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Climate Change and Water Scarcity in Agriculture: Rainwater Harvesting in Semi-Arid Coastal Areas of Vietnam

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Introduction

1.1. Background of the study

Vietnam is an agriculture-based country with approximately 70% of the population located in rural areas (General Statistic Office, 2012). The country has excessive rainfall which averages around 1800 mm per year (Harris, 2006). Rainwater therefore is an abundant resource. However, precipitation is often unevenly distributed in both temporal and spatial terms, which makes it being limited in terms of "ready to use" (Dung & Tinh, 2006). Typically 80 to 90% of the rainfall occurs during the rainy seasons; as a consequence, some regions suffer from floods during rainy seasons and droughts also in dry seasons (World Bank, 2011).

South central coastal Vietnam is a region having exceptionally harsh climate with lowest average rainfall but highest temperature and is in typhoon belt of the country (Chaudhry & Ruysschaert, 2008). Consequently, apart from flash floods occurring in rainy seasons, the region experiences prolonged drought in dry season, leading to critical water shortage, especially for domestic use and agricultural production. In accordance with a recent report of Ministry of Natural Resource and Environment (MONRE), around 60% of agricultural land is not being utilized owing to water shortage for irrigation. The situation is even more serious when it is accompanied with soil erosion and desertification.

Recognizing the problem, the Vietnam Government has paid much attention and allocated enormous investment for the development of water supply systems, especially for irrigation schemes. However, the efficiency of these projects is rather limited due to difficulties of topography, low availability of water sources and high construction & maintenance costs. Hence, finding a new and appropriate solution which can overcome current obstacles for provision of water is extremely necessary.

Rainwater harvesting, a simple and low-cost technology, which has been successfully applied in many areas in the world, including Sub Sahara Africa, Middle East and Asia (Critchley, Siegert, & Chapman, 1991) appears a feasible solution. In Vietnam, Tuan & Hieu (2007) have conducted a research on applying rainwater harvesting technology with agro-forest solutions for sustainable cultivation in coastal region of Vietnam. Results of the project not only solve water scarcity for crops in dry seasons but also protect environment from soil erosion and expansion of desertification.

Within the context of climate change, Vietnam is expected to be one of five countries to experience worst impacts with regards to increase of temperature, increase of sea level rise and more frequency of floods and droughts (World Bank, 2011).

1.2. Rationale for the study

Water scarcity during dry season is one of the major constraints for crop production in south central coastal Vietnam (Slavich, Tam, Thinh, & Keen, 2010). Most of farmers use combination of groundwater and surface water for irrigation. However, use of groundwater for crop cultivation reduces productivity owing to groundwater salinity and the heavy reliance on groundwater is causing significant saline-water intrusion in the coastline (Kyoto University & Oxfam GB, 2007; Slavich et al., 2010). Additionally, the development of surface irrigation systems faces various difficulties regarding to long-distance from water sources leading to high construction cost. While current irrigation solutions encounter with many problems, there is little attention being paid to rainwater harvesting, an alternative that can both lessen salinity issues and overcome distance obstacle.

Through a long-term study of more than one decade on rainwater harvesting, Boer and his colleagues (1994) arrived at a conclusion that runoff from micro-catchment area could be potential irrigation source for establishment, development and growth of trees. This water supply can make a significant difference between death and survival, minimum and good growth of trees. Particularly in dry seasons, the runoff water considerably improves environmental conditions in which trees grow. Large scale application of rainwater harvesting has been implemented in Sub Sahara Africa as supplement irrigation for rainfed agriculture. The applied models not only reduces risk of crop failure but also substantially improve water and crop productivity (Biazin, Sterk, Temesgen, Abdulkedir, & Stroosnijder, 2011).

Therefore, rainwater harvesting is a potential solution for supplementing provision of crop water demand during dry seasons. Given the high variability and low availability, rainwater harvesting still can substantially increase water productivity in dry marginal environments. It is thus the option for agriculture and environment protection in such area (Oweis & Hachum, 2006).

Another main issue of concern in the region is adaptation measures to impacts of climate change with respect to rainfall variability and sea level rise. These adverse impacts make serious threat to more frequent of floods and droughts, and saline-water intrusion. Being confronted with that circumstance, rainwater harvesting has been identified as a technology with the potential of contributing immensely as a coping mechanism for climate change and variability (Ong C., 2006). Given its decentralization and flexibility to local conditions and individual needs, the technique makes itself being an active and potential adaptation to food-water scarcity and environmental protection (Salas, 2007).

During recent years, great deal of efforts on assessment and construction of rainwater harvesting system were carried out in semi-arid area of the south coastline by international and domestic organizations such as GEF (2005) and Oxfam GB (2007), Institute of Water and Environment (Tuan & Hieu, 2007). Even though these projects have brought immense practical experience on applying rainwater harvesting in the region, there is no study on cost-effective of rainwater harvesting models with different crop and planting patterns so as to identify the most economical integration crop-water harvesting application. Furthermore, up to now, there is not any study on mapping potential area of rainwater harvesting as well as vulnerable area to desertification in the region. Therefore, this research is very important and necessary with expected outcomes to improve and address above issues.

Inheriting successful points from Tuan & Hieu models in terms of construction and material, this research aims at calculate and design a new rainwater harvesting structure which separate wind-break or shelterbelt system and crop production into 2 different rainwater harvesting types. Wind-break or shelterbelt systems will be provided water by in-situ rainwater harvesting schemes of catchment strips while crop cultivation in farms still be irrigated by storage ponds throughout the long dry season. Besides that, new design will be considered effects of climate change on rainwater and temperature, which has not been done before, towards the sustainability of the technique.

Furthermore, up to now, there is no study on mapping potential area for application of rainwater harvesting in the region. Also, vulnerable area to desertification should be identified for prioritized actions of the technique. The mapping outputs will support local authorities in planning and developing of water harvesting systems.

National program on responding toclimate change emphasizes that Vietnam consider coping with climate change has a vital role, of which coping activities must relates to sustainable development. Therefore, the proposed rainwater harvesting models which optimum utilization of rainwater harvesting for crop production and at the same time improve environment preventing from soil erosion and desertification will favorably meet with the strategy.

Therefore, this research is very important and necessary with expected outcomes to improve and address above issues.

1.3. Statement of problem

Recent climate change scenarios in Vietnam constructed by Ministry of Natural Resources and Environment in 2009 and updated in 2011 have both shown negative trends of climatic factors in the southern coastal area such as the decrease of rainfall in dry season (despite of increase of the annual amount), increase of average temperature and sea level rise. These detrimental climate trends coupled with existing water shortage will seriously affects to agriculture production. In the absence of appropriate adaptation measure, food security of the coastal region is being threatened.

It is also worthy to note that other water supplying solutions such as dams, reservoirs or transferring water from low-land river basin up to the coastal land is facing with basic constraints of high investment cost. During pending period of these possible solutions, a large scale of rainfed cultivated area in the coast land is being abandoned during dry seasons owing to missing of water, resulting in the expansion of desertification and soil erosion.

1.4. Objectives of the study

The main objective of this study is to identify appropriate rainwater harvesting and potential sitting location so as to address water scarcity in agriculture and adapt to climate change in semi-arid coastal area of Vietnam. Specific objectives as following:

- to select suitable rainwater harvesting techniques in the study area;
- to analyze cost-benefits of water harvesting- crops applications for the most economical solution;
- to apply GIS and Analytic Hierachy Process (AHP) method in locating potential area of rainwater harvesting in the study area.

1.5. Purpose of the study

Main purpose of this study is to address water scarcity for coastal area in south central Vietnam, adapting to effects of climate change.

Inheriting practical experiences of previous rainwater harvesting applications, this research aims at select appropriate water harvesting techniques and cost-effective applications. Furthermore, the research has a purpose of identifying potential rainwater harvesting area and desertification vulnerable area in the province, using GIS and multi-criteria decision making.

Overall outcome of the project is a comprehensive outlook on water harvesting solution in this coastal semi-arid area, answering questions of which is suitable techniques, which are most economical application and where is to apply rainwater harvesting. These contributions toward addressing water shortage for crop cultivation and introduce an active adaptation measure coping with adverse effects climate change, based on community participation.

Chapter 2

Literature Review

2.1. Rainwater harvesting

Rainwater harvesting is defined in a broadest sense as the collection of runoff for its productive use (Critchley et al., 1991). The technique has been applied since ancient time in many parts in the world, including North America, Middle East, North Africa, China and India (Oweis, Ahmed, & Jacob, 1999).

As for crop production, rainwater harvesting is process of concentrating precipitation through runoff and storing it for beneficial uses (Oweis & Hachum, 2006). In other words, it brings available water to target area (cultivated land) for closer to crop water requirement, so that water productivity is increased and economical agricultural production could be achieved. The technique thus often is applied in dry environment where rainfall is less than crop water needs and it is unfavorably distributed throughout crop growing season.

Each rainwater harvesting system has following components: (a) runoff producing catchment, (b) runoff collection scheme, (c) runoff storage facility, and (d) cultivated or cropped area (Oweis et al., 1999).

2.2. Climate change and adaptation to climate change

According to (Ramamasy, 2007)"climate is statistical information, a synthesis of weather variation focusing on a specific area for a specified interval; climate is usually based on the weather in one locality averaged for at least 30 years". So, climate is often defined as the weather averaged over time (typically, 30 years, WMO) (MONRE, 2008)

Weather is the day-to-day state of the atmosphere and its short-term (from hours to a few weeks) variations such as temperature, humidity, precipitation, cloudiness, visibility or wind (Ramamasy, 2007)

Climate change is the natural phenomenon but is accelerated by human acitivities (O'Brien, O'Keefe, Rose, & Wisner, 2006)It can be manifest in the following ways:: slow changes in mean climate conditions, increased inter-annual and seasonal variability, increased frequency of extreme events, and rapid climate changes causing catastrophic shifts in ecosystems (Tompkins & Adger, 2004). In IPCC report (2007), climate change was understood as any changes of climate over time due to natural changes or results of human activities. In accordance with United Nations Framework Convention on Climate Change (UNFCCC), climate change refers to direct or indirect activities of humans, leading to change in global atmosphere components and create changes of natural climate variability observed over comparable time. Regarding climate change views, (Smit & Skinner, 2002) and (Cruz, Harasawa, Lai, & Wu, 2007), climate change is defined as changes through increasing in frequency and intensity of extremes weather events including storm, flood, drought and irregular rain over time and irregular climate signal.

Adaptation is a terminology which is refered to any adjustment, whether it is passive, reactive or anticipatory for responding to ancipitated or actual consequence (Carter, Parry, Harasawa, & Nishioka, 1994).

Adaptation to climate change is the process through which people can reduce adverse effects of climate change on their lives, health and well-being, and might take advantages of the opportunities that changes of climatic environment provide (Feenstra, Burton, Smith, & Tol, 1998).

2.3. Economic analysis of rainwater harvesting systems

Basically, there are three main trends in analyzing economics of rainwater harvesting systems which are i. diversity of cropping patterns and irrigation methods on one rainwater harvesting technology, ii. various rainwater harvesting structures for one fundamental purpose and iii. assessment of specific rainwater harvesting techniques in pilot studies.

In relation to the first trend, Yuan and his colleage (2003) has conducted a study on evaluation of economic feasibility of rainwater harvesting systems as supplemental irrigation for agriculture in semi-arid area. Through various cropping scenarios of local prevailing crops and two irrigation methods including drip irrigation and portable labor irrigation, outputs of the study show importance and usefulness of utilizing rainwater harvesting for cropping, making full use of unoccupied land. It is emphasized that in order to maximize economic benefits, selected crops or cropping patterns should have crop water demand coincide with local rainfall events; particularly in this study tomato is found the most suitable.

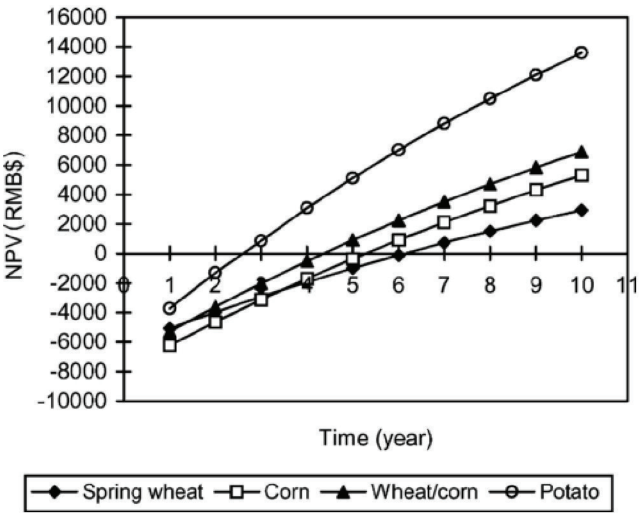


Figure 2.1 Economic analysis of water harvesting with different crops.

(Source: Yuan et al., 2003)

In other areas where indigenous knowledge on rainwater harvesting application is already popular, researches are focused on identifying which is the most economical technique in the study area. One of typical examples for this development is the research of (Machiwal, Jha, Singh, Mahnot, & Gupta, 2004) on planning and design of cost-effective water harvesting structures in northwest semi-arid region of India. Four macro-catchment rainwater harvesting structures at different scales in terms of structure's height were selected including earthen embankment, dry-stone masonry (DSM), upwall cement masonry (UCM) and anicut. Firstly, cost analysis was conducted for determining effective construction cost techniques. Secondly, economic analysis with regards to net present value and benefit-cost ratio was applied in order to select the most economical techniques. Interestingly, outcomes of the study suggested both DSM and UCM are cost-effective techniques as although DSM had higher economic indices than UCM, the latter structure is more suitable to soils than the former one.

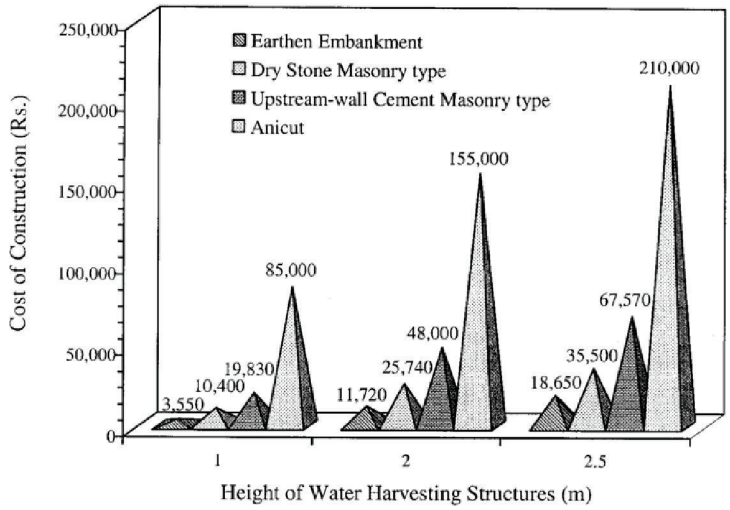


Figure 2.2 Cost comparison of propsed and indigenous water harveting structures
(Source: Machiwal et al., 2004)

Table 2.1 Net benefits without and with the proposed rainwater harvesting structure

Details	Season	Crop	Area (ha)	Cost of cultivation (Rs.[a] ha^{-1})	Gross return (Rs. ha^{-1})	Total cost of cultivation (Rs.)[a]	Total gross return (Rs.)	Net return (Rs.)
Without water	*kharif*	Maize	2.5	744	3240	1860	8100	6240
harvesting	(rainy)	*Urd*	2.0	827	1724	1654	3448	1794
structures	*rabi*	Wheat	1.0	1446	4200	1446	4200	2754
	(winter)	Barley	1.0	1092	2400	1092	2400	1308
Total								**12096.00**
With	*kharif*	Maize	3.5	1687	4800	5905	16800	10895
water	(rainy)	*Urd*	2.5	1450	3486	3625	8715	5090
harvesting	*rabi*	Wheat	2.0	2563	6024	5126	12048	6922
structures	(winter)	Mustard	2.5	1580	6497	3950	16243	12293
Total								**35200.00**

[a] Rs. = Indian Rupees (47 Rs. = 1 US $).

(Source: Machiwal et al., 2004)

The third researching trend of analyzing economy of rainwater harvesting systems is case study on specific conditions. For example, (Mutabazi, Senkondo, Mbilinyi, Tumbo, & Mahoo, 2004) assessed economic benefits of rainwater harvesting for crop production in Tanzania for two types of crops (maize and lablab). Economic outcomes presented high potential of the system ($26.9/person-day of water harvesting model compared to $3.3/ person-day of rainfed system) and was considered as effective solution of poverty reduction. In a similar way, (Sethi, Panda, & Pholane, 2005) estimated and compared benefit-cost ratio of farms with and without on-farm reservoir system (for rice, mustard and fish). Overall results showed great benefits of the integrated water-harvesting model with B/C ratio ranges from 2.63 to 4.23 as lined and un-lined reservoirs.

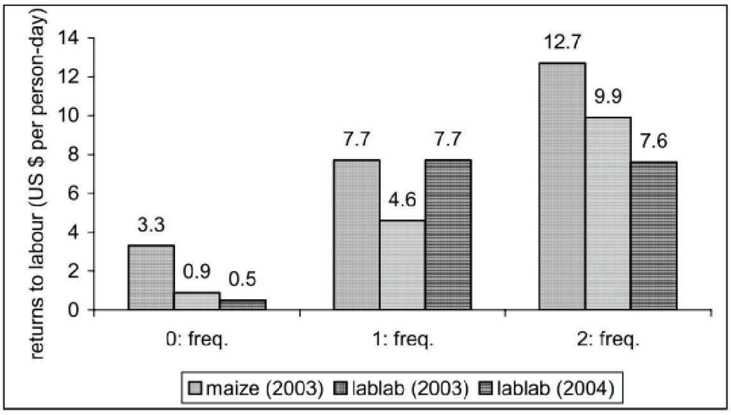


Figure 2.3 Returns to labor of sole maize, lablab during rainy seasons 2003-2004 (Source: Mutabazi et al., 2004)

2.4. Mapping potential area of rainwater harvesting

There have been a large number of researches integrating rainwater harvesting into GIS environment in order to identify potential location for application, runoff potential and suitable area of applying considering not only physical factors such as rainfall, soil, evaporation, topography but also socio-economic factors for the better reliability of obtained results.

Most research on potential map of rainwater harvesting area based on overlaying of thematic maps with different criteria of integrating and assessing. (UNDP & ICRAF, 2007; UNEP & ICRAF, 2005) conducted a research on mapping potential area of rainwater harvesting in Africa. Thematic maps on physical factor of rainfall, land use, topography and constraints were constructed prior to be overlaid for generating potential area. Criteria of the potential selection comes from priority to place having target rainfall, for example less than 1200 mm per year; as for places of higher than this figure, the necessity and incremental benefit of technique will be reduced significantly. Other consideration relating to agricultural land and distance to the farm are evaluated for the mapping.

The similar concept was applied by but the research has categorized physical factors of rainfall, slope, soil, land cover by its relative importance index, given rainwater harvesting structures. Suitability level of above factors was used for ranking the total weighted of different area; as a result, suitable area was ranked as low, medium and high potential.

Table 2.2 Suitability levels of different factors of water harvesting for stone terraces

Suitability values	9	8 – 7	6 – 5	4 – 3	2 – 1
Soil texture	Sandy loam	Sandy clay loam	Clay loam	Loamy sand and sandy clay	Other class
Soil depth (cm)	>100	50-100	30-50	10-30	<10
Slope (%)	18 – 30	10-18	5 – 10	2 – 5	0 – 2
Drainage (m)	0 – 125	125 – 250	250 – 350	350 – 500	>500

Land use/ cover	Cropland	Open bushland	Open bushland with scattered trees	Open wood land with bushes	Riverine vegetation

(Source: Mbilinyi et al., 2007)

Another researching trend is integrating SCS curve number into GIS with or without characteristic of different indigenous rainwater harvesting technology for identifying suitable area. (Gupta, Deelstra, & Sharma, 1997) and (Kadam, Kale, Pande, Pawar, & Sankhua, 2012) estimated water harvesting potential for semi-arid land by firstly integrating SCS-CN method into GIS for estimation of runoff depth, then prioritizing potential runoff generation of basins prior to applying characteristic of indigenous rainwater harvesting model for suitability of different water harvesting techniques. It is similar for a research on identifying potential runoff harvesting site, conducted by (Winnaar, Jewitt, & Horan, 2007). Overall results of these projects presented map of potential of runoff harvesting spatial domain on low, medium or high suitability of application.

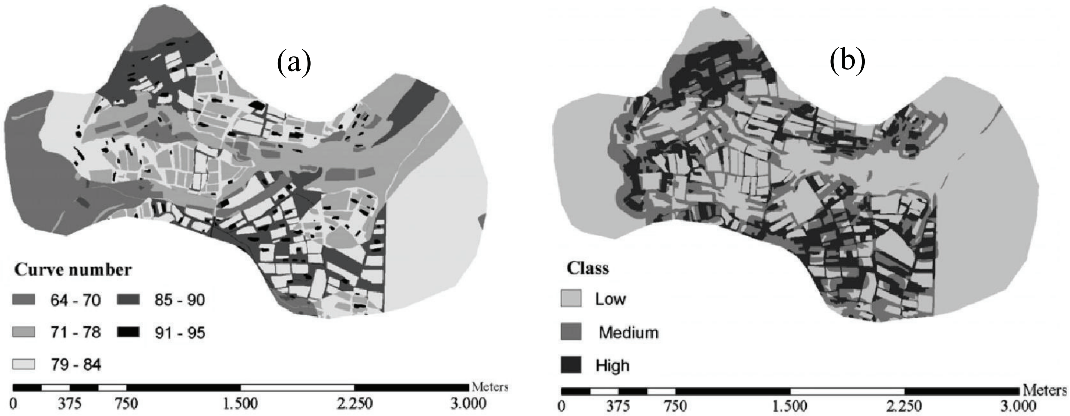


Figure 2.4 Output maps of different curve number (a) and suitability rank level of runoff harvesting (b) in Potshini catchment

(Source: de Winnaar et al., 2007)

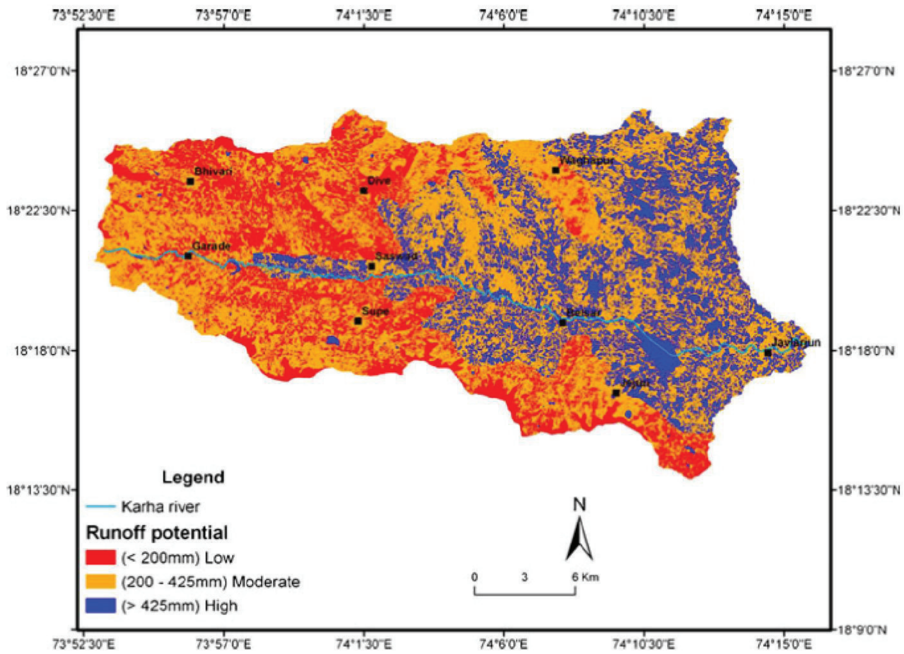


Figure 2.5 Map of runoff potential in upper Karha watershed

(Source: Kadam et al., 2012)

Applying GIS with decision support sytem or mutli-criteria decision making is another development that several researchers pursued such as (Mwenge Kahinda, Taigbenu, Sejamoholo, Lillie, & Boroto, 2009) and (Ali, Yazar, Abdul Aal, Oweis, & Hayek, 2010). These researches shared a similarity of considering wide-range factors from physical to socio-economic and environment so as to reduce risk of failure for application of the technology. Outputs of them then could be exported to common software such as MS Excel for assisting local authority in water harvesting plan.

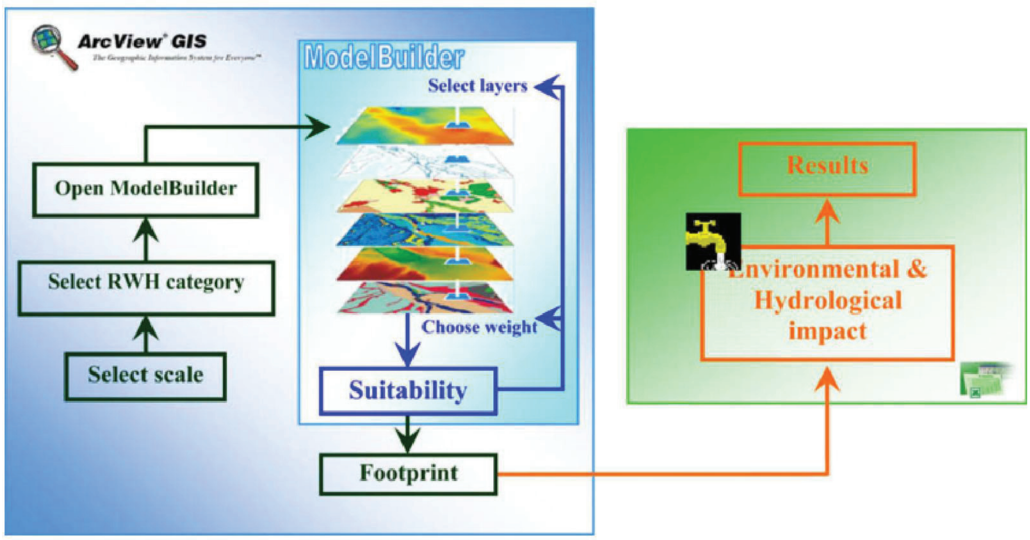


Figure 2.6 Structure of rainwater harvesting decision support system

(Source: Mwenge Kahinda et al., 2009)

2.4.1. Applying Analytic Hierarchy Process in mapping suitability of rainwater harvesting

Analytic: knows as a framework of the word analysis, that means the separating of any material or obstruct being into its ingredient elements.

Hierarchy: the question is that how can human's well deal with most intricacy? Herbert Simon, which scientists knows him father of Artificial Intelligence field and Nobel laureate; he said "Large scale organizations are comprehensively hierarchical in structure. Moreover, they are divided into some units that the units also divided into small units, and they are tuning to subdivide and this process in going on. The hierarchical subdivision is not a property that is exceptional to human organizations. It is common to exactly all intricacy system of that we have knowledge.

Process: defined a process which is a series action, changes, or operate which bring about an end or result. The Analytic Hierarchy Process (AHP) is not model or magic formula which finds the correct answer. Somewhat, it is a process which assists decision-makers to find the best answer. However, in here we will discuss about AHP in more details shortly (Forman & Selly, 2001).

The (AHP) is most useful a structure technique for dealing with extensive decisions. Ruther than recommend a "true" decision, the AHP assist the decision makers find the one which well reasonable their needs and their comprehension of the problem. According to mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been widely studied and refined since then. The AHP technique can provides a universally and rational framework for arranging a decision problem, for symbolize and quantifying its elements, for make a connection between those elements to overall goals, and for evaluating optional solution. The AHP used around the world in vary of decision condition, in many fields such as government, industry, healthcare, business and education. Several companies supply computer software to assist in using the process. Users of AHP first decompose their decision problem into a hierarchy of easily understand sub-problems, each of that can independently analyzed. The elements of the hierarchy can relate to any point of view that decision problem impalpable, carefully measured or approximately estimated, well or poorly realized, anything at all which implement to the decision at hand.

India, a country with extreme population and incredibly increasing trend is under serious lack of natural resources; water in particular. However, previously RWH techniques were ignored, but currently new researchers has brought them to practice again. Generally, RWH is related to the rainfall, land use pattern, demand and some economic aspects of the stake holders. This study will concentrate on number of important RWH techniques for developing a suitable technique for a large scale industrial area in order to fulfill their daily water requirements. By using a mass balance method, Ripple diagram method, analytical method, and sequent peak algorithm method; some efforts were made to identify volume of stored water. By considering number of criterions, AHP method was selected for determining suitable type of RWH method. This entailed presence of various RWH structures in the study area. In terms of monetary advantages cooling affects of the water stored will improve the micro environment of inside of the industry. Consequently RCC Tank was found as most suitable RWH Structure for the company which will meet the requirements. For finding the appropriate size combination and number of the tanks, further AHP was applied. And eventually, four RCC cubical tanks with a height of 4m" was selected as suitable design by RWH method which met the requirements (Jothiprakash, Sathe, & Mandar, 2009).

In a study from Israel-Lebanon a methodology was set for water harvesting reservoirs in a 300Km^2 low rainfall area. The study was conducted by applying a three-step Hydro-Spatial Analytical Hierarchy Process (AHP). The first step was conducted through use of ArcGIS for producing pertinent spatial coverage. Secondly, watershed runoff was calculated by using Watershed Modeling System (WMS). And at third step AHP was used to develop a decision hierarchical structure; later on this was used to categorize reservoirs by considering their suitability and taking Reservoir Suitability Index (RSI) into account. And as a result of the research, a reservoir was set and excavated at the point of outlet of the most suitable Watershed (Jabr & El-Awar, 2004).

Chapter 3

Study Area

3.1. Location

The study area is located in Binh Thuan province, a south central coastal city, having coordinates of 10°56’ North and 108°6’ East. The province has borders with Ninh Thuan in the North, Lam Dong in the North-West, Dong Nai in the West and Ba Ria Vung Tau in the South, with total 8 districts and 125 communes.

Binh Thuan has population of 1.2 million people and population density of 192 person/ km2, which is lower than national average (252 person/ km2). There are 28 ethnic minorities in Binh Thuan, of which Kinh, Cham and Reglay are three biggest communities with 78%, 11.3% and 9.4% respectively (General Statistic Office, 2012).

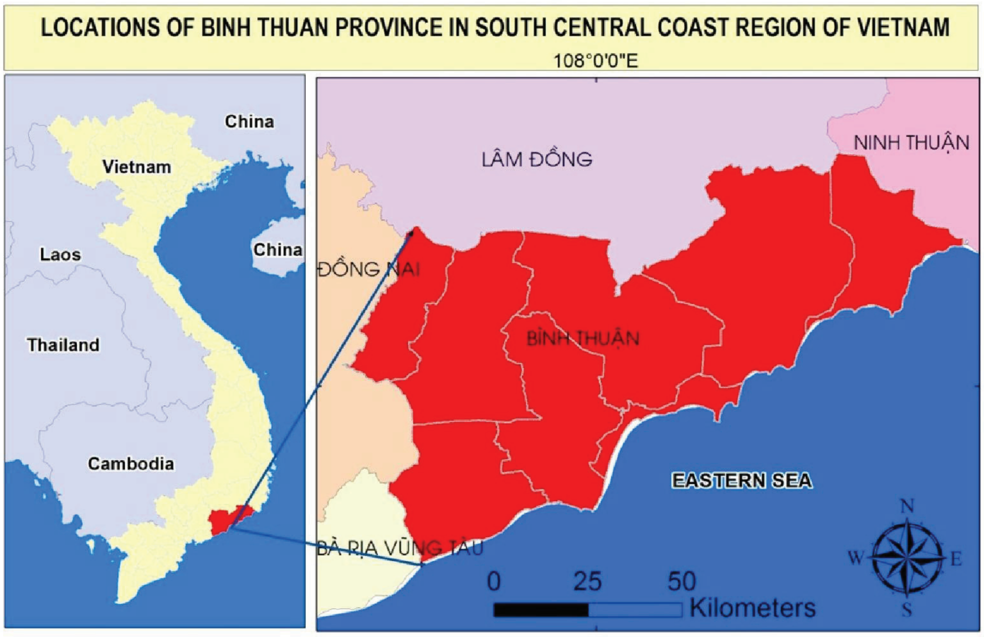


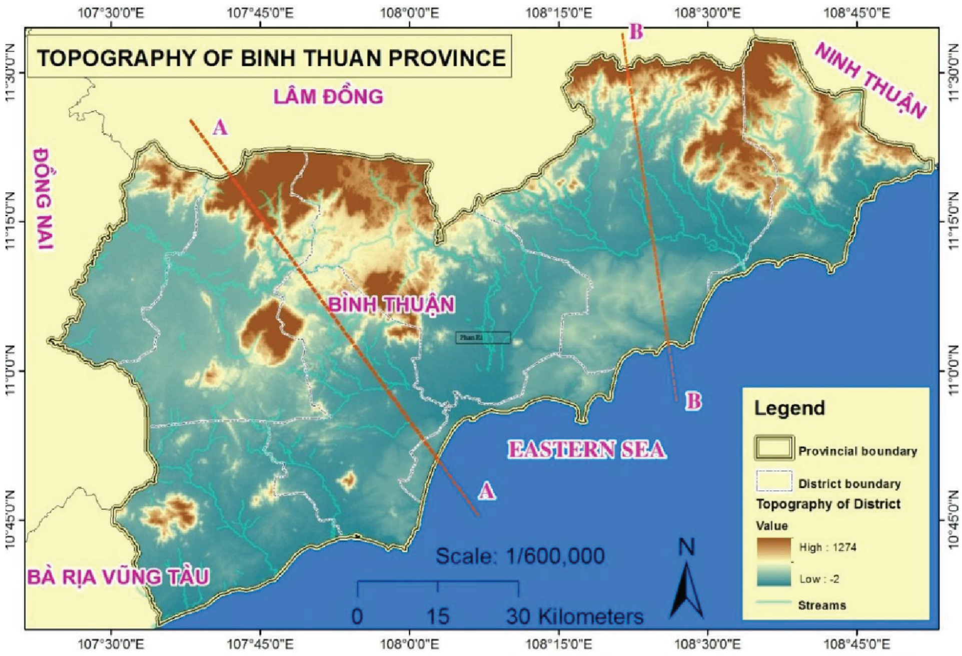
Figure 3.1 Location of Binh Thuan in south central coast region of Vietnam

3.2. Topography

The most typical characteristic of topography here is transfer from mountain land in the west to the low river delta in the middle and some coastal hilly sandy area in the East. According to elevation, we can divide the topography into 4 categories as below:

- Medium mountain (>500m): accounts for 31.65% natural land, mainly in the North and North West of the province;
- Low mountain (200-500m): occupy around 41% of total land, mostly being forest area;
- Hill and coastal sandy dune (100-200m): ranges from North East to South coastal line, having wave shape, account for almost 20% of the land;
- Low delta (5-100m): is delta of main rivers in the province such as Long Song river, Luy river and La Nga river, occupy approximately 10% of the area.

As can be seen that, this topographic pattern can diverse economic development of the province but at the same time leads to constraints to people’s lives and their settlement.



Topography of the province is calculated from SRTM DEM 90 m

Figure 3.2 Topography characteristics of the study area

3.3. Climate

The study area has sunny and hot climate condition throughout year with high evaporation and other characteristics of tropical monsoon climatic pattern. Dry season happens around 7-8 months with merely approximately 10% annual rainfall, as a contrast, rainy season of 4-5 months occupy nearly 90% of annual rainfall. As a result, the province suffers both hazards of prolonged droughts in dry season, leading to critical water scarcity, and flash flood in rainy season.

Table 3.1 Relationship of rainfall in rainy and dry season with annual rainfall

No	Station	Annual rainfall	Seasonal rainfall					
			May to October		November to December		January to April	
		(mm)	(mm)	(%)	(mm)	(%)	(mm)	(%)
1	Phan Thiet	1133,7	1023	90,2	110,7	9,8	5,5	0,48
2	Phan Ri	1068,8	946,9	88,6	121,8	11,4	15,3	1,43
3	Ham Tan	1596,7	1483,8	92,9	112,9	7,1	7,9	0,49
4	Ta Pao	2353.9	2155,7	91,6	198,2	8,4	20,7	0,88

(Source: Department of Meteorology in Binh Thuan province)

a. Temperature:

The area is under high temperature which averages from 25 to 27oC. Hottest months are June to August with around 29oC while December and January are recorded among coldest months with temperature of 21-24oC.

b. Humidity:

The average annual humidity is 79%. The months having highest humidity are November and December, while the lowest month is July.

c. Sunshine hour: Binh Thuan has relatively high sunshine hour, with annual sunny hours is from 2,500 to 3,000. In July, August, September the number of sunny days is lowest and those of December, January, February and March are highest.

d. Wind:

Average wind speed is from 2 to 3 m/s, and highest in October and November. The prevalent wind direction is south-east and north-west in the rainy and dry seasons.

e. Rainfall and evaporation:

These two factors follow opposite trends in the study area. While annual rainfall reduces from 2800mm in the West to only 600-800 mm in the East, the corresponding figures of evaporation increase from 1100mm to 1600 mm.

This leads to a high fluctuation between ratio of rainfall per evaporation among West and East parts of the study area, ranging from 3 to less than 0.5.

Below is an illustration of contradiction in terms of topography, rainfall and evaporation in the study area.

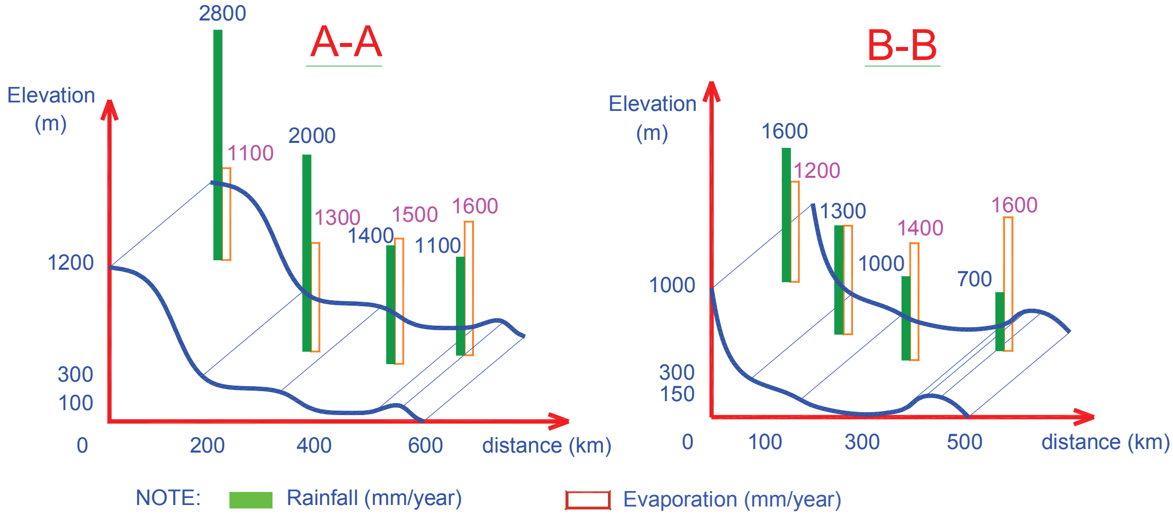


Figure 3.3 Relationship between topography, rainfall and evaporation in study area

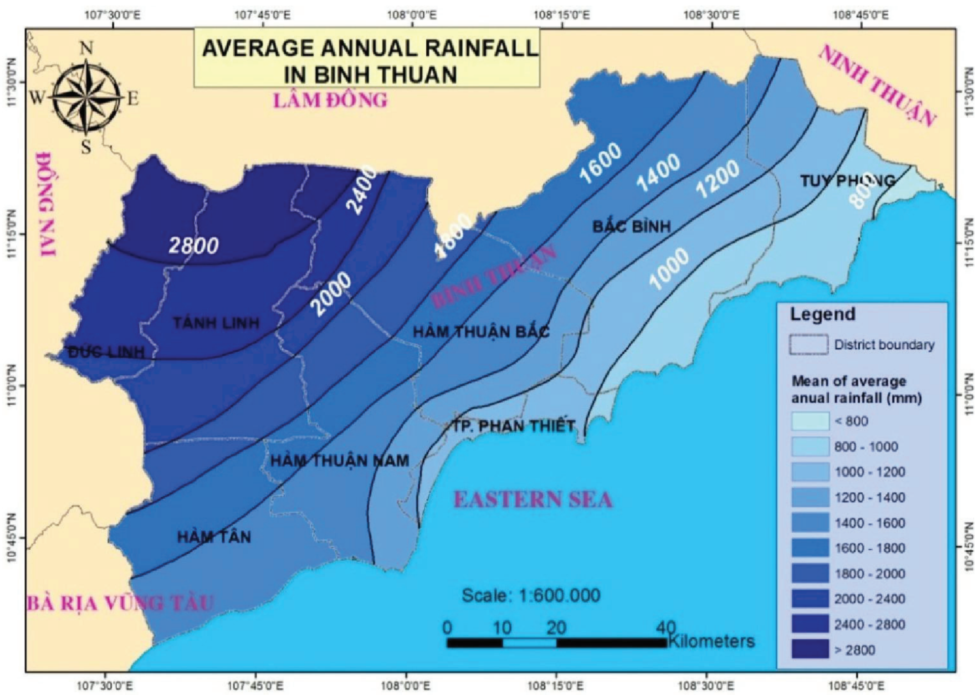


Figure 3.4 Average annual rainfall in the study area

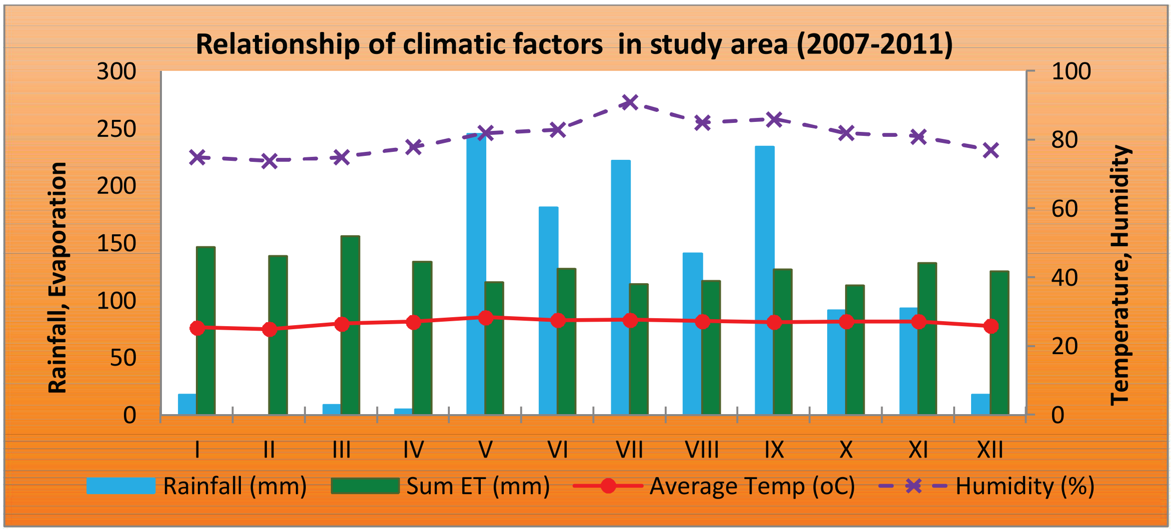


Figure 3.5 Typical relationship of climatic factors in the study area (Phan Thiet station)

- (Source: Department of Meteorology in Binh Thuan province)

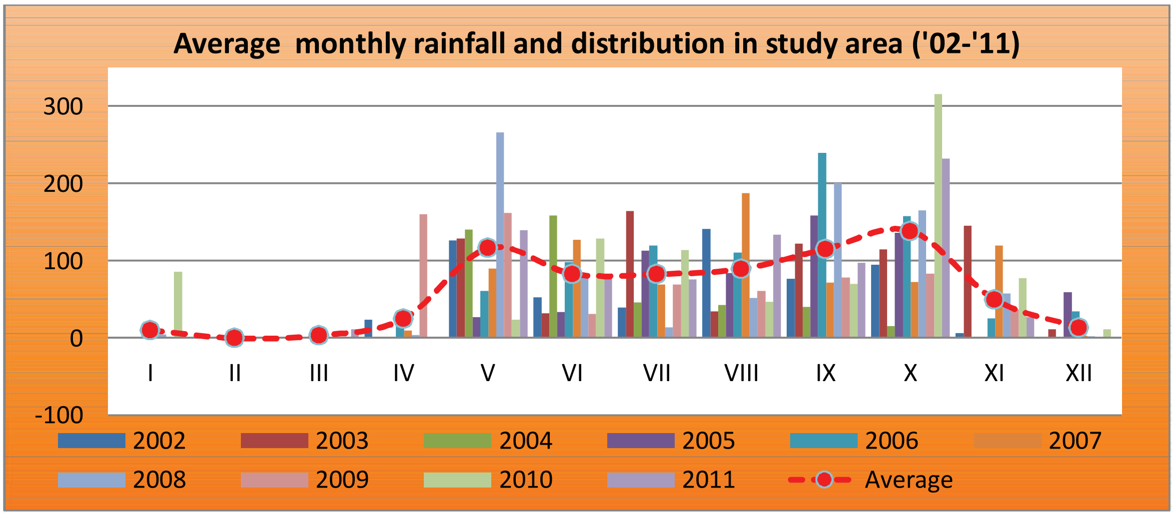


Figure 3.6 Monthly rainfall average and distribution in study area (Bau Trang station)

(Source: Department of Meteorology in Binh Thuan province)

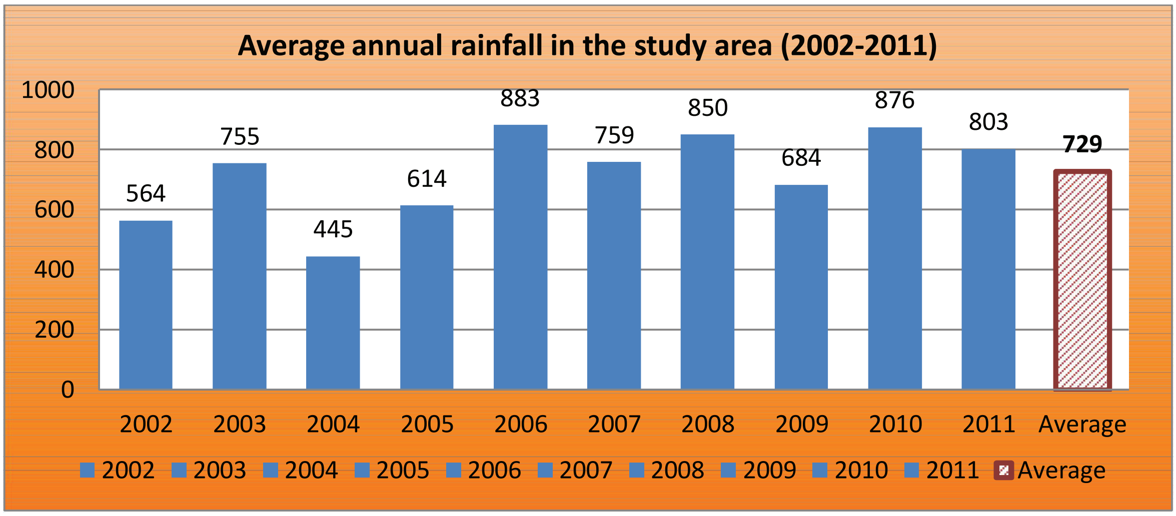


Figure 3.7 Annual rainfall in study area (Bau Trang station) from 2002 to 2011.

(Source: Department of Meteorology in Binh Thuan province)

3.4. Drought

Drought often occurs on the study area, leading to significant damange on production and local people's lives. For example, estimated damange by drought in 2004 is above 14 million US dollar (of which agriculture accounted for above 13 million and one million lost of forest). This was caused by low rainfall, consequently, storage capacity of reservoirs in the area obtained only 40% total capacity.
Furthermore, besides a high difference between rainfall in dry and rainy season, the monthly rainfall largely fluctuate; for example in rainy season, rainfall amount of the highest and lowest month is much different. Therefore, agricultural production faces with many difficulties even in rainy season and particularly long dry season.

Table 3.2 Frequent statistic of drought events (7, 10, 15 days) in the study area

Location	Drought	V	VI	VII	VIII	IX	X	XI	Average
Luy river (Bac Binh district)	7 day	0.86	0.68	0.45	0.50	0.36	0.68	1.18	0.67
	10 day	0.64	0.32	0.14	0.36	0.14	0.41	1.00	0.43
	15 day	0.18	0.09	0.05	0.09	0.00	0.05	0.45	0.13
Phan Thiet city	7 day	0.60	0.43	0.33	0.18	0.28	0.79	1.28	0.56
	10 day	0.30	0.10	0.05	0.00	0.03	0.37	0.83	0.24
	15 day	0,08	0.03	0.00	0.00	0	0.03	0.38	0.07
Ham Tan district	7 day	0.61	0.25	0.20	0.27	0.25	0.70	1.32	0.52
	10 day	0.34	0.09	0.05	0.07	0.07	0.36	0.89	0.27
	15 day	0.14	0.02	0.00	0.02	0.05	0.07	0.52	0.13

(Source: Department of Meteorology in Binh Thuan province)

3.5. Water source

a. Surface water:

General features of rivers and streams in the area are short and steep. Average of coverage of rivers is 0.211 km/km2, maximum is 0.368 km/km^2 (Ca Ty river basin in Phan Thiet city) and minimum is 0.148km/km^2 (Dinh river basin in the South-West).
With 4100 km2 basin area and 290 km length, La Nga is the biggest river in study area; however, most of flow discharges to outside of the province.
River networks are distributed mainly in mountains in the west and central plain, while large coastline land does not have river system. Consequently, this area is currently the most severe water scarcity in the province.

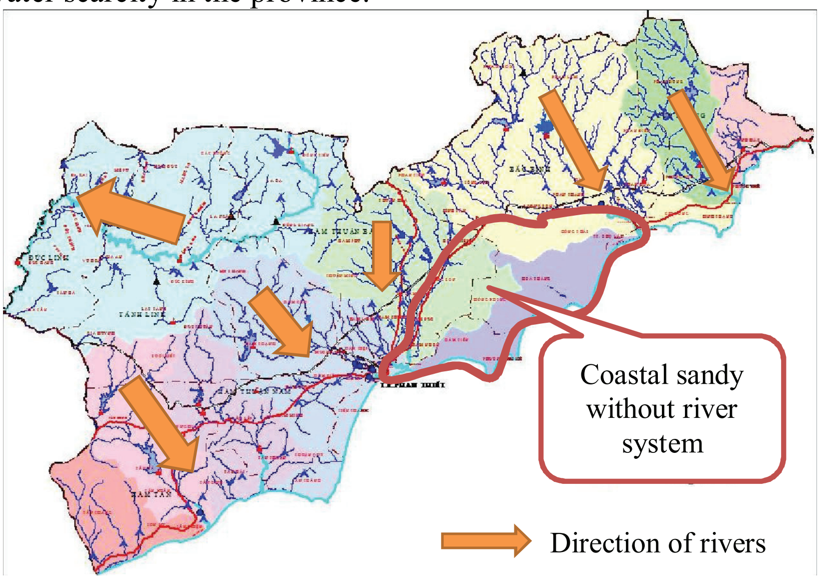


Figure 3.8 Direction and distribution of rivers in the study area

b. Groundwater:

Despite of having multi-level groundwater, ability of groundwater extraction is rather limited due to uneven distribution in both vertical and horizontal scale. Additionally, groundwater levels are narrow and have many seepage lines. Therefore, groundwater can meet with only small and medium water demand.

Potential extraction capacity of groundwater in the province is estimated around 563.3 thousand m^3/day, of which capacity of levels:

- Holocen groundwater level: 135 thousand m^3/day;
- Pleistocen - Holocen: 481 thousand m^3/day;
- Bazan pleistocen: 22 thousand m^3/day.

(Source: Binh Thuan irrigation strategy plan 2011-2020)

Field investigation during data collection shows very limited groundwater extraction ability. Some local households in two coastal communes of Hoa Thang and Hong Phong in Bac Binh district even dig holes of hundreds meters without water. Hence, rainwater is unique water source for them in every normal activities and agricultural production.

3.6. Irrigation

Most of low land plains, having convenient water sources such as rivers and water reservoirs, have been developed irrigation scheme for agriculture. The problem, currently, places in hilly coastal area where out-of-coverage of existing irrigation canals. The figure below illustrates one of planning solution: a 3-stage pumping station, transferring water from Luy river basin to Hoa Thang commune.

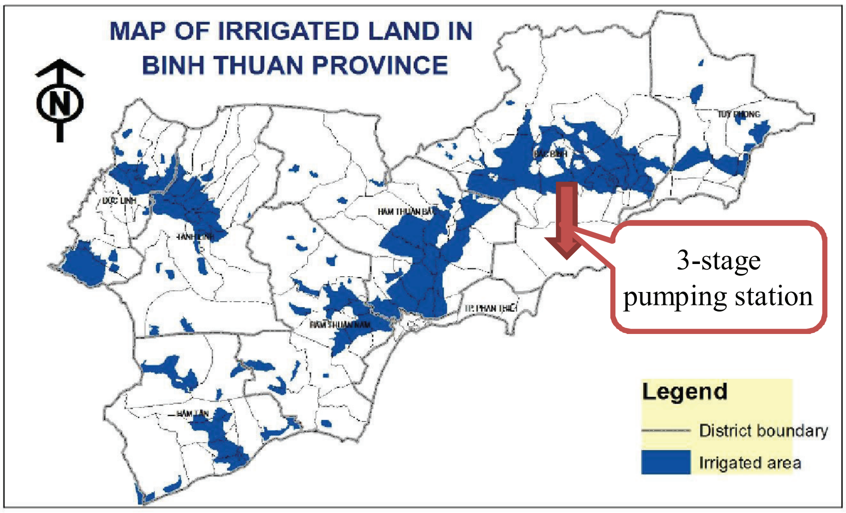


Figure 3.9 Irrigated area in study area_Binh Thuan province

Furthermore, according to data of Binh Thuan Irrigation Company, designed capacity of irrigation infrastructure serve for only 65% annual planting area, around 58,407 ha.

3.7. Agriculture

Agriculture is the major livelihood of local people in the study area. Major agricultural products are rice, corn, short-day crops (cotton, sugarcane), long-day crops (cashew, pepper, rubber and coffee trees), cereal crops (green bean, dry bean, peanuts and vegetable) and fruits (mango, custard apple, grape and dragon fruit...).

Among these products, rice and corn are traditional food crops with steady increase in both planting area and productivity. Casava and beans are planted in rotation between seasons for the purpose of improving soil nutrition and mostly planted on sandy area of coastal land. Major cropping pattern in the province are:

1 Rice pattern: varies from one season in summer upto two or three seasons per year;
2 Rice and vegetable pattern: usually is one or two rice seasons coupled with one season of vegetable;
3 Short-day crops and vegetable: being rotated between types of bean, corn, casava and vegetable;
4 Yearly pattern: these are industrial trees (coffee, cashew, rubber, pepper and tea) or fruit trees such as mango, longan, dragon fruits and particularly grape.

While rice, corn and some long-day trees such as coffee, rubber which request high amount of water either being planted places of convenient water source or supplied by irrigation system, this study area focus crops for coastal land in the absence of irrigation facilities and streams. Below is another example of cropping pattern in sandy land of coastal land:

Table 3.3 Main cropping patterns sandy land in two coastal communes

Cropping patterns	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	------"winter-spring" peanut -------				------ "summer" peanut -------				--------"autumn peanut" ----			
2	------------"empty"-----			---------water melon--------			--------- bean dry ----------			-----empty----		
3	-------"empty" ---------			---------groundnut-----------			--------groundnut----------			----empty-----		
4	----------empty----------			---------------------------casava-------------------------						------empty------		
5	-----------------------Fruit trees (custard apple, mango, cashew, lemon…) ---------------------------											

(Source: Updated from primary data & Nguyen Cong Vinh, 2007)

3.8. Climate change

According to a recent report of World Bank (2011) on Climate change in Vietnam, major effects of climate change on the country are increase of temperature, variation of rainfall in both spatial and temporal scales, and increase of sea level. As a consequence, these impacts threaten to reduce agricultural productivity, increase water scarcity and other extreme weather, damage on ecological system and spread diseases. Following part is some analysis on major effects of climate change on the study area:

- *Increase of temperature*

Statistic measuring data on temperature in the study area shows an increasing trend of temperature by 0.3 degree from 1990 to 2010.

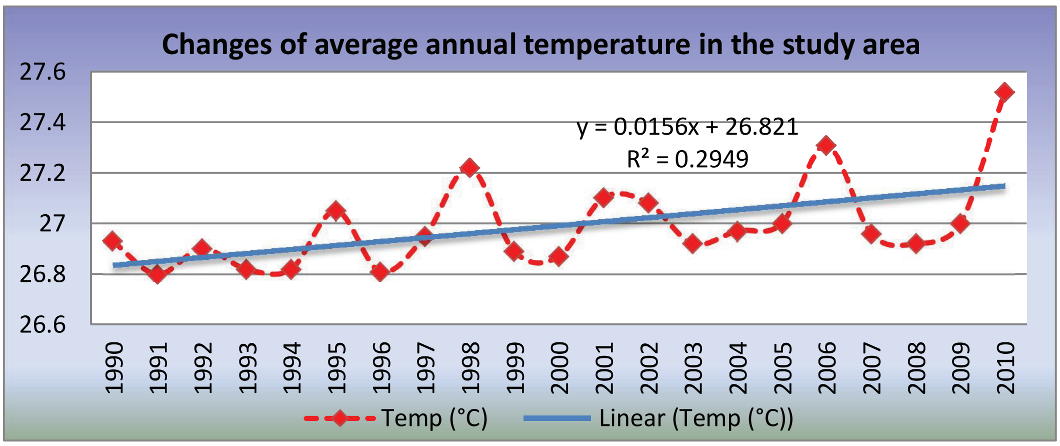


Figure 3.10 Annual temperature in study area (Phan Thiet station)

(Source: Department of Meteorology in Binh Thuan province)

- Variation of rainfall

Although historic data of rainfall in Phan Thiet city from 1957 to 2008 points out an increase in annual rainfall, that amount is uneven distributed both spatially and temporally. Most of increased rainfall occurs in rainy season while dry season has less rainfall (a comparison between rainfall in period of 1983-2008 and 1957-1983). Due to this negative trend, the more intensive and frequent floods are in rainy season, the more severely droughts occur in dry season.

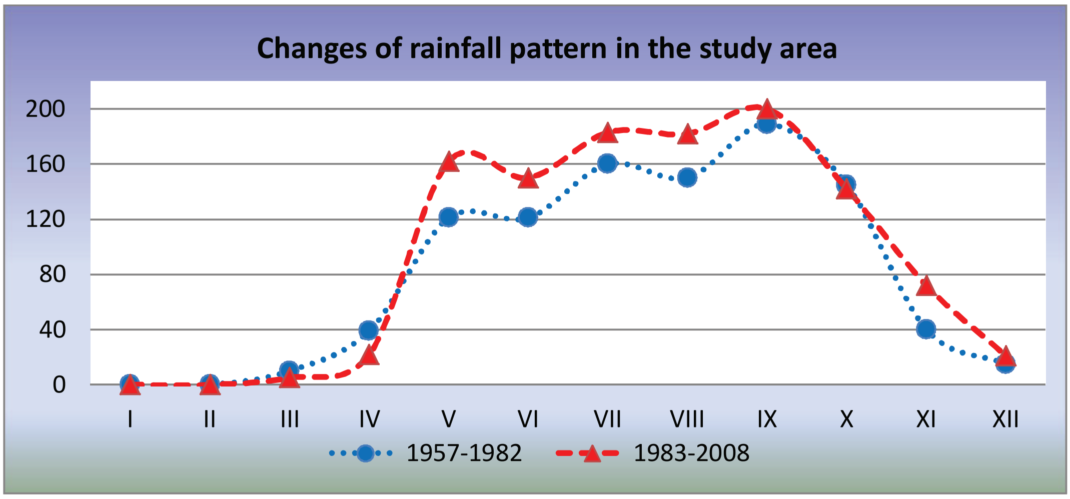


Figure 3.11 Comparison of rainfall pattern between period of 1957-1982 and 1983-2008

(Source: Department of Meteorology in Binh Thuan province)

- Increase of sea level

Measuring data in Vung Tau station from 1980 to 2007 present an increase in sea level. Comparision on maximum sea level during this period shows a rise by 0.2-0.6 cm per year.

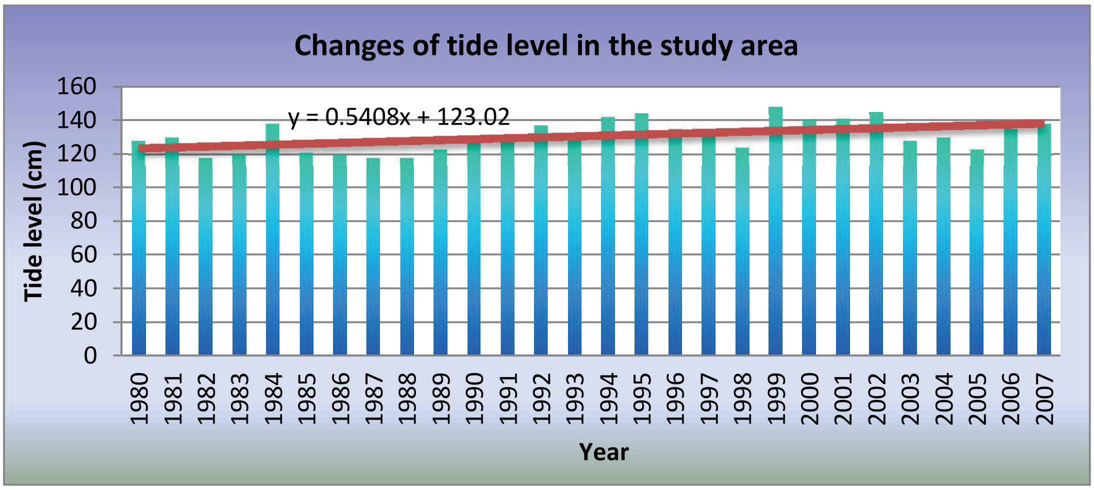


Figure 3.12 Maximum sea level in Vung Tau station (adjacent city of the study area)

(Source: Department of Southern Meteorology in Ho Chi Minh city)

The rise of sea level has been exacerbating river bank erosion and salinity instrusion the study area. Salinity instrusion in Long Song river used reach upto 2km towards the upstream. Similar cases were happened in Luy river and Phan river basin. These detremental impacts significantly affect to both surface and groundwater's quality, hence reducing agricultural producitivity, especially with coastal communes.

Chapter 4

Methodology

4.1. Research approach

The following figure illustrates the methodology approach of the research:

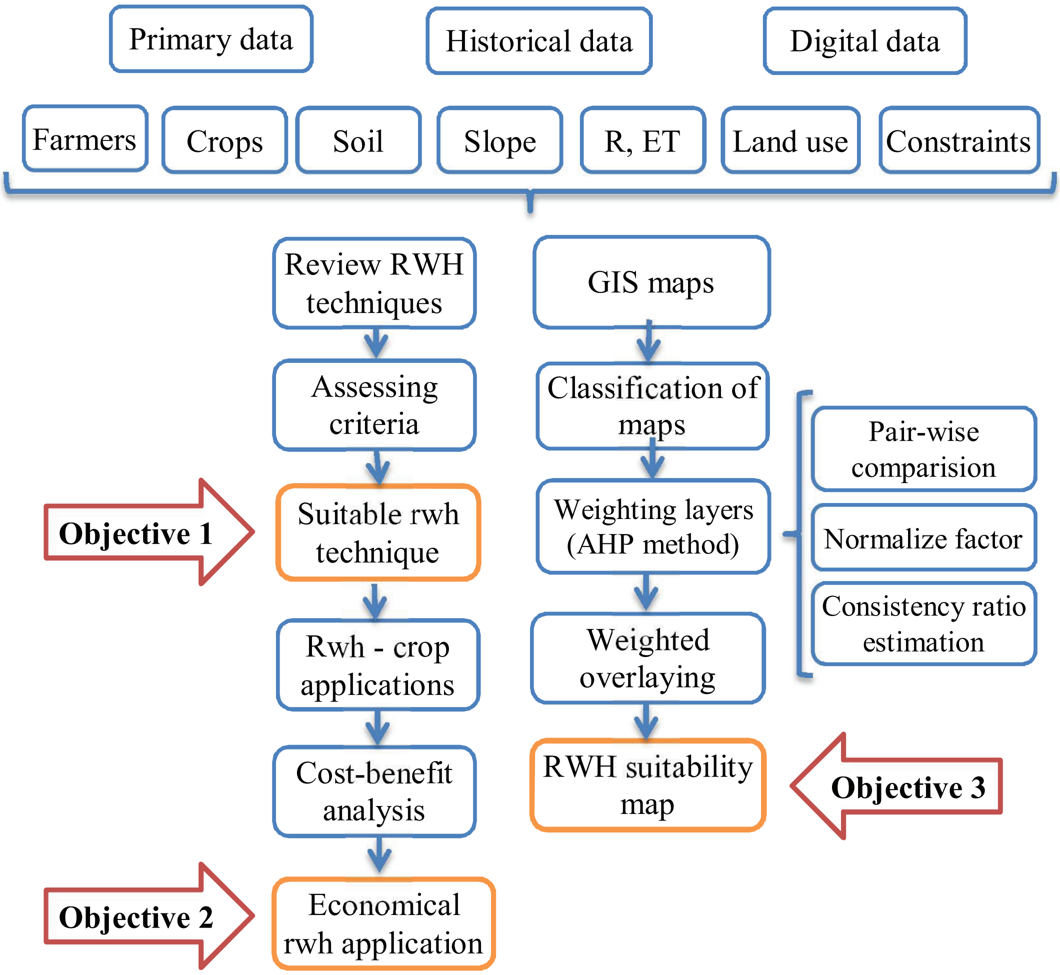


Figure 4.1 The methodology approach of the thesis

Table 4.1 Research study framework

No.	Objectives	Sub-objectives	Tasks	Tools/Output
1	- to select suitable rwh techniques in the study area;	- to review available rainwater harvesting techniques; - to assess suitability of techniques with local conditions of the study area.	- Data collection on rwh techniques, - Conducting site survey and interviews on natural conditions, cropping, farmer's participation; - Selecting main criteria for assessing; - Evaluating suitability of techniques based on proposed criteria.	- Review on characteristic of rwh techniques; - Suitability assessment of techniques in the study area.
2	- to analyze cost-benefits of rwh-crop applications for the most economical solution;	- to calculate necessary parameter of the water harvesting application; - to calculate construction cost and generated benefit of the application - to analyze cost-benefit of water harvesting solutions	- Investigating on local crops, cropping style, price of construction material and fruits; - Calculating water requirement and scope of the water harvesting system; - Calculation construction cost and benefit of the structures; - Analyzing investment and benefits of crop-water harvesting solutions.	- Scope of the water harvesting application in terms of crops, design parameters; - Cost and benefits of the system; - The most economical crop-water harvesting solution.
3	- to apply GIS and AHP method in locating potential area of rwh in the study area.	- to create thematic maps on rainfall, soils, slope & land use; - to calculate weights of maps based on AHP method; - to overlay maps with its weights for potential location of rwh, and considering drought-prone area.	- Site survey for collecting data (climate, soil, topography & land use); - Data processing and reclassifying maps; - Calculating weights of layers (AHP); - Overlaying maps for potential location of rwh in the study area; - Assessing potential location in drought-prone area (based on UNCCD criteria: R/ET<0.65)	- Necessary thematic maps on climate, soil, topography and land use of the study area; - Weights of overlaying maps - Map of potential location of rwh in the study area.

4.2. Identifying suitable rainwater harvesting technique

4.2.1. Selecting criteria

1. Rainfall:

Rainfall is one of the most important factors to consider the appropriate technique of rainwater harvesting as it directly affects to crop water demand and necessary harvesting catchment. In area having low available rainfall plus with high fluctuation of rainfall distribution between rainy and dry seasons in a year, water shortage might experience throughout several growing stages of crops.

Hence, rainwater harvesting with storage capacity is required for ensuring crop's growth or at least its survival over long arid time. In contrast, rainwater harvesting can be implemented without separate storage structure in areas with less erratic rainfall patterns. For example, in some area of Africa or Middle East, there is two rainy seasons during a year, dry spells are significantly reduced, thus in-field rainwater harvesting techniques on soil-moisture content is adequate for crop water demand.

2. Temperature, evaporation, humidity and wind

Apart from relating to crop water requirement, these factors affects to scope of water harvesting. High temperature and evaporation leads to significant losses of harvested water, as a result, it requests prevention measure such as wind-break trees or rooftop covering. Wind speed has to be considered in water harvesting system with storage facility due to its effects on stability of the structure.

3. Water sources:

The availability of water sources plays an important role in determining the necessity of water harvesting or not. Hence, assessment of capacity of the available water sources as well as potential water supplying solutions in target area need to be done prior to apply rainwater harvesting. Generally, channeling surface water from rivers or ponds to the field is more economical than construction of water harvesting structure, as agriculture requests large amount of water. Economy of groundwater's exploitation highly depends on geohydrology conditions and available technology in comparison with water harvesting.

4. Topography

Both runoff generation and infiltration rate, two important factors of a water harvesting system, are strongly under effects of topography. The steeper the topography is, the higher runoff it can generate and the lower infiltration rate is; and vice versa. However, most rainwater harvesting techniques are suitable with some certain range of topography only. Additionally, topography affects to stability of the water harvesting structure and construction volume, thus investment cost. Therefore, topography condition has great effect on selecting appropriate rainwater harvesting techniques in terms of runoff capacity, arrangement of structure's parts and investment.

5. Soil

Similarly, soil characteristics such as soil texture, soil depth soil types greatly affect to infiltration and runoff generation. For example, soils with large amount of clay or silty texture has low infiltration rate, thus it can generate runoff on surface land without any treatment. In contrast, light texture soil such as sandy loam is difficult in generating runoff due to its high infiltration, as a result, treatment of harvesting catchment such as plastic line or concreteness is required.

6. Crops and cropping measures

Different types of crops request different water demand. Therefore, their appropriate water harvesting varies in terms of technique and structure. Cropping solution also affect to the selection whether the technique can be mechanized or not.

7. *Economic* value and investment cost

Basically, investment cost of water harvesting depend on which technique is applied. Any treatment required for runoff generation or storage capacity leads to increase of investment. It is recommended to apply rainwater harvesting with high benefit crops such as fruit or special tree for maximum economic value.

4.2.2. Requirement of a water harvesting system

So as to ensure the sustainability, efficiency and acceptance of local people, water harvesting system must meet the following requirements:

- Suitable with local topography;
- Suitable with traditional cropping activities, people's knowledge;
- Easy operation and simple maintenance;
- Low construction cost, utilizing local material;
- Sufficient supplement shortage water during dry seasons.

4.3. Economic analysis of water harvesting application

4.3.1. Calculation of crop water requirement

According to Crop evapotranspiration - Guideline for computing crop water requirement (Allen, Pereira, Raes, & Smith, 1998), crop water requirement is equal to crop evapotranspiration. Crop evapotranspiration can be estimated directly by measurement or calculated from crop and meteorological data.

In this study, ET_0 and ET_c will be estimated by CropWat 8.0 that uses the Penman-Monteith methods (Allen et al., 1998) for calculating reference crop evapotranspiration. The Penman-Monteith methods to estimate reference evapotranspiration ET_o can be derived:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where:

ET_0: reference crop evapotranspiration [mm day^{-1}],

R_n : net radiation at the crop surface [MJ m^{-2} day^{-1}],

G : soil heat flux density [MJ m^{-2} day^{-1}],

T : air temperature at 2 m height [°C],

u_2 : wind speed at 2 m height [m s^{-1}],

e_s : saturation vapour pressure [kPa],

e_a : actual vapour pressure [kPa],

e_s - e_a : saturation vapour pressure deficit [kPa],

Δ : slope vapour pressure curve [kPa °C^{-1}],

γ : psychrometric constant [kPa °C^{-1}].

Then crop water requirement is calculated by follow relationship:

$ET_c = ET_0 \times K_c$

Where:

ET_0 : reference crop evapotranspiration [mm day^{-1}],

K_c : crop coefficient.

The crop coefficient is determined by experimental. It depends on crop type, climate, soil evaporation and crop growth stages. There are four main stages in crop's growing period, they are:

1. Initial stage,
2. Crop development stage,
3. Mid-season stage,
4. Late season stage.

Due to lack of K_c value for crops under Vietnam conditions, this study will take K_c from FAO, Irrigation and Drainage Paper No.56 (Allen et al., 1998).

To calculate the crop water requirement, data needed in CROPWAT (Smith, 1992) are:

1. Temperature

The (average) daily maximum and minimum air temperatures in degrees Celsius (°C) are required. Where only (average) mean daily temperatures are available, the calculations can still be executed but some underestimation of ET_o will probably occur due to the non-linearity of the saturation vapour pressure - temperature relationship.

2. Humidity

The (average) daily actual vapour pressure, e_a, in kilopascals (kPa) is required. The actual vapour pressure, where not available, can be derived from maximum and minimum relative humidity (%), psychometric data (dry and wet bulb temperatures in °C) or dewpoint temperature (°C).

3. Radiation

The (average) daily net radiation expressed in megajoules per square metre per day ($MJ\ m^{-2}\ day^{-1}$) is required. These data are not commonly available but can be derived from the (average) shortwave radiation measured with a pyranometer or from the (average) daily actual duration of bright sunshine (hours per day) measured with a (Campbell-Stokes) sunshine recorder.

4. Wind speed

The (average) daily wind speed in meter per second ($m\ s^{-1}$) measured at 2 m above the ground level is required. It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ.

Effective rainfall

Effective rainfall in relationship with crop irrigation requirement is the proportion of rainfall which contributes to compensating the water loss in the evapotranspiration process from the cropped field (Dastane, 1978). Effective rainfall can be estimated by both of direct measurement and formulae. There are a lot of existing formulae available for determining the effective rainfall. But in CROPWAT software, effective rainfall for agricultural crops is derived from the USDA-SC empirical formulae only (Smith, 1992).
Equation for calculation of effective rainfall as follows:

$$P_e = (125 - 0.2 \times P_{mon}) \times P_{mon}/125 \quad \text{(for } P_{mon} < 250 \text{ mm/month)}$$

$$P_e = 0.1 \times P_{mon} + 125 \quad \text{(for } P_{mon} > 250 \text{ mm/month)}$$

Where:

P_e : effective rainfall (mm);
P_{mon} : monthly rainfall (mm).

Crop irrigation requirement

Irrigation requirement is calculated by measuring the various ingredient of the soil water balance (Allen et al., 1998). This approach bases on assessing the inflow and outflow of water through the crop root zone over time period. Water supply from irrigation (I) and effective rainfall (P_e) go in to the root zone. Then part of that water supply may become surface runoff flux (R_o) and deep percolation flux (D_p). The root zone may also be supplied water from ground water by capillary rise (C_R). Water can be transferred horizontally by subsurface flow in or out of the root zone, this is represented by ΔSF. However, in the field that slopes are not large then ΔSF can be ignored. Crop evapotranspiration (including soil evaporation and crop transpiration) exhausts water from the root zone. Finally, the change in soil water content (ΔSW) can be measured over time period.

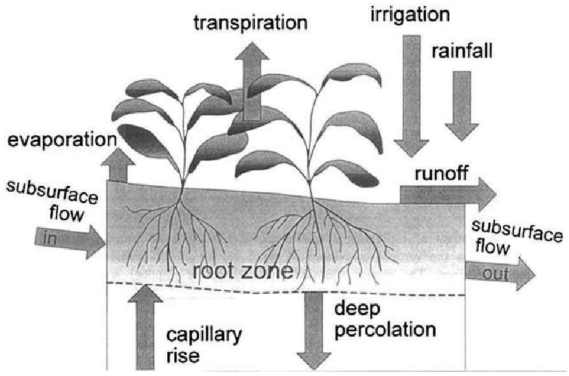


Figure 4.2 Soil water balance of the root zone
(Source Allen et al., 1998)

Calculation of irrigation requirement based on soil water balance equation (Allen et al., 1998) as bellow:

$$ET_c = I + P_e - R_o - D_p + C_R \pm \Delta SF \pm \Delta SW$$

Where:

ET_c : crop evapotranspiration [mm day^{-1}];

I : irrigation requirement [mm day^{-1}];

P_e : effective rainfall [mm day^{-1}];

R_o : runoff due to irrigation [mm day^{-1}];

D_p : deep percolation due to irrigation [mm day^{-1}];

C_R : capillary rise [mm day^{-1}];

ΔSF : difference between subsurface flow in and out of the root zone [mm day^{-1}];

ΔSW: the change in soil water content over time period [mm day^{-1}].

Then:

$$I = ET_c - P_e + R_o + D_p - C_R \pm \Delta SF \pm \Delta SW$$

In this study, CROPWAT is also used for calculating the irrigation requirement.

4.3.2. Calculation of water harvesting parameters

a. Design rainfall

In water harvesting design, the aim is to use a rainfall figure, so-called "design rainfall" that will meet the water requirement and produce a crop with a level of certainty. Because dry environment is characterized by a long and low rainfall in the dry season, thus, applying of average rainfall to design rainwater harvesting structure usually leads to failure (Hai, 1998). Therefore, the best design rainfall is probability rainfall because it is related to the frequency of occurrence or exceedance. For example, if the design rainfall is with 67 percent probability of exceedance, there might has two out of three years in which the rainfall reaches or exceeds the design figure, and thus crop water requirement would be met in two years out of three.

b. Probability analysis

Considering the variability of rainfall in the study area, the long term records of annual rainfall will be collected and then will be ranked from highest to lowest value and be arranged accordingly.
The probability of occurrence for each ranked observation will be calculated from the following equation:

$$P\ (\%) = \frac{m - 0.375}{N + 0.25} \times 100$$

Where:

P : probability of the observation of the rank m
m: the rank of the observation
N: total number of observations used

c. Rainfall-runoff relationships

Since a water harvesting system depends on how much runoff can be collected from a surface catchment, this step is very important. Several rainfall-runoff relationships have been demonstrated in the literature review, in this study, runoff coefficient method has been selected due to its flexible and sufficient reliable obtained from water-harvesting statistic in existing application before.

The method is a relationship between total rainfall and total runoff. Due to simplicity, runoff coefficient method is recognized as the most important method (Hai, 1998). Hudson (1981) has given runoff coefficients for use with the rational method to estimate peak runoff rates. These values based on soil type, land use and degree of slope. The coefficients can be extended to the estimation of runoff depth. Despite of small errors, this is the most comprehensive information.

Table 4.2 Values of runoff coefficient

Topography and vegetation	Soil texture		
	Sandy loam	Clay and silt loam	Clay
Woodland			
Flat (0-5%)	0.10	0.30	0.4
Rolling (5-10%)	0.25	0.35	0.5
Hilly (10-30%)	0.30	0.50	0.6
Pasture			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82
Urban			
Impervious	30%	50%	70%
Flat	0.10	0.30	0.65
Rolling	0.25	0.35	0.80

(Source: Hai, 1998)

d. Design for the required catchment area

A water harvesting scheme consists of catchment area for runoff producing and cultivated area for cropping. For any particular crop, the runoff generated plus with the rainfall falling directly on cropped area should be equal to crop water requirement:

Water requirement = rainfall + runoff

Therefore, the purpose of water harvesting design is to estimate the catchment area required for any given crop so as to ensure sufficient moisture for crop production. Rainfall is normally not adequate to meet crop water requirement. Hence, the amount of collected water should be equal to the extra water required by crop. This procedure is affected by runoff coefficient and the amount of rainfall received. Owing to some inevitably loss of water through deep percolation, efficiency factors is considered. The ratio between catchment area and cultivated land then is calculated by below equation:

$$\frac{Catchment\ area}{Cultivated\ area} = \frac{CWR - R}{R\ x\ C\ x\ E}$$

(Source: Critchley, 1991)

Where:

CWR: crop water requirement, mm;
R : design rainfall, mm;
C : runoff coefficient, 0 < C < 1;
E : efficiency factor, O < E < 1.

The efficiency factor is applied since not all water will be utilized in rootzone for plants. The factor varies greatly between season to season and is commonly used from 0.4 – 0.85 for surface irrigation scheme. Because of poor rainfall distribution, a range of 0.4 – 0.6 is suggested, with lower figure for drier areas (Hai, 1998).

4.3.3. Economic analysis of rainwater harvesting systems

In order to calculate economic value of the rainwater harvesting system, detailed estimates on construction, O&M costs and benefits resulting from crop must be prepared.

Added costs of the application include three major elements:

- Cost of construction: this cost consists of labor renting, material and necessary equipment for allocating water of the reservoir.
- Operation and maintenance cost: It is estimated that each three years requests major maintenance while minor maintenances are conducted every year prior to rainy season. Operation cost covering works of removing dust or water measuring is estimated on monthly basis.
- Cropping cost: it includes purchasing costs of crops, fertilizer, and estimated labor for cropping cultivation.

Benefits of the projects mostly are calculated based on yield of crops. Crops are selected so as to they can make benefits since the first year of application. However, while peanut can be harvested two or three times per year, the corresponding times of cashew, mango and mangosteen are one only.

Furthermore, some types of fruits such as custard apple or mango if having sufficient water supply for growing continuously in dry season can generate fruits in different season (New Year or Christmas) with price of 2 or 3 times higher than the main season.

The most two widely-applied economic indices including net present value (NPV) and benefit-cost ratio (B/C) are used for assessing the economy of proposed models.

1. Net present value

Net present value (NPV) is computed using the following equation:

$$NPV = \sum_{t=1}^{n}[\frac{B_t - C_t}{(1+r)^t}]$$

Where:

B_t and C_t : benefit and cost in year t, respectively.

r : discount rate

2. Benefit-cost ratio:

A benefits-cost ratio compares value of benefits to the present value of costs and is given by the following equation:

$$\frac{B}{C} = \frac{\sum_{t=1}^{n}[\frac{B_t}{(1+r)^t}]}{\sum_{t=1}^{n}[\frac{C_t}{(1+r)^t}]}$$

If the B/C ratio is greater than 1, the present value of benefits is greater than that of costs and the proposed crop-rainwater harvesting system is considered economically viable.

4.4. Mapping suitable location for rainwater harvesting

4.4.1. Type of data

Main purpose of this study is to select appropriate rainwater harvesting which both address water scarcity of agriculture and concurrently assist local people in adaptation to climate change.

Therefore, mapping criteria must consider not only physical factors (rainfall, topography, soil…) but also vulnerability of the community (poverty, livelihood…).

However, due to the unavailability of socio-economic maps in the study area, thus only physical and constraint factors are applied as preliminary reference before practical application. Below is list of digital data and its sources:

Table 4.3 Types and sources of data

No.	Attribute	Layers	Year	Format	Source
1	Physical layers	Rainfall	Average of annuals	ArcGIS	Binh Thuan Department of Meteorology
2		Evaporation	-	-	-
3		Land use	2008	-	Department of Natural Resource (DoNRE)
4		Soil texture	-	MapInfo	-
5		Soil depth	-	-	-
6		Contours	2008	AutoCAD	-
7		Global SRTM DEM	2008	ArcGIS	http://srtm.csi.cgiar.org/
8	Constraint layers	Streams	-	ArcGIS	DoNRE
9		Railways	-	-	-
10		Buildings	-	-	-

4.4.2. Framework of data processing

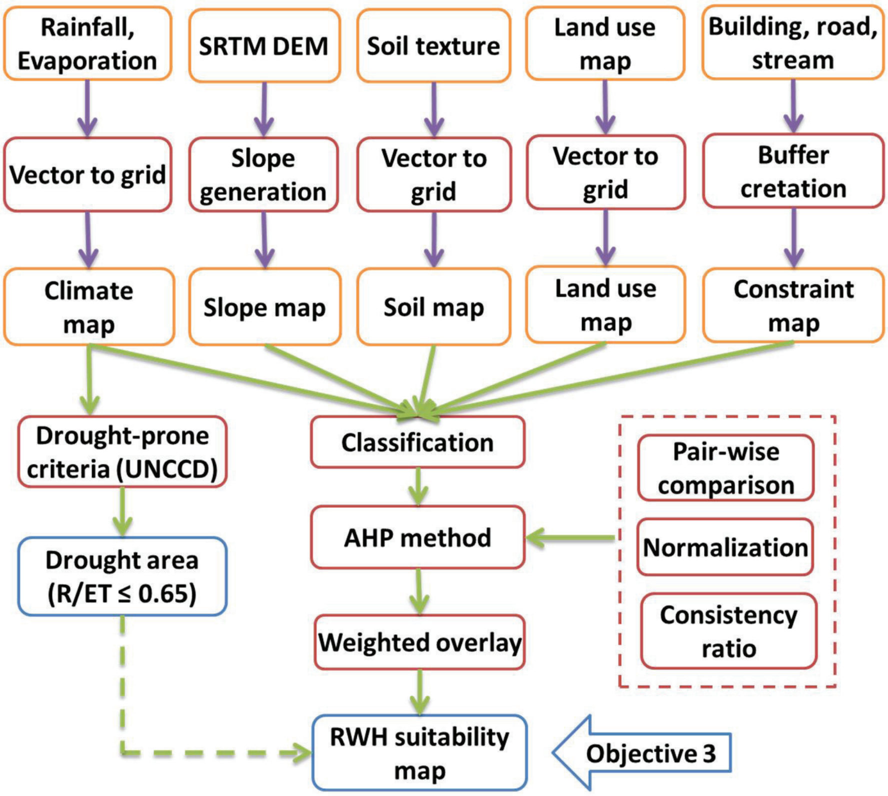


Figure 4.3 Schematic diagram on mapping suitable locations of rainwater harvesting

4.4.3. Determining weights of layers

Analytical Hierachy Process (AHP method)

The AHP technique that has often been used to deal extensive decision making processes. Contrary to conventional 'true decision' the AHP technique allows to account only those factors which are well reasonable and needed for the comprehension of the problem faced by the decision makers.

The uses of AHP often break down their problem into a hierarchal setting of easily understandable sub-problems and analyze each sub-problem independently. Individual attention to subcomponent and interrelation between subcomponent simplify the decision problem in an impalpable, carefully measured or approximately estimated, well or poorly realized, anything at all which implement to the decision at hand.

Relative important weights of layers are calculated by following equation:

$$\mathrm{RIW} = \frac{\mathrm{Vi}}{\sum_{i=1}^{n} Vi}$$

Where:

- RIW: Relative important of factors;
- Vi : mean of *i*th row of the matrix;
- i : Number of the factors.

4.4.4. Model building

Using the overlay functionality in GIS the Water harvesting index (WHI) model was determined by integrating all the previously discussed parameters:

$$\mathbf{WHI} = [(\mathbf{Rw} \times \mathbf{Rr}) + (\mathbf{Sw} \times \mathbf{Sr}) + (\mathbf{STw} \times \mathbf{STr}) + (\mathbf{Lw} \times \mathbf{Lr}) + (\mathbf{Cw} \times \mathbf{Cr})]$$

Where:

- R: rainfall; S: slope; ST: soil texture; L: land use; C: constraints;

- w: weight of layers (individual maps);
- r : rating of values within a layer.

4.4.5. Linear combination method

The suitability analysis is often best approached through the linear combination method (LCM) that assigns the equal or unequal weightings according to the relative importance of various factors considered for the land suitability analysis. The impact is deduced as a weighted sum of various factors considered in the analysis (Hokins, 1977). In the LCM each type of parameters within each factor are rated at varying scales. Each factor is assigned weightings according to its relative importance. The rate of each factor is then multiplied by the weight of the relative factor. The suitability rating is obtained for the desired region is the obtained from the sum of the multiplied ratings. The LCM for the land suitability is often expressed as:

$$\mathrm{Rs} = \sum_{i=1}^{n} (\mathrm{Wi} \times \mathrm{Ri})$$

Where:

Rs : Rate of land suitability
W : Weight of the factor
R : Rate of the factor
i : Number of the factors

In GIS tools applications the overlay methods is is one of the best options available for the analysis of land suitability. Linear combination method can be used to analysis of the overlaid maps for the land suitability. Weight and rate are the two factors which will be calculated in this equation, Weight can be obtained using the various existing methods like AHP whereas level of suitability can be used to assign the rate.

Chapter 5

Results and Discussion

5.1. Selection of suitable rainwater harvesting techniques

5.1.1. Summary of local conditions in the study area

- *Low annual rainfall and the highly uneven distribution:* most of coastal regions receive lower than 1000mm rainfall per year, some regions is only 600mm. Around 90% of rainfall focus on 4-5 months of rainy seasons, the remaining months in dry season does not have rain, accompanied by hot climate leading to severe water scarcity.
- *High temperature, strong wind and high evaporation:* these factors results in high crop water demand, significant losses of water
- *Low ground water level:* It limits provisions of groundwater for cultivation activities.
- *Sandy soil:* high infiltration rate, low ability of water storage. Depth of sandy soil is from few to hundred meters, thus rainfall amount is deeply infiltrated into soil, which is difficult to generate surface runoff. Due to the this characteristic, it is requested for treating catchment area by plastic plate of cement background for increase harvesting efficiency of rainfall.
- *Cropping pattern:* most of cropping patterns in the region is focusing on some typical short-term crops during rainy season, or combination with forest trees.
- *Agricultural land:* is owned by individual farmhouse with total area is from few to tens hectares. Therefore, application of rainwater harvesting technique must be decentralized and enough flexible with different cropping conditions of households. An important advantage of this decentralization of application is mobilizing farmer's participation in construction and O&M of the structure.

5.1.2. Review and suitability of rainwater harvesting techniques:

a. Negarim Micro-catchments

Micro-catchments are diamond-shaped basins surrounded by small earth bunds with an infiltration pit in the lowest corner of each. Runoff is collected from within the basin and stored in the infiltration pit. Micro-catchments are mainly used for growing trees or bushes. This technique is appropriate for small-scale tree planting in any area which has a moisture deficit. Besides harvesting water for the trees, it simultaneously conserves soil

Suitability:

- Rainfall: can be as low as 150 mm per annum.
- Soils: should be at least 1.5 m in order to ensure adequate root development and storage of the water harvested.

Limitations:

- The technique is well suited for hand construction but difficult to be mechanized.

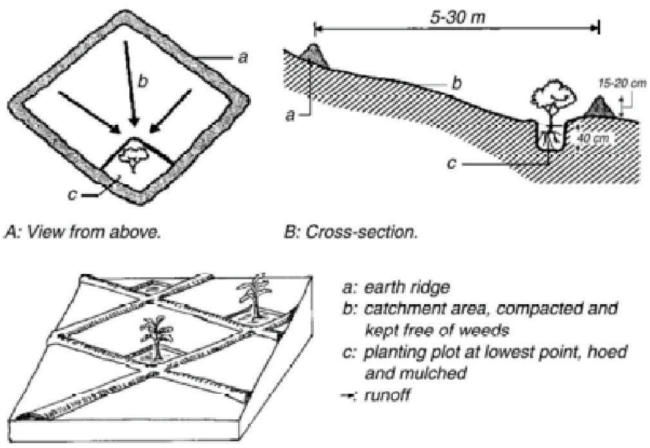


Figure 5.1 Field layout of microcatchments

(Source: Anschutz, Kome, Nederlof, Neef, & Ven, 2003)

The bund height is primarily dependent on the prevailing ground slope and the selected size of the micro-catchment.

b. Contour bunds for trees

Contour bunds for trees are a simplified form of micro-catchments. Construction can be mechanized and the technique is therefore suitable for implementation on a larger scale. As its name indicates, the bunds follow the contour, at close spacing, and by provision of small earth ties the system is divided into individual micro-catchments. Whether mechanized or not, this system is more economical than Negarim micro-catchment, particularly for large scale implementation on even land - since less earth has to be moved. A second advantage of contour bunds is their suitability to the cultivation of crops or fodder between the bunds.

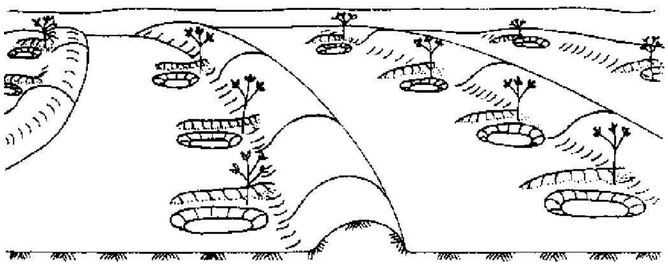


Figure 5.2 Field layout of contour bunds.

(Source: Critchley et al, 1991)

Suitability

- Rainfall: 200 - 750 mm; from semi-arid to arid areas.
- Soils: Must be at least 1.5 m to ensure adequate root development and water storage.
- Slopes: from flat up to 5.0%.
- Topography: must be even, without gullies or rills.

Limitations

- Contour bunds are not suitable for uneven or eroded land as overtopping of excess water with subsequent breakage may occur at low spots.

Bund heights vary, but are in the order of 20 - 40 cm depending on the prevailing slope. It is recommended that the bund should not be less than 25 cm in height. Base width must be at least 75 cm.

c. Semi-circular bunds

Semi-circular bunds are earth embankments in the shape of a semi-circle with the tips of the bunds on the contour. Semi-circular bunds, of varying dimensions, are used mainly for rangeland rehabilitation or fodder production. Depending on the location, and the chosen catchment: cultivated area ratio, it may be a short slope or long slope catchment technique.

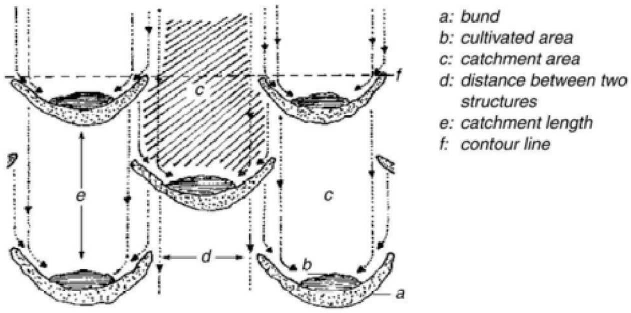


Figure 5.3 Field layout of semi-circular bunds

(Source: (Anschutz et al., 2003)

Suitability

- Rainfall: 200 - 750 mm: from arid to semi-arid areas.
- Soils: all soils which are not too shallow or saline.
- Slopes: below 2%, but with modified bund designs up to *5%.*
- Topography: even topography required

Limitation:

- The main limitation of semi-circular bunds is that construction cannot easily be mechanized.

d. Contour ridges for crops

Contour ridges, sometimes called contour furrows or micro watersheds, are used for crop production. This is again a micro catchment technique. Ridges follow the contour at a spacing of usually 1 to 2 meters. Runoff is collected from the uncultivated strip between ridges and stored in a furrow just above the ridges. Crops are planted on both sides of the furrow. The system is simple to construct - by hand or by machine - and can be even less labor intensive than the conventional tilling of a plot.

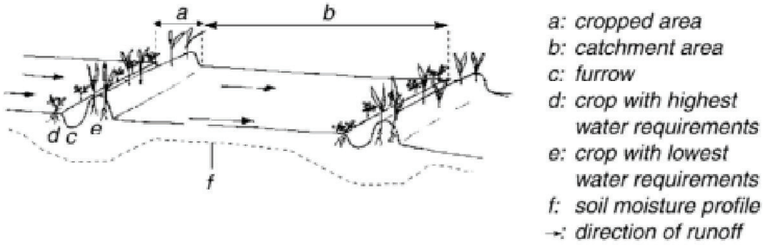


Figure 5.4 Field layout of contour ridge system

(Source: Anschutz, Kome, Nederlof, Neef, & Ven, 2003)

Suitability

- Rainfall: 350 - 750 mm.

- Soils: all soils which are suitable for agriculture. Heavy and compacted soils may be a constraint to construction of ridges by hand.
- Slopes: from flat up to 5.0%.
- Topography: must be even - areas with rills or undulations should be avoided.

Limitations

- Contour ridges are limited to areas with relatively high rainfall, as the amount of harvested runoff is comparatively small due to the small catchment area.

e. Trapezoidal bunds

Trapezoidal bunds are used to enclose larger areas (up to 1 ha) and to impound larger quantities of runoff which is harvested from an external or "long slope" catchment. The name is derived from the layout of the structure which has the form of a trapezoid -a base bund connected to two side bunds or wing-walls which extend upslope at an angle of usually 135». Crops are planted within the enclosed area. Overflow discharges around the tips of the wing-walls.

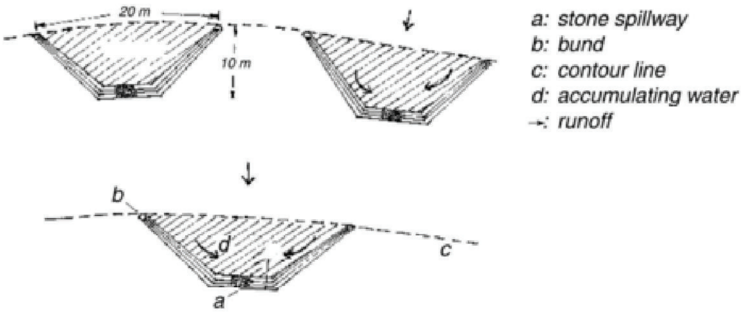


Figure 5.5 Field layout of trapezoidal bunds

(Source: Anschutz et al., 2003)

Suitability

- Rainfall: 250 mm - 500 mm; arid to semi-arid areas.
- Soils: agricultural soils with good constructional properties i.e. significant (non-cracking) clay content.
- Slopes: from 0.25% - 1.5%, but most suitable below 0.5%. Topography: area within bunds should be even.

Limitations

- This technique is limited to low ground slopes. Construction of trapezoidal bunds on slopes steeper than 1.5% is technically feasible, but involves prohibitively large quantities of earthwork.

f. Contour stone bunds

Contour stone bunds are used to slow down and filter runoff, thereby increasing infiltration and capturing sediment. The water and sediment harvested lead directly to improved crop performance. This technique is well suited to small scale application on farmer's fields and, given an adequate supply of stones, can be implemented quickly and cheaply.

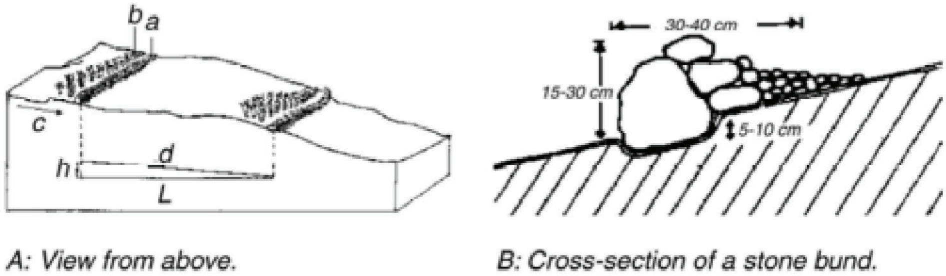


Figure 5.6 Field layout of contour stone bund

(Source: Anschutz et al., 2003)

Suitability

- Rainfall: 200 mm - 750 mm; from arid to semi-arid areas.
- Soils: agricultural soils.
- Slopes: preferably below 2%.

Limitation:

- Be largely dependent on the amount of stone and labour available

g. *Water harvesting with storage facilities*

Water will be collected by catchment area and then transferred to unground storage. Catchment could be either natural ground or treated surface, particularly in drought area where rainfall amount is not enough to create surface runoff or in lands having high seepage coefficient such as sandy soil. Prior to be stored, water will be transferred to sedimentation tank to reduce sediment content.

Storage facilities play an important role to the efficiency of the technique, determining whether water could be stored adequately throughout cropping period or it will be evaporated or seepage. Following parts will examine some common types of this technique.

Figure 5.7 Rainwater harvesting with sand-cement storage pond in Vietnam

(Source: Tuan & Hieu, 2007)

Suitability:

- Rainfall: it is suitable in semi-arid area with uneven distribution of seasonal rainfall
- Soil: sandy soil is highly recommended where other water techniques are difficult for applying
- Slope: land with medium slope, up to 15% is suitable so that ensuring convenience in getting water and sufficient capacity.

Limitation:

- Lab experiment is requested for determining appropriate mixing ratio. It requests trained workers under supervision of technical staff for construction.

5.1.3. Comparison of water harvesting structures:

Based on structure basis, there are two main water harvesting systems with or without storage facilities. Below is an analysis of multi-criteria of these two water harvesting systems.

Table 5.1 Comparison of water harvesting with or without storage facility

No.	Criteria	Rainwater harvesting without storage facilities	Rainwater harvesting with storage facilities
1	Ability to supplement water under uneven rainfall distribution	Limited capacity as water is stored as soil moisture only; Water harvesting is sufficient for crops during short dry spells after rain events.	Good capacity, depending on scope of storage facilities.
2	Construction cost	Low	Medium
3	Maintenance cost	Low	Low
4	Loss of cultivation land	Low	Low
5	Operation and maintenance	Simple	Simple
6	Recommendation	- Short-term crops - Soil with medium to good water storage capacity - Medium annual rainfall with relative even distribution in year.	- Short-term crops and long-term tree - Almost all types of soil - Uneven rainfall distribution

Based on the above comparison, both rainwater harvesting structures have certain advantages and disadvantages. However, due to high difference between rainfall in dry and rainy season, the light texture soil, water harvesting systems without storage facility do not meet the water requirement of crops.

5.2. Economic analysis of water harvesting applications

Due to limited time availability as well as constraints in data collection, the cost-benefit assessment of rainwater harvesting application will be conducted later on.

5.3. Identifying suitable locations for rainwater harvesting

5.3.1. Thematic maps of different criteria

1. Rainfall map

Rainfall is one of the most important criteria for rainwater harvesting. The rainfall map has produced from rain gauge points by using interpolation with spline method. Several methods exist for interpolation like kriging, IDW (Inverse Distance Weighted) and spline. For the rainfall spline method shows best result.

Table 5.2 Rainfall classification

No.	Rainfall (mm/year)	Explaination	Class
1	600-800	Critical rainfall & severe water shortage	9
2	800 - 1000	Low rainfall	8

3	1000 - 1200	Low to moderate rainfall	7
4	1200 - 1400	Moderate rainfall	5
5	1400 - 1600	Moderate to high rainfall	4
6	1600 - 1800	High rainfall	2
7	> 1800	Very high rainfall	1

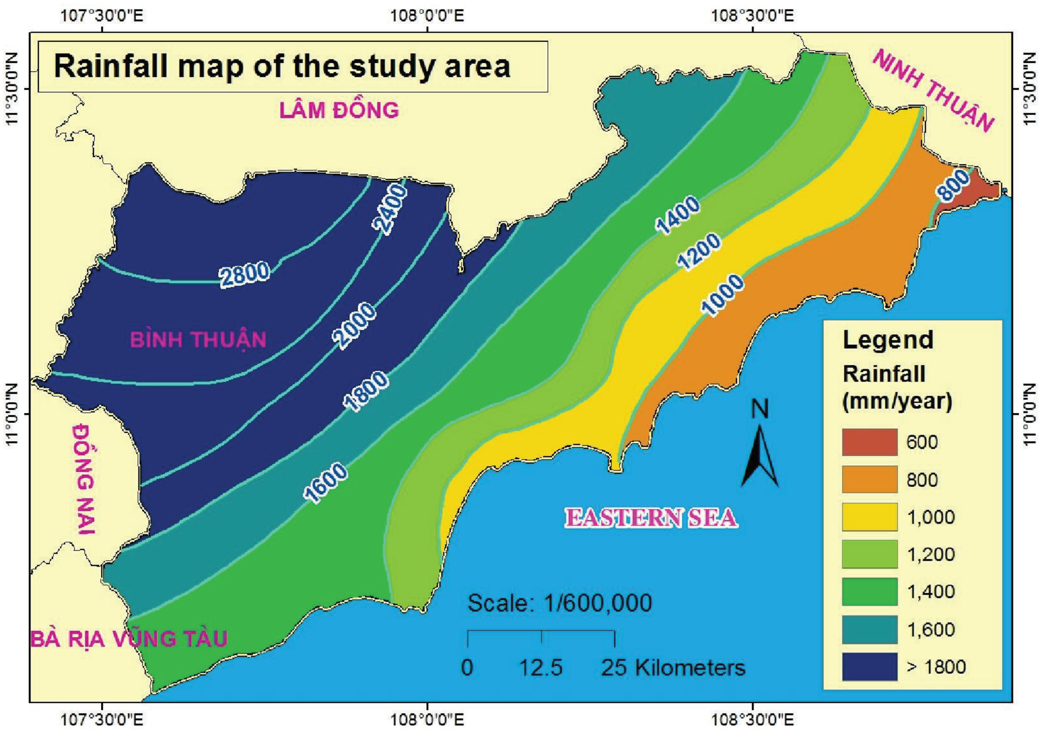


Figure 5.8 Rainfall of the study area

2. Slope feasibility map

Slope is one of the most significant factors for rainwater harvesting. The slope map has been generated from the global Digital Elevation Model (DEM) with resolution of 90m. Slope in study area varies from 0 to approximately 68 degree. The classification is given in the following table:

Table 5.3 Slope classification

No.	Slope (degree)	Explaination	Class
1	0 - 2	Slight slope, highly suitability	9
2	2 - 5	Gradual slope	7
3	5 - 8	Uphill slope	5
4	8 – 15	High slope	3
5	> 15	Steep slope	1

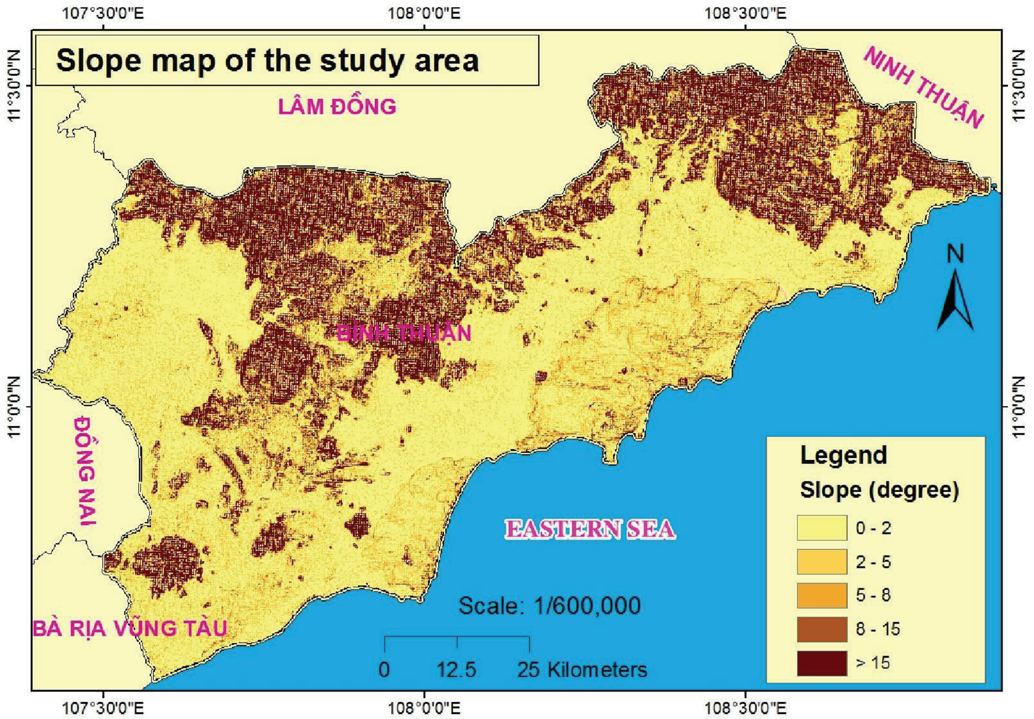


Figure 5.9 Slope map of the study area

3. Soil texture feasibility map

The study area exhitbits various types of soils which includes sandy loam, loamy, clay, rocky and salinity soil. The classification of soil type is illustrated as below:

Table 5.4 Soil texture classification

No.	Soil type	Explaination	Class
1	Sandy loam	Highly suitable (coastal sandy area)	9
2	Sandy clay loam	Suitable	8 – 7
3	Clay loam	Moderate suitable	6 – 5
4	Loamy sand & sandy clay	Low to moderate suitable	4 – 3
5	Others	Low suitable (rocky, salinity soil)	2 -1

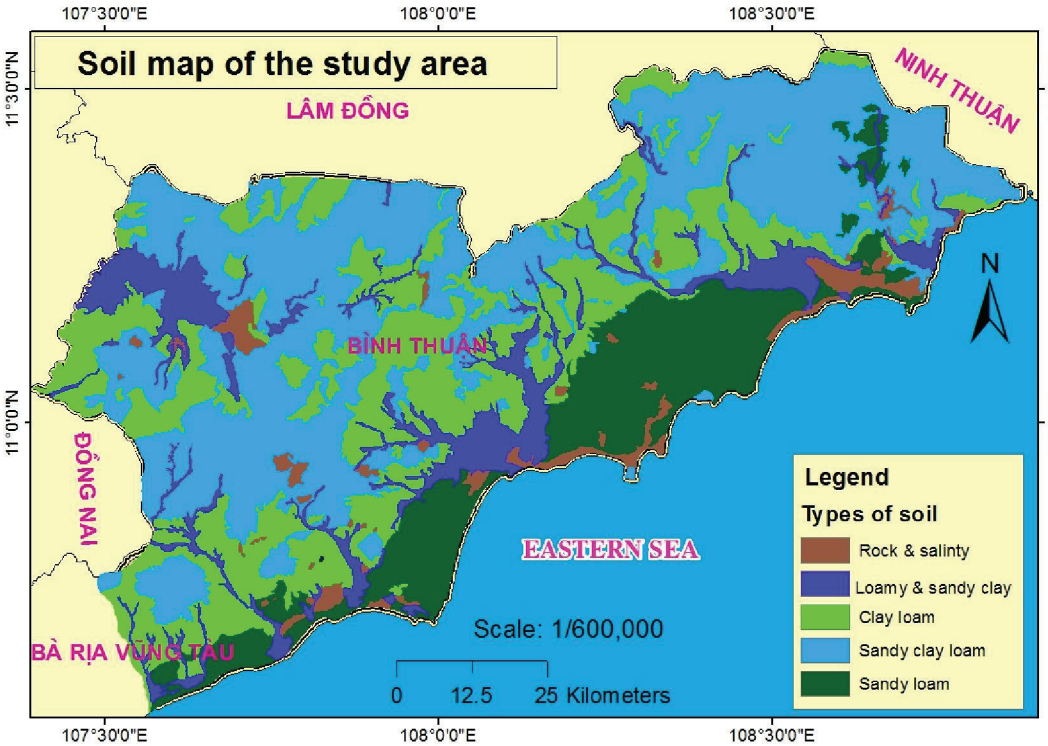


Figure 5.10 Soil texture of the study area

4. Land cover feasibility map

Land cover map is obtained from the local Department of Natural Resources and Environment, which was created in 2008. The study area was classified into crop land, open bush land, open bush with tree, forest and others.. The final result of land cover feasibility map is shown in the following figure.

Table 5.5 Land cover classification

No.	Land use	Explaination	Class
1	Crop land	Highly suitable	9
2	Short-term tree	Suitable	8 – 7
3	Long-term tree	Moderate suitable	6 – 5
4	Forest land	Low to moderate suitable	4 – 3
5	Others	Low suitable (construction, resident)	2 -1

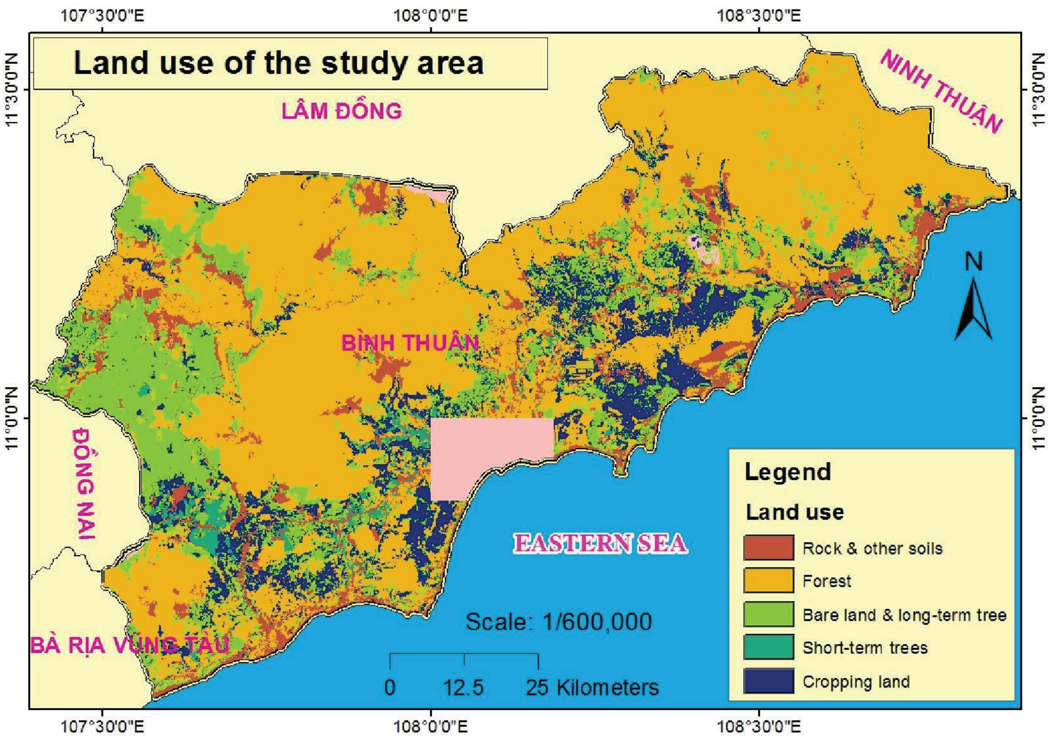


Figure 5.11 Land use of the study area

5.3.2. Multi-criteria decision analysis by AHP method

So as to minimum effects of personal bias in allocating weights of factors, the method Analytic Hierarchy Process (AHP) will be applied. AHP involves various factors or criteria which have varying importance in cumulative decision making. The weight will assigned to the each factors based on the impotency compare with other factors. For calculating the weight in the AHP method the pair wise comparison matrix need to be created. The output of the matrix will be considered as weight of each factor. Then the weights are determined by normalizing the vector associated with the maximum value of the ratio matrix. The three steps of the methods are:

1. Generation of the pair-wise comparison matrix
2. The criterion weights computation
3. The consistency ratio estimation

Table 5.6 Scale for pair-wise comparisons

Scale	Degree of preference
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

(Source: Saaty & Vargas, 2012_ *First published in 1980)*

Pair-wise comparison matrix for rainwater harvesting

Table 5.7 Pair-wise comparison of evaluation factors

	Rainfall	Slope	Soil texture	Land use
Rainfall	1.00	1.00	2.00	0.50
Slope	1.00	1.00	3.00	0.50
Soil texture	0.50	0.33	1.00	0.33
Land use	2.00	2.00	3.00	1.00
Total	4.50	4.33	9.00	2.33

Normalized pair-wise comparison matrix and factor weightings

In pair-wise comparison the values in each column of the comparison matrix for rainwater harvesting are summed, and after that divided every element of column with its column total then the Normalized pair-wise comparison matrix is acquired. The factor's weights are obtained from average of the elements in each of the normalized pair-wise comparison matrix.

Table 5.8 Normalized pair-wise comparison matrix and factor's weights

	Rainfall	Slope	Soil texture	Land use	Total
Rainfall	0.22	0.23	0.22	0.21	0.89
Slope	0.22	0.23	0.33	0.21	1.00
Soil texture	0.11	0.08	0.11	0.14	0.44
Land use	0.44	0.46	0.33	0.43	1.67
Total	1.00	1.00	1.00	1.00	

Allocated weights of selected factors for rainwater harvesting

Table 5.9 Relative Importance Weight of factors

Factor	Relative Importance Weight
Rainfall	0.22
Slope	0.25
soil texture	0.11
Land use	0.42

Consistency ratio estimation

Consistency ratio estimation is one of the steps of AHP method that determines the consistency of various factors in the process. The estimates of weighted sum vector are derived by multiplying the weight for first factor times with the first column of the original pair-wise comparison matrix. Similar multiplying is performed for the second weight times to the second column and process is completed for all columns.

The consistency vector can determine as follow:

$$Consistency\ vector = \frac{Weighted\ sum\ vector}{FActor\ wweight}$$

Table 5.10 Consistency vector

Factor	RIW	weighted sum vector	consistency vector

Rainfall	0.22	0.90	4.06
Slope	0.25	1.01	4.05
soil texture	0.11	0.44	4.02
Land use	0.42	1.69	4.06

The last one step of this method is the estimation of consistency index before calculating consistency ratio. The computation of consistency index is calculated by the following equation.

$$Consistency\ index\ (CI) = \frac{\lambda - n}{n - 1}$$

Where:

λ : average consistency vector

n : number of factor (criteria) under consideration

$$\lambda = \frac{4.06 + 4.05 + 4.02 + 4.06}{4 - 1} = 4.05$$

$$CI = \frac{4.05 - 4}{4 - 1} = 0.015$$

Consistency ratio is computed by the following formula:

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

Table 5.11 Inconsistency indices

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	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

(Source: Saaty, 2012)

$$CR = \frac{0.015}{0.9} = 0.017 < 0.1$$

Table 5.12 Weight assignment by AHP method

Factors	Category	Weight	Rate	Suitability
Rainfall (mm/year)	600 - 800	0.22	9	High
	800 – 1200		8 – 7	Moderate to high
	1200 – 1600		6 – 5	Moderate
	1600 - 1800		4 – 3	Low to moderate
	> 1800		1	Low
Slope	0 - 2	0.25	9	High
	2 - 5		7	Moderate to high
	5 - 8		5	Moderate
	8 -15		3	Low to moderate
	>15		1	Low
Soil texture	Sandy loam	0.11	9	High
	Sandy clay loam		8 – 7	Moderate to high

	Clay loam		6 – 5	Moderate
	Loamy sand & sandy clay		4 – 3	Low to moderate
	Others		2 -1	Low
Land use	Crop land	0.42	9	High
	Short-term tree		8 – 7	Moderate to high
	Long-term tree		6 – 5	Moderate
	Forest land		4 – 3	Low to moderate
	Others		2 -1	Low

5.3.3. Water Harvesting Index

$$WHI = [(Rw \times Rr) + (Sw \times Sr) + (STw \times STr) + (Lw \times Lr) + (Cw \times Cr)]$$

Where:

- R: rainfall; S: slope; ST: soil texture; L: land use; C: constraints;
- w: weight of layers (individual maps);
- r : rating of values within a layer.

5.3.4. Rainwater harvesting suitability map

After overlay all the suitability maps using the formula above the final suitable map of rainwater harvesting has been created.

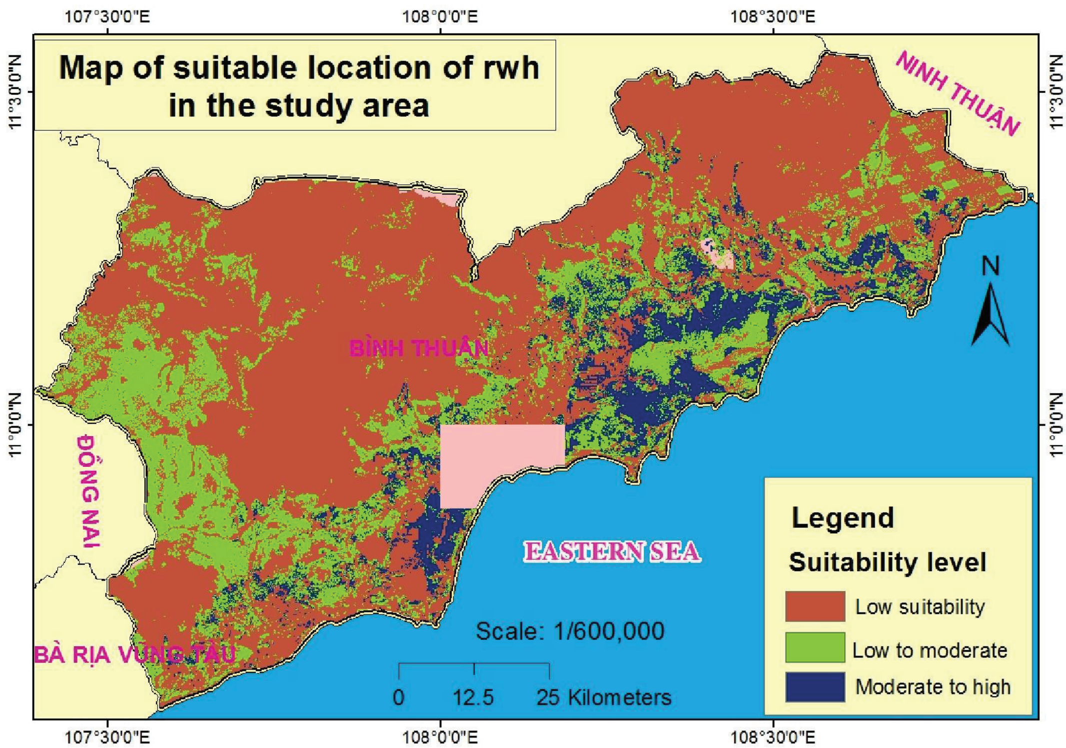
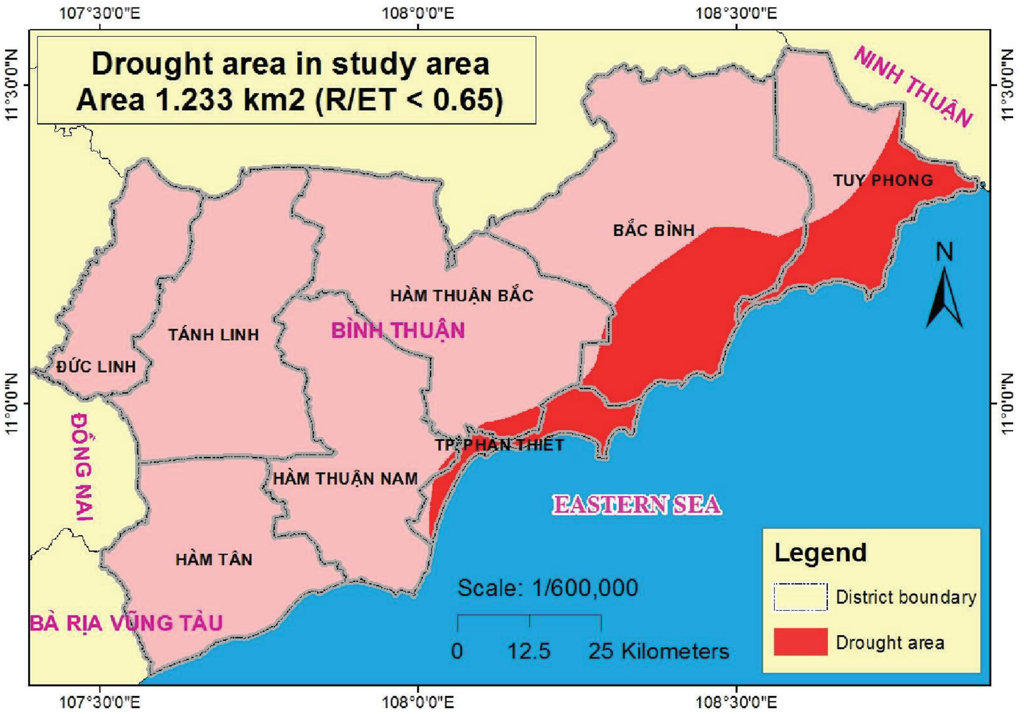


Figure 5.12 Rainwater harvesting suitability map

Rainwater harvesting land suitability classification with area and percentage

No	Suitability	Total weights	Area(Sq.km)	Percentage
1	Low	1 – 5	5197	68
2	Low to Moderate	5 - 7	1714	22

3	Moderate to high	7 - 9	747	10
Total			**2501.0001**	**100**



Chapter 6
Conclusion and Recommendation

6.1. Conclusion

The focus of the study is to identify suitable rainwater harvesting technique and its potential location for addressing water scarcity in agriculture and adapting to climate change. Based on assessment on local natural conditions in terms of soil, climate and topography, the research propose to apply rainwater harvesting models with treated catchment of plastic sheet or cement background and separate storage facilities in order that the system can collect and store water efficiency.

With regards to potential location of rainwater harvesting, Analytical Hierarchy Process method is applied to allocate weights of mapping factors, with the purpose of minimizing bias from author's decision. Results of the mapping procedure reveal that approximately 747 km2 (around 10% of total area) is considered "moderate to highly" suitable for applying of rainwater harvesting. Around 1714 km2 and 5197 km2 are moderate and low suitable area respectively.

Furthermore, the research evaluates drought-prone area in the study area based on desertification criteria on United Nation of Combating Desertification (UNCCD). In case that ratio of rainfall per evaporation is less than or equal to 0.65, the region appears drought-prone. Calculating results presents that around 1233 km2 along coastline of the study area is vulnerable to desertification. Particularly, around 20% of this area is selected as highly suitable for rainwater harvesting. This demonstrates the importance of rainwater harvesting solution in coping with water scarcity in the region.

6.2. Recommendation

- Based on above result, rainwater harvesting is a feasible and practical solution for addressing drought situation in the region, thus it is recommended to combine rainwater harvesting development strategy in master plan on water resources of the region.
- Further research on applying rooftop rainwater harvesting for drinking and household purpose should be conducted, considering priority on water quality.

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