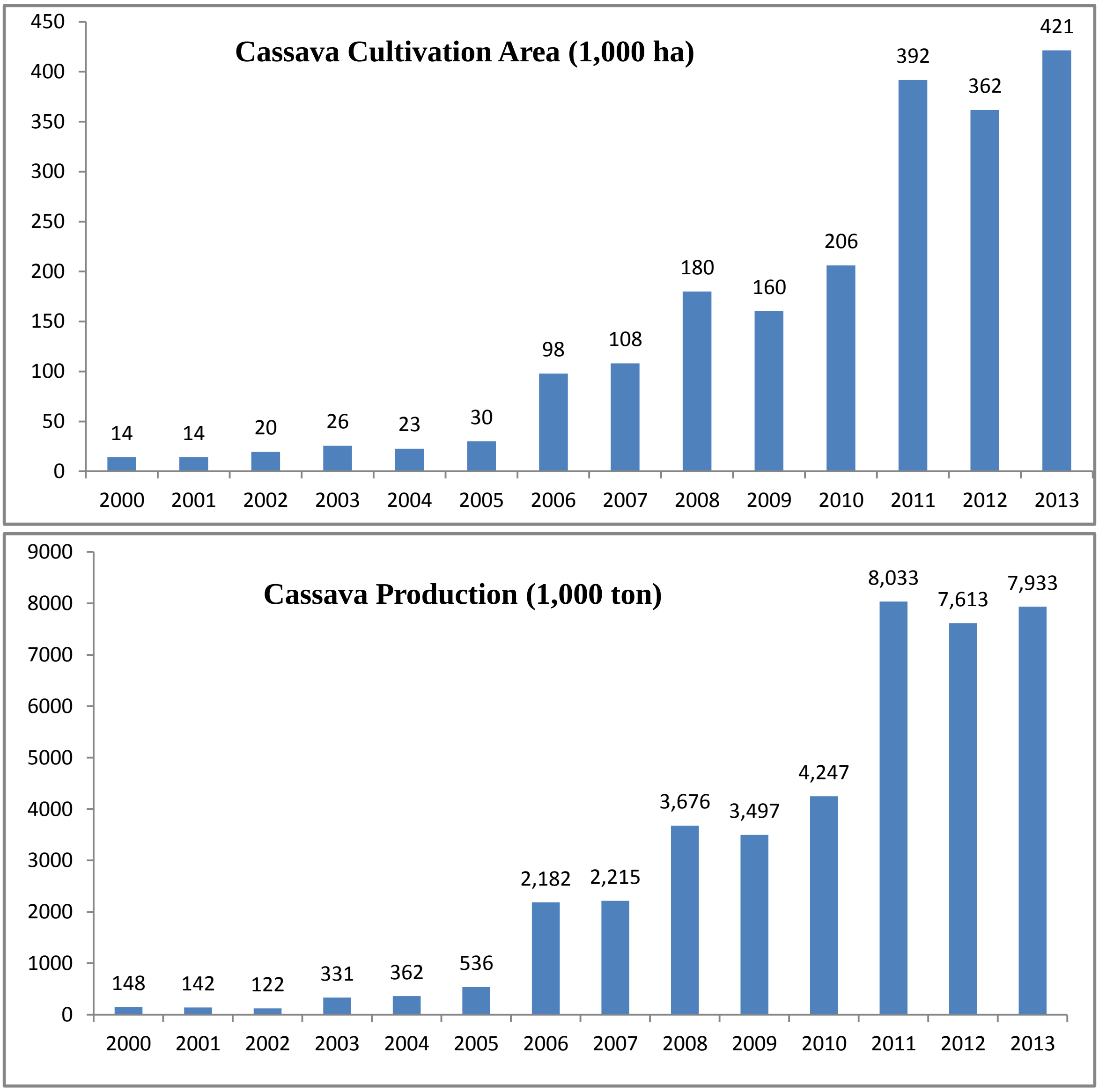


Figure 2.8 Cassava cultivation area and production for each year from 2000 - 2013 [9, 10, 29, 30]

In recent years, Cambodia's formal cassava exports have been concentrated on just three markets: Thailand (for raw cassava or dry chip), Vietnam (raw cassava and cassava starch) and China (dry chip and starch) [8]. Historically, cassava exports have also been recorded with Malaysia and China although not with regularity. It is difficult to assess the exact value of Cambodia's cassava exports as most of was sold as informal, unrecorded, cross-border trade with Vietnam and Thailand whereas some estimates put the value of informal cassava trade at 200 – 300 million US Dollars each year. However, formal exports of cassava have been increasing recently as production capacity increases. In 2011, total formal exports were 5.3 million US Dollars (Table 2.5) with increasing in fresh/dried cassava export volumes during 2007 – 2012 [8]. According to recent assessments of the cassava sector, it has been concluded that Cambodia is now potentially one of the top five global exporters of fresh/dried cassava in the world.

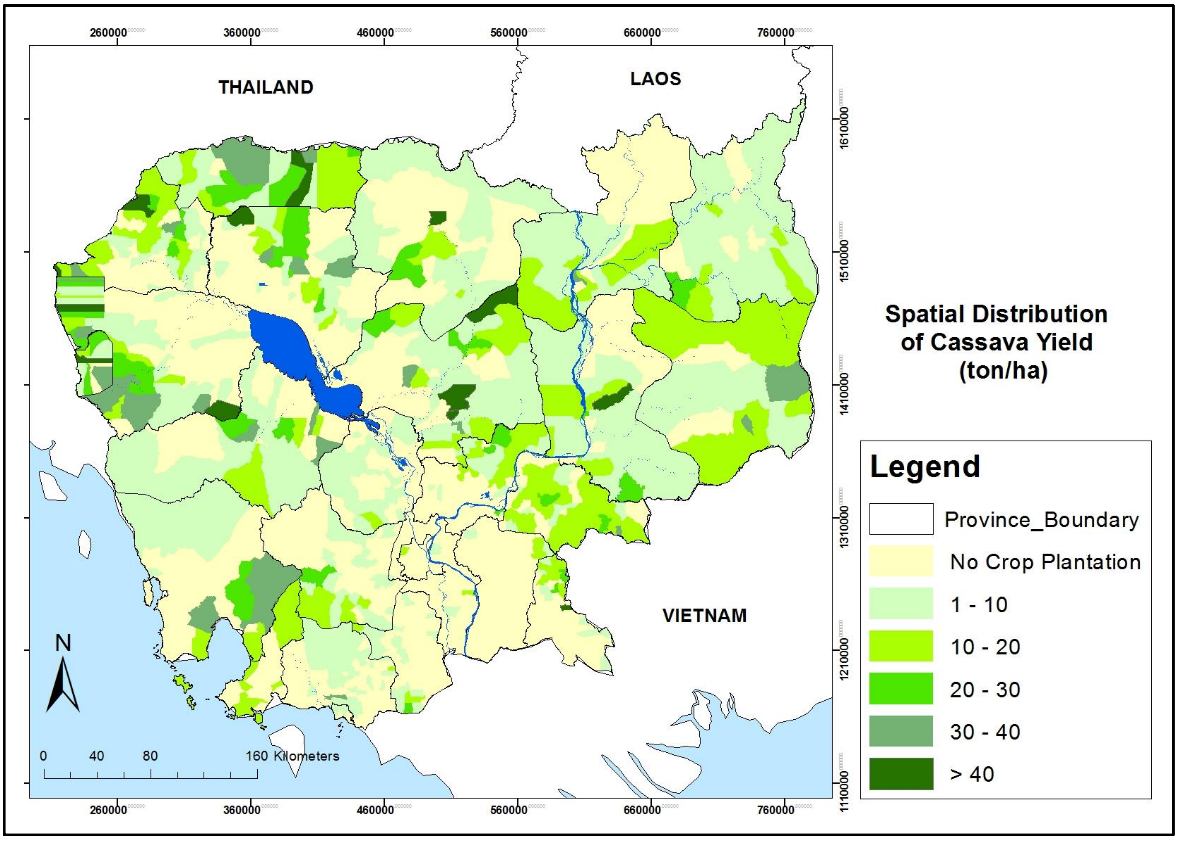


Figure 2.9 Spatial commune distributions of cassava production map [31]

Table 2.4 Cassava production in each province in 2013 [10]

No	Provinces Name	Harvested Area (ha)	Production (ton)
1	Banteay Meanchey	55,666	953,125
2	Battambang	61,695	1,699,123
3	Kampong Cham	67,625	1,327,847
4	Kampong Chhnang	1,737	10,116
5	Kampong Speu	3,402	101,765
6	Kampong Thom	36,725	530,379
7	Kampot	816	1,839
8	Kandal	27	216
9	Koh Kong	334	6,956
10	Kratie	46,810	1,042,378
11	Mondul Kiri	10,271	157,505
12	Phnom Penh	72	535
13	Phreah Vihear	12,650	139,150
14	Prey Veng	1,969	35,442
15	Pursat	6,583	181,357
16	Ratanakiri	13,590	273,794
17	Siem Reap	11,510	158,763
18	Phreah Sihanuok	470	6,110
19	Steung Treng	19,622	58,200
20	Svay Rieng	17,597	273,129
21	Takeo	1,331	11,979
22	Udor Meanchey	25,125	528,631
23	Kep	100	1,468
24	Pailin	25,648	433,575
	Total	**421,375**	**7,933,382**

Table 2.5 Cambodian cassava exports 2007-2011 [8]

	2007	**2008**	**2009**	**2010**	**2011**
Cassava dried chip					
Volume (1,000 t)	2.76	22.29	66.75	24.00	93.50
Value ($ million)	0.6	0.5	0.9	0.4	2.3
Cassava starch					
Volume (1,000 t)	23.63	10.29	31.28	13.72	16.72
Value ($ million)	4.3	1.6	4.8	2.5	3
Total Cassava Export ($ million)	**4.9**	**2.1**	**5.7**	**2.9**	**5.3**

2.8 Bioethanol Status in Cambodia

The technology for biofuel production is not new and has been evolving in Cambodia through various uncoordinated experiments. Therefore, the technology for basic oil extraction and processing is locally available, but facilities for purification are still lacking. Some plants have been established with private funding where company vehicles are used to test the quality of the bioethanol product. The technology required is readily adaptable in the Cambodian context, and the level of skill needed is not high [32]. Therefore, fermentation of ethanol from cassava feedstock, one of alternative potential feedstock for bioethanol production, seems to be a feasible alternative for short term solution for the country. On the other hand, biogas production, as one of byproduct, is also a good option to aid development in rural areas, especially for the generation of electricity for lighting, or gas for cooking. With substitute in gasoline to form gasohol that can be reduce some of gasoline import as well as greenhouse gas (GHG) emission reduction due to it friendly to environment, the ethanol production from cassava program is a key issue of solution to increase not only famer’s income, surplus of cassava product, but also reduce of GHG emission in Cambodia [32].

Until now, the Cambodian government has not established any policies or initiatives for the development of biofuels. It has started a series of discussions to promote the development of biofuels but the final results have not been announced yet [11]. According to some reports released by institutes such Asian Development Bank (ADB) and Japan Development Institute (JDI), for instance, the bio-energy policy in Cambodia is expected to follow the precedent in Thailand. The JDI report suggests that bio-ethanol plans for Cambodia can be developed using the same raw materials used in Thailand. Meanwhile, cassava, maize, rice and sugarcane (molasses) are supposed to be the main feedstocks for bioethanol production in Cambodia [4]. In the case of cassava, as it is not a major crop for food in Cambodia, a lot of foreign capital has been invested into cassava plantation to produce bioethanol, making it as potential export industry of the country. In recent years, the business sector has shown major interest in producing starch, alcohol, and ethanol – mainly from cassava partly by leasing land to grow the crop and through concessions granted by the RGC [4]. As in 2008, for instance, one concession has already been granted to MH Bio-Energy Group, the Korean company, which has started to produce ethanol with a production capacity of 40 million liters per year from 85,000 tonnes of tapioca chips (a dried cassava product) and aims to use 300,000 tonnes of chips in 2010. According to company, with increasing cassava production from about 2.2 million tonnes in 2006 to about 5.0 million tonnes in 2011 of fresh root, the additional production will be processed to ethanol. Production of the additional cassava will be undertaken partly by smallholders and partly by concessions given to the companies that will produce the ethanol [32].

Nevertheless, there is currently no clear policy on biofuel development and production or use of biofuels in Cambodia, given the government’s intention to promote biofuel production and utilization to reduce the country’s reliance on imported petroleum fuels. It is assumed that 5% of the country’s liquid fuel demand for road transport will be substitute by biofuels in 2035. A study by the ERIA research project [11] put the estimation that a possible production capacity of bioethanol from cassava was 93.9 million liters per year in 2011. The supply potential of bioethanol is estimated to be 2533.5 ktonnes in 2035 expanding from 1324.3 ktonnes in 2010. Under this assumption Cambodia’s demand for bioethanol is projected to reach 19.4 ktonnes, respectively, as seen in Fig. 2.10 [11, 33].

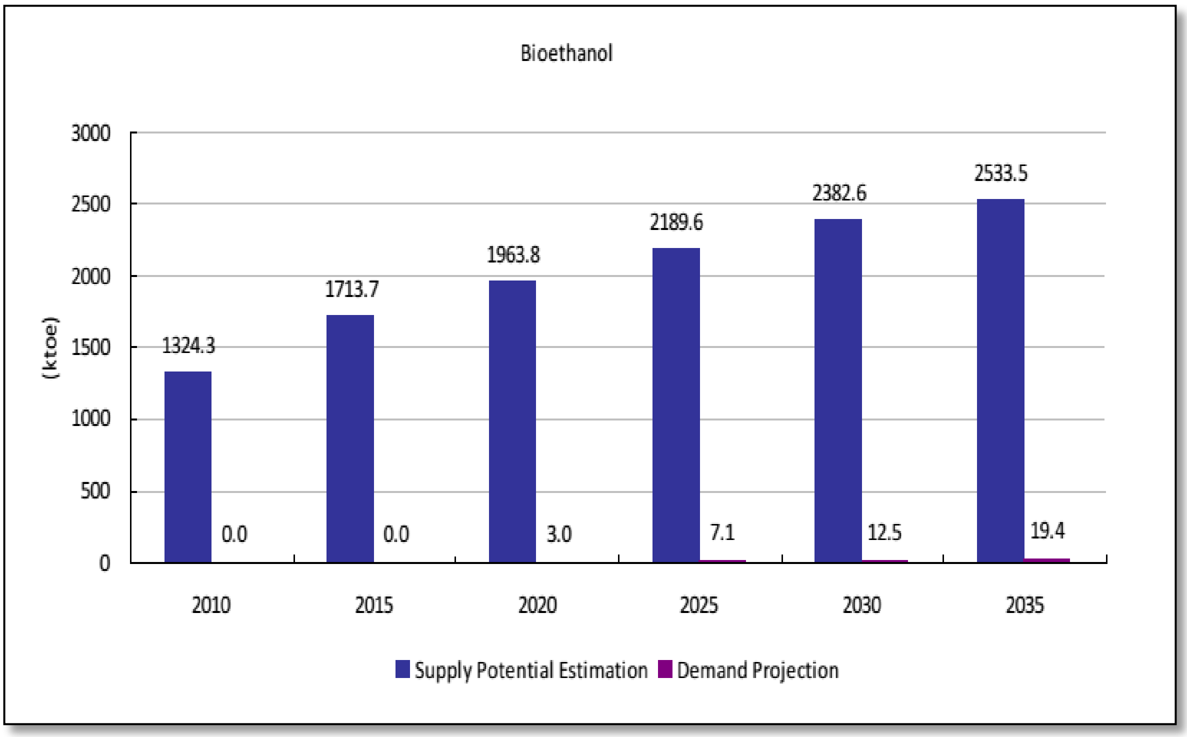


Figure 2.10 Bioethanol demand and supply potential estimation through 2035 in Cambodia [11]

2.9 Perspective of Cassava as an Energy Crop

Many characteristics of cassava, including high drought and heat tolerance, little requirement for agricultural fertilizers, and high starch content, make it as one of the most attractive plants for starch production in the future. Therefore, starch from cassava is considered as a high quality compared to other starch feedstock. The starch content of cassava is accounted of 70 - 85% of dried base and 28 – 35% of wet base [34]. Cassava starch is used as raw material in many industries such as food, animal feed, and textile industries especially for producing ethanol which now internationally well developed. Cassava starch is now considered one of the best fermentable substances for the production of ethanol [4, 34]. Due to rapidly increasing of world population and global climate change issue (increasing in greenhouse gas emission), on the other hand, it is predicted that the production of cassava will increase over the next few decades, and, as a result, cassava is now an international priority for crop improvement for bioethanol production which experienced used to substitute in gasoline to form gasohol. In Africa and Asia, cassava is mainly grown by small-scale farmers which mostly use for agro-industrial processing [35].

Furthermore, apart from its traditional role as a food crop, cassava is likely to increase its value by becoming an important biofuel raw crop for bioethanol production. High yields of starch and total dry matter, in spite of drought conditions and poor soil quality, together with low agro-chemical requirements, resulted in less energy input that accounted only 5–6% of the final energy content of the total cassava biomass. These issues translate to an energy profit of 95%, assuming complete utilization of the energy input in the total biomass. The energetic and economic aspects of using cassava as a biofuel crop are well known in many documents. A direct comparison of bioethanol production from different energy crops, for example, was reviewed by Wang, W [35] with a detail on the biofuel conversion performance study and its related energy input in this crop compared to other energy crops such as maize, sugarcane and sweet has also been presented (Table 2.6). The study found that the annual yield of bioethanol from cassava was higher than for any other crops, including sugarcane [36].

Table 2.6 Comparison of ethanol yields from different energy crops [35]

Crops	**Yield (ton/ha/year)**	**Conversion rate to ethanol (liter/ton)**	**Overall ethanol yield (liter/ha/year)**
Cassava	40*	150	6,000
Sugarcane	70	70	4,900
Corn/maize	5	410	2,050
Wheat	4	390	1,560

Note: * This assumes a rather optimistic yield of 40 ton/ha. Currently, the average yield of cassava production in Cambodia was about 22 tonnes/ha [10].

2.10 Bioethanol Production from Cassava

There are many steps involved in processing cassava root for ethanol production (Fig. 2.11). After harvesting, cassava roots is processed into stable form, chopped into chips and transported to drying floors which used sun light, free energy source, to dry the cassava chip. Once the chips are dried, it can be transported to storehouse under controlling condition and used as required. During storage, however, the starch's yield decreases depending on storage temperature. In 8 months storage, for example, typically it is accounted 5% reduction of starch yield. Furthermore, small-scale starch production (some parts of Viet Nam and Java island of Indonesia), the production tends to be inefficient with large losses and frequently produces with poor quality starch [37].

The processing of ethanol is described in the Figure 2.11. Briefly, there are three main basic steps for ethanol production. The first step is milling and liquefaction process. In this process, it used enzymatic to breaks down starch molecule to build its block molecules such glucose. The second step is fermentation process. In this step, the process used yeast to convert glucose to ethanol. The last step is purification process. In this step, the process is distillation to separate ethanol from other reaction products and inter-materials. However, in industrial scale, the process is carried out with two distinguishable technologies − wet milling process and dry grinding process [34]. These two processes differ from each process according to operation, capital costs, types of co-products produced, and the flexibility to produce different kinds of primary products. The principal of the process are the feedstock preparation steps and amount and types of co-products recovered. The similarity of both wet mill and dry-grind facilities is that when the starch has been recovered, it is converted to ethanol product [34].

In the wet milling process, the cassava chips are solaced in an acid condition to soften the material which results in the separation of starch from other components. In this step, the fibers are recovered after several separation steps. Then, the starch and protein are separated, respectively. In this process, the steams (most recovered before fermentation step) are fractionated while several co-products can be recovered in the same time [34]. In the dry grinding process, on the other hand, cassava dried chips were grinded by hammer mills or roller mills. In this step, the ground material is mixed with water, with enzymes, and cooked. After the fermentation, the only one co-product (fibers) was produced that is separated at the end of the whole process. This is known widely used as animal feed [38, 39]. According to Kueneman (2010) [37], about 435 liters of 95% ethanol can be produced from a ton of dry cassava chips, while a ton of refined cassava starch produces about 570 liters.

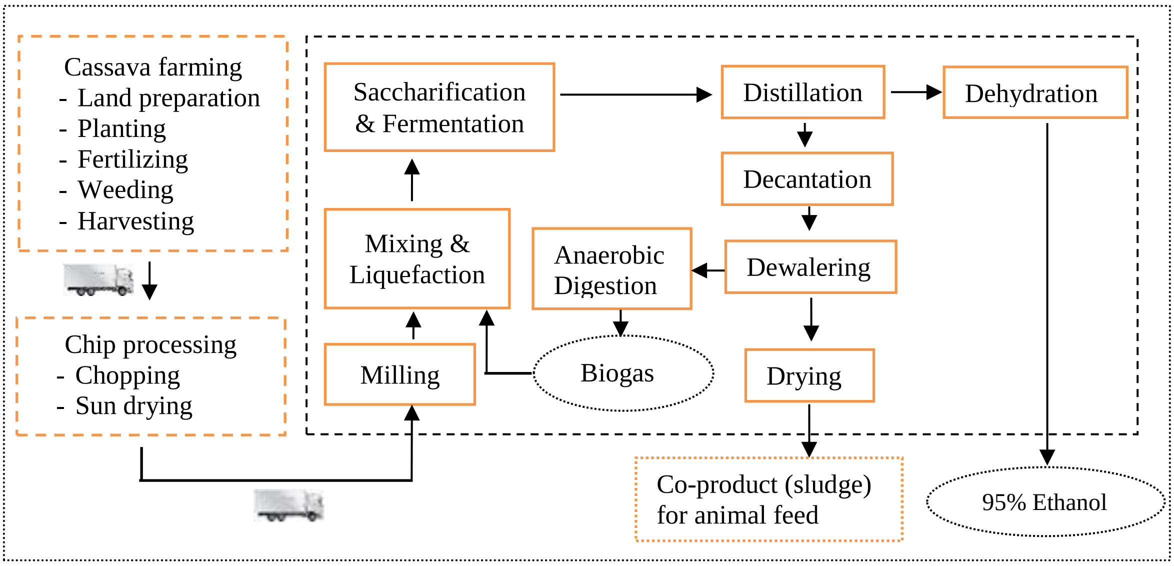


Figure 2.11 Flowchart of cassava ethanol production [38]

CHAPTER 3
CASSAVA AGRONOMY

3.1 Overview of Cassava Agronomy

Cassava (*Manihotesculenta*) is the third largest source of carbohydrates for human food consumption in the world with an estimated annual world production of 208 million tonnes. In Africa, which is the largest center of cassava production, it was grown on 7.5 Mha and produces about 60 million tonnes per year. In addition, it is a major source of low cost carbohydrates and a staple food for 500 million people in the humid tropics [34].

Figure 3.1 Cassava plant in early age and root set age

3.1.1 Climatic Conditions

As a drought tolerant crop, cassava can be planted in areas having unpredictable rainfall [12]. The preferably annual rainfall is minimum 6 months with at least 50 mm per month [40]. In Latin America, almost 30% of cassava is cultivated under subtropical conditions with frost in sometime during the winter, resulted in damaging crop growing, while in Asia accounted about 15% and followed by Africa 10% only. In Latin America and Africa, 40-45% of cassava are grown in both the humid and seasonally dry zones, 10-15% in the semi-arid zone, and about 20% are grown in the upland area with year-round cool temperatures (<22°C). In Asia, however, 26% are planted in the semi-arid zone, and almost no cassava is grown at high elevations [41]. Therefore, the best condition for cassava plantation are in areas with an annual well-distributed rainfall of 1000-1500 mm, mean temperature of 25 – 29°C, and a soil temperature 30°C; otherwise, below 10°C the plant stops growing, but it can also tolerate to semi-arid conditions with less rainfall of 500 mm also [42].

3.1.2 Soil Conditions

Cassava is considered a tolerant crop that can be grown in a wide variety of soil types. The best soil conditions for cassava growing are well-drained and not extremely stony or shallow (soil depth ≥ 30 cm). Furthermore, cassava is also tolerant of high levels of aluminum (Al) and manganese (Mn) in the soil, but does not thrive well in extremely sandy, salt affected, clayey or waterlogged soil [40]. With well recognized for its excellent tolerance to drought condition and holding capability to grow in impoverished soils, cassava; however, can be grown in all soil types even in form of either in fertile soil or acid soil (pH 4.2-4.5), but not in alkaline soil (pH > 8) [42]. Despite of that; therefore, cassava prefers loosen-structured soil included light sandy loams and loamy sands for its root formation [12]. In Asia, 55% of cassava plantation is cultivated on Ultisolssoil, which is characterized by low pH and low nutrient content. Another 18% is grown on Inceptisols (also low in N, P and K), 11% on Alfisols (high cation exchange relative to high pH and high fertility), 9% on Entisols (very sandy soil) soil type where mainly found in Java island of Indonesia [43]. In Latin America, 70% of cassava is grown on almost equal proportions of Ultisols, Alfisols, Oxisols, and also on lower proportions of Entisols, Inceptisols and Mollisols. In Africa, on the other hand, according to the Collaborative Study of Cassava in Africa (COSCA) [44], about 10% of cassava production is constrained by low soil fertility (grown on Oxisols, Ultisols and Entisols), shallow soil depth or texture, and another 4% by poor drainage. Moreover, other 50% of cassava growing areas are constrained by high acidity (pH < 5.5) [41]. Thus, it is unlikely that acidity is the main limiting factor as cassava is known to tolerate pH of 4.0-4.2 and high levels of exchangeable Al (up to 85% saturation) [32].

3.1.3 Elevation and Topography Condition

In Africa, 80% of cassava is grown in the lowland areas and 20% in the highland areas where found in subtropical highlands, such as mainly in Zambia and Madagascar on steep slopes of 10-50% [43]. In Asia, however, most cassava is cultivated on gentle slopes of 0-10%. In southern China, Northern Vietnam, and on Java island, for example, cassava is grown on steep slopes of 15-50% [45]. In Latin America, moreover, about 417,000 ha of cassava plantation are found in the highlands area. In southern states of Brazil, for instance, cassava is found on gentle slopes of less than 10%, on slopes up to 40%, and occasionally on steeper slopes, but it is fewer plantations because of intensive mechanical land preparation serious erosion can occur under those conditions [41, 46].

3.1.4 Nutrient Requirements

Nutrient applications are a significant factor in enhancing the cassava yield. Applying nutrients to the soil can enable the maintenance of soil health and improves depleted or poor soils quality. However, nutrient depletion can occur after land has been under continuous cultivation for many years. About 2.3 kg of nitrogen (N), 0.4 kg of phosphorus (P) and 3.0 kg of potassium (K) are removed from the soil for every 1 ton of cassava roots harvested. The application of nutrients, more importantly, helps to replace the lost nutrients and maintain soil fertility to enable continuing high yields in subsequent farming seasons [40]. However, N-P-K fertilizers are not a good ideal for cassava according to expert knowledge, due to if too much nitrogen (N) applied; cassava will produce too much foliage (cassava does not require a high nitrogen), and if too much phosphorus (P); it will incurs unnecessary expense of money. However, if too little potassium (K), it will cause problem due to cassava requires more K for the formation of roots. Technically, a common fertilizer recommendation for long-term cassava production is the ratio of ($N:P_2O_5:K_2O$) of 10:5:15 fertilizer brand [37]. To reach a moderate fresh root yield of 15 t/ha, about 80 kg of N, 10-20 P_2O_5 kg and 50 kg K_2O/ha is recommended to apply on. Moreover, to maintain a high yield of 30 t/ha, annual application of 150 kg N, 20-30 kg P_2O_5 and 150 kg K_2O /ha may be required [37, 41]. However, to determine the exact quantity of fertilizers to apply on a given plot is depending on many factors that vary from one soil type to another. Moreover, a simple way to determine the fertilizer requirement is linked to the cassava root yield [40]. Organic fertilizers, on the other hand, often play an excellent enhancer's role for soil fertility. It is important to ensure that a balanced fertility approach is used to maintain soil fertility and quality. Moreover, combined use of organic and chemical fertilizers are the best accomplished enhancement as known the chemical fertilizers are the main source of nutrients while the organic sources improve the micro-nutrients and soil's physical condition [37].

3.1.5 Cultivation Practice

Generally, planting seeds (cassava stem) remain from 15-20 cm long with at least 7 to 10 nodes with diameters of 1.5 - 2.5 cm (Fig. 3.2). To ensure good propagation, good-quality stakes obtained from mature plants with 9 - 12 months [37]. The appropriate time of cultivation is usually at an early period of rainy seasons when the soil has enough moisture for stem germination. When planted, however, the stakes are pushed or inserting into the soil horizontally, vertically or slanted; depending on soil structure. Moreover, for loosen and friable soil, the stakes (cassava stem) are planted by pushing vertically (standing as pillar), or slanted approximately 10 cm in depth below the soil surface with the buds facing upward, respectively. This planting method gives higher root yields, better plant survival rates and is easily for plant cultivation and root harvesting [41]. The horizontal planting practices are suited for heavy clay soils condition. Planting with 100 x 100 cm spacing (10,000 plants/ ha) is typical, however, less spacing with 100 x 80 cm or 80 x 80 cm, and larger spacing ranked from 100 x 120 cm, or 120 x 120 cm, is recommended for in fertile sandy soil and fertile soil, respectively [34].

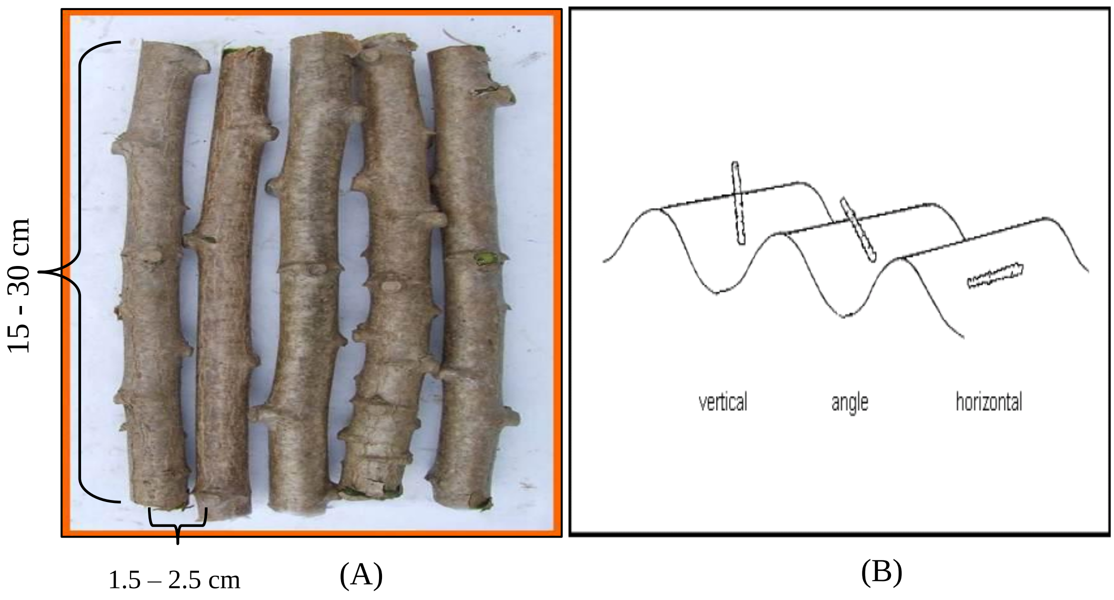


Figure 3.2 Cassava planting practice (A) cassava stake, (B) planting technique

3.1.6 Harvesting Practice

Normally, the harvesting stage is done at any time between 6-18 months, yet harvested on average at 10-12 months after planting often provided a good yields (almost 300-365 days) [34]. However, too early or late harvesting, it may lower root yields and root starch contents. The actual practice of harvesting, farmers are relying on economic factors such as market demand, labor available, and root prices. Furthermore, root harvesting can be accomplished manually by cutting stems at a height of 40 - 60 cm above the ground and roots are then pulled out by using the iron or woody stalk with a fulcrum point in between the branches of the plant. In modern farming, tractor plays an importance role for root harvesting (Fig. 3.3). Plant tops are cut into pieces for replanting (next planting seeds), cassava stem, leaves are used for making animal fodder and roots are delivered to the market for direct consumption or to processing areas for subsequent conversion to primary products as flour, chips, and starch [12].

Figure 3.3 Cassava harvesting practices

CHAPTER 4
METERIALS AND METHODS

4.1 GIS Approach for Land Suitability Evaluation

The GIS-based land suitability evaluation, which uses the applications of overlay techniques, was widely used by American landscape architects in the late 19th and early 20th century [16, 17]. This overlay techniques was employed as the classical procedure in the GIS-based approach for land suitability analysis. This method evolved a hand-drawn overlay through a computer-assisted overlay technique [16, 47-49]. Three major groups of these approaches of the GIS-based land-use suitability analysis were distinguished: (i) computer-assisted overlay mapping, (ii) multi-criteria evaluation methods, and (iii) AI (soft computing or geo-computation) method [16, 17]. For the computer-assisted overlay techniques, the manual method was developed in case of mapping and combining large datasets [47, 50]. Integrating GIS with multi-criteria decision making (MCDM) method which was the combination and manipulation of the geographical data and the decision maker's preferences according to the specified decision rules [51, 52]. AHP, one of the MCDM methods, is a powerful approach which used to solve complex decision problems based on an additive weighting process in which several relevant attributes are represented through their relative importance. Recently, integrating GIS and AHP approach methods based on decision techniques have been widely accepted for land use suitability analysis. Moreover, the AHP has been extensively applied in the land suitability evaluation [14].

4.2 Land Suitability Evaluation Based on FAO

The Food and Agriculture Organization (FAO) Framework has been widely used for land suitability evaluation. Land suitability evaluation is an assessment of land performance when used for specified purposes, especially for land use planning. It involves the execution and interpretation of basic surveys of a climate, soils, vegetation, precipitation, and other aspects of alternative form of land in terms of land use requirements which refer to a set of land characteristics that determines the production and management conditions of land use. The land characteristics refer to an attribute of land that can be measured or estimated, such as slope angle, rainfall, soil texture, and available water capacity. Moreover, land mapping units which determined by resources survey are normally descript in the terms of land characteristic [53, 54]. The land characteristics in the FAO Framework are classified into 25 types (Table 4.1).

Land quality is land that acts in a distinct manner in its influence on the suitability of land for a specific kind of utilization. Somehow, lands qualities may be expressed in positive or negative way include moisture availability, erosion resistance, flooding hazard, nutritive value of pasture, and accessibility. Characteristics factor employed to determine limits of land suitability classes or subclasses which are known as diagnostic factor. Diagnostic factor refer to the output from or the required input to with a specified use which serves as a basis for assessing the suitability of a given area of land for that usage. For every diagnostic factor there will be a critical value or set of critical values, which are used to define suitability class limits [53].

Land suitability classification is summarized in Figure 4.1. Depending on the purpose, scale and intensity of the study, either the full range of suitability orders, classes, subclasses, and units may be distinguished, and the classification may be restricted to the higher two or three categories [53]. According to this framework, the structure for the suitability classification for this study is followed the suitability class where composed of four categories [53, 54]. Each classification is an appraisal and grouping of land units in term of their suitability for a defined use as follow:

I. Land Suitability Orders: refer to the reflecting kinds of suitability. S: suitable, N: not suitable.
II. Land Suitability Classes: refer to the reflecting degrees of suitability within orders such as S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable).
III. Land Suitability Subclasses: refer to the reflecting kinds of limitation or main kinds of improvement measures required within classes (Ex: S2m, S2e, etc.).
IV. Land Suitability Units: refer to the reflecting minor differences in required management within Subclasses such as S2e-1, S2e-2.

The suitability classes of land for a particular use are categorized as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) (Table 4.2). In land suitability applications, physical factors are normally weighted and rated in linear combinations. A map represents each evaluation criteria with ordinal values (S1, S2, S3, and N) that indicating the level of suitability with respect to a sub factors, based on the crop requirements [55].

Table 4.1 Land characteristics of the FAO Frameworks 1984 [54]

1. Radiation regime	14. Soil toxicities
2. Temperature regime	15. Pets and diseases
3. Moisture availability	16. Soil workability
4. Oxygen availability	17. Potential for mechanization
5. Nutrient availability	18. Conditions for land preparation
6. Nutrient retention capacity	19. Conditions for storage and processing
7. Rooting conditions	20. Conditions affecting timing of production
8. Conditions affecting germination	21. Access within the production units
9. Air humidity as effecting growth	22. Size of potential management units
10. Condition for ripening	23. Location
11. Food hazard	24. Erosion hazard
12. Climatic hazard	25. Degradation hazard
13. Excess of salts	

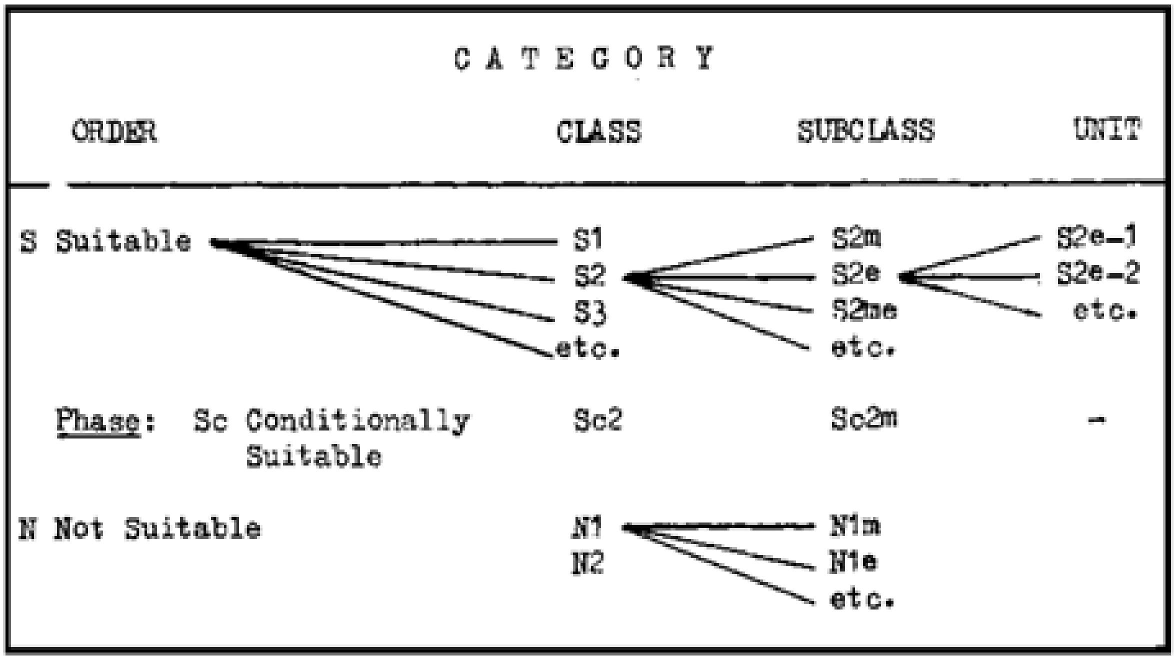


Figure 4.1 Structure of the suitability classification [53]

Table 4.2 Structure of land suitability classification [53, 56]

Classification	Description
Highly suitable (S1)	Land without limitations or with only minor limitations that will not significantly reduce productivity nor require extra input.
Moderately suitable (S2)	Land having limitation that will not reduce productivity or increase the inputs required to maintain productive compared to S1, but still clearly suitable and offering attractive benefits for use.
Marginally suitable (S3)	Land holding limitations so severe that benefits are reduced and/ or require increased inputs so that this expenditure is only marginally justified.
Not suitable (N)	Land that cannot support a specified land use type on a sustained basis. Either the land use is technical or cannot be sustained because it leads to progressive destruction of land and water resources or is financially unprofitable.

4.3 The Methodological Work Flow

In this study, the research is divided into two main tasks following the objectives.

- **Task 1:** estimate the current quantities of cassava feedstock in Cambodia to produce bioethanol; and
- **Task 2:** to find suitable areas for future possible expansion of cassava plantation in Cambodia and future possible bioethanol production.

4.3.1 Current Quantity of Cassava Feedstock to Produce Ethanol (Task 1)

4.3.1.1 Estimate Land Suitability Area for Cassava Plantation

Land suitability map for cassava plantation was made using GIS overlay technique, which available in ArcGIS 10.1, where the spatial data of each factor were kept and displayed as GIS spatial layer. The suitability assessment for cassava plantation in Cambodia was based mainly on the method described by FAO (1976) integrated with weight and score of each factor. Figure 4.2 show about the schematic of work flow procedure of Task 1.

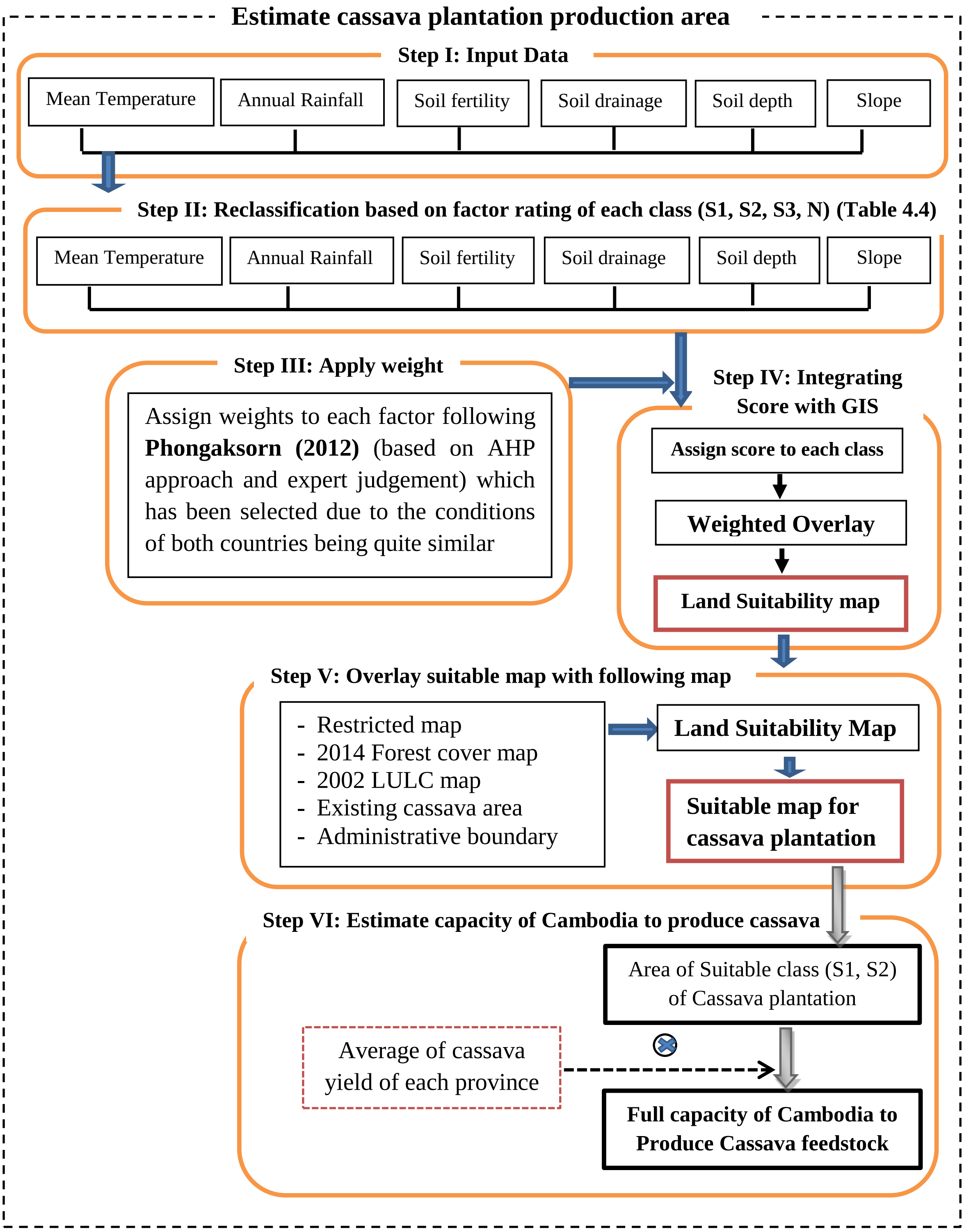


Figure 4.2 Schematic of work flow procedure of Task 1

a) Data Sources and Analysis

To define zoning for cassava production area in Cambodia, this approach needs several GIS data and ArcGIS software for displaying to perform suitable area based on FAO 1976 such as climatic data (mean temperature and rainfall data), soil characteristics (included soil drainage, soil depth, and soil fertility), and elevation data (slope data). In addition, provincial boundary, restricted area (conservation area, protected forest, and flooded area), 2002 LULC map, and 2014 forest cover map were also retrieved for the analysis. Each data is collected from various sources (Table 4.3). The map projection is WGS 1984, zone 48 and scale 1:2,000,000. The following table shows the map sources used in this study:

Table 4.3 Data sources used in this study

No	Variable	Data Sources	References
1	Mean temperature	WorldClim	[57]
2	Annual Rainfall	WorldClim	[57]
3	Soil drainage	Harmonized World Soil Database	[58]
4	Soil Depth	Harmonized World Soil Database	[58]
5	Soil fertility	Notice of Soil Map of Cambodia	[59]
6	Topography	Shuttle Radar Topography Mission, or USGS	[24]
7	LULC2002	General Directorate Agriculture	[26]
8	Forest cover 2014	Open Development Cambodia	[27]
9	Restricted area	Open Development Cambodia	[60]

➢ **Climatic Data**

The mean temperature and annual rainfall data used in this study were derived from the observation data from 1950-2000 periods, respectively [57]. The climate elements considered were mean temperature and annual rainfall distribution in the course of the year. The data were generated through spatial interpolation of average monthly climate data from weather stations of global, regional, national, and local sources which used thin-plate smoothing spline algorithm implemented in the ANUSPLIN package for interpolation, using latitude, longitude, and elevation as independent variables [61]. The data layers were generated from weather stations on a 30 arc-second resolution grid (often referred to as 1 km^2 resolution). Then, the data were projected to WGS 1984 zone 48 with scale 1:2,000,000 by using ArcGIS 10.1 to mask with Cambodia boundary map and then display, characterized, and analysis. These two factors are quite important for identifying suitable areas for cassava plantation, which has been used to quantify growing period variability and to estimate each grid-cell by the variability of agro-climatically attainable crop yields. It is the fundamental factor that controls the formation and persistence of drought conditions. For this purpose, mean temperature and annually rainfall data with a sufficient spatial resolution is needed which detailed in World Climate Database [61].

➢ **Soil Characteristic Data**

The Harmonized World Soil Database (HWSD) contributes scientific knowledge for planning sustainable expansion of agricultural production. On the basis of soil parameters provided by HWSD, there are seven keys soil qualities important for crop production such as nutrient availability, nutrient retention capacity, rooting conditions, oxygen availability to roots, excess salts, toxicities, and workability [58, 62]. In this study, only two soil qualities were derived from HWSD such as rooting conditions (soil depth) and oxygen availability to roots (soil drainage). In addition, soil fertility was also accounted as a major land quality that plays important role in the land suitability evaluation for the agriculture crop. It was developed under Cambodia-United Cooperation Agreement by Charles Crocker (1962) and Cambodia Team which divided into 16 soil types [25]. These soil types were established into 3 main groups: higher fertility, medium fertility, and low fertility (see Appendix C.4) [59]. These soil data (soil depth and drainage) were extracted from the Harmonized World Soil Database (HWSD) [58] which used to display as main factor for define suitable area for cassava plantation in Cambodia. The soil data were projected to WGS 1984 zone 48 with scale 1:2,000,000 by using ArcGIS 10.1 to mask with Cambodia boundary map and then display, characterized, and analysis. The raw resolution approximately 10 km of soil quality factor were resampling to 1 km resolution which will be used to analyze and define zoning.

➢ **Slope Data**

The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the world. In this study, slope data were considered as one factor among several factors, which released the Shuttle Radar Topographic Mission (SRTM) data, a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) with 1 km^2

resolution which updated on November 16, 2009 [24]. This data is currently distributed free of charge by USGS and is available for free download from the Shuttle Radar Topographic Mission (SRTM) Data [24]. The slope data was projected to WGS 1984 zone 48 with scale 1:2,000,000 by using ArcGIS 10.1 to mask with Cambodia boundary data [24]. In Cambodia, the terrain is predominantly flat through a country especially in the middle part which found lower slope (<5%). In the North-East region and South-West regions considered with a higher slope (>20%) can be found. The highest mountain in Cambodia, Phnom Aural, at 1,771 meters height—is in the South-West region [20].

- **Land Use Land Cover (LULC) 2002**

Since there is no official map of current land use-land cover (LULC) published for analysis, 2002 LULC map was the only available LULC for estimating the production area for cassava plantation [26]. 2002 LULC map was the fundamental map which has been used not only by non-organization for estimating the crop production area, but it was also used as the based map for main crop by Ministry of Agriculture, Forestry, and Fishery (MAFF). This map was classified into 8 categories as detailed in section 2.5. The map was produced and generated by Japan International Cooperation Agency (JICA) since 2002 with the scale of 1:1,500,000 [26] which was provided by General Directorate of Agriculture (GDA), under the authorization of Ministry of Agriculture, Forestry, and Fisher (MAFF), Cambodia. In this study, 2002 LULC map was used to define the location of each proportion of forest cover, paddy field, upland crops, grassland, shrubland, barren land and rocks, and urban built up area.

- **Forest Cover 2014**

In 2006, Cambodia's Department of Forestry Administration (DFA) published a map showing Cambodia's forest cover in 2002 [63]. Then in 2011, the Forestry Administration (FA), supported by the International Tropical Timber Organization and the Government of Denmark, published Cambodia Forest Cover 2010, which included maps of forest cover change between 2006-2010, and between 2002-2010 [64]. As no official maps or analysis of forests specific to Cambodia have been published since this date, Open Development Cambodia (ODC) decided to create a set of updated forest cover maps in 2014 (see Appendix C.3) [27]. This updated 2014 forest cover reveals a continuing trend in forest cover loss particularly dense forest across Cambodia since 1973. For the first time in the 41-year period, the percentage of non-forest ground cover (48.4%) is larger than that of forest cover (47.7%). This map was created using satellite images from January and

February 2014 with the resolution of 30 x 30 meters and scale of 1:2,500,000 [27]. The classification of this map was detailed in section 2.6. In this study, this map was used to determine the abundant land (forestland changed to other land) based on non-forest area where these areas will be the potential for cassava expansion area.

- **Restricted Area Map**

In this study, the restricted map was included conservation areas, protected forest areas, and flooded areas. The conservation area and protected forest is clearly defined and recognized for its natural, ecological and/or cultural value. It is given extra protection to support the long term conservation of wildlife, nature, ecosystems, and cultures contained within the area. According to Royal Degree in 1993, the protection of natural areas recognized 23 protected areas, which at the time covered more than 18% of the country's total land area (see Appendix C.1). The royal decree divides the areas into four distinct categories:

- Natural parks (sometimes described as 'national parks')
- Wildlife preserves
- Protected scenic view areas (sometimes described as 'protected landscapes)
- Multi-purpose areas.

In addition, flooded areas were also taking into account as the restricted areas for cassava plantations due to the cassava crop being harvested around 8 – 12 months, respectively, while flooded areas where mostly found under paddy fields. These area was detail and provided by Open Development Cambodia (ODC) [60].

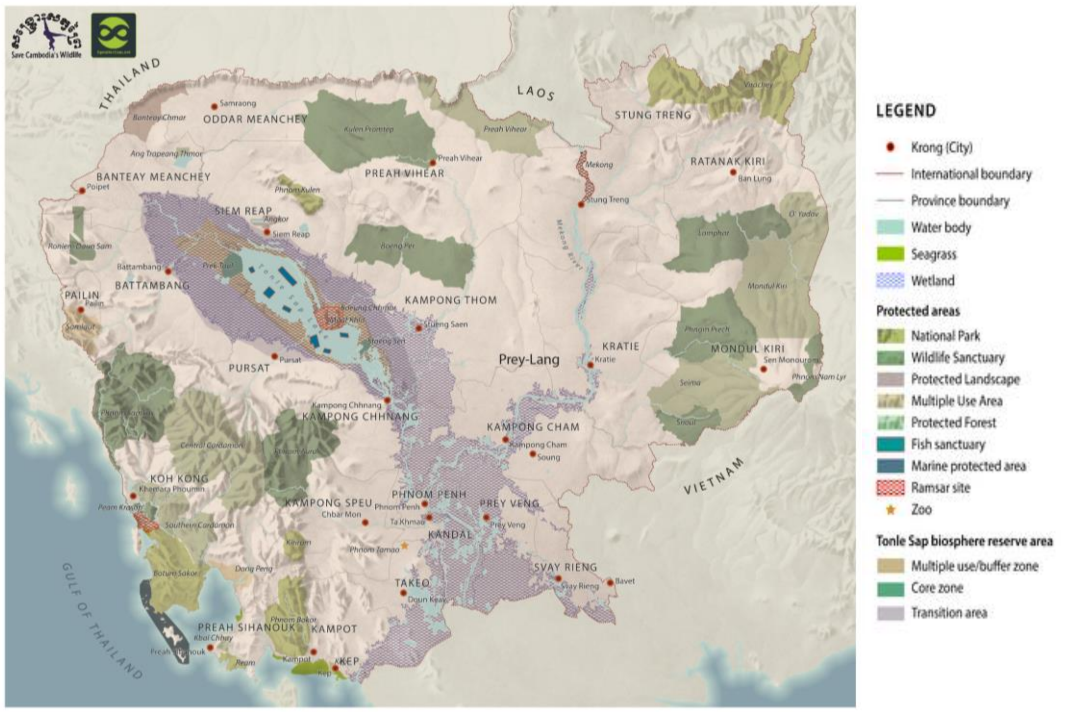


Figure 4.3 Conservation area and protected forest map of Cambodia [60]

b) Reclassification of Each Factors According Factor Rating

All the data were collected along with a set of the identified physical factors for estimating the land suitability for cassava plantation. In this study, six physical factors were derived as described in Sub-Section (a), which is set as main factors (or criteria) for cassava requirement to display and define land suitability for cassava crop plantation in Cambodia. Moreover, all factors map were projected to WGS 1984, zone 48 and scale of 1:2,000,000, with 1 km^2 of pixel resolution, respectively. Each maps were identified based on the manually of qualitative land evaluations for cassava crop following the FAO framework [53, 54]. Therefore, all physical factors map were reclassified into four suitability classes based on the structure of FAO land suitability classification of factor rating score (Table 4.4) for cassava plantation — highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) [18, 55, 65, 66].

Table 4.4 Land use requirements for cassava plantation [67, 68]

Land use requirement			Factor rating classes and scores			
Land quality	Factor	Unit	S1	S2	S3	N
			1	0.8	0.5	0
Temperature	Mean temp	^{o}C	25-29	30-32 24-14	33-35 13-10	>35 <10
Moisture availability	Annual rainfall	mm	1,600–2,500	1,200–1,600	900–1,200	<900
Oxygen availability	Soil drainage	class	Very well/ well	Moderately well/somewhat well	somewhat poor	Very poor/ poor
Rooting condition	Soil depth	cm	>100	50-100	25-50	<25
Soil workability	Soil fertility	class	highly fertility	Moderately fertility	Marginally fertility	Very low fertility
Erosion hazard	Slope	%	0-5	5-12	12-20	>20

c) Determination of Weight and Score for each Factor

The weight and score for each factor chosen in this study were determined based on the AHP approach [14, 15]. AHP is one of the most extended Multi-Criteria Decision Making (MCDM) techniques that provide a structural basis for qualifying the comparison of decision elements and criteria in a pair wise technique which normally were calculated in Microsoft Excel [55, 65, 69]. This method evaluates the relative significant of all factors involved by assigning a weight for each of them in a hierarchical order. For the last level of the hierarchy, a suitability score for each class of each factor are given. This method usually implemented using Pairwise Comparison Method (PCM) which simplified each factor rating among decision criteria and expert judgement. In land suitability application, all factors have to be weighted and rated score to be summed up from 0 to 1 for each category. On the other hand, each factor in the last layer was classified into 4 suitability classes (S1, S2, S3, and N) and their suitability scores were presented in the standardized format ranging from least suitable (0) to most suitable (1) [18, 65]. In this analysis, weight and score for each factor chosen in this study were determined rely on recent study in Thailand done by Phongaksorn (2012) [68], which is based on AHP approach given and detailed in Appendix A where experts' opinions were asked to calculate the relative importance factors involved (Table 4.5).

Table 4.5 Weight of each factor done by Phongaksorn (2012) [68]

Weight of each factor based on AHP	
Factor	**Weight**
Mean Temperature	0.041
Annual rainfall	0.117
Soil Fertility	0.417
Soil Drainage	0.218
Soil Depth	0.132
Slop	0.076

d) Land Suitability Assessment for Cassava Plantation

The land suitability map was made using GIS overlay technique available in ArcGIS 10.1 integrated with weights and scores based on the AHP approach where the spatial data of each factor is kept and displayed as GIS spatial layer. The spatial data of each factor were kept and displayed as a GIS spatial layer [18, 65]. The main steps to produce land suitability map for cassava crop are: finding suitable factors (input data) to be used in the analysis, assigning factor priority, weight and class weight (rating) to the parameters involved and generating land suitability map of cassava. This study selected six criteria in the form of six GIS-based layers in determining what areas are the best suited for cassava plantation. Each criterion received a weight and a score which represented its relative importance in the suitability evaluation. There are four stages in the procedure. The first stage is reclassified of each criteria according to each suitability score (Table 4.4). At the next stage, spatial data of the six factors as a set of GIS layers were overlaid together for final suitability classification for cassava plantation. Then, the total score for suitability is achieved by multiplying criterion score with its appropriate weight and adding all weighted scores (see Equation 4.1). The analysis was done in vector-based format [66]. Let $\boldsymbol{R_s}$ be the total suitability score for each land unit, $\boldsymbol{n}$ be the number of factors, $\boldsymbol{W_i}$ be the multiplication of all associated weights in the hierarchy of ***i***th factor (as seen in Table 4.6), and $\boldsymbol{S_i}$ be the rating score given for the defined class of the ***i***th factor found on the assessed land unit (Table 4.6) [68]. The equation of suitability score is shown below.

$$\boldsymbol{R_s = \sum_{i=1}^{n} (W_i \times S_i)} \qquad \textit{Eq. 4.1}$$

Moreover, total suitability scores from each land unit had a score ranging from 0 to 1 and were assembled to create land suitability maps for cassava plantation. Finally, all data in the final map were reclassified into four suitability classes (S1, S2, S3, and N) according to the FAO framework of suitability index (Table 4.6) namely: highly suitable (0.76 – 1), moderately suitable (0.51 – 0.75), marginally suitable (0.26 – 0.5), and not suitable (0.00 – 0.25), respectively [18, 68].

Table 4.6 Score of land suitability classification [67, 68]

Classes	**Score of land suitability**	**Suitability Index**
Highly suitable (S1)	0.8 – 1.0	0.76 – 1
Moderately suitable (S2)	0.4 – 0.8	0.51 – 0.75
Marginally suitable (S3)	0.2 – 0.4	0.26 – 0.50
Not suitable (N)	0.0 – 0.2	0.0 – 0.25

4.3.1.2 Estimate the Capacity of Cambodia to Produce Bioethanol

a) Estimate Capacity of Cambodia to Produce Cassava

Scenario 1: Estimation of forestland change by overlaid of 2002 LULC map and 2014 forest cover map

Since there is no official map of the current LULC have been published, the forestland change is estimated based on the 2002 LULC map and 2014 forest cover map while the state data of crop statistic 2013 was used as a reference data to find the change of agriculture land between 2002 and 2014. In order to estimate the maximum capacity of Cambodia to produce cassava, forestland change estimation within the period of 2002 and 2013 is a very important step to find the area converted from forest to non-forest area. This converted area will take into account for estimation suitability for cassava cultivation. To this end, the overlay analysis between 2002 LULC map (Fig. 2.5), 2014 forest cover map (Fig. 2.6), and province boundary map plays important roles to extract the converted area (forest changed to non-forest) from 2002 to 2013 (see Appendix B.1). In addition, the estimation of suitable area will analyze on current existing cassava area, upland crops, and abundant land (forest changed to non-forest area) by overlay of 2002 LULC map (Fig. 2.5), 2014 forest cover map (Fig. 2.6), land suitability map, and province boundary map. Moreover, restricted area (Fig. 4.3) (including conservation areas, protected forest, restricted area) (see Appendix C.1), and flooded areas are overlaid during the evaluation process as it is unlikely that these areas would not be employed for cassava plantation while the paddy field were taking into account as not likely to grow cassava. At the end of this process, the land suitability map for cassava plantation is generated with four classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). To this end, only two classes, highly suitable (S1) and moderately suitable (S2), are taken into account for this evaluation. On the other hand, the most recent average of cassava yields of each province is very importance to define quantity of cassava feedstock. Let ***MQCF*** be maximum quantity of cassava feedstock, ***ASC*** be area of suitable class (S1, S2), and ***ACYEP*** be average cassava yield of each province. Thus, the maximum quantity of cassava feedstock (***MQCF***) for bioethanol production can be calculated as Equation 4.2 below.

$$\boldsymbol{MQCF = ASC * ACYEP} \qquad \textit{Eq. 4.2}$$

b) Estimate Current Capacity of Cambodia to Produce Bioethanol

To estimate current cassava feedstock potential for ethanol production, the most recent cassava yields of each province play crucial roles to define current cassava feedstock (Fig. 2.9). In addition, all utilizations of cassava feedstock included total local cassava consumption, and total cassava export (inform of starch and dried chip), are used to find the potential cassava feedstock for bioethanol production which these data obtained from national crop reports statistic, and literature review. Let ***CQCF*** be currently quantity of cassava feedstock, ***TLCC*** be total local cassava consumption, ***TCE*** be total cassava export, and ***CFF*** be conversion factor of cassava fresh root (6.6 kg of fresh root can be fermented to 1 liter of bioethanol) [4]. Thus, bioethanol production potential (***BiPP***) can be calculated as Equation 4.3 below.

$$\boldsymbol{BiPP} = [\boldsymbol{CQCF} - (\boldsymbol{TLCC} + \boldsymbol{TCE})] * \boldsymbol{CFF} \qquad \textit{Eq. 4.3}$$

4.3.2 Suitable Area for Future Expansion of Cassava Plantation Area (Task 2)

4.3.2.1 Future Possible Expansion Area

In this study, the future expansion area for cassava cultivation is analyzed based on the abundant land (forestland converted to abundant or unused land) estimated by overlaid map between 2002 LULC map and 2014 forest cover map while the state data of crop statistic 2013 are used as a reference data to find the change of agricultural land between 2002 and 2014. With this analysis, the grassland, shrubland, urban land, and barren land are assumed as in 2002 LULC map due to the lack of current data especially current LULC. The next process is to overlay forest change map (comparison of 2002 LULC map and 2014 forest cover map), restricted map (Fig. 4.3), province boundary map, and spatial distribution of cassava plantation (Fig. 2.9), with land suitability map to identify the future expansion area at the provincial level with the suitable class of S1 and S2 only (Fig. 4.4). Therefore, the obtained suitability map will be applied to real cultivation practice to find area where cassava can be further expanding in Cambodia. This phase allows us to find information about where the cassava can be cultivated across the various land suitability zones as details in Figure 4.4 below.

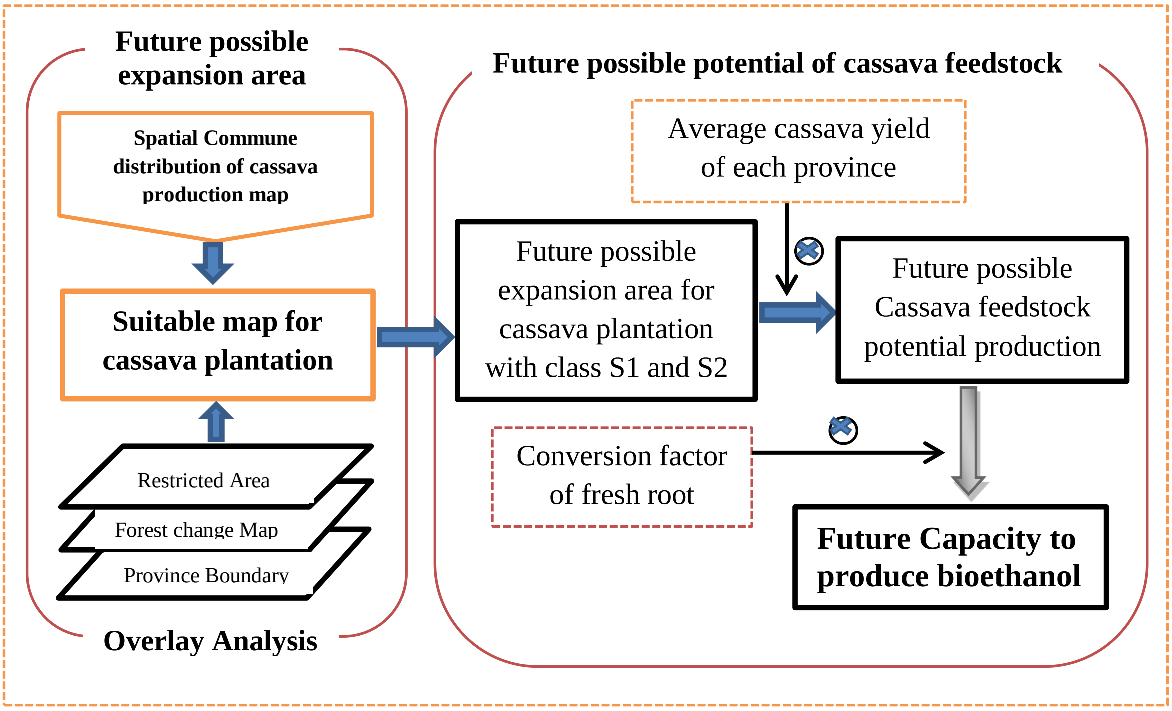


Figure 4.4 Schematic of work flow procedure of Task 2

4.3.2.2 Future Possible Cassava feedstock Potential to Produce bioethanol

Scenario 2: Estimation of future capacity of Cambodia to produce ethanol based on the expansion area

The future capacity of Cambodia to produce ethanol is estimated based on future possible quantities of cassava feedstocks where this cassava production is assessed based on future possible expansion area of both classes: highly suitable (S1) and moderately suitable (S2) and current cassava yield of each location. In this section, two sub-scenarios are set to estimate the capacity bioethanol that Cambodia can produce

Sub-Scenario 2.1: assumption of 100% of future possible cassava feedstock produced bioethanol

In this scenario, the current productions of 8 million tonnes in 2013 are assumed for export and local consumption. Let ***FCPBi*** be future capacity to produce bioethanol, ***FACP*** be future area of cassava plantation (S1, S2), ***ACYEP*** be an average of cassava yield of each province, and ***CFF*** be the conversion factor of fresh root. Hence, future possible capacity of Cambodia to produce ethanol (***FCPBi***) can be calculated as Equation 4.4 below.

$$\boldsymbol{FCPBi} = (\boldsymbol{FACP} * \boldsymbol{ACYEP}) * \boldsymbol{CFF} \qquad \textit{Eq. 4.4}$$

Sub-Scenario 2.2: assumption of keeping the share of the curr ent production for bioethanol production plus additional future production

For this scenario, the current quantity of cassava feedstock included total local cassava consumption and total cassava export (inform of starch and dried chip), are assumed as in Section 2.7.2 due to there is no official report been published for current consumption. Let ***PFCPBi*** be potential future capacity to produce bioethanol, ***FCCF*** be future capacity of cassava feedstock, ***TLCC*** be total local cassava consumption, ***TCE*** be total cassava export, ***CRPY*** be cassava remaining in previous year, and ***CFF*** be conversion factor of cassava fresh root. Thus, the potential future capacity to produce bioethanol (***PFCPBi***) can be calculated as Equation 4.5 below.

$$P\boldsymbol{FCPBi} = [\boldsymbol{FCCF} - (\boldsymbol{TLCC} + \boldsymbol{TCE}) + \boldsymbol{CRPY}] * \boldsymbol{CFF} \qquad \textit{Eq. 4.5}$$

CHAPTER 5
RESULTS AND DISCUSSION

The results of land suitability assessments of cassava feedstock for ethanol production are presented in this chapter. The results are presented in maps and table format with discussions for each section. In addition, this chapter is divided into two main sections. First, the results of Task 1: estimate the current quantities of cassava feedstock in Cambodia to produce bioethanol. Second, the results of Task 2: to find suitable area for future possible expansion of cassava plantation and future possible bioethanol production.

5.1 Estimate Current Quantity of Cassava Feedstock to Produce Bioethanol (Task 1)

5.1.1 Estimate Land Suitability for Cassava Crop in Cambodia

Land suitability map for cassava plantation was made using GIS overlay technique which available in ArcGIS 10.1 where spatial data of each factor were kept and displayed as a GIS spatial layer. The suitability assessment for cassava plantation in Cambodia was based mainly on the method described by FAO (1976) integrated with AHP approach.

5.1.1.1 Classification of Each Factor Based on FAO Framework

Figure 5.1 shows the mean temperature classification derived from observation data from 1950-2000, respectively, of Cambodia which ranged from 18.2 to 29.8°C. This figure shows the results of mean temperature classification following FAO guidelines where class S1, S2, S3 and N ranged the value from 25-29°C, 14-24 or 30-32°C, 10-13 or 33-35°C, and <10 or >35°C, respectively. The result obtained that the mean temperature in Cambodia is under S1 and S2 only which is considered mostly suitable for cassava plantation throughout the country.

Figure 5.2 shows the annual rainfall classification derived from observation data from 1950-2000, respectively, of Cambodia which ranged the value from 1,000–3,512 mm/year. This figure shows the results of annual rainfall classification follow FAO guidelines in which each classes S1, S2, S3, and N ranged value from 1,600-2,500 mm/year, 1,200-1,600 mm/year, 900-1,200 mm/year, and <900 mm/year, respectively.

The results showed that the annual rainfalls of Cambodia were under the class of S1, S2, and S3, represented 56.59%, 38.94%, and 4.47%, respectively. Therefore, the rainfall of Cambodia mostly suited for cassava plantation throughout the country due to the favorable annual rainfall for cassava plantation required from 500–2,500 mm/year.

Figure 5.3 shows the soil fertility classification of Cambodia developed under Cambodia-United Cooperation Agreement by Charles Crocker (1962) and Cambodia Team divided into 16 soil types. These soil types were established into 3 main groups: higher fertility, medium fertility, and low fertility as for S1, S2, and S3 represented 35.31%, 21.07%, and 14.92%, respectively (see Appendix C.4). However, one more class which considered as class (N) about 25.73% was added as very low fertility which stands for soil type of acid lithosole where this soil type are strongly to moderately acid reaction with very low in organic carbon (C) and total N, very low to moderate in extractable P, very low to low in exchangeable K, and very low in effective cation exchange capacity where was not recommended for crop lands by MAFF as it is recommended for national park in the west side and mountainous area.

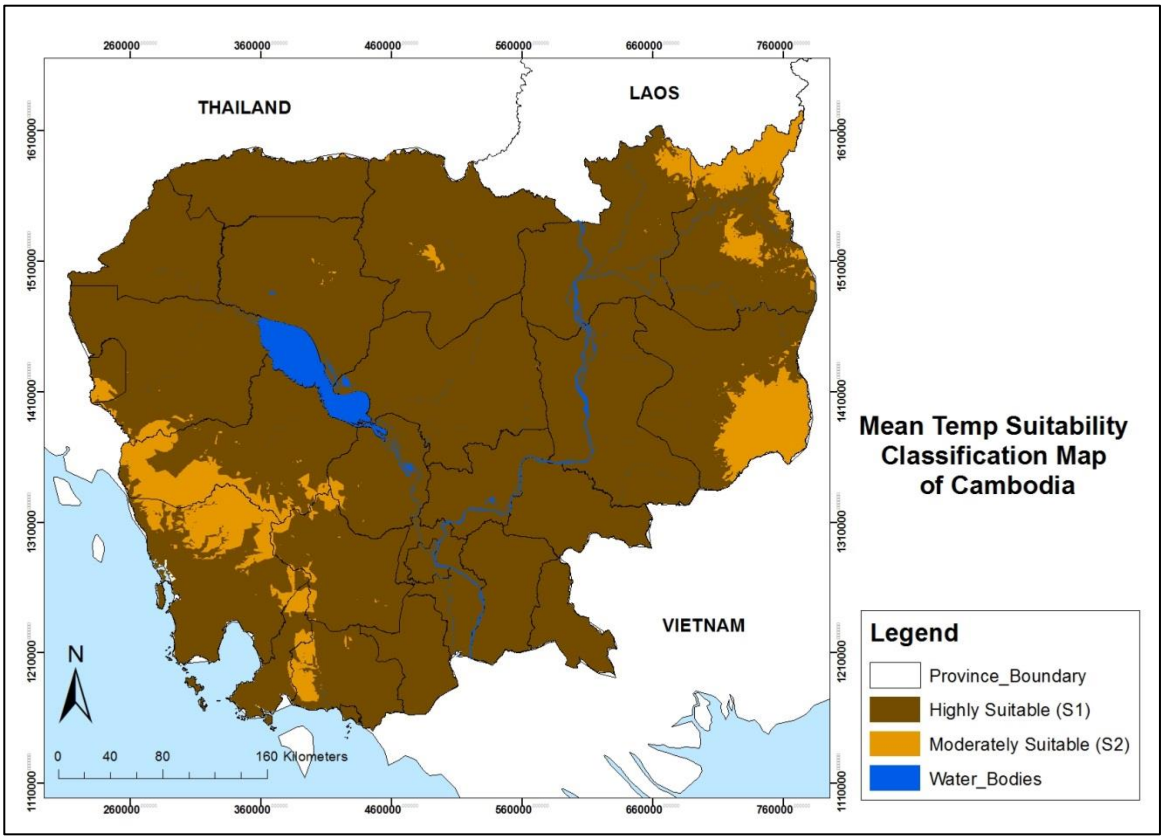


Figure 5.1 Mean temperature suitability classification map for cassava plantation

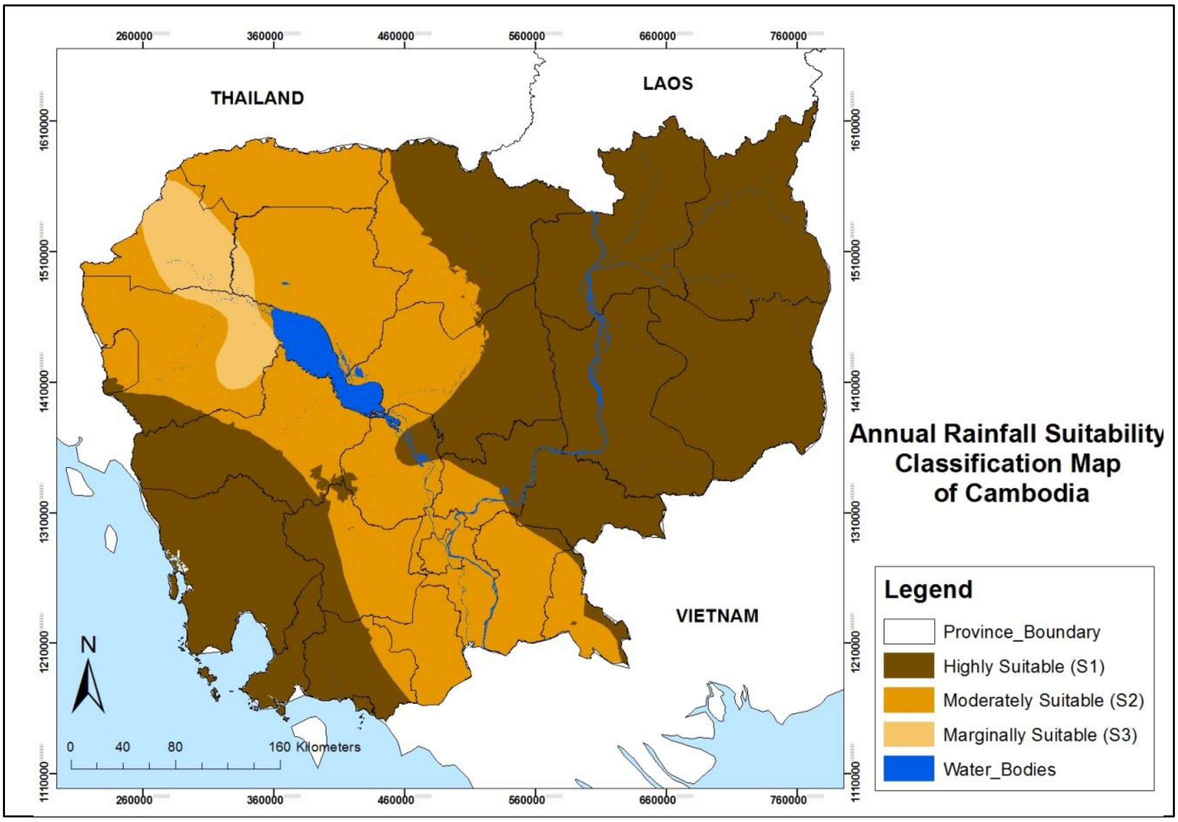


Figure 5.2 Annual rainfall suitability classification map for cassava plantation

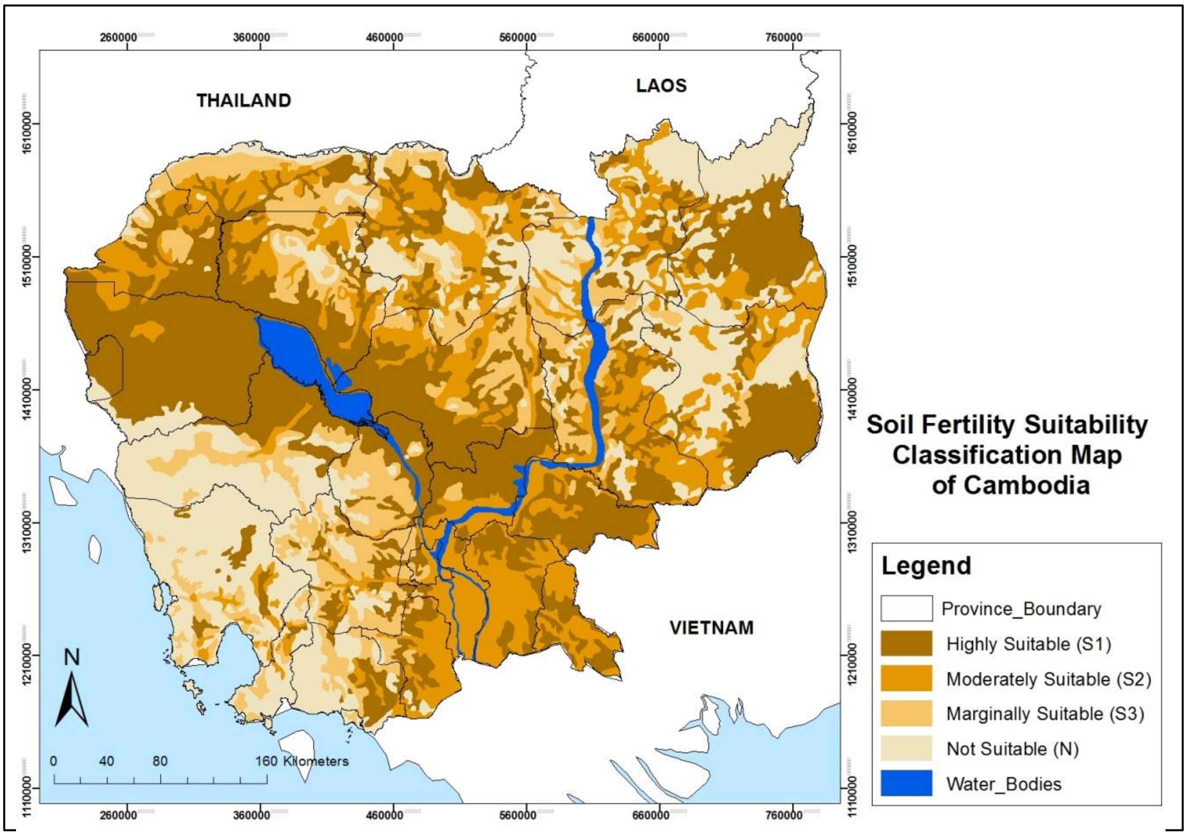


Figure 5.3 Soil fertility suitability classification map for cassava plantation

Figure 5.4 shows the soil drainage (oxygen availability to roots) suitability classification of Cambodia derived from world soil data base (HWSD) [58]. This figure shows the results of classification of drainage class followed FAO guideline which each class S1, S2, S3, and N ranged from very well/well, moderately well/somewhat well, somewhat poor, and very poor, respectively. The results represented 47.10%, 23.34%, 16.82%, and 10.82% of classes S1, S2, S3, and N, respectively. It indicated that class S3, and N was found under flooded land of Tonle Sab basin and Mekong delta where currently under paddy field, lake, and other flooded shrub which consider was not good for cassava plant. These areas normally got flooded in the rainy season especially in September, October, November, and December, respectively.

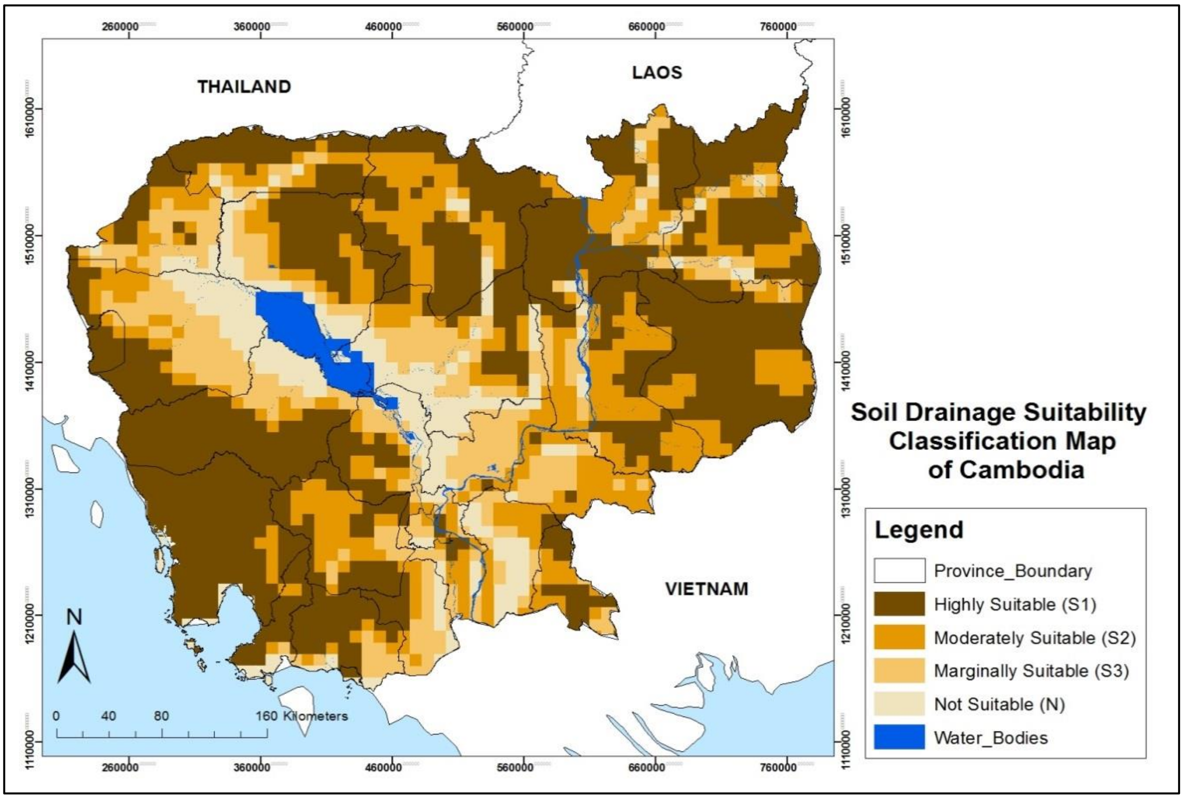


Figure 5.4 Soil drainage suitability classification map for cassava plantation

Figure 5.5 shows the soil depth (obstacle to root) suitability classification map of Cambodia derived from world soil data base (HWSD) [58]. This figure shows the results of classification of soil depth class followed FAO guidelines for which each classes S1, S2, S3, and N ranged the depth levels as >100cm, 50-100cm, 25-50cm, and <25cm, respectively. The results classification of S1, S2, S3, and N are presented of 67.88%, 12.96%, 16.66%, and 0.58%, respectively. The results stated that about 80% of the country area under S1 and S2, except mountainous areas where located in the South-West and North-East part found under class S3 and class N.

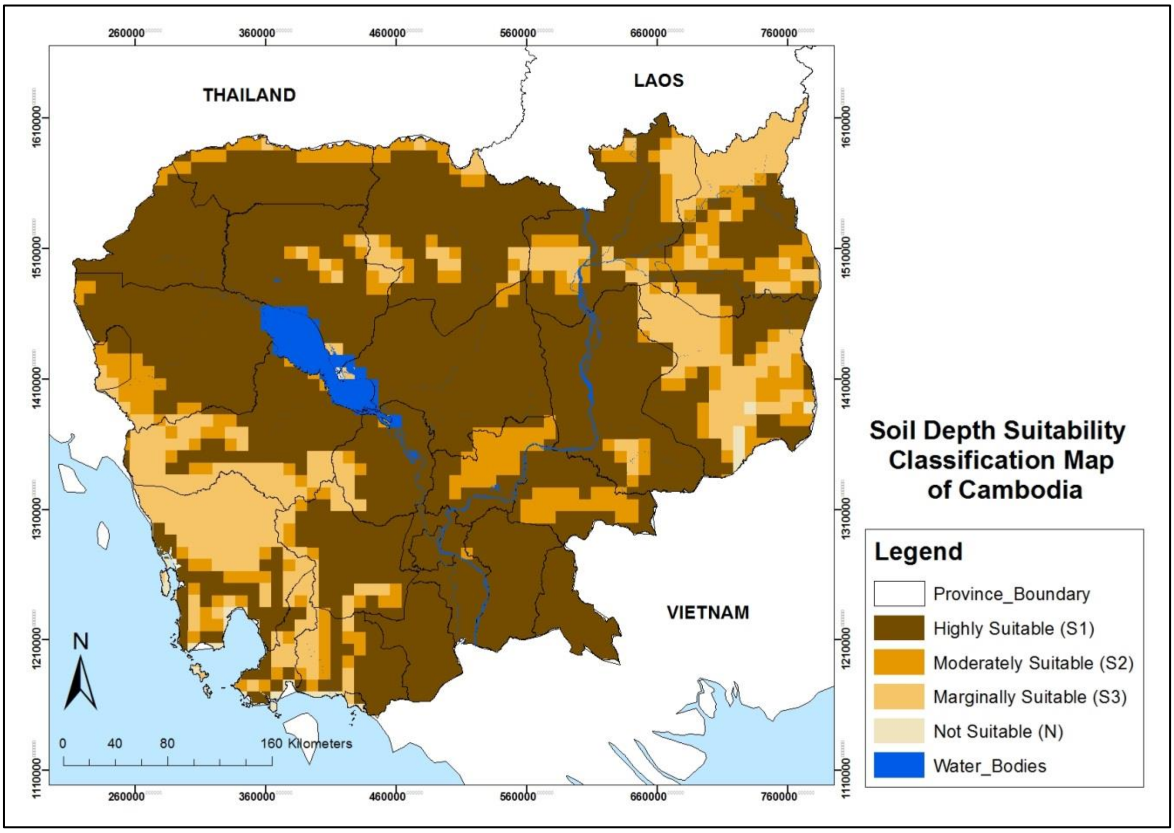


Figure 5.5 Soil depth suitability classification map for cassava plantation

Figure 5.6 shows about the slope suitability classification of Cambodia generated from a digital elevation model. It was released from the National Aeronautics and Space Administration (NASA) and Shuttle Radar Topographic Mission (SRTM) for over 80% of the world. This figure shows the results of slope classification follow FAO guideline in which each classes S1, S2, S3, and N ranged the slope classes from 0-5%, 5-12%, 12-20%, and >20%, respectively. The results indicated that the slope of Cambodia under each class S1, S2, S3, and N, represented 80.49%, 8.28%, 4.00%, and 4.86%, respectively. Thus, about 90% of Cambodia's physical landscape has good slope condition for cassava plantation (slope lower than 5%). Unsuitable class is mainly found in the mountainous areas in the South part and North-east part of Cambodia which identified as steep slope around major hill and mountains.

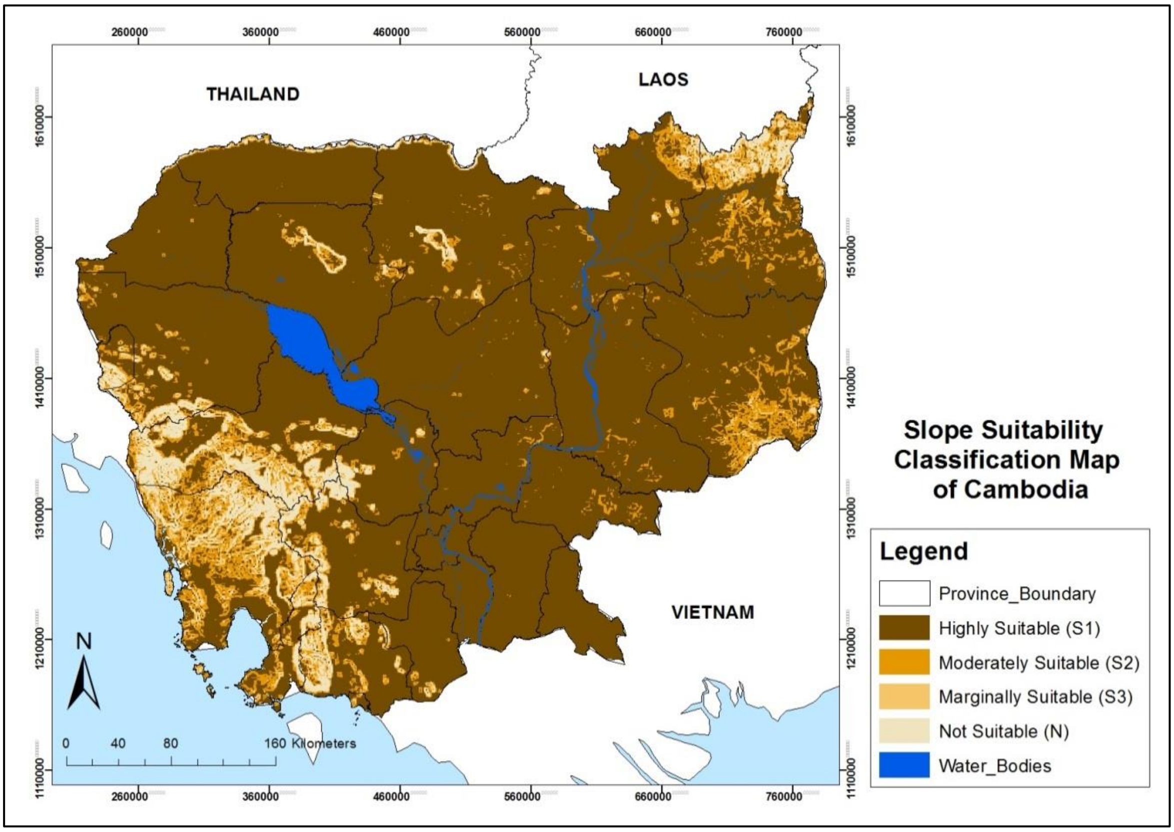


Figure 5.6 Slope suitability classification map for cassava plantation

5.1.1.2 Land Suitability Assessment

The suitable areas for cassava crops could ideally be relatively high productivity, maximizing the socio-economic benefits and the nature conservation under the current policy of the Government to control agricultural land expansion. In consequence, a cassava land suitability map (Fig. 5.8) was conducted from overlaying of each physical land suitability factor (Fig. 5.1, 5.2, 5.3, 5.4, 5.5, 5.6). These physical land suitability maps are not equally important in influencing the selection of potential sites. Therefore, it is necessary to assign appropriate weight to reflect their relative importance. Each factor's weight and score have different important according to export judgement. In this study, weight and score were given to six factors followed Phongaksorn (2012) [68] based on the AHP approach given and detailed in Appendix A.

Figure 5.7 shows about the weight of each factor based on AHP approach done by Phongaksorn, (2012) [68] (see Appendix A). This figure indicates that soil fertility (included soil texture, nutrient availability index) was the most important criteria that would provide high productivities within the soil of higher fertility; however, it will provide low yield on clay soil as well low soil fertility. Thus, soil fertility was rated between moderate to strong and strong important (4) more than annual rainfall as well as soil depth. The soil fertility was also rated as moderate importance (3) more than the soil drainage. Furthermore, it was also rated as very strong important (7) than annual mean temperature and slope factor. In addition, the soil drainage was considered as the second most important due to cassava crop needed to grow in well soil drainage for root decay protection. Moreover, soil depth was also generated as the next most important criteria because the depth of soil is respond to root seek nutrients. The last important factor was annual rainfall because there was not much difference in the annual rainfall in Cambodia 1,000–3,512 mm/year which can be considered suitable for cassava plantation. On the other hand, the weight of slope data and mean temperature was not significant factor. They are only considered the four and the fifth important factor, respectively, due to in Cambodia approximately 80% of Cambodia located highly suitable area (<5% slope) for cassava plantation, while mean temperature was given the lowest weights due to there was not difference in the mean temperature (18.2 – 28.9^{o}C) because through the country obtained only two classes namely highly suitable (S1) and moderately suitable (S2).

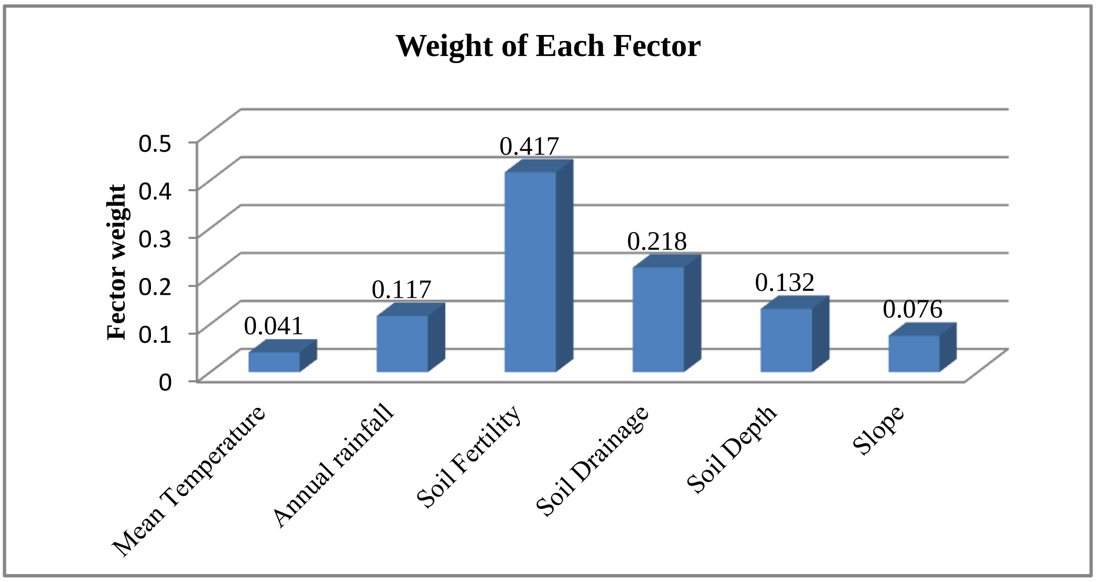


Figure 5.7 Factor weight of each factor based on AHP follow (Phongaksorn, 2012) [68]

Table 5.1 shows the results of land suitability map for cassava plantation that was identified by the overlay technique in ArcGIS 10.1. The map contains suitability score ranged from 0 to 1 which express a higher score present a higher suitability level. The map was reclassified into four suitability classes based on the structure of the FAO suitability classification index namely: the highly suitable (S1) (0.76–1.00), the moderately suitable (S2) (0.51–0.75), the marginally suitable (S3) (0.26–0.50), and not suitable (N) (0.00–0.25). This figure shows the results of land suitability classification for cassava plantation in which class S1, S2, S3, and N represent 50.65%, 29.39%, 11.71%, and 5.27%, respectively. Thus, most of the lands in Cambodia were considered suitable for cassava plantation because approximately 80% of the territory located under highly suitable (S1) and moderately suitable (S2) classification.

Table 5.1 Suitability area for cassava plantation in Cambodia

Suitability Class	**Suitability Index**	**Area (ha)**	**Proportion (%)**
Highly Suitable (S1)	0.76 – 1.00	9,200,307	50.65
Moderately Suitable (S2)	0.51 – 0.75	5,340,694	29.39
Marginally Suitable (S3)	0.26 – 0.50	2,126,978	11.71
Not Suitable (N)	0.00 – 0.25	957,078	5.27
Water Bodies		552,017	2.98
Total		**18,103,895**	**100.00**

Figure 5.8 shows the land suitability area for cassava plantation in Cambodia. This map represents the land suitability map of six layers. Therefore, this map shows where and to what extent the production of cassava would be suitable throughout Cambodia. On this basis, it can be concluded that the most of the land suitability area for cassava production is in the area of the Tonle Sap basin and upper and lower Mekong River. Here, one can find the largest contiguous area classified as highly suitable (50.65%). The highly suitable class (S1) mainly located in the Tonle Sap basin (under current paddy field) and Eastern and Western part of the upper and lower Mekong that are characterized by very rich soil fertility where under current agriculture land and upland area which mostly considered being abundant land and under forest cover. In similarity, the moderately suitable class (S2) (29.39%) are mainly characterized as potential for cassava cultivation which found on the moderate soil fertile characterized by ministry of agriculture, forestry and fishery (MAFF). These area found in Northern and Southern part of Cambodia where use under current upland crops and forestland. However, the marginally suitable class (S3) (11.71%) was found in the area with low sensitivity of low

fertile soil. These areas found in the mountainous area where mostly considered for forestland and other conservation areas. Because of those areas extremely shallow soil which will increased risk of cassava root condition. On the other hand, not suitable classification (N) (5.27%) has been found in steep slope (>20%) of the mountainous area, especially found on the acid lithosole where this soil type was not recommended for crop land. In these regions, the terrain elevates over the upper maximum of cassava growth and as a consequence, the transition from marginally suitable to not suitable area is recognizable. The effect of slope is also visible. In the north-east and south-west of Cambodia, there is a steep slope assessed as not useable for agriculture, especially for cassava cultivation.

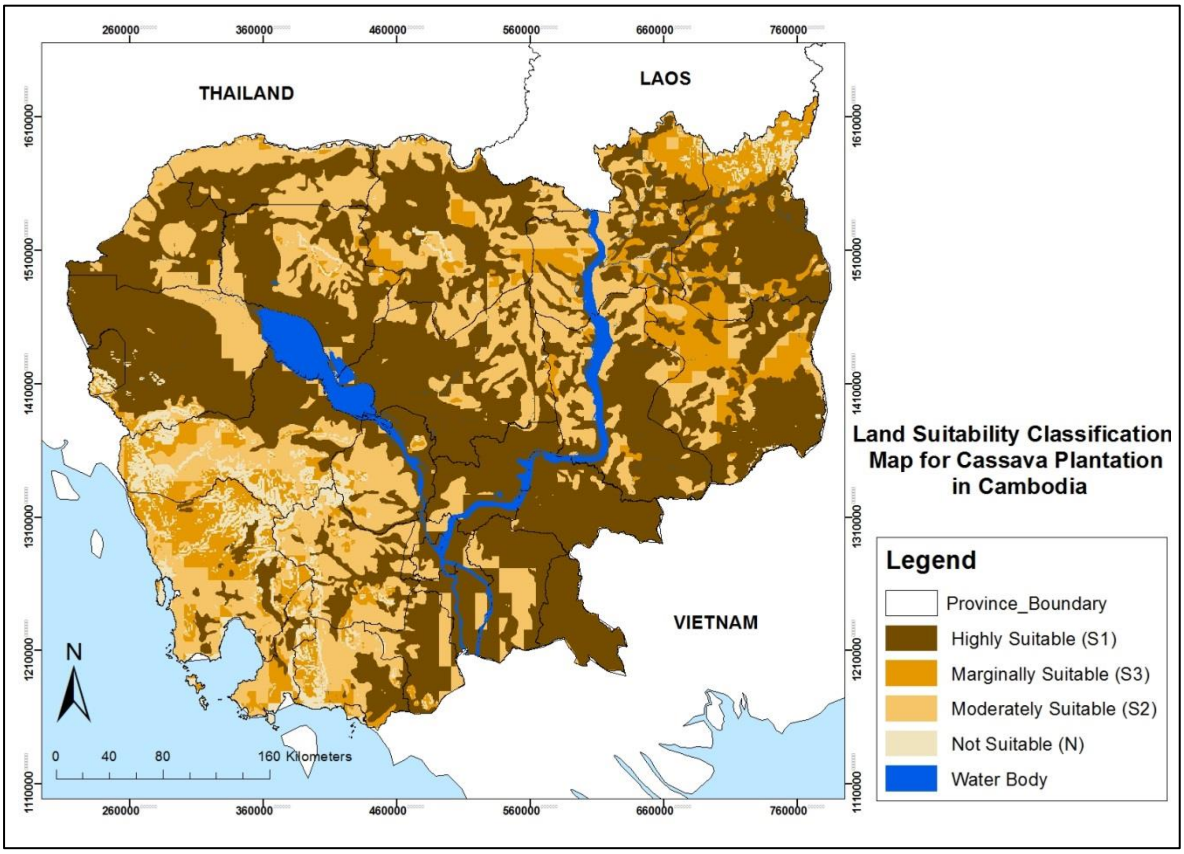


Figure 5.8 Land suitability map for cassava plantation

The final suitability map shows land suitability area for cassava plantation in Cambodia. It can be expected that the yield in highly suitable (S1) areas is higher than in marginally suitable (S3). There are some other limitations in the present suitability approach and in the resulting suitability map. The map is representing the suitability based on six variables. Therefore, using this map for cassava cultivation area predictions is risky. Hence, it would be favorable to estimate the cassava suitability area based on the actual location and current yield of each location in Cambodia in order to minimize the risk of an error due to non-representative of some important map such as soil texture or nutrient status data, terrain, etc.

5.1.2 Estimated Suitable Area for Cassava Plantation

5.1.2.1 Estimation of Forestland Change from 2002 to 2014 Scenario

Due to insufficient data or information, current official land use land cover map has not been published for analysis. The state data of crop statistic 2013 was used to quantify the change in agricultural land during 2002 to 2013. Additionally, 2002 LULC map (Fig. 2.5) and 2014 forest cover map (Fig. 2.6) are the most recently available data which set as the based map to document the change of forestland over 2002 - 2014. Figure 5.9 shows the land use categories of the overlaying between 2002 LULC map (Fig. 2.5) and 2014 forest cover map (Fig. 2.6). This map was categorized into 10 main LULC classes namely: forestland, paddy field, upland crops, converted area, existing cassava area, grass land, shrubland, urban and built-up lands, barren land and rocks, and water bodies. The area coverage of each LULC class is reported in Table 5.2.

Table 5.2 Area of each land use category in updated LULC map of Cambodia

Land Use Category	Area (ha)	Proportion (%)
Forest cover	8,659,112	47.69
Paddy field	3,052,420	16.81
Upland crops	690,922	3.80
Converted land	1,767,239	9.73
Existing cassava area	421,375	2.32
Grassland	1,078,249	5.94
Shrubland	1,883,692	10.37
Barren and rocks	36,840	0.20
Urban build-up area	18,068	0.10
Water bodies	552,017	2.98
Total	**18,103,895**	**100.00**

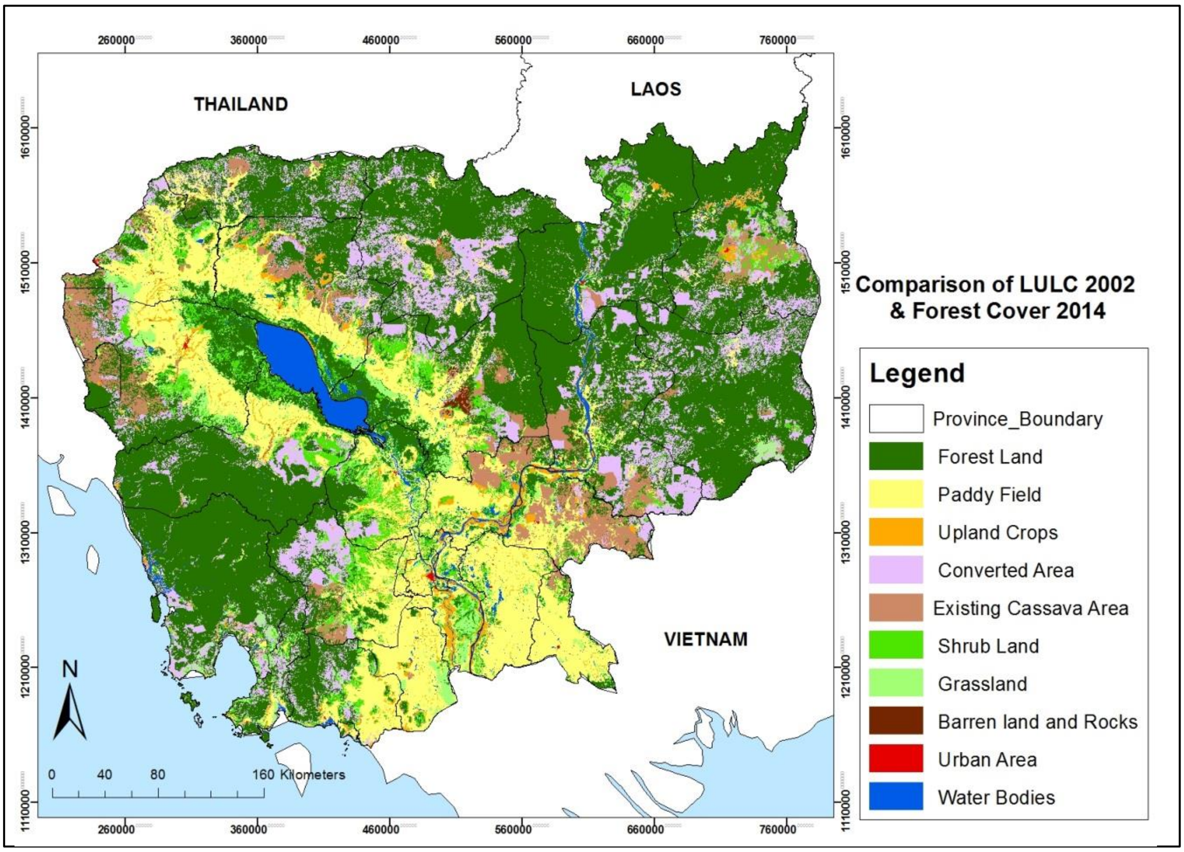


Figure 5.9 Updated LULC map of Cambodia using 2002 LULC map and 2014 forest cover map

Table 5.2 shows the logical gap filling data of 2002 LULC map, 2014 forest cover map, and state data of agriculture statistic 2013. Due to the insufficient of information or data of current land use, which is why combinations of difference data sources were needed for the determination of land use change within the period of 2002 – 2013. The area of current paddy field, upland crops, and cassava area were based on current agriculture report 2013 represented 16.81%, 3.80%, and 2.32%, respectively (see Appendix D.3). Simultaneously, the current grassland, shrublands, urban areas, and barren land were assumed as the data in 2002 LULC map (Table 5.2) which represented approximately 5.94%, 10.97%, 0.10%, and 0.20%, respectively. This assumption was made due to insufficient data which related to the change of these areas.

Based on LULC (2002) [26], the agricultural land presented about 24.04% corresponding to 4.3 Mha (Table 2.2). However, based on state data of MAFF report 2013, the agricultural land was approximately 4.51 Mha (24.9%) (including rubber plantation), (Table 2.3). Therefore, from 2002 to 2013, agriculture land was not significantly changed (increased from 24.04% to 24.9%) while in the same period the forestland have lost from 56.65% to 47.68%, respectively. According to 2014 forest cover map [27], the forestland remain approximately 47.68% (corresponding to 8.65 Mha) while non-forestland approximately 8.78 Mha accounted of unused land, paddy field, upland crops, current cassava production area, barren land, urban built up, etc., were documented approximately 48.64%. Therefore, from 2002 to 2013, approximately 9% of forestland has vast area declined within this period which was considered as the additional potential land for cassava production. Hence, a gap filling data are needed to analyze the area where have change and available for cassava plantation.

Table 5.3 and Figure 5.10 show some important issues related to the change in forestland to unused land (currently unused land) during 2002 to 2014. These changing areas could be served as the additional potentially for future cassava cultivation due to within this period the agriculture land was not increased significantly. In this investigate, the abundant land refer to the land where currently unused for any agriculture purpose after converted from forestland. This converted land (currently unused) was analyzed by 2002 LULC map (Fig. 2.5) overlaid with forest cover 2014 (Fig. 2.6). The changing area mostly located in Preah Vihear, Kraities, Stung Treng, Ratanakiri, Mondulkiri, and Kampong Speu provicce. As the analysis reveal, approximately 1.7 Mha of the abundant land would be available for additional to cassava growing area. In consequence, within this land, approximately 0.83 Mha of the abundant land were found under highly suitable class (S1) followed by 0.61 Mha found under moderately suitable class (S2) whereas approximately 0.3 Mha were found under marginally suitable (S3) and not suitable (N) where considered as not suitable for allocated to cassava plantation area.

Forestry Administrative (FA) [63] reported that the forest cover had declined mostly in the north-west part of the country including Battambong, Oddar Meanchey, Siem Reap, and Banteay Meanchey provinces while in the North-East part of the country occurred in Rattanakiri, Steng Treng, Kratie, Kompong Thom, and Preah Vihear provinces due to many different driving forces of decreasing such as the results of rapidly of expanding demand for agricultural lands and timber in combination with infrastructure development, land encroachment, illegal logging, development projects, fuelwood consumption and poverty specifically the conversion of forestland to Economic land Concessions (ELCs) [2] (see Appendix C.2). In addition, according to JDI (2012) [4], for instance, they stated that over 1 Mha (6% of Cambodia's land area) has been granted as economic land concessions in forested areas and former forest concessions land.

Table 5.3 Classification of suitable areas with forest change to non-forestland between 2002 and 2014

Land Use Category	Highly Suitable (S1)		Moderately Suitable (S2)		Marginally Suitable (S3)		Not Suitable (N)	
	ha	%	ha	%	ha	%	ha	%
Forestland	3,408,546	37.05	2,634,020	49.32	1,709,230	80.36	831,628	86.89
Forest Change to Non-Forestland	835,523	9.08	614,698	11.51	165,078	7.76	82,877	8.66
Other Land*	4,956,237	53.87	1,848,545	34.61	252,670	11.88	43,115	4.50
Water Bodies	-	-	243,431	4.56	-	-	-	-
Total	**9,200,307**	**100.00**	**5,340,694**	**100.00**	**2,126,978**	**100.00**	**957,078**	**100.00**

Note: * Other land: including agriculture land, urban area, barren land, shrubland, and grassland

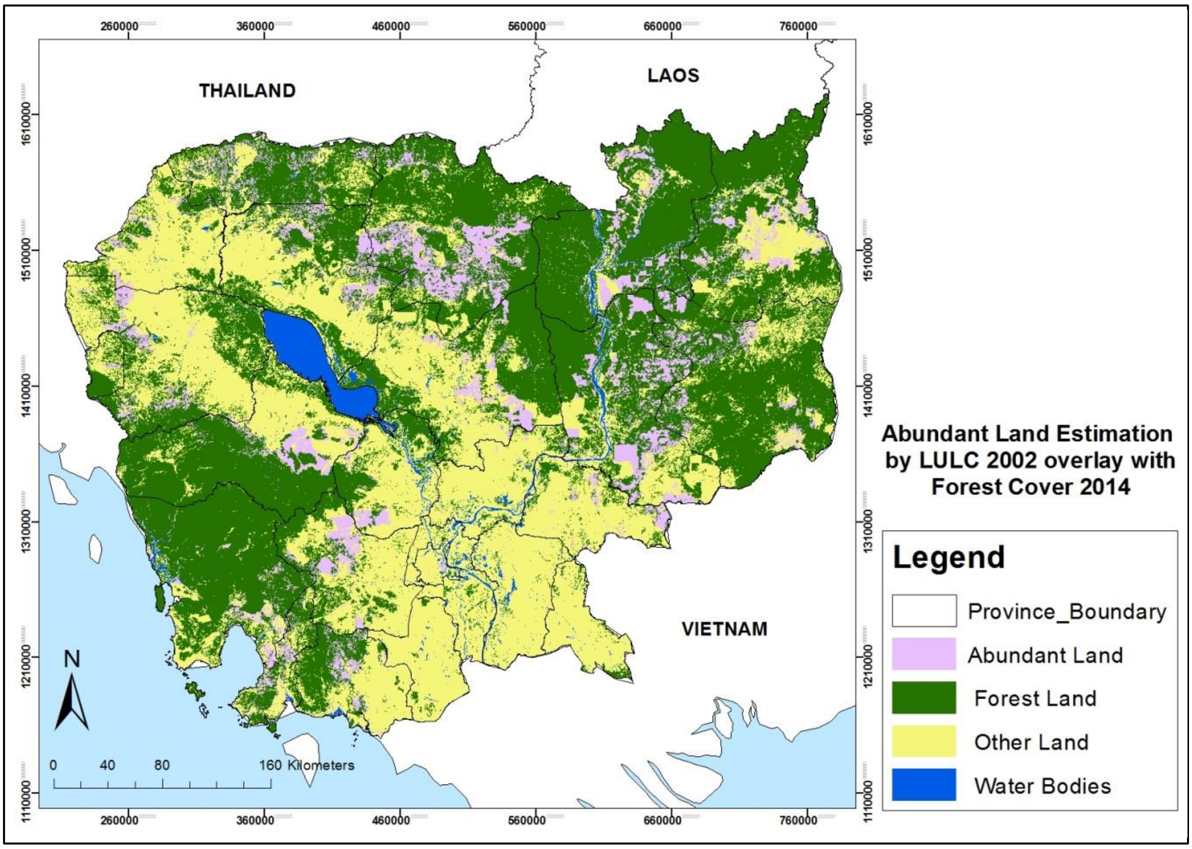


Figure 5.10 Forestland changed to non-forest area map from 2002 to 2014

5.1.2.2 Suitability Classification Map for Cassava Plantation in Cambodia

In additional analysis, the possible suitability classification map was performed by overplaying the suitability map (Fig. 5.8), the updated LULC map (Fig. 5.9), province boundary map, and restricted areas (conservation areas, protected forests, and flooded areas) (Fig. 4.3). This analysis was assessed to find the suitability area for cassava plantation throughout the country where taken into account of converted land (abundant land) (1.76 Mha), current cassava plantation (0.42 Mha), and upland crops (0.69 Mha included corn, yam, vegetable, peanut, mung bean, soy bean, sesame, and sugarcane), which summarized in Table 5.5 (see Appendix B.2).

Figure 5.11 and Table 5.4 show the results of suitable area classification of Cambodia for cassava plantation through the current cassava existing area, upland crops, and other abundant land based on national non-forest area of 2014 forest cover map, 2002 LULC map, and annual agriculture report 2013 (see Appendix D.3). This analysis obtained that within total land area, approximately 9.64% (corresponding to 1.7 Mha) were found under highly suitable (S1) which located mostly in Kampong Cham, Battambang, Kraties, Ratanakiri, Preah Vihear, Kampong Thom, and Siem Reap provinces, followed by approximately 5.01% (corresponding to 0.9 Mha) were found under moderately suitable (S2) which found in following provinces such as Kratie, Preah Vihear, and Siem Reap province, etc. However, approximately 1.11% was found under marginally suitable (S3) and approximately 0.65% was also found under not suitable (N) which both two classes were considered as not suitable for cassava plantation in this study.

On the other hand, considering current existing cassava area versus suitable map, it was obtained that approximately 75.66% of current production area were found under highly suitable (S1), followed by approximately 20.97% found under moderately suitable (S2), whereas approximately 2.51% of the current plantation area found under marginally suitable (S3). Furthermore, approximately 0.87% found under not suitable area (N) where these two classes provided low yield in term of production and high risk in term of investment (Table 5.4).

According to the MAFF report (2013) [10], the current cassava productions area were found plenty cultivation with provide high yields in Pailin, Kampong Cham, Battambang, Banteay Meanchey, Kratie, and Kampong Thom provinces accounts about 74% of the total production (Table 2.4). Therefore, considering on the current plantation area, other upland crops, and abundant land, it reveals that the present cassava growing area are still limited compare to the suitable area (2.66 Mha of S1 and S2) found in analysis (Table 5.4). Thus, it is still highly possible to replace or expanding growing area of cassava by converting the existing agriculture areas and other abundant land which being used for other crops/trees to cultivate this energy crops instead or planting to where it is newly converted found under the classes of S1 and S2 (Fig. 5.11).

Table 5.4 Proportion of suitability classification area and possible cassava production

Suitability Class	**Suitable Area**		**Existing Cassava Area**	
	Area (ha)	Proportion* (%)	Area (ha)	Proportion** (%)
Highly Suitable (S1)	1,751,621	9.64	318,796	75.66
Moderately Suitable (S2)	909,234	5.01	88,352	20.97
Marginally Suitable (S3)	201,492	1.11	10,571	2.51
Not Suitable (N)	118,564	0.65	3,657	0.87
Total	**2,980,911**	**16.41**	**421,375**	**100.00**

Note: * Share calculated from the total area of Cambodia.

** Share referring to the current total cassava production area.

Cambodia could potentially become a bioethanol exporter in future if the huge of abundant land were used for growing cassava. Recently, foreign investment to cassava cultivation to produce bioethanol has increased since it was known as promising crop for bioethanol production; thus, Cambodian government should play an important role to work hand-in-hand with the private sector to strengthen this energy crop to meet the needs as substitute of gasoline with bioethanol production as planned and exported. Moreover, the clear policy of bioethanol production and clear future target of bioethanol demand and land use planning for agriculture land could also been set to secure crop production especially cassava feedstock in order to attract more foreign investment in the cultivation of cassava to produce bioethanol.

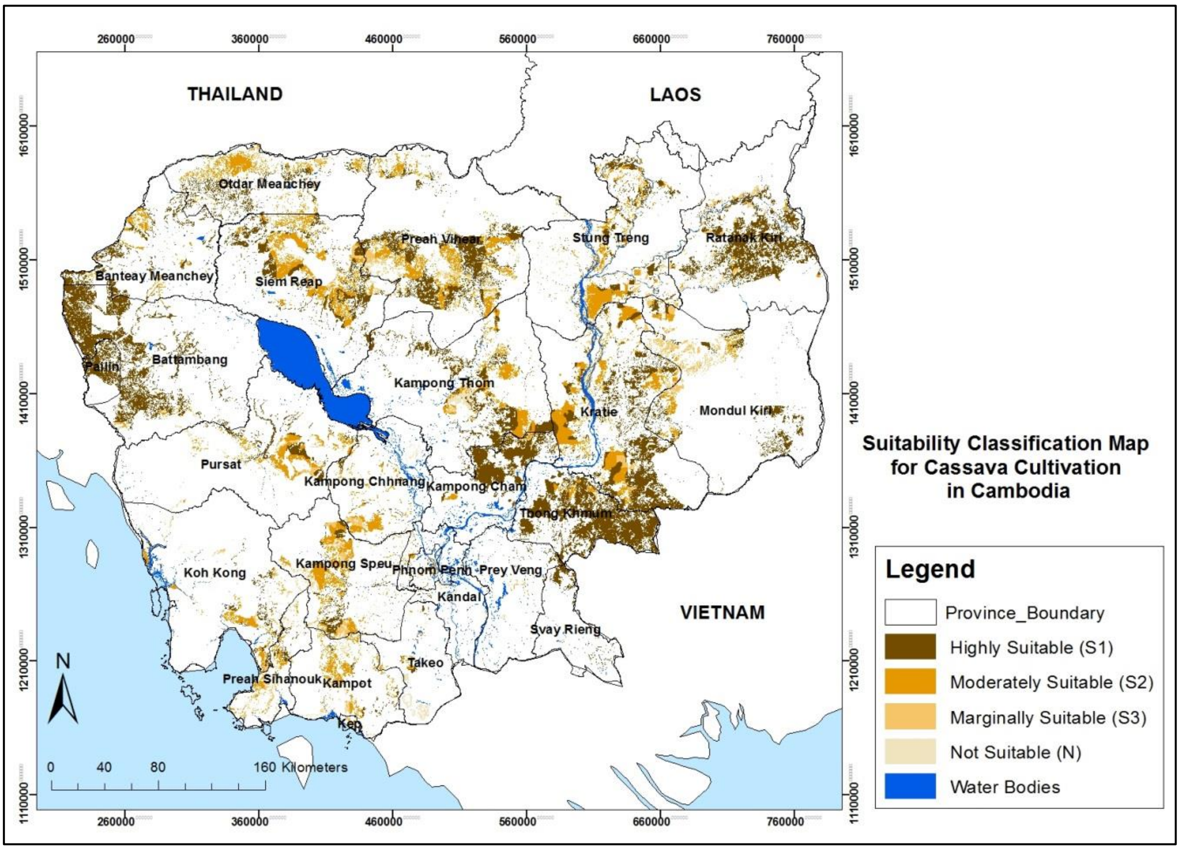


Figure 5.11 Suitability classification map for cassava plantation by province

5.1.3 Full Capacity of Cambodia to Produce Bioethanol

Until now, the Cambodian government has not established any policies or initiatives for the development of energy feedstock for bioethanol production yet. The clear policies of the government related to the land use planning for energy crops are very important to secure energy feedstock in the country. Meanwhile, the Royal Cambodian Government (RGC) is planning to attract more foreign investment in the cultivation of cassava to produce bioethanol. Recently, foreign investment to cassava cultivation to produce bioethanol has increased. Therefore, Cambodia has the potential to become a bioethanol exporter in future if the huge of unused land was used for the growing cassava to produce bioethanol.

Table 5.5 shows maximum cassava and bioethanol production estimation through the suitable area (S1 and S2). The results indicated that the possible areas for cassava plantation were approximately 2.66 Mha throughout the country (estimated on current cassava area, upland crop, and abundant land) with the yield estimation of approximately 51 million tonnes per year (based on each province cassava yield). In addition, with this production, approximately 8,502 million liter of ethanol production was estimated through the fermented all the cassava production (51 million tonnes). With assumption of 5 million tonnes of fresh root used for export and local consumption as in 2011; thus, approximately 46 million tonnes of fresh root potentially to be fermented to ethanol production of approximately 7,668 million liters per year corresponding to 6,038 ktoe (1toe = 1270 liters) of ethanol production per year.

Table 5.5 Full capacity of Cambodia to produce cassava and ethanol

Suitable Classes	Area (ha)*	Production (million tonnes/year)**	Possible Ethanol (million liters/year)***
Highly Suitable (S1)	1,751,621	34.63	5,771
Moderately Suitable (S2)	909,234	16.38	2,730
Total	**2,660,855**	**51.01**	**8,502**

Note: ***** The median from Table 5.4

** The production was calculate based on each province average cassava yield (Fig. 2.9)

******* 6.6 kg of cassava fresh roots can be fermented to 1 liter ethanol [4]

5.1.4 Current Capacity of Cambodia to Produce Bioethanol

According to national report [8], Cambodia Trade Integration Strategy (CTIS) 2014-2018, the higher prices in the world market have urged Cambodian farmers to shift other crops by growing more cassava instead. As the production increased, more cassava exports were also raised in the form of fresh tubers or dried chips while most of the processing taking places in abroad. In 2011, the formal exports have accounted about 93,500 tonnes of dried chips and 16,720 tonnes of starch (correspond to 314,006 tonnes of fresh root equivalents). According to the United Nations Development Program (UNDP) [8], most of informal exports are fresh tubers that could have generated about 161 million US dollars in 2010 which corresponded to approximately 3.8 million tonnes of fresh roots equivalent. However, the total cassava starch processing capacity in Cambodia was estimated around 920,000 tonnes (fresh root equivalent) per year which the total cassava production exceeded 7.9 million tonnes. It is estimated that approximately 20% to 30% of cassava starch produced in Cambodia is consumed domestically, especially for animal feed which accounted for approximately 276,000 tonnes of fresh root equivalent (see Appendix D.2). Due to there is no official report mentioned about the remaining production, approximately 3.6 million tonnes of cassava (fresh root equivalent) (45%) was estimated by subtract the total production subtract by all consumption (exports and local consumptions). Therefore, these productions were assumed to be the potential production to produce ethanol.

Table 5.6 shows the production of cassava feedstock that was exported and utilized in 2011. Based on export data in 2011, approximately 55% of the production have been exported and utilized in Cambodia. However, approximately 45% of the production was not been recorded as it was used either for local consumption or export. This production was assumed as the current potential production to produce bioethanol. With assumption of the utilization of both export and consumption are constant as in 2011, 55% of exports and consumptions and 45% of the production were remaining, therefore, approximately 3.6 million tonnes (Table 5-6) of fresh roots can be fermented to ethanol.

Table 5.6 Cassava production and utilization in 2011

Cassava Utilization	Fresh root (ton)	Proportion (%)
Total Export	4,102,241	51.06
Total Local Consumption	276,000	3.44
Cassava Remain*	3,655,602	45.50
Cassava Production	**8,033,843**	**100.00**

Note: * No record of cassava remaining has been found. It was calculated by total production subtracting total exports and consumptions data in 2011.

ERIA Research Project Report [11] puts the estimation that a possible production capacity of ethanol from cassava would be about 1,324.3 ktoe per year in 2011. In 2035, the supply potential of ethanol was estimated to be 2533.5 ktoe per year (corresponding to approximately 1 Mha of cassava plantation) (Fig. 2.5). However, the consumption of gasoline fuel demand for road transportations will be 388 ktoe per year in 2035. It is assumed that 5% of the country’s liquid fuel demand will be substituted by biofuels in 2035 [11]. If the target were reached, Cambodia is expected to see an annual demand of

24.6 million liters (correspond 19.4 ktoe) of ethanol in 2035 (Fig. 2.5). Therefore, based on current 45% of cassava feedstock remaining (Table 5.7), the possible ethanol productions were estimated to reach 545 million liters (6.6 kg of fresh root can be fermented to 1 liter of ethanol) which corresponds to 429 ktoe (1toe = 1270 liters) that totally enough for the demand projection. Hence, under this assumption, the potential production of approximately 520 million liters of ethanol will be the supply potential to export to the world market.

ERIA Research Project Report [11] also reported that Thailand's export of ethanol was about 139 million liters while the total production was 402.2 million liter in 2011. Simultaneously, it could be seen that the current ethanol production of 520 million liters that Cambodia could produce (produced from the 3.6 million tonnes of cassava fresh root) can potentially be exported to the global market, which is higher than Thailand's export in 2011. However, this production is still limited if compare to the supply potential production where projected to be 2533.5 ktoe per year by ERIA in 2035.

5.2 Future Possible Cassava Feedstock Potential for Bioethanol Production (Task 2)

5.2.1 Classification of Future Possible Expansion Area at Provincial Level

Table 5.7 shows the estimation of the unused land (currently abundant or unused) of each province (forestland changed to non-forestland) which considered as the potential areas for future possible cassava expansion area. This potential area was estimated based on non-forest area (2014 forest cover map) subtract all land use category such as paddy field, current cassava plantation, other upland crops, grassland, shrubland, barren lands, and urban area (Table 5.7). Due to the insufficient data for analysis; therefore, the state data of crop statistic 2013 were used as the actual reference data of paddy field, upland crops, and current cassava land of each province while the area of grassland, shrublands, urban areas, and barren land and rocks where assumed as in 2002 LULC map. From the analysis of forestland change during 2002-2014 (see Section 5.1.2.1), the results indicated that from 2002 to 2014, the current increasing of cassava plantation area was located in the upland crop (shifting cultivation between cassava and other crop such as corn, soybean, mung bean, seas am, etc.) whereas the converted area (approximately 1.7 Mha) could serve as potential additional area for the future cassava plantation.

Table 5.7 The combination data of 2002 LULC, 2014 forest cover, and MAFF 2013 report

Provinces Name	Total Area (ha)	Forest Cover (ha)	Non-Forest (ha)	Current Cassava (ha)	Current Rice Area (ha)	Upland Crops (ha)*	Other Land (ha)**	Unused Land by Province (ha)***
B. Meanchey	610,424	132,706	477,718	55,666	243,030	13,759	134,673	30,390
Battambang	1,180,412	425,980	754,432	61,695	307,575	289,860	20,579	74,722
K. Cham	912,877	124,356	788,521	67,625	221,388	98,598	394,086	41,027
K. Chhnang	507,472	160,810	346,662	1,737	156,217	13,296	141,425	33,987
K. Spue	694,448	206,540	487,908	3,402	116,274	4,647	285,065	78,519
K. Thom	1,222,604	543,935	678,669	36,725	256,731	6,828	285,301	93,085
Kampot	467,035	176,491	290,545	816	144,810	6,053	89,044	49,822
Kandal	294,634	24,010	270,624	27	106,168	52,745	111,391	293
Kep	13,983	3,178	10,805	100	3,550	984	5,226	944
Koh Kong	1,082,428	866,796	215,632	334	10,374	280	149,144	55,500
Kraties	1,165,199	612,468	552,732	46,810	46,976	13,708	206,822	238,416
Mondul kiri	1,363,297	983,886	379,411	10,271	22,920	9,438	220,191	116,991
Ot. Meanchey	660,947	415,021	245,926	25,125	65,305	4,749	60,311	90,437
Pailin	107,477	57,098	50,379	25648	8,159	65,986	-	3,345
Phnom Penh	60,959	3,168	57,791	72	13,591	1,371	39,726	3,031
P. Sihanuk	248,499	131,525	116,973	470	16,483	443	62,399	37,178
Preah Vihear	1,400,267	910,752	489,515	12,650	77,697	49,624	52,199	298,346
Prey Veng	453,643	14,251	439,391	1,969	372,095	6,504	57,142	1,782
Pursat	1,151,198	733,845	417,353	6,583	120,746	19,522	186,293	84,290
Ratanak Kiri	1,168,899	743,488	425,411	13,590	27,172	5,520	262,977	116,153
Siem Reap	1,042,564	398,839	643,725	11,510	202,285	9,735	308,480	111,775
Stung Treng	1,171,052	953,836	217,216	19,622	27,805	8,488	23,924	173,378
Svay Rieng	283,435	22,174	261,261	17,597	186,971	3,511	52,434	748
Takeo	344,155	13,959	330,196	1,331	298,098	5,273	24,034	1,460
Total	**17,607,908**	**8,659,112**	**8,948,796**	**421,375**	**3,052,420**	**690,922**	**3,172,865**	**1,735,177**

Note: * Upland crop includes corn, yam, vegetable, peanut, mung bean, soy bean, sesame, and sugarcane [10]

** Other land includes urban land, barren land and rocks, grassland, and shrubland of each province based on 2002 LULC map.

*** Unused land by province was estimated by non-forest area (2014) subtracting current crop lands (crop statistic 2013 of each province), grassland, shrubland, barren land, and urban lands area of each province based on 2002 LULC map

Figure 5.12, Figure 5.13, and Table 5.8 show the results of potential suitable areas in each province for future expansion of cassava production. These results concerned only two classes namely: highly suitable (S1) and moderately suitable (S2) where it provided high yield at each locations. However, for class S3 (marginally suitable) and class N (not suitable), these two classes were not considered for cassava plantation due to in term of providing low yield, and economic conditions or investment cost. The results indicated that within 1.7 Mha of abundant land, approximately 0.83 Mha was found under the highly suitable areas (S1) where mostly located in the proportion of Preah Vihear, Kratie, Stung Treng, Ratanakiri, and Mondulkiri, represented 19.42%, 16.58%, 11.59%, 8.30%, 6.94%, and 6.14%, respectively. In addition, approximately 0.61 Mha was found under moderately suitable (S2) where mostly in Preah Vihear, Kratie, Stung Treng, and Siem Reap represented about 17.36%, 13.04%, 10.16%, and 9.04%, respectively (Table 5.8). Both two classes S1 and S2 represent about 1.45 Mha while marginally suitable class (S3) and not suitable class (N) shared in small proportion of each province (see Appendix D.5).

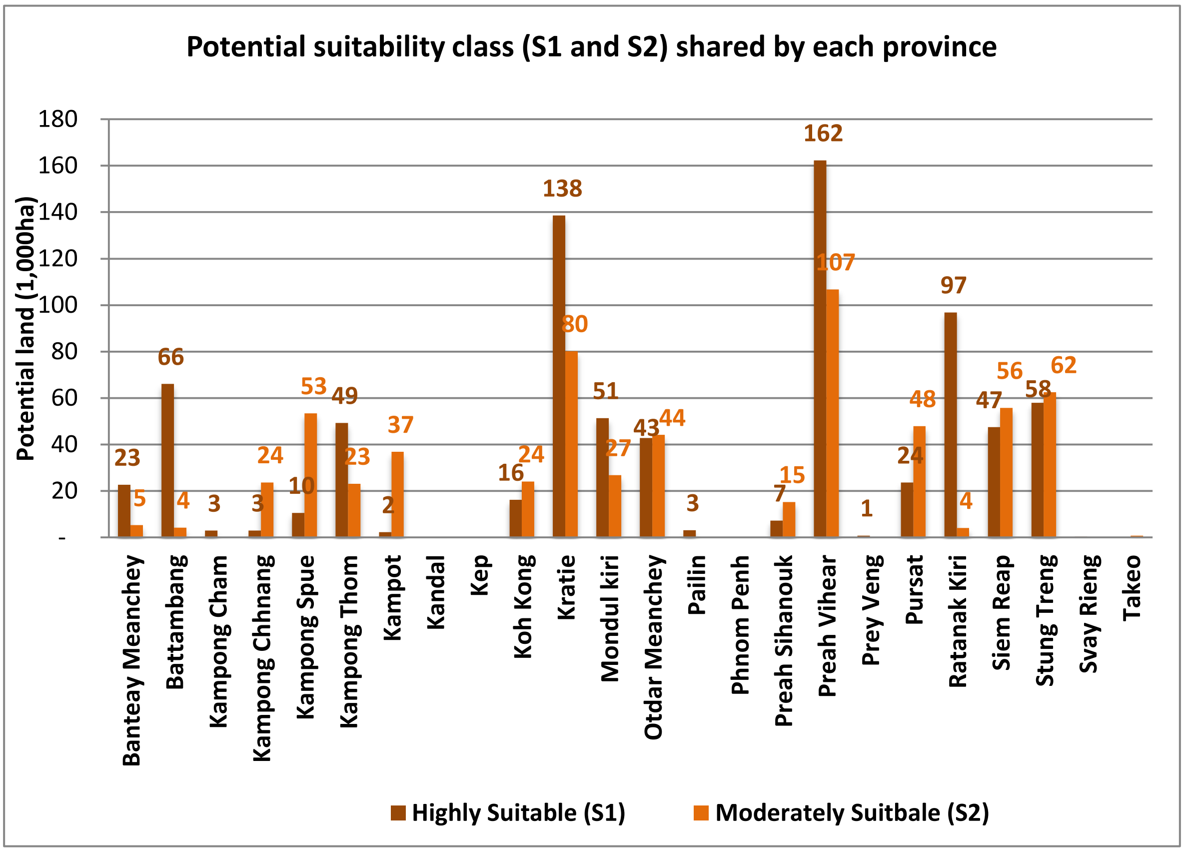


Figure 5.12 Potential area of each province within two suitability classifications S1 and S2

Table 5.8 Land suitability classification potential for future expansion at provincial level

Provinces Name	Highly Suitable (S1)		Moderately Suitable (S2)		Marginally Suitable (S3)		Not Suitable (N)	
	ha	%	ha	%	ha	%	ha	%
Banteay Meanchey	22,616	2.71	5,208	0.85	13	0.01	2,753	3.32
Battambang	66,030	7.90	4,203	0.68	1,509	0.91	2,980	3.60
Kampong Cham	2,847	0.34	199	0.03	-	0.00	3,778	4.56
Kampong Chhnang	2,937	0.35	23,652	3.85	5,462	3.31	1,936	2.34
Kampong Spue	10,498	1.26	53,396	8.69	8,480	5.14	6,145	7.42
Kampong Thom	49,208	5.89	23,060	3.75	567	0.34	20,249	24.43
Kampot	2,178	0.26	36,774	5.98	5,054	3.06	5,816	7.02
Kandal	-	-	7	-	-	-	286	0.35
Kep	-	-	84	0.01	165	0.10	696	0.84
Koh Kong	16,181	1.94	24,029	3.91	10,303	6.24	4,987	6.02
Kratie	138,496	16.58	80,147	13.04	14,113	8.55	5,660	6.83
Mondul kiri	51,291	6.14	26,730	4.35	38,293	23.20	276	0.33
Otdar Meanchey	42,741	5.12	44,091	7.17	2,321	1.41	1,283	1.55
Pailin	3,045	0.36	-	-	-	-	300	0.36
Phnom Penh	-	-	29	-	-	-	3,002	3.62
Preah Sihanouk	7,230	0.87	15,156	2.47	8,966	5.43	5,826	7.03
Preah Vihear	162,285	19.42	106,710	17.36	24,975	15.13	3,376	4.07
Prey Veng	762	0.09	-	-	-	-	919	1.11
Pursat	23,529	2.82	47,829	7.78	8,148	4.94	4,702	5.67
Ratanak Kiri	96,814	11.59	4,023	0.65	13,635	8.26	1,680	2.03
Siem Reap	47,394	5.67	55,640	9.05	7,821	4.74	860	1.04
Stung Treng	57,970	6.94	62,454	10.16	14,949	9.06	2,005	2.42
Svay Rieng	320	0.04	3	-	-	-	425	0.51
Takeo	-	-	725	0.12	118	0.07	617	0.74
Tbong Khmum	31,149	3.73	548	0.09	186	0.11	2,319	2.80
Total	**835,523**	**100.00**	**614,698**	**100.00**	**165,078**	**100.00**	**82,877**	**100.00**

Several provinces such as Kratie, Preah Vihear, Stung Treng, Mondorukiri and Ratanakiri were designated as the 4th Economic Development Zone (EDZ) by the government for a further development regions priority in the agricultural sector [2]. These provinces have large scale potential area (Table 5.8, Fig. 5.12) where the effective of available land could be considered for cassava plantation. Based on the Japan

Development Institute (JDI) [4], it was estimated that nearly 1 Mha of both side of Upper Mekong River, Kratie, and Stung Treng Provinces have a great potential of abundant lands where can be converted into large scale lands for agricultural projects possibly for industrial crop such as cassava, sugarcane, corn, soybean, and other tree products. Therefore, the management of these areas is comprehensive and addresses the issue of converted area. Hence, it is found that approximately 1.45 Mha were the potential area for future possible expansion of cassava production area beside current plantation area. These area mostly located in Preah Vihear, Kratie, Stung Treng, Ratanakiri, Mondulkiri, Siem Reap, and Otdar Meanchey province (Fig. 5.12).

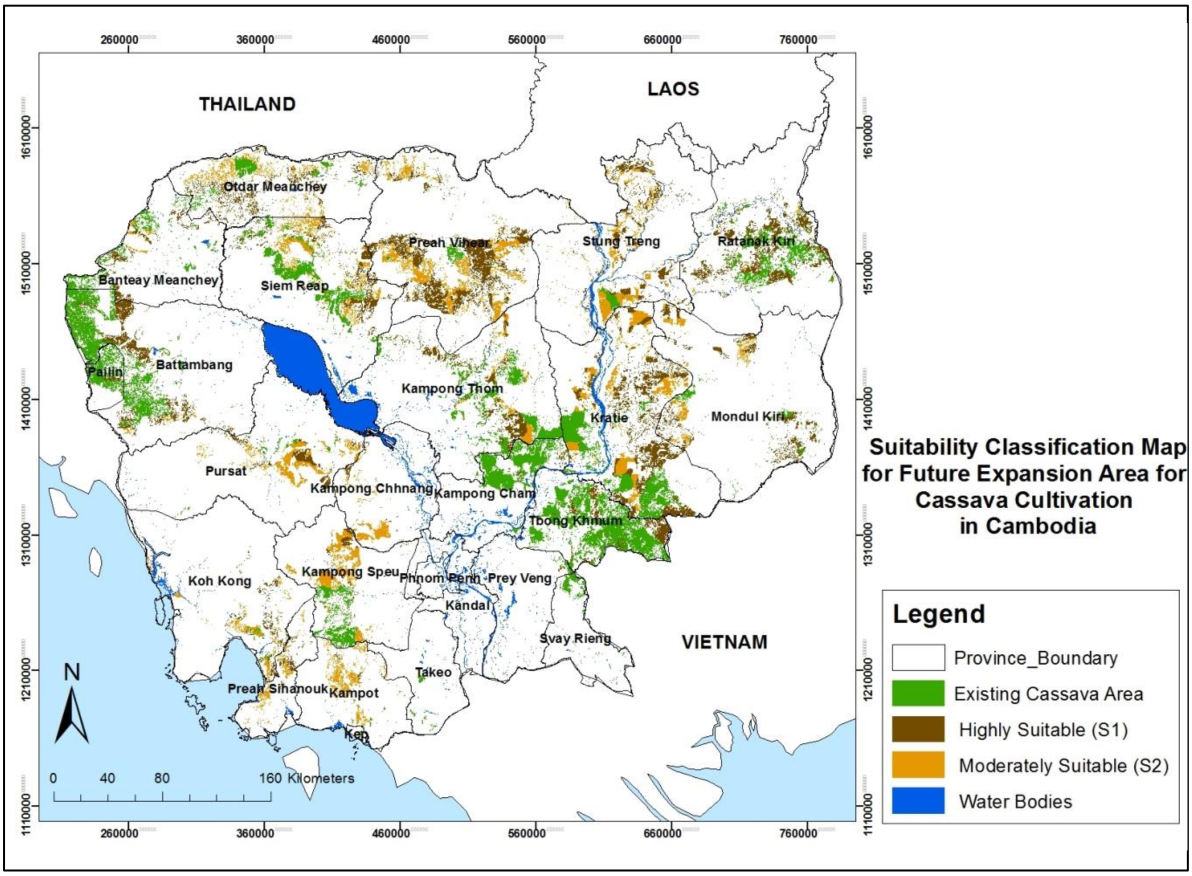


Figure 5.13 Future potential land suitability classifications map for cassava plantation by provincial level

Given the possibility of potential land availability and yield for cassava under highly suitable (S1) and moderately suitable (S2), the expansion area of cassava to meet bioethanol demand would have a relatively lower effect on cassava-based food security due to this expansion being considered only on the abundant land (1.45 Mha of S1 and S2).

However, the current upland crops and current cassava production area (1.1 Mha) was not taking in to account for this analysis. On the other hand, given the information on cassava adaptability to climate and soil, the procedure for estimating land suitability for expansion and intensification, it becomes possible to consider and decide where and with what production system a certain development target for bioethanol could be met sustainably or supply potential as well as demand needed and with minimum negative impact on food security.

5.2.2 Future Possible Bioethanol Production Potential in Cambodia Scenario

5.2.2.1 Assumption of 100% of future possible cassava feedstock produced bioethanol scenario

Table 5.9 shows the future possible potential area of cassava plantation and ethanol capacity of each province based on highly suitable (S1) and moderately suitable (S2). The results indicated that the future possible areas for cassava plantation were approximately 1,450,221 ha. The potential production was estimated approximately 26.59 million tonnes per year that could be fermented to the potential bioethanol production for more than 4,028 million liters corresponding to 3,171 ktoe (1 toe = 1270 liters) (see Appendix D.5). In addition, the assumption of this scenario is that the current production of 8 million tonnes (421,375 ha) were used for export and local consumption (increase as double) in 2035.

Since there is no clear policy on biofuel development in Cambodia, yet the Royal Government of Cambodia (RGC) promoted biofuel production and utilization to reduce the country’s reliance on import petroleum fuels as there has been some plants according to Lieng (2013) [3]. According to the IEA report [5], the gasoline consumption in Cambodia was about 178 ktoe in 2012 (see Appendix D.4). The average growing rate of gasoline consumption since 2005 until 2012 was 9 ktoe per year [5]. Therefore, in 2020, the gasoline consumption will be reach to 242 ktoe per year. According to ERIA Research Project Report [11], the consumption of liquid fuel demand (for gasoline) for road transportation will be 388 ktoe per year in 2035. Hence, it is matched with annual growing rate of 9 ktoe of gasoline and growing rate of GDP 7% until 2030.

Based on Bio-ethanol Development Plan (2007-2020) [4], proposed by the Japan Development Institute (JDI), Cambodia can achieve E20 in 2020. In this study, 20% blending of ethanol with gasoline targeted by 2035 was set to estimate the demand prediction and supply potential. In addition, with assumption of 20% of the country’s gasoline demand substituted by bioethanol in 2035, if the target was achieved, Cambodia is expected to see annual demand for bioethanol of 77.6 ktoe, respectively. Therefore, in case of 1.45 Mha of potential area have been used for cassava cultivated (Table 5-8), approximately 3,928 million liters (corresponding to 3,093 ktoe) of bioethanol production are the supply potential for export to the world market.

Table 5.9 Future possible cassava feedstock and possible bioethanol production potential

Suitable Classes	**Area (ha)***	**Production (million tonnes/year)****	**Potential Ethanol (million liters/year)*****
Highly Suitable (S1)	835,523	15.63	2,368
Moderately Suitable (S2)	614,698	10.96	1,660
Total	**1,450,221**	**26.59**	**4,028**

Note: ***** The median from Table 5.8

** The production was calculated based on each province average yield (Fig. 2.9)

****** 6.6 kg of cassava fresh roots can be fermented to 1 liter ethanol [4]

5.2.2.2 Assumption of keeping the share of the current production for bioethanol production plus additional future production scenario

By keeping the share of current export and consumption as in 2011, approximately 55% (4.37 million tonnes) of cassava productions were consumed domestically and exported. Moreover, 45% (3.65 million tonnes) of the current cassava feedstock can be fermented at approximately 545 million liters per year (1.5 million liters/day) of ethanol production which corresponds to 429 ktoe (1 toe = 1270 liters). Keeping the share of 45% of current cassava feedstock for bioethanol, the total future ethanol productions were estimated by additional current potential of bioethanol production. Therefore, the total future production is projected to be 3,600 ktoe per year. Based on the assumption of 20% blending of ethanol with gasoline (demand for bioethanol of 77.6 ktoe) targeted by 2035, the future potential of ethanol production would be 3,522 ktoe potentially for supply or export to the international market.

ERIA Research Project Report [11] estimates that the supply potential of bioethanol (mainly based on cassava) in Cambodia is 2533.5 ktoe per year (corresponding to approximately 1 Mha of cassava plantation) in 2035. Therefore, the supply potential estimation in this study was approximately 3,522 ktoe higher than the supply potential projection by ERIA due to the different production area estimation. However, this estimation is still small if compare to Vietnam (mainly based on molasses) which supply potential bioethanol projection is 9049.9 ktoe and Thailand (mainly sugarcane and molasses) which the supply potential estimation to is 9300.0 ktoe in 2035.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This chapter presents the conclusion of suitable area for cassava plantation with estimation of current quantity of cassava feedstock to produce bioethanol and potential area for future possible expansion with the potential bioethanol production estimation. This study employed the GIS integrated with AHP approach based on recent studies in Thailand and FAO framework to assess land suitability evaluation for cassava production area in Cambodia. From the analysis, this study arrives at the following conclusion:

- Most of abundant land, existing cassava production area, and upland crops, suitable for cassava plantation accounting for approximately 2.6 Mha were under highly suitability (S1) and moderately suitable (S2) while 0.3 Mha of marginally suitable (S3) and not suitable (N) were considered as not suitable areas for cassava cultivation. Thus, it indicated that Cambodia's agriculture land exclude paddy field have highly possible to replace or expanding growing area for cassava by converting the existing agriculture areas which being used for other crops/trees to cultivate this energy crop instead or planting to where it is newly converted or unused land.
- Regarding the future expansion area, due to the insufficient of information and data, the combination data of 2002 LULC map, 2014 forest cover, and crops statistic 2013 played an important criterion for offering the crucial information to examine the spatial matching between the potential suitability areas and the current LULC patterns. This information helped to identify the converted area (forest changed to non-forestland) where it was considered for future potential expansion area. Among 1.7 Mha of potential area (abundant land) of 24 provinces, five provinces namely: Preah Vihear, Kratie, Stung Treng, Ratanakiri, and Mondulkiri, were potentially to expanse cassava plantation beside the existing area due to most of plenty of abundant land were found approximately 1.45 Mha under highly suitable area (S1) and moderately suitable area (S2), respectively.
- For the current situation, about 55% (4.3 million tonnes) of cassava production are consumed domestically and exported while the other 45% (corresponding to 3.6 million tonnes) of current quantity of cassava feedstock potentially for fermented to

bioethanol production of 545 million liters per year (429 ktoe), which corresponds to the daily capacity of 1.5 million liters per day that Cambodia can produce in 2011. On the other hand, with future potential expansion of cassava plantations under S1and S2 (1.4 Mha), the future potential production was estimated approximately 26.59 million tonnes per year that could be fermented to the potential bioethanol production for more than 4,028 million liters (corresponding to 3,171 ktoe). Therefore, with keeping the share of current production for bioethanol production with the future potential, the total future production projected to be 3,600 ktoe per year. Thus, the effect of this potential supply is depends on the consumption and export status. Larger export and utilization, less potential supply is. In addition, with the assumption of 20% of gasoline consumption substitute with ethanol in 2035; thus, the future potential of ethanol production would be 3,522 ktoe potentially for supply or export to the international market.

- The use of GIS integrated with weights and scores (based on recent study in Thailand) for suitable area analysis could provide a guide map for decision makers to consider crop shifting in order to achieve better agricultural production. However, the weight values may be different if there is difference in number and types of factors, number, and sets of expert samples, and study area. However, this investigation provides information at national level that could be used not only a reference for cassava production planning, as well as for evaluating the national potential for this energy crop supply, but also useful for other investigators who could use these results for diverse studies.
- On the other hand, in this study, several uncertainties existed and affected the result of this analysis. Firstly, it came from difference year of the climatic data and lack of soil quality data such as soil texture, soil nutrient, etc. Secondly, it came from the resolution of the map especially soil depth and soil drainage (10 km^2 resolution) and scale of the map such as 2002 LULC map (1:1,500,000) and 2014 forest cover map (1:2,500,000) that can make the different in the adjustment of the georeferenced. Finally, it came from the assumption of shrubland, grassland, barren land, and urban area as in 2002 LULC map. Within this period 2002-2013, the area of urban area should be expanding or increasing significantly.

6.2 Future Recommendations

There are some limitations that need to be addressed and explored in future research; therefore, satellite imagery processing and ground survey is required to accurately check what kind of land has been changed. Due to the limitation of research within one year; thus, for further field survey is impossible. That is the reason why the combination from difference source of data was proposed and the numbers of assumption was made in this study.

Since only small numbers of land resources factors have been considered for this research, for further suitability studies, it is recommended that the selection of more factors as well as creates the soil data base and land information system of Cambodia, such as current climate data and soil quality of Cambodia (soil texture, soil nutrient, terrain, irrigation facilities, socio-economic) and other land unit map which related to the cassava requirement should be encourage. This will gives much certainty progress and improves the land suitability analysis.

Moreover, it is strongly recommended that satellite imagery processing for current land use land cover, accuracy assessment, and ground survey with the appropriate period of the research should be proposed and managed. In addition, the research can be extended to explore the application of other information sources such as remote sensing images, Global Positioning System (GPS), etc., which should be encouraged as it will help bring real changes to land use and management strategies.

Finally, the clear policy with clear target and mechanism from the government related to land use for bioenergy crop and bioethanol production plan are the fundamental roles to display the need of current and future demand and supply potential. The government should take some action such as formulate a Cambodian Bio-energy Plan and Act as soon as possible with setting a clear future target and measure to achieve the goal. In addition, the government should promote Bio-ethanol mainly using cassava feedstock by expand planting area to a few Mha targeting to be a next bioethanol exporter.

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APPENDIXES

Appendix A: Estimate weight and score for each factor using AHP approach

In this study, due to the limitations of the research period, the weight and score of each factor was assigned following Phongaksorn (2012) [68] where has done in Thailand entitled of "GEOSPATIAL LAND SUITABILITY MODELING FOR BIOFUEL CROPS USING FUZZY AHP" with eight factors was taking in to account namely: mean temperature (F1), annual rainfall (F2), soil drainage (F3), nutrient status (F4), soil depth (F5), reaction (F6), soil texture (F7), and slope (F8).

Due to the data of soil texture, nutrient status, and reaction data of Cambodia was not available for this analysis, the soil fertility of Cambodia (the only available data) was used instead of these soil properties (soil texture, nutrient status, and reaction). Thus, the soil fertility weight of this study was estimated by the sum up weight of nutrient status (F4), reaction (F6), and soil texture (F7).

The procedure of the AHP for assigning priority weights of the various criteria consists of three major steps (Saaty, 1980): construct pairwise comparison matrices (PCM), compute factor weights, and estimate consistency ratio (CR).

- **Step I:** Construct the PCM of the physical factors by assigning the AHP

$$x_{ij} = \left(a_{ij}{}^{1} \times a_{ij}{}^{2} \times \cdots \times a_{ij}{}^{b} \times \ldots \times a_{ij}{}^{k}\right)^{1/k}$$

Where,

X_{ij} = a geometric mean of the AHP comparison value of dimension i factor to j

a_{ij} = the PWC value of dimension i factor to j, $b = 1, 2, \ldots, k$ and $i, j \in \{1,2,\ldots,n\}$.

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
F_1	**1**	0.300	0.230	0.230	0.290	0.410	0.350	0.550
F_2	3.310	**1**	0.420	0.610	0.970	1.070	1.260	1.520
F_3	4.280	2.410	**1**	1.520	1.790	1.520	2.060	2.440
F_4	4.280	1.630	0.660	**1**	2.660	2.450	1.770	2.440
F_5	3.410	1.030	0.560	0.380	**1**	1.700	1.520	1.830
F_6	2.430	0.930	0.660	0.410	0.590	**1**	1.010	2.230
F_7	2.880	0.790	0.490	0.560	0.660	0.990	**1**	1.100
F_8	1.820	0.660	0.410	0.410	0.550	0.450	0.910	**1**
Sum	**23.410**	**8.750**	**4.430**	**5.120**	**8.510**	**9.590**	**9.880**	**13.110**

- **Step II:** Compute the priority weights for cassava

$$w_i = \frac{1}{n}\left[\sum_{j=1}^{m}\left(\frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}\right)\right]$$

$\sum_{i=1}^{n} x_{ij}$ be the sum of column j of the matrix A, and $\sum_{j=1}^{m}$ be the sum of row i of the matrix A

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	Sum	W_c
F_1	0.043	0.034	0.052	0.045	0.034	0.043	0.035	0.042	**0.328**	0.041
F_2	0.141	0.114	0.095	0.119	0.114	0.112	0.128	0.116	**0.939**	0.117
F_3	0.183	0.275	0.226	0.297	0.210	0.158	0.209	0.186	**1.744**	0.218
F_4	0.183	0.186	0.149	0.195	0.313	0.255	0.179	0.186	**1.647**	0.206
F_5	0.146	0.118	0.126	0.074	0.118	0.177	0.154	0.140	**1.052**	0.132
F_6	0.104	0.106	0.149	0.080	0.069	0.104	0.102	0.170	**0.885**	0.111
F_7	0.123	0.090	0.111	0.109	0.078	0.103	0.101	0.084	**0.799**	0.100
F_8	0.078	0.075	0.093	0.080	0.065	0.047	0.092	0.076	**0.606**	0.076

- **Step III:** Estimate the consistency ratio (CR)

$$CV = \frac{1}{n}\left[\frac{1}{w_i}\left[\sum_{j=1}^{m}\left(\left(\sum_{j=1}^{m}\left(\frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}\right)\right)\times x_{ij}\right)\right]\right]$$

$$\lambda_{\max} = \frac{CV}{n}$$

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

$$CR = \frac{CI}{RI}$$

Where,

- **λ_{max} :** Average value of consistency vector
- CV: Consistency Vector
- CI : Consistency Index
- CR: Consistency Ratio
- RI: the Random Inconsistency indices

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	Sum	CV
F_1	0.330	0.282	0.400	0.380	0.305	0.365	0.280	0.336	2.677	65.283
F_2	1.092	0.940	0.731	1.007	1.019	0.952	1.008	0.927	7.676	65.603
F_3	1.412	2.265	1.740	2.508	1.880	1.353	1.648	1.488	14.295	65.571
F_4	1.412	1.532	1.148	1.650	2.793	2.181	1.416	1.488	13.621	66.121
F_5	1.125	0.968	0.974	0.627	1.050	1.513	1.216	1.116	8.590	75.885
F_6	0.802	0.874	1.148	0.677	0.620	0.890	0.808	1.360	7.179	64.674
F_7	0.950	0.743	0.853	0.924	0.693	0.881	0.800	0.671	6.515	65.147
F_8	0.601	0.620	0.713	0.677	0.578	0.401	0.728	0.610	4.927	64.828
					Sum CV					**66.639**

- **Step IV:** Estimate the λ_{max} , CI, and CR for cassava

Cassava		
λ_{max}	*CI*	*CR*
8.330	0.047	0.035

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Appendix A.1 Calculate each factor's suitability score

Suitable Classes		**Mean Temp**	**Soil Fertility**	**Soil Drainage**	**Soil Depth**	**Slope**	**Rainfall**
Suitable class	**Weight / Score**	**0.041**	**0.417**	**0.218**	**0.132**	**0.076**	**0.117**
Highly Suitable (S1)	**1**	0.041	0.417	0.218	0.132	0.076	0.117
Moderately Suitable (S2)	**0.8**	0.033	0.334	0.174	0.106	0.061	0.094
Marginally Suitable (S3)	**0.4**	0.016	0.167	0.087	0.053	0.03	0.047
Not Suitable (N)	**0**	0.00	0.00	0.00	0.00	0.00	0.00

Appendix B: Estimate suitable area for cassava plantation

Appendix B.1: Estimate Forest cover changed by overlaid of 2002 LULC MAP and Current Forest Cover 2014

2002 LULC MAP - Forest 2014	Dense forest (ha)	Mix forest (ha)	Non-forest (ha)	Water (ha)	Total (ha)
Agriculture Lands	10,889	104,280	4,160,132	90,723	4,366,024
Forest Lands	2,778,813	4,546,863	2,093,172	33,103	10,235,443
Grass Lands	35,908	370,086	630,988	86,267	1,078,249
Shrublands	96,461	755,721	991,042	85,468	1,883,692
Soils and Rocky	768	884	30,307	2,874	36,832
Settlement	11	-	16,934	615	18,068
Water Bodies	10,536	49,060	121,640	357,383	541,619
Total	**2,931,386**	**5,826,893**	**8,745,213**	**656,433**	**18,159,925**

Appendix B.2: Calculate area of suitability classification

Suitable area	Area (ha)	Proportion (%)
Forest Cover	4,632,882	25.51
Paddy Fields	3,352,256	18.46
Highly Suitable (S1)	1,751,621	9.64
Moderately Suitable (S2)	909,234	5.01
Marginally Suitable (S3)	201,492	1.11
Not Suitable (N)	118,564	0.65
Grass Lands	345,858	1.90
Shrublands	718,296	3.95
Restricted Areas	5,591,956	30.79
Water Bodies	541,737	2.98
Total	**18,103,895**	**100.00**

Appendix C: Forest, conservation area, and soil type of Cambodia

Appendix C.1: Protected forest area and conservation area of Cambodia

Details	Area (ha)	Provinces
Multiple Use Management Area		
Dong Peng Multiple Use Area	27,700	Koh Kong
Amlaut Multiple Use Area	60,000	Battambang
Tonle Sap Biosphere Multiple Use Area	316,250	Kampong Chhnang, Kampong Thom, Siem Reap, Battambang, Pursat
National Park		
Kirirom National Park	35,000	Kampong Speu, Koh Kong, Preah Sihanouk
Preah Monivong National Park	140,000	Kampot
Phnom Kulen National Park	37,500	Siem Reap
Botum Sakor National Park	171,250	Koh Kong
Kep National Park	1,152	Kampot
Ream National Park	150,000	Preah Sihanouk
Virachey National Park	332,500	Stung Treng
Techo Sen Russey Treb Cambodian Royal Academy National Park	11,435	Preah Vihear
Protected Landscape		
Angkor Wat Protected Landscape	10,800	Siem Reap
Preah Vihear Temple Protected Landscape	5,000	Preah Vihear
Protected Landscape Banteay Chmar	81,200	Banteay Meanchey, Oddar Meanchey
Koh Kae Protected Resort	3,508	Preah Vihear
Beng Mealea Protected Area	315	Siem Reap
Sombo Prey Kok Temple Cultural Resort	2,982	Kampong Thom
Cultural Resort of Banteay Chmar Temple	780	Banteay Meanchey
Cultural Resort of Banteay Top Temple	108	Banteay Meanchey
Ramsar Site		
Stung Treng Ramsar Site	14,600	Stung Treng
Boeung Chhmar and Associated River System and Floodplain Ramsar Site	28,000	Kampong Thom, Siem Reap
Koh Kapik and Associated Islets	12,000	Koh Kong
Wildlife Sanctuary		
Phnom Prich Wildlife Sanctuary	222,500	Ratanak Kiri, Mondul Kiri
Lomphat Wildlife Sanctuary	250,000	Ratanak Kiri, Mondul Kiri
Kulen Promtep Wildlife Sanctuary	402,500	Siem Reap, Preah Vihear
Phnom Samkos Wildlife Sanctuary	333,750	Koh Kong
Beng Per Wildlife Sanctuary	242,500	Kampong Thom

Phnom Namlear Wildlife Sanctuary	47,500	Mondul Kiri
Phnom Aural Wildlife Sanctuary	253,750	Koh Kong, Pursat, Kampong Chhnang
Trapeang Lpeou Wildlife Sanctuary	8,305	Takeo
Roniem Daun Sam III Wildlife Sanctuary	2,121	Battambang
Roniem Daun Sam II Wildlife Sanctuary	21,335	Battambang
Roniem Daun Sam I Wildlife Sanctuary	16,565	Battambang, B. Meanchey
Anloung Pring Crane Sanctuary	217	Kampot
Snuol Wildlife Sanctuary	75,000	Kratie
Peam Krasop Wildlife Sanctuary	23,750	Koh Kong
Total	**3,341,873**	

Data Source: Open Development Cambodia (ODC) (2014c)

Appendix C.2 Forestland change to non-forestland

a) Deforestation in Prey Lang, Cambodia

b) Deforestation in Preah Vihear province

c) Deforestation in Stung Treng province

d) Deforestation in Ratanakiri province

e) Forestland changed to crop land in Pursat province

Appendix C.3: Statistics of Forest cover of each province from 1973-2014 (in hectare) by Open Development Cambodia

Provinces	1973	1989	2000	2004	2009	2014
Banteay Meanchey	240,698	194,800	177,110	60,229	152,467	132,706
Battambang	747,898	736,975	696,024	439,539	633,401	425,980
Kampong Cham	622,928	500,465	513,318	425,390	377,625	124,356
Kampong Chhnang	232,423	206,844	201,769	215,794	121,630	160,810
Kampong Speu	375,709	371,428	350,457	337,540	263,794	206,540
Kampong Thom	806,560	695,250	748,532	765,474	709,333	543,935
Kampot	246,455	233,869	241,167	229,309	200,900	176,491
Kandal	129,874	76,258	83,390	131,246	32,473	24,010
Koh Kong	1,076,877	1,068,067	1,022,184	1,050,486	975,085	866,796
Kratie	1,057,880	993,914	1,011,775	978,575	869,399	612,468
Mondulkiri	1,228,872	1,225,129	1,228,260	1,213,981	1,074,626	983,886
Phnom Penh	13,440	7,210	8,615	11,707	2,655	3,168
Preah Vihear	1,310,568	1,270,768	1,234,156	1,155,736	1,210,872	910,752
Prey Veng	82,720	30,826	38,662	69,737	11,158	14,251
Pursat	950,110	928,224	900,273	868,648	874,770	733,845
Ratanakiri	1,116,499	1,108,012	1,096,391	1,019,882	1,014,534	743,488
Siemreap	680,720	654,829	618,327	568,095	595,954	398,839
Preah Sihanouk	234,369	203,818	191,857	210,346	162,148	131,525
Stung Treng	1,133,366	1,101,852	1,087,710	1,085,574	1,038,935	953,836
Svay Rieng	38,529	28,712	29,506	35,676	30,773	22,174
Takeo	77,268	50,472	38,830	51,429	24,258	13,959
Oddar Meanchey	591,263	541,187	486,985	447,932	482,376	415,021
Kep	5,444	4,242	4,986	4,115	3,248	3,178
Pailin	95,092	94,650	93,012	71,697	66,025	57,098
Total	**13,095,560**	**12,327,802**	**12,105,296**	**11,448,138**	**10,928,441**	**8,659,112**

Data Source: ODC (Open Development Cambodia) (2014b). Forest Cover Data and Analysis. Retrieved 25 May, 2015, from http://www.opendevelopmentcambodia.net/maps/downloads/download-forestcover-data-and-analysis/

Appendix C.4: Soil fertility classification of Cambodia

Soil Type	Area (ha)	Proportion (%)	Fertility class
Acid Lithosols	4,542,131	25.3	Lower fertility
Coastal Complex	228,465	1.3	Lower fertility
Planosols	166,536	0.9	Lower fertility
Plinthite podzols	1,816,460	10.1	Lower fertility
Red-yellow podzols	2,571,678	14.3	Lower fertility
Alluvial Lithosols	1,523,256	8.5	Medium fertility
Alumisol	329,727	1.8	Medium fertility
Brown Alluvial Soils	132,565	0.72	Medium fertility
Cultural hydromorphics	1,419,051	7.9	Medium fertility
Plinthitic hydromorphics	118,393	0.7	Medium fertility
Basic Lithosols	348,281	1.9	High Fertility
Brown hydromorphic	681,349	3.8	High Fertility
Grey hydromorphics	1,706,815	9.5	High Fertility
Lacustrine Alluvial Soils	1,044,566	5.8	High Fertility
Latosols	663,657	3.7	High Fertility
Regurs	637,896	3.6	High Fertility

Data Source: ODC (Open Development Cambodia) (2014a). Cambodia: Soil Fertility Map. Retrieved 22 December, 2014, from http://www.opendevelopmentcambodia.net/download/maps/atlas/en/SoilFertility.jpg

Appendix D: Crop statistics of Cambodia

Appendix D.1: Cassava production in between 2000 – 2013

Year	Harvested Area (ha)	Production (Million ton)
2000	14,245	148
2001	14,239	142
2002	19,563	122
2003	25,740	331
2004	22,749	362
2005	30,032	536
2006	97,918	2,182
2007	108,102	2,215
2008	179,945	3,676
2009	160,326	3,497
2010	206,226	4,247
2011	391,714	8,033
2012	361,854	7,613
2013	421,375	7,933

Data Sources: MAFF report 2010, 2011, 2012 and 2013 Annual Report of Agriculture Crops of Cambodia. Ministry of Agriculture, Forestry, and Fishery.

Appendix D.2: Cassava export and utilization

Type of Utilization	Type of production	Production (ton)	Fresh Root Equivalent (ton)
Cassava Export data 2011	Dry chips*	93,500	233,750
	Starch**	16,720	80,256
	Informal export (Estimated 161 Million USD/year)***		3,788,235
Local Consumption data 2010	starch	57,500	276,000
	Dry chips	No data	-
Total cassava Production			**7,933,382**
Cassava Remaining	**Estimated by total production subtract all production**		**3,555,141**

Notes: * 2 – 2.5 kg of fresh root can be produce 1 kg of dry chip

** 4.8 kg of fresh root can be produce 1 kg of starch (http://www.thaitapiocastarch.org/article24.asp)

*** 42.5 US dollars per ton of fresh root [7]

Appendix D.3: Agriculture Statistics of Cambodia in 2013

Provinces Name	Total Area (ha)	Forest Cover (ha)	Non-Forest (ha)	Cassava (ha)	Rice (ha)	Corn (ha)	Red Corn (ha)	yam (ha)	Vegetable (ha)	mung bean (ha)	Peanut (ha)	soy bean (ha)	Sesame (ha)	Sugarcane (ha)
Banteay Mean chey	610,424	132,706	477,718	55,666	243,030	5,158	4,349	173	2,917	834	71	162	95	267
Battambang	1,180,412	425,980	754,432	61,695	307,575	118,294	117,533	134	1,699	16635	452	24,254	10,859	136
Kampong cham	912,877	124,356	788,521	67,625	221,388	29,159	13,442	1,628	9,681	8243	5,028	18,812	12,605	2,026
Kampong Chhnang	507,472	160,810	346,662	1,737	156,217	2,185	-	1,078	4,606	2834	1,123	-	1,470	1,299
Kampong Spue	694,448	206,540	487,908	3,402	116,274	589	-	301	1,172	1941	601	-	43	2,747
Kampong Thom	1,222,604	543,935	678,669	36,725	256,731	630	-	217	1,088	507	501	3,585	300	21
Kampot	467,035	176,491	290,545	816	144,810	1,755	-	760	2,126	876	530	-	6	635
Kandal	294,634	24,010	270,624	27	106,168	20,182	17,522	78	10,218	3855	34	-	856	667
Kep	13,983	3,178	10,805	100	3,550	241	-	173	511	-	59	-	-	67
Koh Kong	1,082,428	866,796	215,632	334	10,374	73	-	28	165	-	14	-	-	701
Kraties	1,165,199	612,468	552,732	46,810	46,976	4,664	4,087	162	1,073	227	1,028	840	1,627	3,669
Mondul kiri	1,363,297	983,886	379,411	10,271	22,920	443	-	-	435	3101	3,671	1,769	19	27
Otdar Mean Chey	660,947	415,021	245,926	25,125	65,305	198	10	28	596	160	207	3,480	70	312
Pailin	107,477	57,098	50,379	25648	8,159	32,227	32,212	-	62	490	134	690	171	14
Phon Penh	60,959	3,168	57,791	72	13,591	270	-	57	937	57	-	-	50	8
Preah Sihanuk	248,499	131,525	116,973	470	16,483	160	-	43	240	-	-	-	-	65
Preah Vihear	1,400,267	910,752	489,515	12,650	77,697	11,125	4,825	534	1,383	7214	4,314	18,652	1,577	898
Prey Veng	453,643	14,251	439,391	1,969	372,095	2,143	2,064	3	996	462	308	-	528	263
Pursat	1,151,198	733,845	417,353	6,583	120,746	6,557	5,426	185	987	1876	197	1,349	2,945	320
Ratanak Kiri	1,168,899	743,488	425,411	13,590	27,172	119	-	34	48	539	327	4,385	68	64

Siem Reap	1,042,564	398,839	643,725	11,510	202,285	1,105	-	710	4,230	2655	100	535	400	760
Stung Treng	1,171,052	953,836	217,216	19,622	27,805	1,793	282	190	1,127	1540	951	2,175	430	645
Svay Rieng	283,435	22,174	261,261	17,597	186,971	13	-	543	2,929	-	12	-	14	7,535
Takeo	344,155	13,959	330,196	1,331	298,098	665	-	384	3,223	706	292	-	3	642
Total	**17,607,908**	**8,659,112**	**8,948,796**	**421,375**	**3,052,420**	**239,748**	**201,752**	**7,443**	**52,449**	**54,752**	**19,954**	**80,688**	**34,136**	**23,788**

Data Source: MAFF. (2013) Annual Report of Agriculture Crops of Cambodia 2013. Ministry of Agriculture, Forestry, and Fishery.

Appendix D.4: Fuel oil consumption in Cambodia from 2000 – 2012

Variable	**Fuel consumption in Cambodia (in kiloton) from 2000 to 2012**												
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
LPG	16	17	20	22	28	30	32	35	38	41	44	103	110
Moto gasoline	113	107	112	104	102	110	119	129	139	150	158	166	178
Diesel	316	384	320	336	344	375	400	434	451	451	467	487	578

Data Source: IEA. (2012). Cambodia: Fuel Oil Consumption Statistic 2012. Retrieved 03-April, 2014, from
http://www.iea.org/statistics/statisticssearch/report/?country=CAMBODIA&product=oil&year=2012

Appendix D.5: Potential area estimation of bioethanol production

Provinces Name	Total Area (ha)	Forest Cover (ha)	Non-Forest (ha)	Current Cassava (ha)	Current Rice Areas (ha)	Other Upland Crops (ha)*	Average Cassava Yield (t/ha)	Potential Areas by Map (ha)**	Potential Production Cassava (ton)	Potential Ethanol Production (1,000 liter/year)***
Banteay Mean Chey	610,424	132,706	477,718	55,666	243,030	13,759	19.75	27,823	549,462	91,577
Battambang	1,180,412	425,980	754,432	61,695	307,575	289,860	36.03	70,233	2,530,595	421,766
Kampong cham	912,877	124,356	788,521	67,625	221,388	98,598	19.69	34,743	684,005	114,001
Kampong Chhnang	507,472	160,810	346,662	1,737	156,217	13,296	5.82	26,589	154,849	25,808
Kampong Spue	694,448	206,540	487,908	3,402	116,274	4,647	29.91	63,894	1,911,267	318,545
Kampong Thom	1,222,604	543,935	678,669	36,725	256,731	6,828	15.00	72,269	1,084,030	180,672
Kampot	467,035	176,491	290,545	816	144,810	6,053	2.25	38,952	87,785	14,631
Kandal	294,634	24,010	270,624	27	106,168	52,745	8.00	7	53	9
Kep	13,983	3,178	10,805	100	3,550	984	15.00	84	1,260	210
Koh Kong	1,082,428	866,796	215,632	334	10,374	280	20.83	40,210	837,426	139,571
Kraties	1,165,199	612,468	552,732	46,810	46,976	13,708	22.27	218,643	4,868,802	811,467
Mondul kiri	1,363,297	983,886	379,411	10,271	22,920	9,438	15.33	78,022	1,196,460	199,410
Otdar Mean Chey	660,947	415,021	245,926	25,125	65,305	4,749	23.13	86,833	2,008,857	334,810
Pailin	107,477	57,098	50,379	25648	8,159	65,986	17.90	3,045	54,516	9,086
Phon Penh	60,959	3,168	57,791	72	13,591	1,371	7.43	29	217	36
Preah Sihanuk	248,499	131,525	116,973	470	16,483	443	13.00	22,386	291,016	48,503
Preah Vihear	1,400,267	910,752	489,515	12,650	77,697	49,624	11.00	268,995	2,958,945	493,157

Prey Veng	453,643	14,251	439,391	1,969	372,095	6,504	18.00	762	13,724	2,287
Pursat	1,151,198	733,845	417,353	6,583	120,746	19,522	27.55	71,359	1,965,882	327,647
Ratanak Kiri	1,168,899	743,488	425,411	13,590	27,172	5,520	20.50	100,838	2,067,140	344,523
Siem Reap	1,042,564	398,839	643,725	11,510	202,285	9,735	15.10	103,034	1,555,688	259,281
Stung Treng	1,171,052	953,836	217,216	19,622	27,805	8,488	20.00	120,424	2,408,484	401,414
Svay Rieng	283,435	22,174	261,261	17,597	186,971	3,511	15.74	323	5,084	847
Takeo	344,155	13,959	330,196	1,331	298,098	5,273	9.00	725	6,524	1,087
Total	**17,607,908**	**8,659,112**	**8,948,796**	**421,375**	**3,052,420**	**690,922**		**1,450,221**	**27,242,072**	**4,028,345**

Notes: * Upland crop included corn, yam, vegetable, peanut, mung bean, soy bean, sesame, and sugarcane (MAFF, 2013)

****** Potential area was estimated by overlay of 2002 LULC map, Forest cover 2014, and Suitable map of class S1 and S2

*** Potential ethanol production was estimated by 6.6 kg of cassava fresh root can be fermented to 1 liter of ethanol (JDI, 2007)