Master Thesis in Geographical Information Science nr 128

Considering future precipitation in delineation locations for water storage systems - Case study Sri Lanka

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2021
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Kanchana Nirmali Bandaranayake (2021). Considering future precipitation in delineation locations for water storage systems- Case study Sri Lanka**.**
Master degree thesis, 30/ credits in Master in Geographical Information Science
Department of Physical Geography and Ecosystem Science, Lund University

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Acknowledgements

I would like to express my gratitude to Luma GIS program – Lund University for enrolling me as a master's degree student and offering me the opportunity to complete the course through distance learning with a flexible time frame.

And I would like to extend my gratitude to the course coordinator, Dr. David Tenenbaum for his continuous support. Also, my gratitude goes to all the teachers who generously dedicated their time and knowledge in order to support the students throughout this course.

Besides, my heartful gratitude goes to my thesis supervisor, Vaughan Phillips for all the valuable feedbacks, encouragements and support during the thesis.

Finally, I am thankful to my mom for encouraging me to complete the course and to my husband for supporting whenever needed.

Abstract

Demand for the usable water is accumulating globally in parallel with the population growth and the industrial revolution. Nevertheless, availability and accessibility of the usable water is progressively subsiding due to many environmental and socio-economic reasons. This discrepancy can lead the world to a water crisis unless it takes necessary actions to enhance the sustainable use of existing water while maximizing the water storage capacities for the future use. Having said that, paying less attention to the highly related factors while implementing new water related projects, does not seem supportive in achieving their goals. This paper intends emphasizing the importance of consideration of the expected changes in the associated environmental and socio-economic factors in the long run when locating water storage systems. Although this study has been limited to the consideration of the precipitation factor, the methodology used in this paper is compatible with utilizing the expected variations in other related climatic factors.

The project focuses on Sri Lanka. Having a year-round rainfall, the country has still been incapable of fulfilling the annual water requirement of the population. Adding new water storage systems focusing on maximizing the rainwater harvesting by taking the future precipitation pattern into account, is considered as one of the effective solutions to tackle the issue. This study focuses on delineate locations for terrestrial water storage systems by taking the future precipitation pattern in the year 2050 into consideration. Despite delineating new locations for water storage systems, the study also points out the available water features within the country that are vulnerable to be dried out in the future mainly due to the change of precipitating pattern**.** Other related geographical, environmental, and socio-economic factors are integrated with the future predicted precipitation data in delineating the results. Thresholds and weighted linear combination methods were utilized in prioritizing the related conditions at the primary location selection. Pairwise comparison method was utilized in assigning the weights. Additionally, the GIS framework introduced in the paper can be applied to any geographical location based on the availability of data.

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List of acronyms

DEM	Digital Elevation Model
DOM	Department Of Meteorology
GCM	Global Climate Models
GHG	Greenhouse Gas
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
MAP	Mean Annual Precipitation
MCM	Million Cubic Meters (10^6 m^3)
RCP	Representative Concentration Pathways
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USAID	United States Agency for International Development

1. Introduction

1.1 Motivation

Water, being one of the main necessities of the living species, is one of the treasurable endorsements provided by the nature. Although about 71% of the earth's surface is covered by water, over 96% of the earth's water is saline. The remaining 4% which is considered as freshwater, is not fully available for direct use. Over 68% of the freshwater is locked up in the ice and glaciers and is unusable. It is about 30% of the freshwater that contributes to the usable water capacity in the world. This is less than 1% of the total water availability on the earth. The major part of the usable water is contributed by rain and stored in streams, rivers, lakes as well as groundwater (Perlman 2016).

Demand for water is projected to increase by 55% between 2000 and 2050 globally due to the growing demand from manufacturing (+400%), electricity (+140%) and domestic use (+130%) (OECD 2012). Besides, food production is expected to grow by 70% in order to feed the growing population by 2050 (FAO 2009). Water withdrawal for energy, used for the cooling power stations, are also expected to be increased by over 20% within the year 2010 – 2035 (Wada et al 2016). In other words, the near future presents one big loss of freshwater after the next. This stresses that the sustainable use of water has become the utmost responsibility of the human being at present. Besides, expanding the storage systems maximizing the rainwater harvesting is visibly important in order to mitigate the water related issues in future.

This project focused on Sri Lanka. Located in the tropical region, the country is rich with a year-round Monsoonal and intermediate Convectional rainfalls. The mean annual rainfall varies from under 900 mm in the driest parts (southeast and northwest) to over 5000 mm in the wettest parts (western slopes of the central highlands) (DOM 2019).

The 103 natural river basins located around the country cover about 90% of the island with the catchment areas ranging from 620 km^2 to 2700 km^2 within the southwestern part of the country (Bogahavita 2006). As per the statistics available in Department of Surveying, Sri Lanka, the country consists of 18,387 medium-to large-scale water reservoirs including both functioning and abandoned reservoirs (Panabokke et al. 2002). As reported by the Sri Lanka National Water Development Report published in 2006, there are about 13,000 man-made reservoirs, 11,250 small tanks (man-made lakes or ponds constructed by local people with indigenous skills during king’s era) and 12,950 small scale diversion weirs (anicuts) available within the country. These water resources currently serve the rural communities with their water requirements for agriculture, drinking, sanitation and livestock. Contribution of water volume by these water resources to the total surface water availability is about 43,000-45,000 MCM annually (Imbulana et al. 2006). Although there is no accurate source that could provide the exact number of water reservoirs and other water resources available in the country, these figures imply that the country is saturated with a large number of water storage systems compared to its extend and population.

Although the country reports a higher number water storage systems, the Sri Lanka National Water Development Report published in 2006 indicates that the present water capacity has not been able to meet the annual water requirement of the country. The country reports frequent water scarcities in many parts as a result of spatial and temporal variations in rainfall and of changing weather patterns (Ariyabandu et al. 2004).

On rainfall distribution, Sri Lanka has traditionally been classified into three climatic zones, wet zone, dry zone and intermediate zone (**Figure 1**). The wet zone covers the south-western region including the central hill country and receives relatively high mean annual rainfall over 2,500 mm without pronounced dry periods. The dry zone covers predominantly the north and east part of the country, being separated from the wet zone by the intermediate zone. The dry zone receives a mean annual rainfall of less than 1,750 mm with a distinct dry season from May to September. The intermediate zone receives a mean annual rainfall between 1,750 to 2,500 mm with a short and less prominent dry season (CHM 2017)

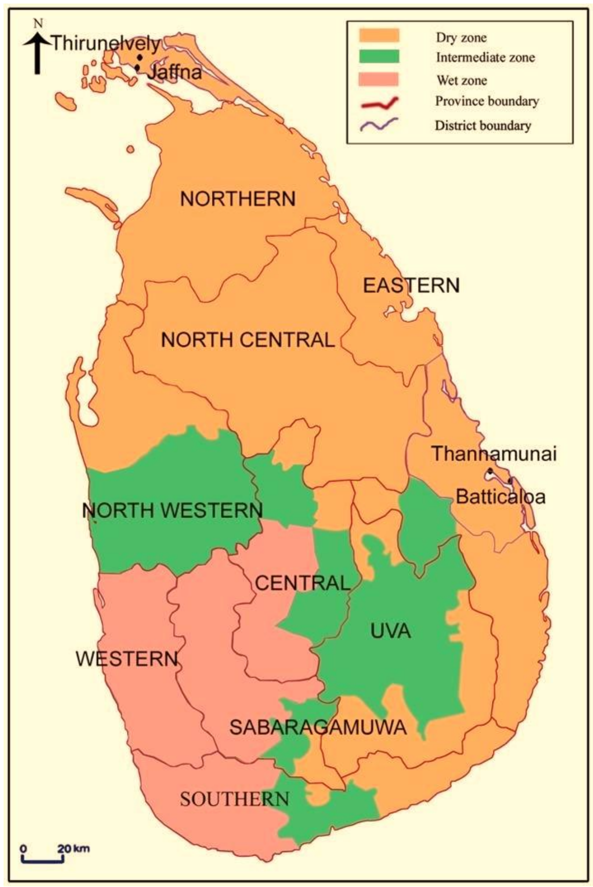

Figure 1:The climatic zones of Sri Lanka
Source: Ramasamy et al. 2012

Sri Lanka receives a moderate to high rainfall throughout the year influenced by the monsoon winds of the Indian Ocean and Bay of Bengal. But a large amount of rainwater joins back to the water cycle without being used due to the lack of proper mechanism in water resource management and rainfall harvesting. As per the Sri Lanka National Water Development Report 2006, a high discrepancy between the annual rainfall and the available water volume can be identified throughout the country (**Table 1**). Although the runoff is estimated to be about 35-40% of the annual rainfall of the country, this is estimated to be as high as 65% over the wet zone (Imbulana et al. 2006). And the river discharge within the dry zone is estimated to be less than 30% of the rainfall, even during high rainfall seasons due to a high infiltration rate (MOE 2010).

District	Annual Rainfall (mm)	Equivalent Water Volume (bcm)
Ampara	1601	6.9
Anuradhapura	1368	9.6
Badulla	2060	5.8
Batticaloa	1643	4.4
Colombo	3254	2.1
Galle	3371	5.5
Gampaha	2575	3.6
Hambantota	1131	2.9
Jaffna	1238	1.2
Kalutara	3980	6.3
Kandy	2375	4.5
Kegalle	3612	6.1
Kilinochchi	1285	1.6
Kurunegala	1701	8.2
Mannar	1140	2.3
Matale	1942	3.9
Matara	2540	3.3
Moneragala	1607	8.9
Mullaitivu	1364	2.7
Nuwara Eliya	2638	4.5
Polonnaruwa	1693	5.5
Puttalam	1251	3.8
Ratnapura	2982	9.7
Trincomalee	1587	4.2
Vavuniya	1407	3.5
Sri Lanka	**1861**	**120.0**

Table 1: Average annual rainfall and equivalent water volumes in billion cubic meters (bcm) for each district
Source: Sri Lanka National Water Development Report 2006

A majority of the water storage systems in the country have distributed within the dry zone where the average annual rainfall is less than 1750 mm. The highest rainfall of the dry zone is recorded within 3 months from October to January which counts about 80% of its annual rainfall. The South West Monsoon (SWM) receives from May to September is considered as the highest and longest rainy season in the country. However, during this rainy season, the dry zone falls within the rain shadow zone by leaving the area to a more dryer with strong wind. During SWM, the daily evaporation rate of the dry zone rises to between 5.5 mm to 7.0 mm. The annual average evaporation within the dry zone is estimated to between 1700 mm to 1900 mm, which exceeds the average annual rainfall of the area (Panabokke et al. 2002). The dry zone of Sri Lanka receives most of the rainfall during North East Monsoon (NEM) and First Inter Monsoon season (FIM) (Imbulana et al. 2006). However, a decreasing trend of rainfall during these two seasons has been identified within the dry zone (**Figure 2**) (Jayatillake et al 2005). The reduction of rainfall during these periods and reduction of rainfall in the upper catchment areas of the major rivers, will result in severe and more frequent drought conditions in the dry zone. This is an unfavorable condition for the dry zone which consists of a major part of the total irrigated area of the country (Imbulana et al. 2006).

Only a fewer number of water storage systems have located within the Intermediate and wet zones where, the annual rainfall between 1,750 mm to 2,500 mm and over 2500 mm respectively

(Punyawardena 2010). Rain being the only source of water for these storage systems, this divergence is identified as the major drawback in the process of maximizing the rainwater harvesting and minimizing the surface runoff in the country (**Figure 3**). Despite this, majority of the water storage systems are not operating with their full water capacities due to many reasons. Although no adequate studies have been carried out on abandoned water storage facilities in the country, as per the Department of Agrarian Development, about 2716 water storage systems have become abandoned by the year 2000 due to many reasons.

Rainfall Season	1931 - 1960		1961 - 1990		Change	
	Rainf fall mm	CV %	Rainf fall mm	CV %	mm	%
First Inter Monsoon (Mar - Apr)	299.7	23%	268.3	27%	-31.5	-10.5%
South-West Monsoon (May - Sep)	547.0	21%	556.2	16%	+9.2	+1.7%
Second Inter Monsoon (Oct-Nov)	566.9	22%	558.1	23%	-6.7	-1.1%
North-East Monsoon (Dec - Feb)	591.5	31%	478.5	42%	-113.0	-19.1%
Annual (Jan - Dec)	2005.1	12%	1861	14%	-144.1	-7.1%

Figure 2:Change & Variability of Mean Rainfall during Different Rainfall Seasons
Source: Jayatillake et al, 2005

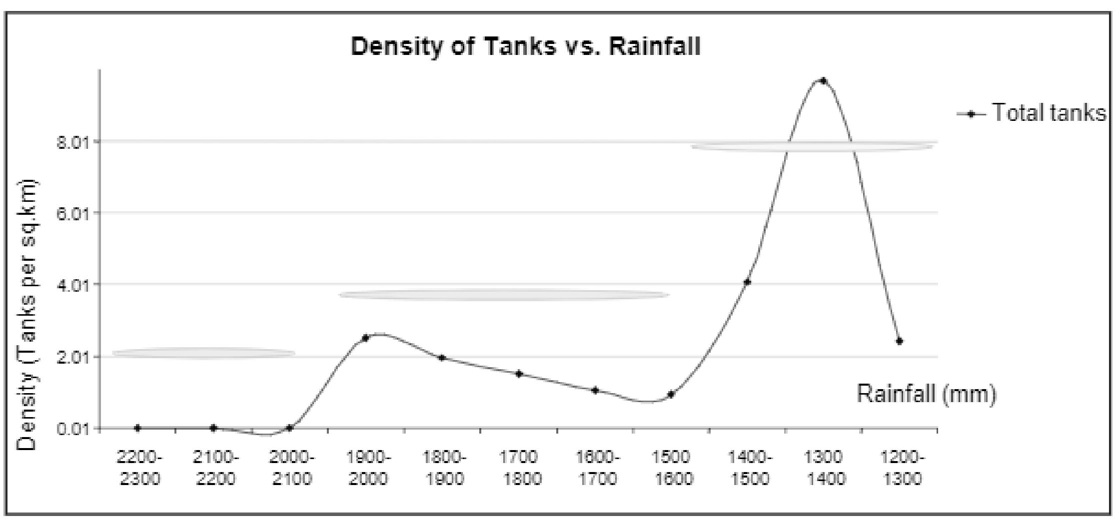

Figure 3:Density of Tanks Vs. Rainfall
Source: Gangadhara et al. 2005

Domestic water requirement of the rural population of the country is mainly fulfilled by the ground water extracted through domestic wells and tube wells. However, being a limited source of water, quality and quantity of the ground water is highly sensitive to the human activities and the environmental changes. Over-extraction, pollution, higher concentration of harmful natural minerals and low recharge rate due to temperature increase have been identified as the limiting factors of using well water in many parts of the country in the present (Pathmarajah 2016).

Many researchers pointed out that the water withdrawal has increased within the country. As per the water withdrawal data published by Food and Agricultural Organization – UN for year 1990, 2000 and 2005, an increasing trend of water withdrawal by agriculture, industry and municipality can be identified in the country (**Table 2**). In 2005, the total water withdrawal was an estimated 12.95 km^3, of which about 11.31 km^3 (87.4 percent) for agriculture, 0.81 km^3 (6.2 percent) for municipalities and 0.83 km^3 (6.4 percent) for industries. From the total water withdrawal for agriculture, dry zone accounts for more than 90% mainly due to the higher share of irrigational activities within the zone (IWMI 2007).

The total cultivated area of the country is estimated as 1.86 million ha in 2003 (DCS, 2003). Among this, about 632,000 ha area is reported as irrigated cultivation (Meegastenne 2005) and the balance area is reported as rainfed cultivation. It is estimated that 90% of the irrigated cultivation has been reserved by paddy cultivation. The paddy area irrigated by major to minor irrigation systems have increased from 414,616 ha to 512,459 ha within 1980 – 2003 (Imbulana et al. 2006).

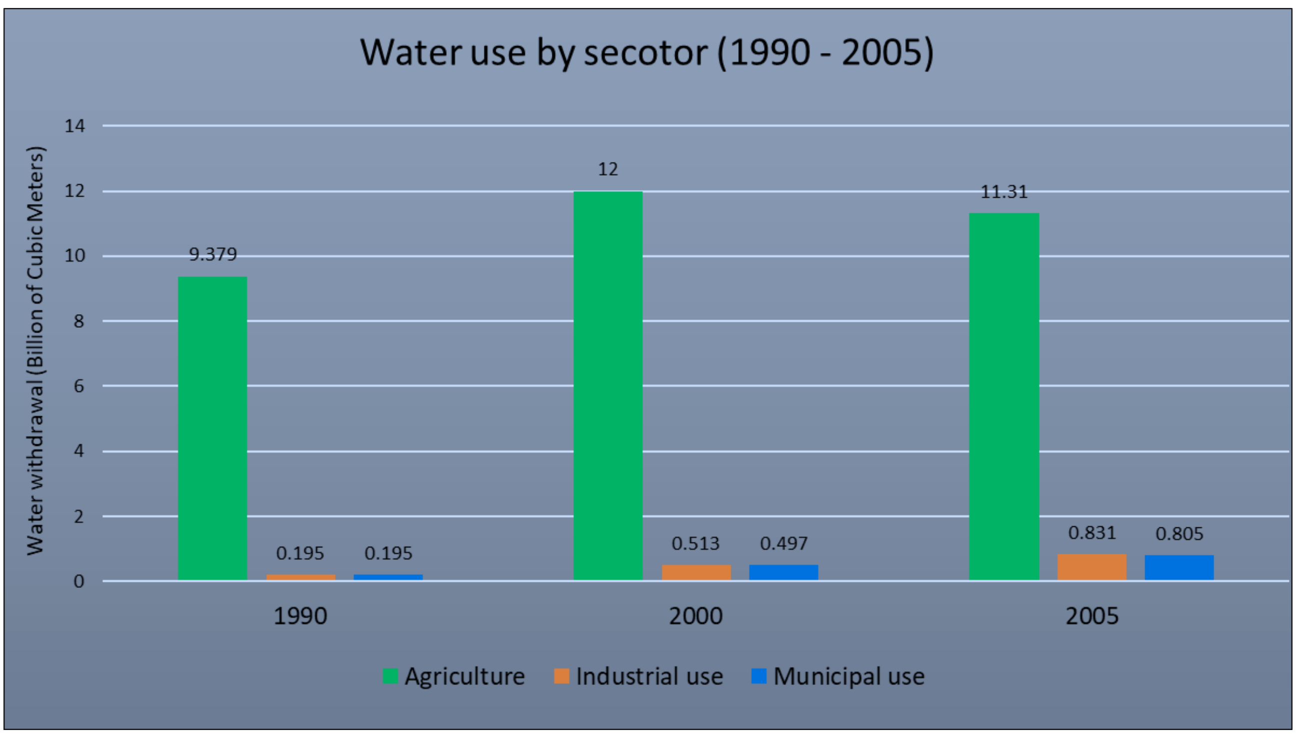

Table 2: Water Withdrawal by Sector
Source: FAO - Sri Lanka Water

In order to facilitate with this increasing water demand of the country, various large-scale water storage development projects have been initiated by the Sri Lankan government within the last 50 years. The area irrigated by the major irrigation schemes have increased by about 110 percent from 1963 to 1993, and the total water managed area has increased by 17 percent during the period 1989-1999 (FAO 1999). Particularly with the termination of an ethnic crisis during the last 3 decades, the country is undergoing through a rapid development in different sectors focusing on uplifting the economy of the country. Among them, large scale irrigation and hydropower projects have reserved a key portion of the budget due to their unswerving influence on the country's economy. Several new water storage system projects have been initiated within the last 5-10 years in the country. These projects mainly focus on facilitating a year around water supply mainly for agricultural, hydropower requirements and other industrial requirements of the most needed areas (**Table 3**).

Type of reservoir (nos)	Main purpose	Climatic Zone	Cost (Rs) (million)
Menik Ganga (Weheragala) Development†	Increasing cropping intensity, provision of drinking water, providing water to the Lunugamvehera National Park	Dry Zone	1,772
Deduru Oya Reservoir†	Increasing cropping intensity, enhancing productivity of existing agricultural lands under minor irrigation schemes, additional hydro-electricity to national power grid and providing drinking water	Dry Zone	6,500
Rambukkan Oya Reservoir†	Increasing cropping intensity and development of new land, providing pipe-borne water	Dry Zone	2,500
Moragahakanda and Kalu Ganga Development†	Increasing cropping intensity and increased extent of crop lands, provision of domestic and industrial water, adding 20 MW of hydro-electricity, annual production of 4500 MT of inland fish	Dry Zone and Wet Zone	48,950
Yan Oya Reservoir Scheme*	Increasing cropping intensity and increased extent of crop lands, provision of domestic and industrial water	Dry Zone	8,700
Uma Oya*	Increasing cropping intensity and increased extent of crop lands, provision of domestic and industrial water, 120 MW of hydro-electricity. Mainly a diversion scheme from wet to dry zone.	Dry and Wet Zone	75,000

Table 3: On-going and planned investments for major development of irrigation water resources
Source : Randora, National Infrastructure Development Program and Ministry of Irrigation and Water Resources Management

Water storage projects in the country have been initiated with advanced standardized investigations on environmental and socioeconomic factors considering the present and the near future scenarios. The environmental impact assessment studies have been mostly carried out by recognized international entities while geographic and socio-economic conditions were evaluated by different professional bodies of the country. As per the project reports, a trend of utilization of traditional procedures and assessments focusing on present and near future scenarios can be identified. The Daduru Oya river basin project has been commenced by utilizing the present rainfall, temperature, groundwater, and socio-economic factors. Although precipitation factor was not evaluated in this project, it was mentioned that the rainfall is the only source of water for the Daduru Oya river basin (Somaratne et al. 2003). As per the project report, the selection criteria set up during the site selection for the Inginimitiya reservoir were, reasonable conditions of physical infrastructure, recurrent but not chronic water shortage, representative size of the command area and potential for diversified cropping (IIMI 1992). According to the prototype system developed by IWMI for managing the national water resources data and information, implementation of water resource projects utilizes only the basic data such as topography, geology and land use for the selection of suitable locations (Matin et al. 2010). These factors clearly stress that the attention of the stakeholders has limited to the present and the near future environmental and socio-economic scenarios within the study and not been extended to the anticipated changes in the future scenarios.

Being located in the tropical region, the climate of the country is continuously subjecting to changes and is straining the country in different ways (Imbulana et al. 2006). Temperature, and the quantity and the spatial distribution of the rainfall are expected to show a higher variation in the long run compared to the present scenarios (Eriyagama et al. 2010). Besides, the recent analysis of the spatial pattern of rainfall indicates an expansion of the dry zone over the country. The brunt of the impact of climate change on water resources is expected to be borne by the northeast and the east dry zone of the country; they will become even drier by the 2050s (De Silva 2006). Being a majority of the water reservoirs located over the dry zone, this is an alarming condition in terms of the water storage capacity within the dry zone in future. Although the spatial pattern of the rainfall projections over the country displays contradictory results, almost all the projections agree on an increase of annual mean precipitation over the wet zone of the country (Eriyagama et al. 2010).

Although there are several environmental policies, legal enactments and policies that contain provisions that could contribute to reducing or mitigating the effects of climate change. Subject of climate change and methodology for mitigating the effects have not been directly addressed in them within the country. Lack of studies conducted on the future climate scenarios or the contradictory results projected during studies with respect to future rainfall have been identified as the main reason behind this situation (Eriyagama et al. 2009).

As per De Silva (2006), harvesting rainwater and storing during the higher rainfall seasons within the wet zone and transfer excess rainwater to the dry zone is considered as the most efficient and cost-effective solution for the water resources adaptation for future climatic change in the country. It is also considered that increasing storage through a large and small surface water facilities is critical to meeting the water requirements of the twenty-first century (Keller 2000). Rain being the ultimate natural source of water, selecting high precipitation areas for new water reservoirs considering both present and future precipitation scenarios is expected to be a tactful decision considering the expected changes in the precipitation. This will be able to contribute a higher rainwater storage to the usable water volume of the country by minimizing the surface runoff. This water storage can be utilized during the low rainfall seasons in order to maintain a year around water supply in the country. Besides, the excess water collected within the high rainfall areas can be transferred to the low rainfall areas, specifically to the dry zone where the drought period is longer. This approach is particularly suitable for small countries like Sri Lanka. Transferring water from one area to another is not expected to be a challenging and expensive process for small counties.

These inferences provide a correct approach to the decision-making process to contemplate the future precipitation prediction data in the feasibility assessment during the water related projects. This approach is expected to maximize the rainwater harvesting and mitigating the foreseeable precipitation changes issues in the long run within the country.

This paper proposes utilizing the present and the future precipitation prediction data in delineating the locations for new water reservoirs in the country. It is expected that including present precipitation data in the analysis will be able to address the water shortage issue from present to the future scenarios. Besides, consideration of higher rainfall areas based on the available present precipitation data will be a real-world convincing factor in order to contemplate the importance of using precipitation data in site selection for a water reservoir.

The proposed reservoirs will be small to large scale artificial man-made terrestrial water features that can collect and store water for different usages. Two sets of results are generated in the study considering both the present and the future precipitation prediction data. The first set of the results will allow to select the most appropriate locations for new water reservoir based on both the future and the present precipitation data. The selected locations will be able to preserve the geographic, environmental and socio-economic conditions for a water reservoir while overlapping with the highest rainfall areas considering both present and expected future precipitation scenarios. It is expected that the water reservoirs constructed over the selected locations will be able to collect and store a high volume of rainwater across the year. These water reservoirs are anticipated to facilitate the water scarcity areas during low rainfall seasons.

The second set which is not suitable based on either of the precipitation scenarios, and are overlapping with the existing water resources, are flagged as highly vulnerable water resources that will be less usable in future. As per the analysis, these water features will receive lower rainfall considering the present and the expected future rainfall patterns. Rainfall being the only source of water of the reservoirs, the selected water features are not expected to provide an adequate contribution to the water volume in the country for the future requirements.

The approach proposed in this study is particularly focused on mitigating the precipitation change impacts on water availability in the country. Although the paper limits to the consideration of the precipitation changes, main aim of this project is to motivate the consideration of the predicted future climatic and environmental scenarios in the current projects in mitigating the expected issues in the future. This research is expected to be further developed by expanding the consideration of the other future predicted scenarios on different climatic, environmental and socio-economic factors.

Findings in this paper are expected to be considered in the decision-making process within different industries. This varies from the Department of Irrigation to many other stakeholders who are interested on maximizing the project efficiency by taking the most relevant data types into consideration under different scenarios. This includes the Department of Energy, who has a concern on maximizing the hydropower by adding new reservoirs, the Department of Consumer who is intending on developing the inland fishery industry by adding new inland water features etc. Despite the public entities, there are many private entities that have a concern on water related issues can also make use of the results and frameworks introduced in the study. Considering Sri Lanka, IWMI is conducting large scale research projects within the country as well within the Asian and the African region on sustainable use of water and land resources. The results generated in the study can be further justified by comparing the conclusions made in their research projects.

Besides the main purpose, a distributed GIS framework which can be utilized at any geographic location with the availability of required data is introduced in the paper. The analysis method utilized in the study can be customized by prioritizing the requirements while changing thresholds and weights based on the data type and the requirement.

1.2 Objectives of the study

The study considers the impact on water reservoir projects arising from future climate change of precipitation patterns up to 2050. As an approach to the main objective, requirement for new water storage systems, present and expected future water related issues, possible changes in the precipitation pattern and the status of rainwater harvesting in Sri Lanka are discussed. As the main outcome, the most suitable locations for water storage systems are delineated based on the present and future precipitation patterns of the country while preserving the geographical, environmental, socio economic advisability of the locations.

Besides the main outcome, the study also points out the possible water storage systems that will be vulnerable to being dried out due to the changes in the precipitation pattern in the future. The study further introduces a GIS framework for similar projects that is compatible with any geographical location utilizing any number of data types.

2. Background

2.1. Requirement of new water feature

2.1.1. Current Issues

Considering Sri Lanka, the available water sources and resources have not been able to fulfill the requirements of the water necessities in the country. The Sri Lanka National Water Development Report 2006 projects that "*Considering the subsequent water resources development it can be estimated that about 11,000 MCM of water are developed and are being utilized annually (about 1,600 litres/capita/day). Out of this total withdrawal, 85% or more is used for irrigated* *agriculture. Therefore, it appears that the present level of development of water for basic needs is small compared to annual water requirements*" (Imbulana et al. 2006). As per the research carried out by IWMI, among the 12,000 to 16,000 small tanks available in the country, about half of the tanks have become unusable by today (IWMI 2014). Besides these figures, Department of Agrarian Services, Sri Lanka, has also reported that 7,753 small tanks have been abandoned within the dry zone (**Table 4**). Lower regional rainfall and higher annual evaporation in the semiarid climate of the area that most of the water storage systems are located, have been identified as the primary reasons for the higher number of abandoned tanks. Besides, the unfavorable soil types which the tank bunds made from, poor accessibility, water pollution due to the epidemic water plants, locating away from human habitats, poor maintenance, ignorance and undefined technology used in the construction are identified as secondary reason for the abundancy (Panabokke et al. 2002). Moreover, the Food and Agricultural Organization – UN reported that the renewable water resources are gradually decreasing in the country. With the increase of population, renewable water resource per capita has gradually decreased within the last 50 years (**Table 5)**.

Province and area (km^2)	Number of small tanks		Total
	Operating	Abandoned	
Northern 3,709	608	816	1,424
North Central 10,365	2,095	1,922	4,017
North Western 7,760	4,200	2,273	6,473
Southern 2,849*	653	757	1,410
Lower Uva 2,901*	16	543	559
Eastern (South of Mahaweli) 3,885*	-	1,017	1,017
Eastern (North of Mahaweli)*	48	425	473
Total	7,620	7,753	15,373

***** Includes only the dry zone part of the province
Table 4 : Number of operational and abandoned small tanks within each province in dry zone
Source: Panabokke et al. 2002

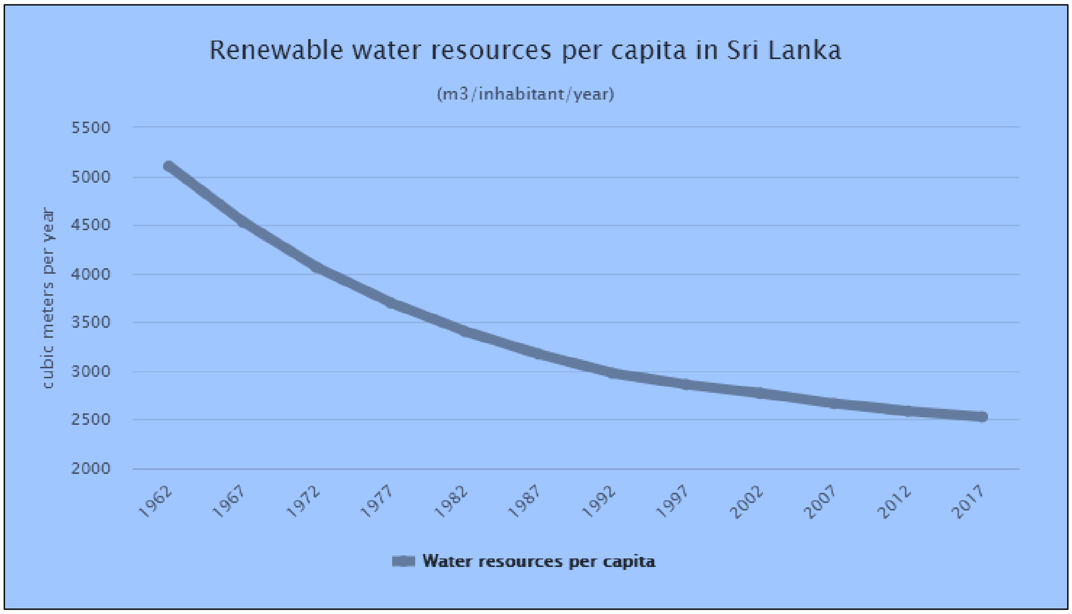

Table 5:Renewable Water Resource Per Capita - Sri Lanka
Source: FAO - Sri Lanka Water

About 80% of the rural water needs of the country are met from groundwater by means of dug wells and tube wells. These groundwater resources are widely used for domestic uses, small scale commercial and industrial purposes, and small-scale agricultural purposes (Panabokke et al. 2005). However, the shallow ground water is now been subjected to stress of over-extraction. Groundwater is being limited in quantity; over-exploitation could lead to a long-term water scarcity issues particularly over the dry zone (Weerasinghe et al. 2005). Besides, salt-water intrusion, contamination of Iron, Manganese and Fluorides have also been reported from various parts of the country by limiting the use of ground water over the affected areas (UNEP 2005). The groundwater volume of the country has been highly affected by the reduction of natural recharge. This effect has been mainly driven by the reduction of infiltration due to increase of temperature (Shah et al. 2011). Research conducted on the ground water status in the South Asia concluded that the region may faces a reduction in groundwater recharge by 10% in the 2050s as a result of climate change (Clifton et al. 2010). This implies that groundwater is an unreliable source of water and is not expected to provide an adequate contribution to the water requirement of the country in the future.

Accommodating with water requirements during the drought seasons has become another challenge in Sri Lanka. The water scarcity criterion developed by UN and IWMI indicated that the country is not going through a seasonal or year-round water scarcity in the present scenario (Amarasinghe et al. 1999). Although this implies that the country is maintaining a sufficient water storage throughout the year, unfortunately the country suffers from the water scarcity more frequently. It has been identified that an average drought of a serious nature occurs every 3-4 years, while severe droughts occur every 10 years (Imbulana et al. 2006). Hence a good mechanism to maintain a continuous water supply during the drought seasons is compulsory for Sri Lanka. But this is not the case in the country during the present scenario.

As per reports, drought seasons are continuously affecting the livelihood and the economy across the country in a negative manner. In 2004, an estimated 52, 651 ha of crops were damaged in 7 districts due the unavailability of proper water supply during the drought season (Imbulana et al. 2006)**.** Effect of the insufficient water supply varies from agricultural purpose, day to day uses to the hydropower generation. This results a constant disturbance on water and power supply during the drought season, even if it is short. This is a very common situation in Sri Lanka, especially within the urban areas. This affects in a different way within the rural areas which the agriculture is the main livelihood. Much of the agriculture in Sri Lanka is irrigated and depends on the supply of water through the canals and rivers from main reservoirs. Insufficient water availability during the drought season for agricultural purpose is directly affects the economic index of the country.

Irregular distribution of the available water reservoirs around the country is another major issue in Sri Lanka. A majority of these water reservoirs have been built up within the last 100-500 years during the King's era (Wijesuriya et al. 2005). The ancient kings focused on constructing these water storage facilities only within their kingdoms to conserve the power within a limited area. This leads to an imbalance distribution of water resources throughout the country (**Figure 4**). This is one of the main reasons to confine the agricultural activities to limited areas within the country. Food production has been limited by the unavailability of sufficient water over many parts of the country even if the topography, climate and the soil condition are favorable for agriculture. Price of the local food in other parts of the country are highly affected by this reason.

Although the north part of the country is more or less managed by the available water resources, water requirements of the other parts of the country are fulfilled by transferring the water through channels from the north. At present, the Department of Irrigation, Sri Lanka, disburses a large amount in maintaining and adding new channels in order to regulates the water supply throughout the country for both the domestic and the industrial necessities.

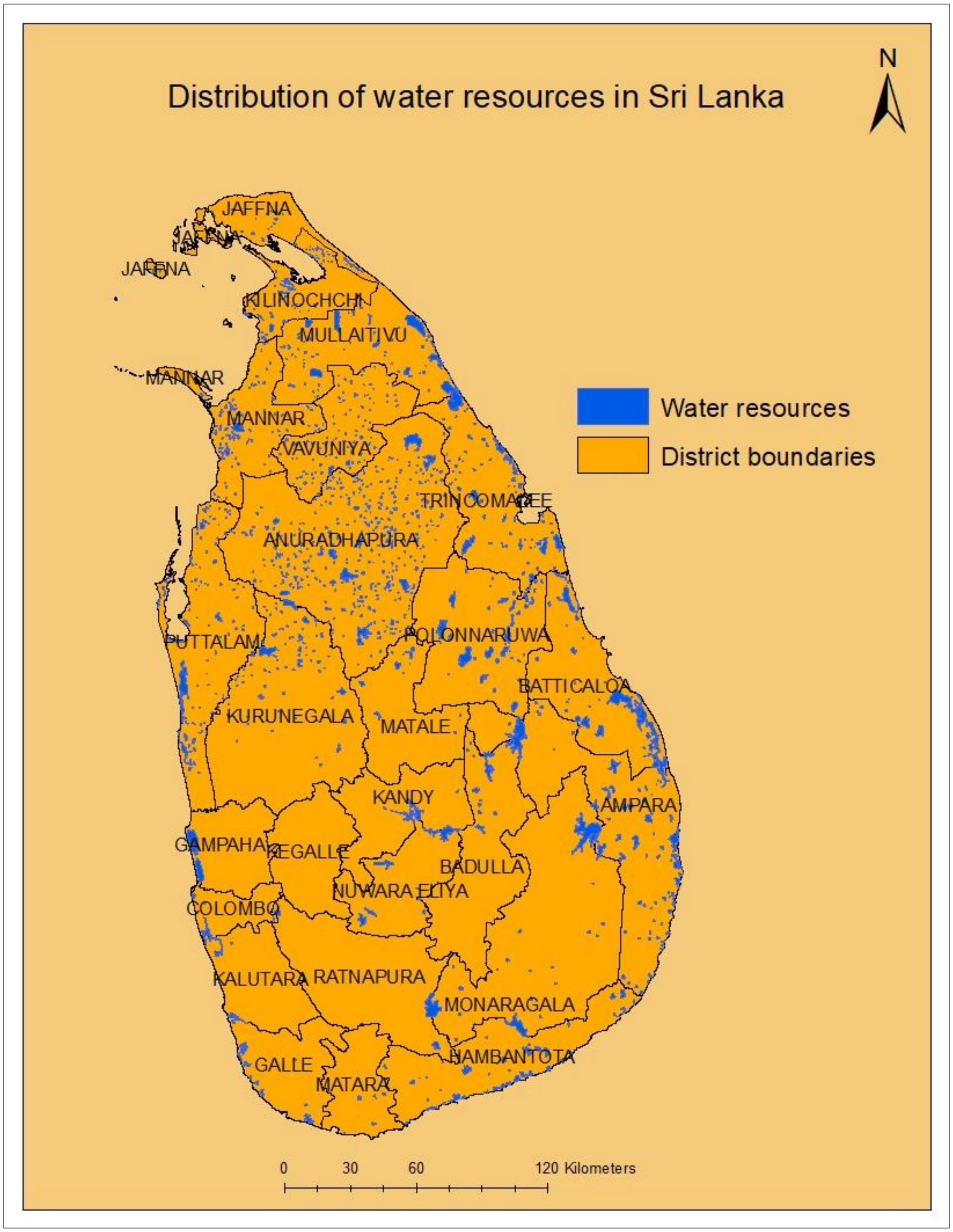

Figure 4:Distribution of water resources in Sri Lanka
Source: Survey Department of Sri Lanka

2.1.2 Expected issues in the future

As per the population figures published by the World Bank (**Figure 5**), Sri Lanka demonstrates a continuous growth of population since the year 2012. This is a red light to the government to alert that the demand for the main necessities of the country will be parallelly increased. Sri Lankan government should take necessary steps to facilitate the expected excess population by implementing new projects focusing on adding additional resources to the country. Among them, increase of water storage facilities, addition of new power units to the system and expanding agricultural activities will be visibly important.

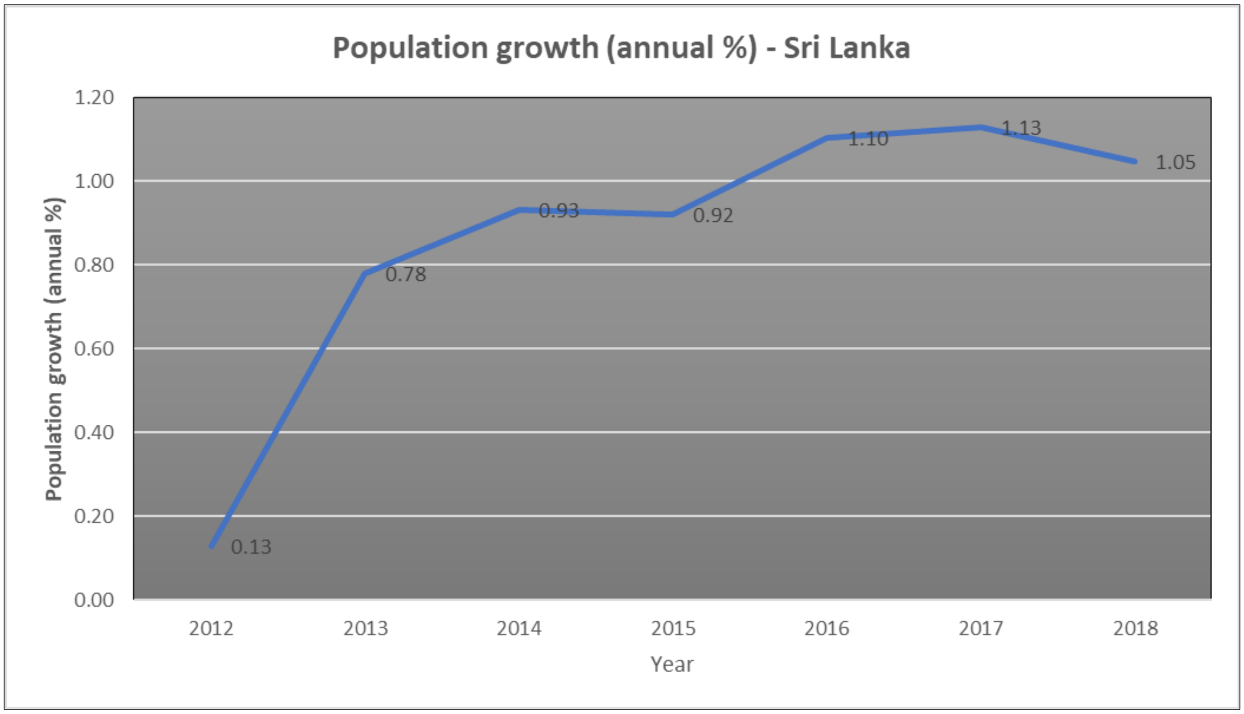

Figure 5:Population growth (annual %)
Source: The world Bank Data

Even though Sri Lanka is an agricultural country, the present local food production has failed to fulfill the requirements of the current population. As per the resources, food items amounting Rs.300 billion are imported annually (Abeyratne 2017). This can be reduced in the future by facilitating the agricultural sector as well as the inland fishery industry focusing on a higher local food production. This will directly affect the economy of the country in a positive manner.

Besides, degradation of the cultivable lands is another major issue in the country (**Table 6**). As per the figures available from 1871 to 2000, the land-man ratio in Sri Lanka has decreased from 2.7 ha/man to 0.3 ha/man. But the actual ratio for the arable land is as low as 0.15 ha/man. This will be further reduced by the growth of population and land degradation (Mapa et al. 2002). As per the research conducted in the field, if the currently developed water supply is properly managed, only a part of these water savings is adequate for meeting future irrigation demand in 2040 (Amarasinghe 2009). To address this issue, the Department of Agriculture should take necessary steps to maximize the sustainable use of the available arable lands in the country. Furthermore, it is parallelly important to extend the number of cultivable lands by facilitating them with the required irrigational, economical, and other physical resources.

Crop	Land area (.000 ha)			Percent Change
	1946	1962	1982	(1962-1982)
Paddy	370	460	499	+8.73
Tea	215	231	207	-10.04
Rubber	232	229	171	-25.47
Coconut	433	466	416	-10.75

Table 6:Changes in extents of lands under major crops
Source: Mapa et al. 2002

Environmental changes are another factor that affect many sectors in future. Changes in the temperature, precipitation and evaporation will provide a higher contribution towards the inland water capacity in future. It is found that mainly small-scale farmers struggle with the climate change impacts. This issue can be addressed by improving the performance of the existing irrigation systems and maximizing the usage of water at the individual frame level (UNDP 2013).

2.2. Precipitation and trends – Present and Future scenarios

A climatic year of the country begins in March and ends in February. Sri Lanka gets its main rainfall in four seasons; First Inter Monsoon season (FIM), South West Monsoon season (SWM), Second Inter Monsoon season (SIM) and North East Monsoon season (NEM) (**Figure 6**Error! Reference source not found.). Besides, the country also gets convectional rainfall between the two inter monsoon periods (DOM 2019). The FIM occurs from March to April and the average annual rainfall during this period is about 260 mm. The SWM rains occur from May to September mainly due to monsoonal wind. The average annual rainfall during this period is about 546 mm. The average annual rainfall during SIM is about 548 mm and this period falls in October to November. The NEM rains occur from December to February and the average annual rainfall during this period is about 459 mm (DOM 2019). The 60% of the country's rainfall is contributed by the combination of SIM and SWM from May to December and the contribution of rainfall by NEM and FIM are 26 % and 14 %, respectively (Abeysekera et al. 2016). The dry zone of Sri Lanka receives most of the rainfall during NEM and FIM (Imbulana et al. 2006).

In light of research into precipitation trends in the country, the mean annual precipitation of the country has decreased by 144 mm during the period of 1961-1990 compared to the estimated for the period of 1931-1960 (**Figure 2 and Figure 7)** (Chandrapala 1996; Jayatillake et al. 2005). The rainfall data collected for the period of 1949-1980 overs 13 stations reveal decreasing trends with steeper downward trends in the recent decades (Jayawardene et al. 2005). There is a wide disparity in the magnitude of changes that have taken place in different rainfall seasons and different spatial locations (Eriyagama et al. 2010). Long term fluctuations in the precipitation pattern have been observed by many studies. Shantha et al. (2005) observe a 39% decrease in mean annual rainfall in the Mahaweli headwater areas in the central highlands of the country from 1880 to 1974.

Bandara et al. (2004) indicate that the rainfall on the western slopes of the central highlands has declined significantly from 1900 to 2002. This is expected to be in a further change within the next 10-30 years in the country (USAID 2015). This has also been justified by the latest research conducted in the field (Burt et al. 2014).

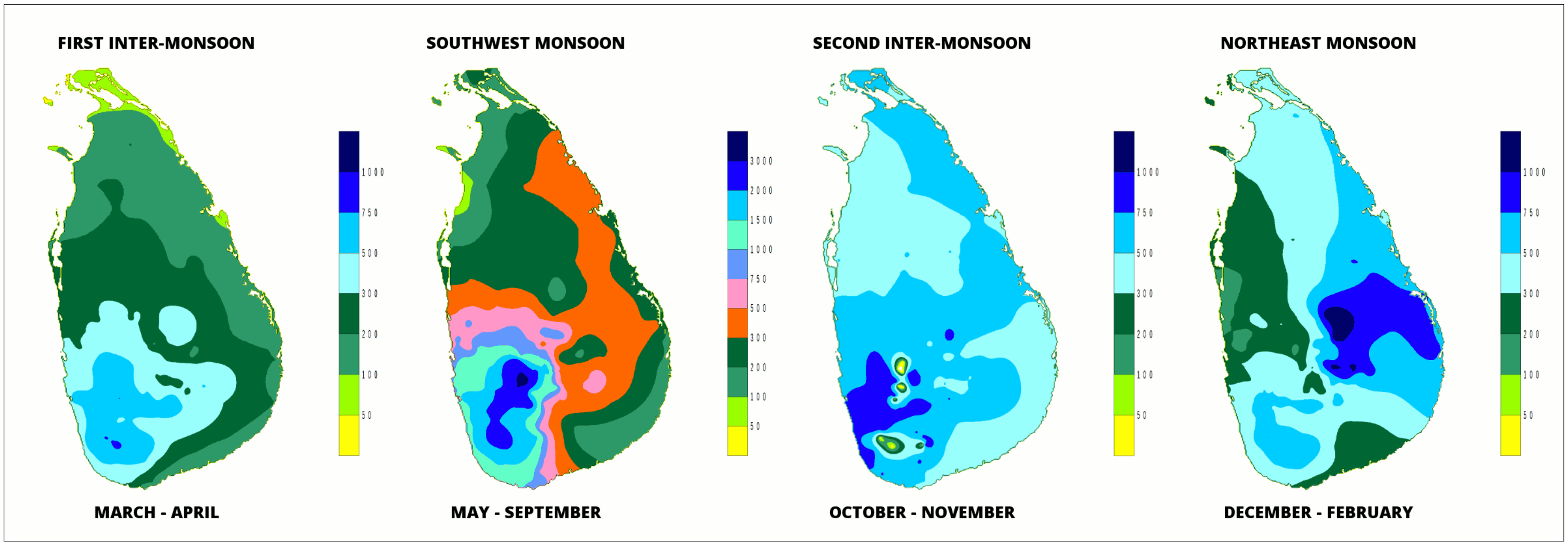

Figure 6:Seasonal Rainfall of Sri Lanka
Source: Department of Meteorology – Sri Lanka

As reported by IWMI, Sri Lanka is confronting an uncertain precipitation pattern in the future (IWMI 2013). Besides, there are many researches conducted in Sri Lanka to prove that the precipitation pattern of the country changes during the future. As per Basnayake et al. (2004b) and Basnayake et al. (2004a), there will be an increase of rainfall throughout the country by the 2025, 2050 and 2100 based on the IPCC scenarios A1F1, A2 and B1. Also, De Silva (2006) projects an increment of rainfall within the wet zone, northwestern and the south western dry zones while reduction of rainfall in other dry zones and increased rainfall in the intermediate zone by the 2050 under the IPCC A2 scenario. Further Shantha et al. (2005) project a 17% reduction in rainfall in the upper Mahaweli watershed by the 2025. Apart from these changes in the precipitation patterns, temperature together with the other climatic factors are expected to affect the evapotranspiration and soil moisture across the country by the 2050 (De Silva 2006; De Silva et al. 2007).

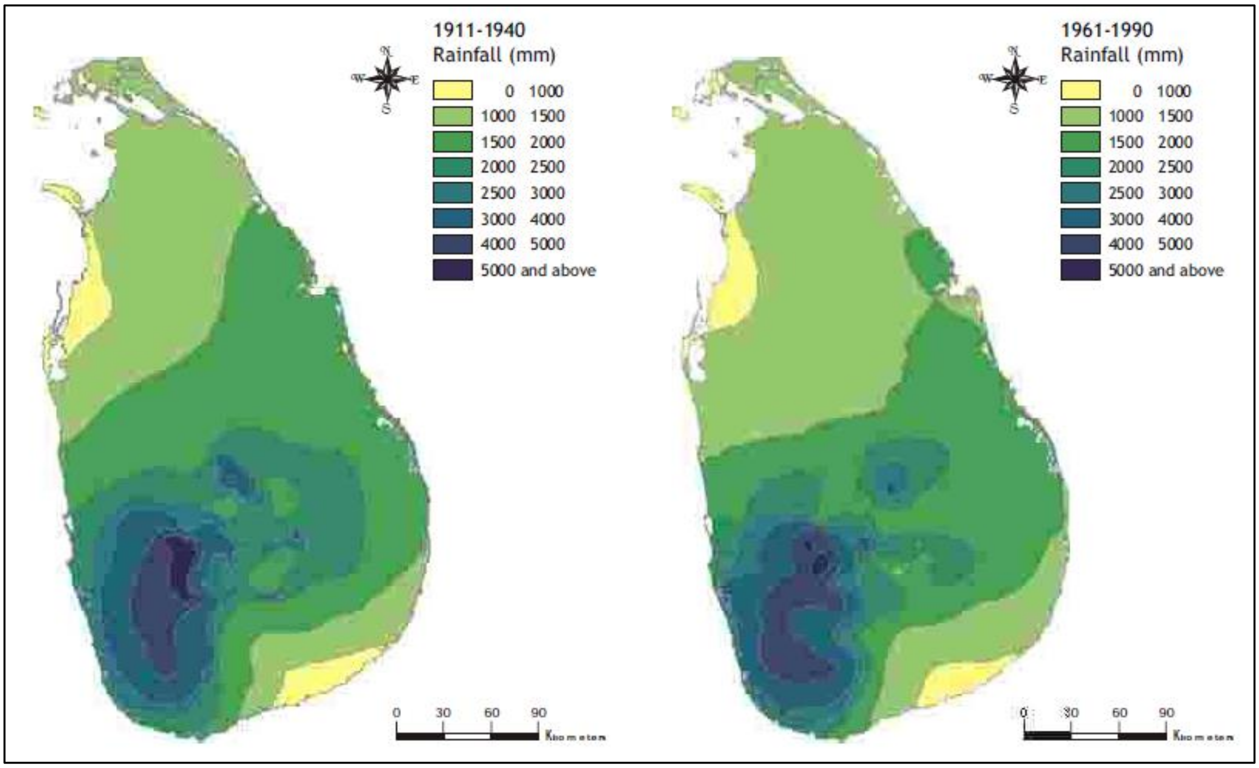

Figure 7:A comparison of average precipitation during (a) 1911-1940, and (b) 1961-1990, indicating expansion of the dry zone (MAP < 1,750 mm)
Source: Imbulana et al. (2006). Prepared by Ratnayake U. R., Department of Civil Engineering, University of Peradeniya, Sri Lanka

2.3 Rainwater harvesting in Sri Lanka

Rainwater harvesting is an acquainted concept in Sri Lanka since the past. A majority of the water resources available in the country have been constructed by the great rulers in the ancient king's era targeting the conservation of rain and runoff water for day to day and agricultural necessities (**Table 7**). The famous quote of the Sri Lankan King, King Parakramabahu the Great (1153-86 AD) that "*Let's not allow a single drop of water to flow into the sea without being used for the benefit of mankind*. ", is an indication of the commitment of the ancient rulers and the people to conserve water and minimize the runoff (Ariyananda 2009). With intense agricultural activity, primarily the cultivation of rice which depend on unreliable monsoon rains, the ancients had constructed canals, channels, water-storage tanks, and reservoirs to provide continuous supply of irrigation waters through rainwater harvesting (Brohier 1935).

With an adequate amount of rainfall receive in the country, harvesting rainwater is an effective and tactful option for maximizing the water storage capacity in the country. But according to studies on urban areas in Sri Lanka, about 60% of the rainwater flows directly into the sea without benefitting the people due to the lack of storage capacities (Strand 2012). As per the Sri Lanka National Water Development Report, 2006, only 1.3% of the Sri Lankan population consumes rain harvested water. The majority of the balance population is served with pipe born water while the balance is served with the water extracted from wells or tubes (DCS 2002).

The capital expenditure for providing pipe born water for a large community is a challenge for any developing country. Moreover, the Sri Lankan government has failed to maintain neither the continuation of water supply nor fulfills the demand due to the lack of resources. Despites that, it is an additional cost added to the monthly expenses of the consumers. Further, the larger community that is served by the well and tube well water is expected to be reduced due to the continuous decline of groundwater table in the country. These factors stress that rainwater is the only reliable and economical source of water for a country rich with a year-round rainfall. This provides not only the access to safe water, but also it supports regulating the distribution of water availability across the country. Utilization of the rainwater varies from agricultural purposes, hydropower requirements as well as providing safe drinking water to the community. While the first two purposes require small to large storage capacities, third needs domestic storage systems based on the consumption.

In order to maximize the utilization of rainwater within smaller communities, the Ministry of Urban Development and Water Supply of Sri Lanka has implemented the National Rainwater Policy. The policy made it compulsory of rainwater harvesting in certain categories of buildings in the municipal and urban council areas. And it is intended to promote rainwater harvesting in the rural areas as well (Imbulana et al. 2006).

No.	Name	Year	River Basin	Gross Capacity (MCM)
1	Senanayake Samudra	1956	Gal Oya	949.78
2	Randenigala	1986	Mahaweli	863.84
3	Victoria	1984	Mahaweli	723.24
4	Maduru Oya	1983	Maduru Oya	598.29
5	Samanala wewa	1992	Walawe	278
6	Udawalawe	1973	Walawe	269.41
7	Lunugamwehera	1984	Kirindi Oya	225.73
8	Kotmale	1985	Mahaweli	173.49
9	Ulhitiya	1982	Mahaweli	145.51
10	Kantale	1869	Per Aru	140.62
11	Minneriya	1903	Mahaweli	135.68
12	Parakrama Samudra	1952	Mahaweli	134.45
13	Kaudulla	1960	Mahaweli	128.28
14	Moussakelle	1969	Kelani Ganga	123.95
15	Kalawewa	1887	Kala Oya	127.75

Table 7:Fifteen largest reservoirs in Sri Lanka
Source: Sri Lanka National Water Development Report 2006

3. Methodology

3.1. Overview

Various GIS tools available in the ArcMap (ESRI 2017) software were utilized in the data preparation and the location selection process. With the development of technology, GIS has increased its effectiveness in parallel as a tool in handling the spatial data in many applications. GIS technology allows its users to capture, store, manipulate, analyze, manage and present the geographical data by compressing a complex data handling process into a simple process. GIS analysis is famous for its characteristics of cost effectiveness, time saving and high accuracy. These advantages of GIS support various types of projects in many ways. Today, project planners have identified GIS as a powerful tool in many fields. Among them application of GIS in the water resource planning and management has recognized as one of the most effective application areas of GIS. This is due to its compatibility of handling large amount of data available in different formats (Leipnik et al. 1993). Beside this, it also been identified that the application of GIS is not limited to the data analysis stage, it also applicable during the project feasibility, operational and the maintenance stages as well. This is a vast use of a data management tool within such project.

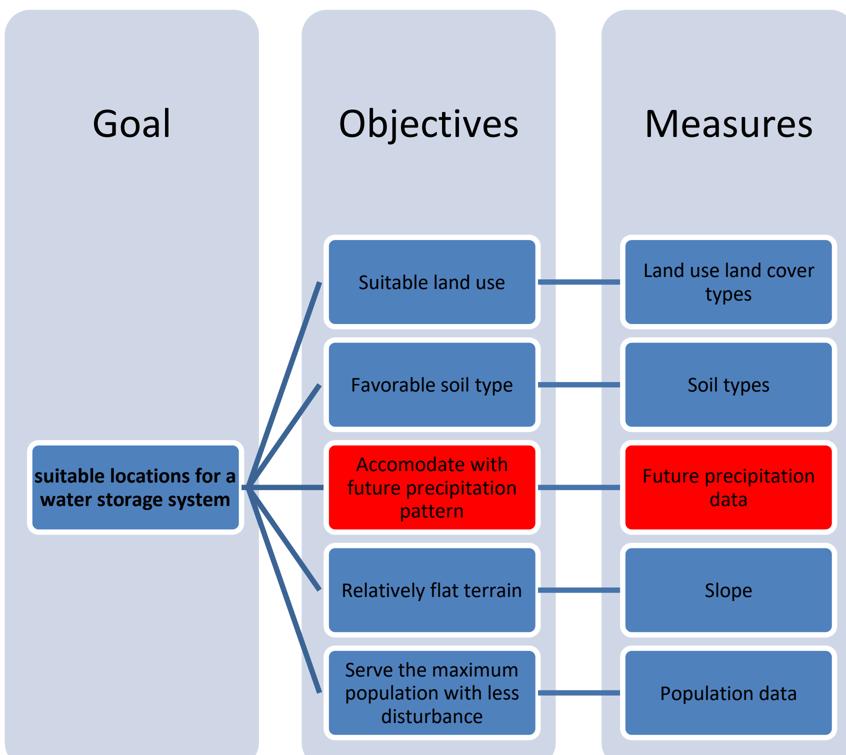

Figure 8:Conceptual model

3.2. Data used

The main goal of this study is to emphasize the importance of utilization of the future precipitation prediction data in delineating the locations for water resource. Project objectives and the related measures are identified as per the **Figure 8**. The preliminary selection of the location is done based on the basic data types such as topography, soil type, land use type and population. Most suitable areas based on the future precipitation prediction data is merged with the selected preliminary locations to extract ideal locations for water features. The selected locations will be able to accommodate with the changes in the precipitation pattern in future while preserving the advisability of the geographic and socio-economic factors for a water storage system. Moreover, present precipitation data is also be used in the study in order to increase the reliability and the efficiency of the outcome.

Future precipitation prediction data was collected from the WorldClim, a free global climate data source available online. This is a climate projection from the Global Climate Models (GCM) that was downscaled and calibrated (bias corrected) using the 'current' climate (from 1960 to 1990) as baseline. This is considered as the most recent climate projection that is used in the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC) report (**Figure 9**). This data set has been produced considering the Greenhouse Gas (GHG) scenario of the Representative Concentration Pathways (RCP) 2.6. The RCP 2.6 assumes that the global annual GHG emissions (measured in CO2-equivalents) peak between 2010 -2020, with emissions declining substantially thereafter (Meinshausen et al. 2011). Considering the present concern on reducing the emission of GHG and the active global awareness on the outcomes of the increase of GHG, the RCP 2.6 scenarios is assumed to be provided a realistic prediction compared to the other three RCP scenarios.

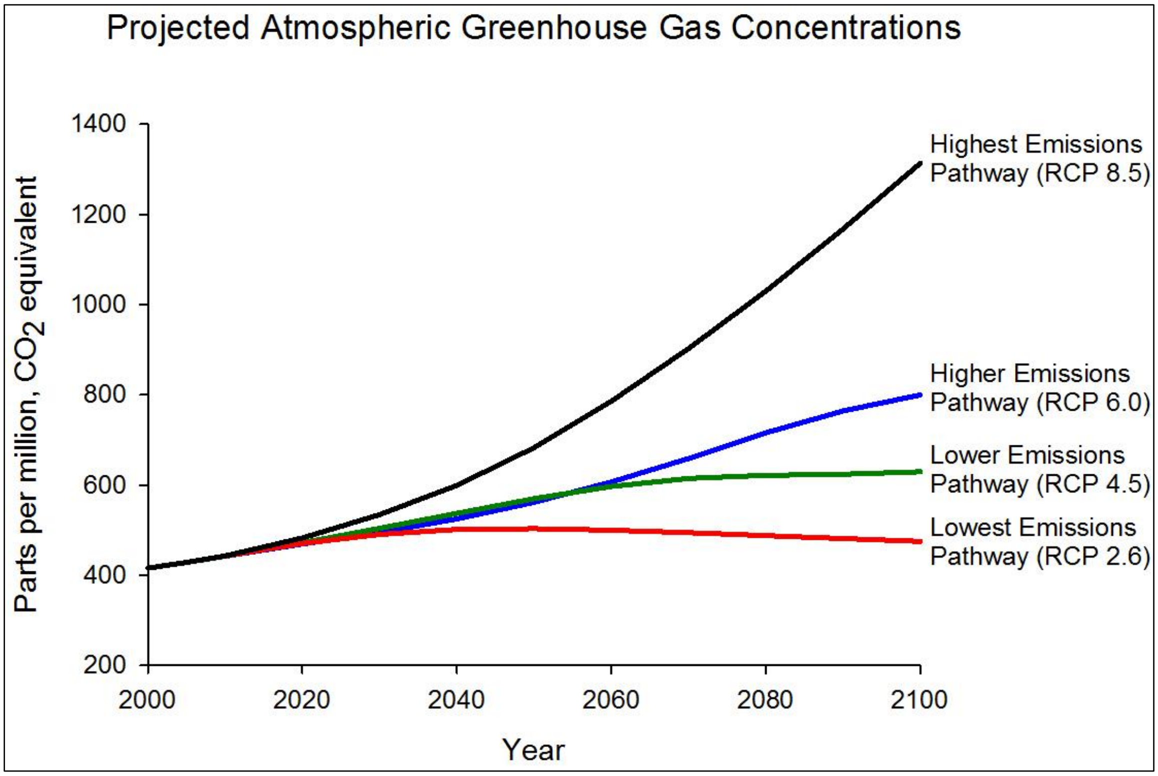

Figure 9:IPCC AR5 Greenhouse Gas Concentration Pathways
Source: Graph created from data in the Representative Concentration Pathways Database (Version 2.0.5)

During this climate projection, the predicted monthly precipitation data from 2041 to 2060 have been averaged in order to generate the predicted average monthly precipitation values in mm in the year 2050 (**Figure 10**). Spatial resolution of the data used was 30 seconds which represents about 900 m at the equator. Data was available in GeoTIFF format (Hijmans et al. 2005).

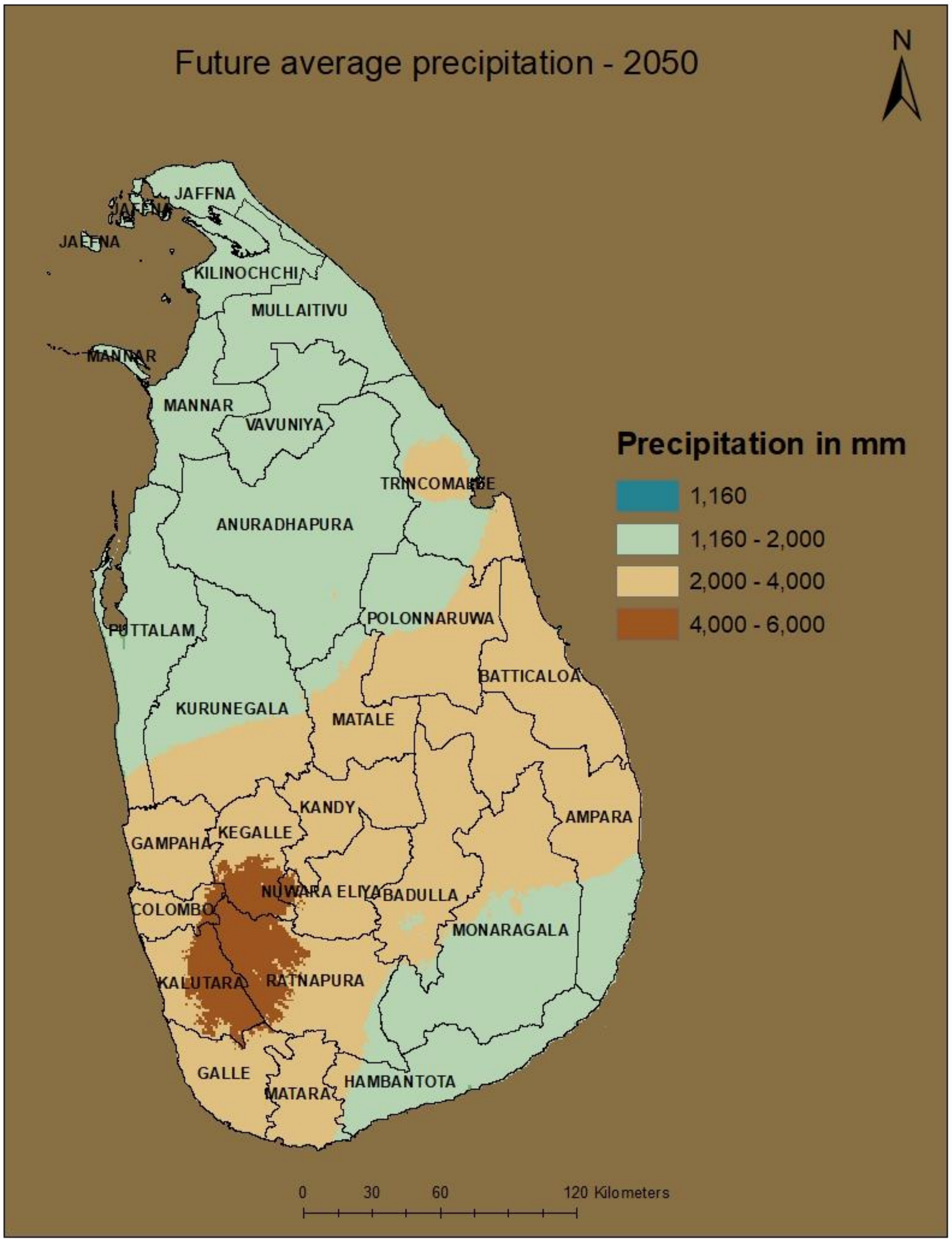

Figure 10:Projected Annual Mean Rainfall in 2050
Data source: WorldClim

As per the precipitation projection, around 50% of the country will have a moderate to high rainfall in the year 2050. Highest rainfall will be recorded mainly over the major parts of 3 districts, namely Rathnapura, Kegalla and Kaluthara. Despite this, some parts of the country's capital, Colombo district and a small part of the district Nuwaraeliya will also expect to record a higher rainfall in the 2050. A major part of the areas categorized under the dry zone will be expecting to receive the lowest rainfall in the future based on this projection.

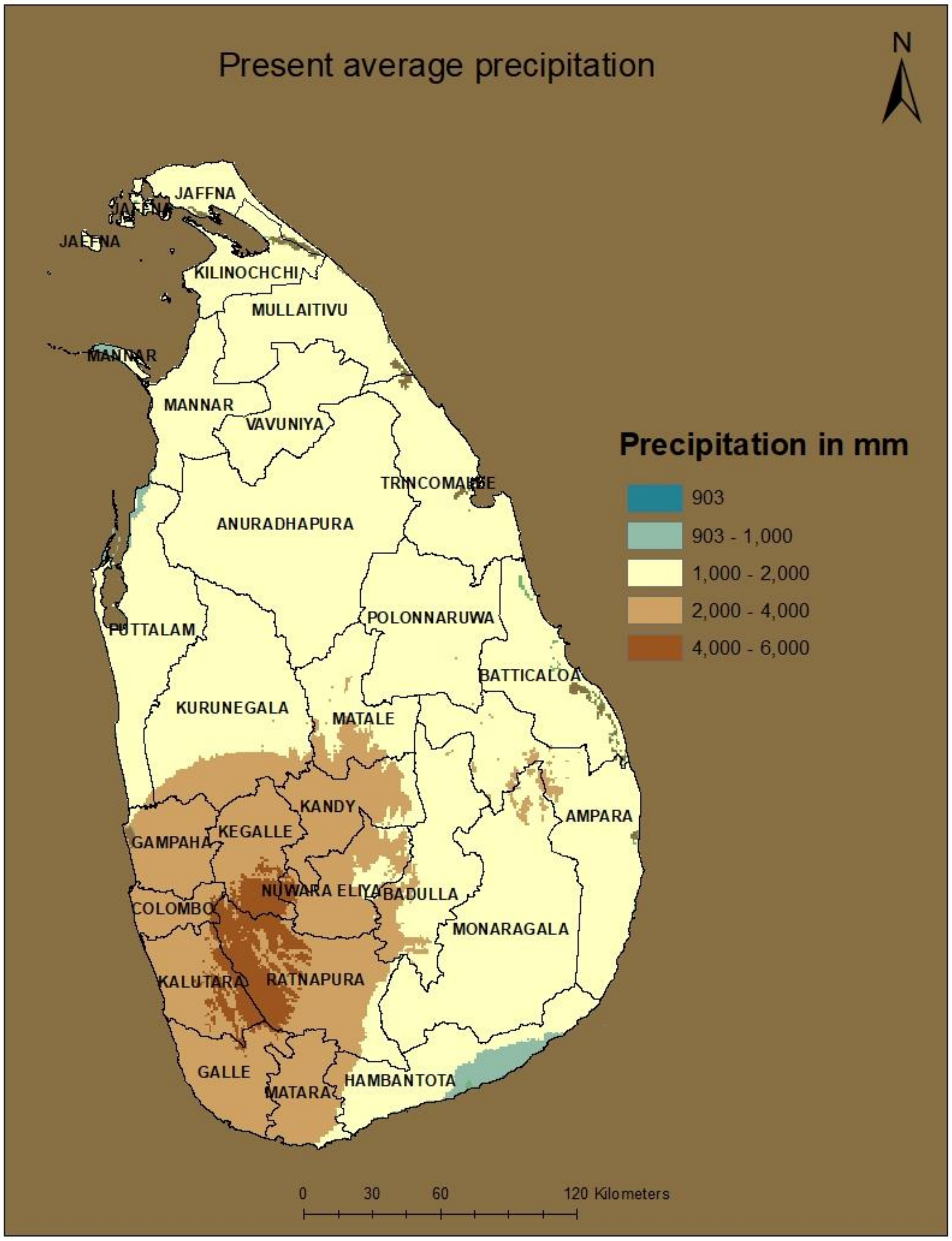

Figure 11:Present Annual Rainfall - Average from 1970 to 2000
Data source: WorldClim

Current precipitation data was also collected from the WorldClim, a free global climate data source available online. This data set has been generated by summarizing the average monthly precipitation data from 1970 to 2000 (Fick et al. 2017). Although the data was available at different spatial resolutions, 30 second resolution data was used in the analysis in order to be compatible with the resolution of the future precipitation data set. Data was available in GeoTIFF format.

As shown on the **Figure 11**, summarized present precipitation data over the 30 years of period shows that the highest rainfall has recorded over four adjacent districts in the south west of the country. Districts Colombo, Kaluthara, Gampaha, Gall, Matara, Rathnapura,Kegalla, Nuwara Eliya and Kandy have recorded > 2000 mm mean annual rainfall during the study period. Due to their locations along the south west coastline, the districts Colombo, Gampaha and Kaluthara are directly impacted by the south-western monsoon from May to September. This causes these three districts to increase its vulnerability to recurrent flooding. This is due to the increment of average rainfall coupled with heavier rainfall events, with knock-on impacts to the infrastructure, utility supply and the urban economy of the area. As a result of its geographic location and the richness of the biodiversity, district Rathnapura and Kegalla also report higher rainfall over the major parts of the areas. Although the district Kagalla reports a moderate to higher rainfall throughout the area, Rathnapura district shows a greater variation in the rainfall pattern within its boundary. The south-western monsoon passes along the north side of the district provides a higher rainfall over those areas while leaving the southern part of the district dry.

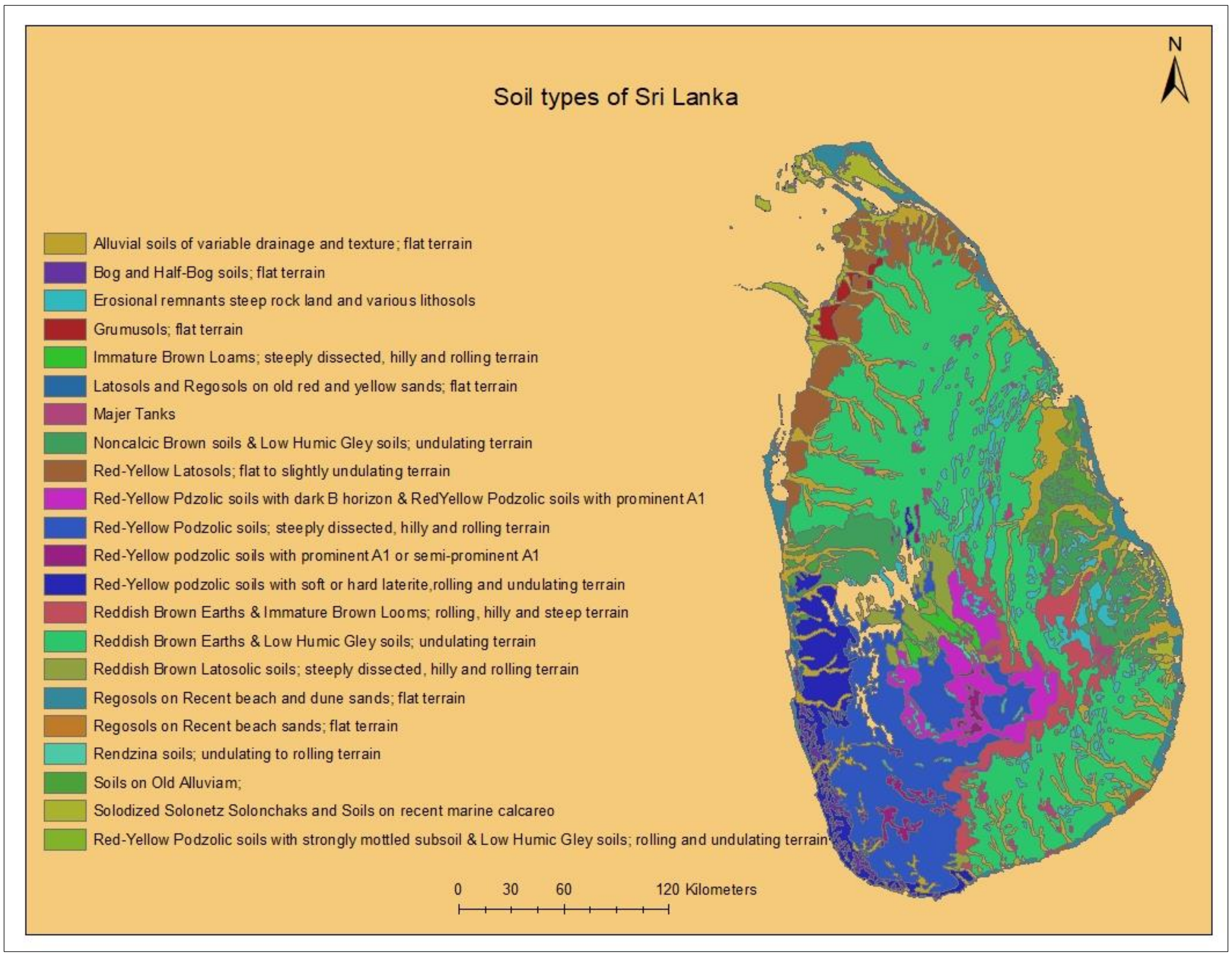

Figure 12:Soil types of Sri Lanka
Data source: IWMI 2014

The vector soil layer was extracted from the Water Information System for Sri Lanka (IWMI 2014). This layer has been derived from the 1:1650 000 map published by the Arjuna Atlas of Sri Lanka. Although the country consists of over 10 variations of soil types (**Figure 12**), Radish brown and Red-Yellow pdzolic soils found to be the dominating soil types across the country. The soil types with low infiltration property are considered as the most suitable soil types for a water reservoir. Among them, clays and silts clay and silty and clayey sands and gravels have been identified as the ideal soil types for water related projects. Coarse-textured sands and sand gravel mixtures, Sandy Loam, Loam, Silt Loam, Loamy Sand, Sand and all peat, muck, and mineral soils with high organic matter content have been identified as less suitable soil types for water resources (Hayes et al.).

Topography of the country delineated from the contour data collected from the Department of Surveying, Sri Lanka. The country is divided into three topographic zones based on its distinguished elevation: lowland, upland, and highland. Elevation below 100 m altitude, typically consists of the coastal area is categorized as the lowland (**Figure 13**). The upland varies from 100 m to 500 m above the sea level. A major part of the country is categorized into the upland area which consists of slightly undulated terrain. Elevation above 500 m altitude is classified as highland. Although the area covered by highland is minimal, it consists of about 150 mountain peaks ranging between 1000-2000 m in height and about 12 peaks ranging from 2000 m to 2500 m in height. All the highest mountains including the highest peak, Puduruthalagala which rises to 2525 m above the sea level have located within this topographic zone (Manchanayake et al. 1999). For the analysis, the vector contour layer was converted to a Digital Elevation Model (DEM) using the ArcMap 10.1. A slope map was formed using the DEM. Steep slopes are rarely economic for water reservoirs and give limited storage so, where steep slopes (i.e. over 4-5 percent) were given a low priority in the analysis (Stephens 2010). Considering Sri Lanka, a major area consists of less than 0.5-degree slope providing a favorable condition for water storage system. It is clear from the slope map that the slope is descending from the central highlands towards the coastal area gradually. This is a favorable condition for runoff water harvesting within the low land areas.

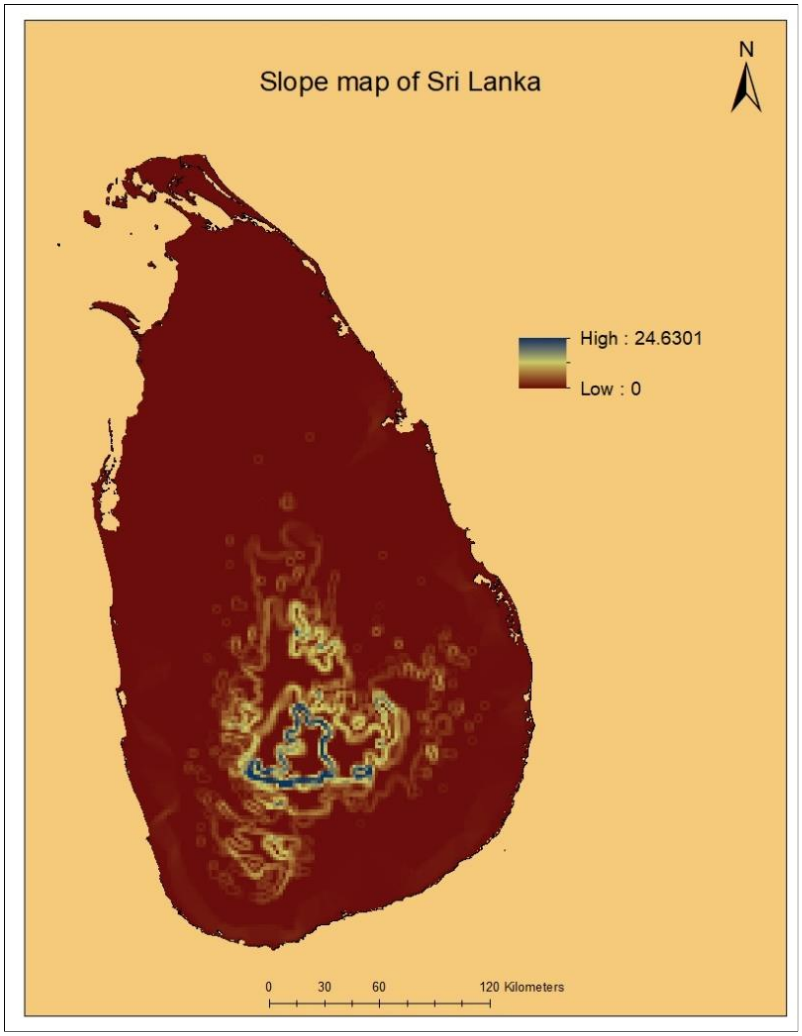

Figure 13:Slope map of Sri Lanka
Data source: Department of Surveying, Sri Lanka

The land use land cover map was obtained from the Department of Surveying, Sri Lanka. As per the **Figure 14**, the country has been classified in to 10 different land cover classes under different land use types. Forest, being the dominating land cover type, covers almost 36% of the country. This contain the dense forest which is about 70% of total forest area and the open forest covering the balance 30% of the total forest area. Vegetation cover acquires about 20% of the total country area while paddy cultivation acquires about 60% of the total agricultural land area within the country. Balance agricultural area has been occupied by tea and rubber cultivations, the main exports of the country and the coconut cultivations. The forest area has been less prioritized in the location selection due to its environmental value. The country is currently undergoing through the consequences of the degradation of forest cover and increase of bare lands. Seasonal flood and landslide are some of the common disasters that the country is exposing currently. Hence, utilization of forest cover for unconventional purposes has been limited in the analysis. Similarly, cultivated areas have also been considered as less economical in utilizing for unconventional purposes. This has also been restricted by the current land use legislations in the country. Considering its economic and environmental conditions, open areas which have been categorized under the other land category, have been identified as the most appropriate land cover type for water storage system. Despite that, undefined and garden areas have also been identified as satisfactory land cover type for such projects.

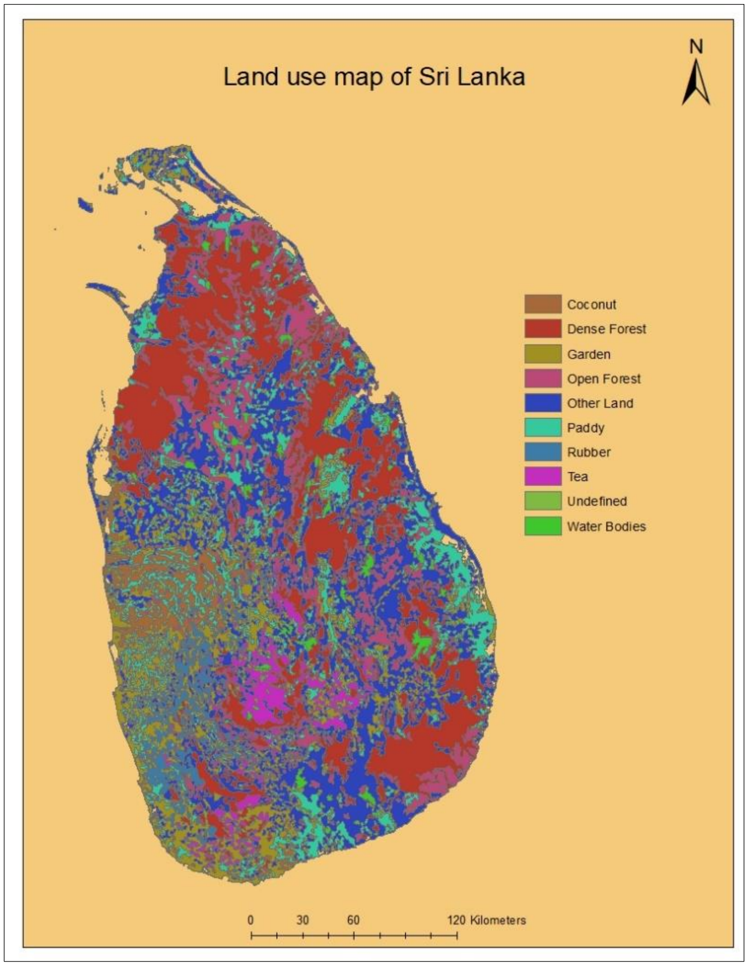

Figure 14: Land use map of Sri Lanka
Source: Department of Surveying, Sri Lanka

Population data were extracted from the WorldPod (**Figure 15**), which provides an open access to free spatial archive demographic data over the Africa, Asia and Central and South America regions. This data set has been mapped using the WorldPOP modelling version 2b (v2b) for the 2015 with approximately 100 m spatial resolution at the equator. This depicts the population per pixel (ppp) over Sri Lanka. As per the data set, the highest population density is recorded within the city of Colombo, which also known as the commercial capital of Sri Lanka. Although the city of Colombo is smaller in its area, it has created the highest number of job opportunities and has become the commercial hub of the country. The city is mainly populated with the people not native to the place, but with the migrants from other parts of the country in search of employment opportunities. Today, facilitating this crowd with the basic necessities has become a challenge to the Sri Lankan government. About 90% of the population living within the city of Colombo are facilitated by pipe born water for their domestic necessities. Due to the un-availability of water resources within this area, water supply of Colombo is highly depending on the water availability of the reservoirs located outside of the city boundary. Although the city of Colombo records a higher annual rainfall, the city neither has a mechanism nor resources for rainwater harvesting in the present.

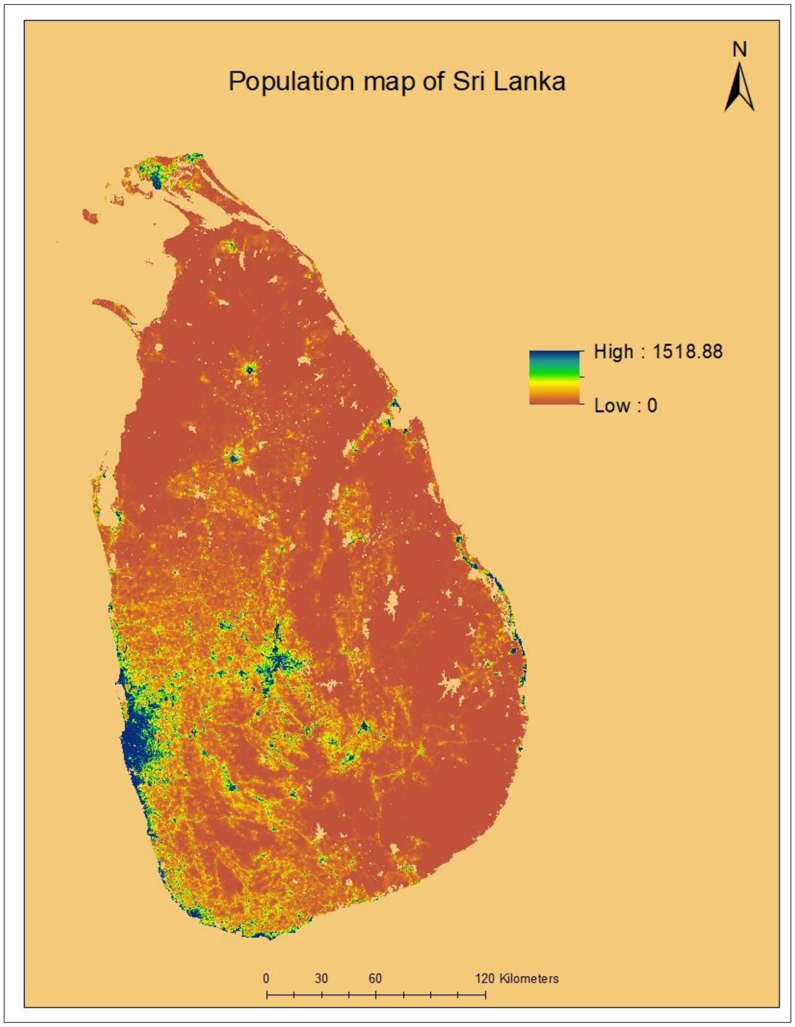

Figure 15:Population map of Sri Lanka – 2015
Data Source: WorldPod

3.3. Preliminary location selection

The suitable locations based on the widely used criteria were delineated as the preliminary location selection. In this project, soil type, slope, population, and land cover types have been taken into consideration during the preliminary location selection. The weighted overlay method was used in the selection. Ranks and weights were assigned to each data type based on their relative influence in the selection of location.

Infiltration factor of the different soil types was taken into consideration while assigning the ranks on the soil data set. Clay is considered as the best material for building strong, impermeable reservoirs (Weatherhead et al. 2009). Soil types contain clay and clay loam demonstrate the lowest infiltration rates and the sandy and silty soil types demonstrate the highest infiltration rates. (**Table 8**). Favorable soil types available over the flat to slightly undulating terrain were assigned the highest ranks while the less usable soil types were assigned a lower rank. Besides, soil types available over the hilly terrain, steep rock land, dunes and the beach areas also assigned low weights in order to have a lower priority in the selection due to their unfavorable geographical and topographical suitability.

Soil type	Infiltration rate in mm per hour
Clay	1-5
Clay Loam	5-10
Silt Loam	10-20
Sandy Loam	20-30
Sand	Over 30

Table 8: Long term infiltration rates for soil types
Source: Development Planning and Research Associates, United States, 1983

The vector contour layer of the country was used to generate the slope map through the Digital Elevation Model (DEM) using the ArcMap 10.1. The DEM raster layer was re-sampled to 100 m resolution to compatible with the population raster data set. Steep slopes are rarely economic for water reservoirs and give limited storage so, where steep slopes (i.e. over 4-5 percent) were given low priority (Stephens 2010). The highest priority was assigned to the flat terrain where the slope was less than 1%. Topography of the terrain is considered to be the most dominant factor when delineating the suitable location for an aquatic storage system.

Existing water bodies, forests and cultivated land were identified as the least suitable areas for the purpose. Existing water bodies were excluded from the analysis due to the fact that the study only focuses on finding new locations for water bodies. Besides, the existing spatial distribution of water storage systems has failed to fulfil the water requirements of the country. Instead, altering the distribution pattern of the existing water storage systems based on the rainfall pattern is expected to achieve the project purpose. Being not tagged with a specific land cover type, undefined and other land cover types are considered as the less important land cover types available in the data set. Due to the fact that, these two land cover types are not belonging to any of the important land cover types such as water bodies, forests or cultivated lands, a higher rank was assigned to these two land cover types in the location selection. However, land cover type is considered as a less dominant factor during the preliminary location selection.

The population density of the country was also taken into account during the preliminary location selection. It is expected that the water reservoir projects commence should be less distractive to the human settlements considering the relocation and other related settlement costs attached. Further, less populated areas are expected to be supportive in collecting surface runoff water over a large bare surface with minimum wastage. This is an important factor when considering the maximization of the rainwater harvesting. As reported by DCS 2014, a higher percentage of arable lands are presented within the low populated areas in the country (**Table 9**). Specifically, low populated districts Batticaloa, Ampara, Trincomalee, Anuradhapura and Polonnaruwa represent more than 70% percent of the arable lands from their total agricultural land extend. A smaller percentage of the total agricultural area has been cultivated with the permanent crops. Facilitating with an uninterrupted water availability over these arable lands will be able to boost the agricultural productivity focusing on a high local food production within the country for the future needs. Considering these factors, the most suitable area for a new aquatic storage system is considered to be the least populated areas. It is expected that, prioritizing low populated areas in water reservoir project will directly support in maximizing the cultivation over the arable lands while reducing the cost of resettlement. However, population density is considered as the least important factor among the criteria considered.

District	Agricultural Land extent (Acres)	Percentage distribution of Agricultural area by use		
		Arable Land	Land Under Permanent crops	Other land
Colombo	65,324	19.6	62.5	18.0
Gampaha	170,453	21.7	65.9	12.4
Kalutara	222,583	19.0	62.9	18.1
Kandy	254,263	16.7	59.3	24.0
Matale	183,541	34.8	49.2	16.0
Nuwara Eliya	228,145	13.0	72.8	14.2
Galle	210,609	19.4	62.2	18.4
Matara	207,799	21.0	63.5	15.5
Hambantota	235,020	45.1	42.9	11.9
Jaffna	53,741	62.1	23.0	14.9
Mannar	41,808	67.0	28.1	4.9
Vavunia	64,687	62.7	26.0	11.3
Mullaitivu	63,838	60.6	23.5	15.8
killinochchi	75,043	64.7	25.8	9.5
Batticaloa	107,335	86.3	7.3	6.4
Ampara	215,344	82.2	7.4	10.4
Trincomalee	88,359	82.5	7.3	10.2
Kurunagala	672,774	35.6	53.7	10.7
Puttalam	255,648	25.0	59.3	15.7
Anuradhapura	536,477	72.0	16.7	11.3
Polonnaruwa	209,194	74.0	13.0	13.0
Badulla	295,228	37.7	43.6	18.8
Monaragala	320,441	51.6	39.2	9.3
Ratnapura	372,142	14.0	67.3	18.7
Kegalle	253,805	10.9	70.1	19.0
Sri Lanka	**5,403,600**	**39.8**	**45.9**	**14.3**

Table 9:Agriculture Land Extent and Percentage Distribution of Agricultural Area
Source: DCS 2014

3.3.1 Assigning of weights

During the analysis, weights are assigned to each criterion based on their relative influences in site selection for water reservoir. In this study, the pairwise comparison method was adopted to assign weights to each criterion. The method proposed by Thomas L. Saaty (1977) is in the context of the Analytical Hierarchy Process (AHP). According to Saaty (1977), pairwise comparison method is an effective method for the determination of relative importance when several criterions are analyzed.

In this method, a ratio matrix (comparison matrix) is constructed by comparing every criterion with each other on a scale of 1-9 using the fundamental scale introduced by Saaty (1977). These values then be used for calculating the weights of each criteria. The numbers are assigned to the ratio matrix are based on the opinions on experts, decision makers or by referring to previous studies. However, comparison matrix is mostly relying on subjective judgment which could lead to illogical results with bias. In order to evaluate the consistency of the matrix, a Consistency Ratio (CR) is calculated. If the CR value is less than its acceptable maximum of 0.10, the consistency of the matrix is considered as acceptable (Saaty 1987).

The pairwise comparison method is conducted under the following steps:

- Step1: Determination of importance of each individual criterion
- Step2: Determination of relative importance of every criterion compared to each other (filling the comparison matrix)
- Step3: Weight determination
- Step4: Assessment of the consistency by calculating the CR.

Step1: Determination of importance of each individual criterion

Based on the previous studies on site selection for water reservoirs, the order of the importance of each selected criterion was assigned as per the **Table 10**:

Criteria	Order of importance
Slope	1
Soil	2
Land Use	3
Population	4

Table 10: Order of importance

Step2: Determination of relative importance of every criterion compared to each other (filling the comparison matrix)

The fundamental scale introduced by Saaty (1977) was used in assigning the values in the comparison matrix (**Table 11**). The scale contains the values from 1 to 9 which represent the intensity of the importance of one criterion compared to another.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favor one activity over another
5	Essential or strong importance	Experience and judgement slightly favor one activity over another
7	Demonstrated importance	An activity is strongly favored, and its dominance is demonstrated in practice.
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values of the two adjacent judgements.	When compromise is needed

Table 11:The fundamental scale and its description
Source: Saaty 1977

Based on the order of importance presented in the **Table 10** and the fundamental scale introduced in the **Table 11**, the pairwise matrix was filled as **Table 12**. As per Saaty (1977), if an intensity value is assigned to the criteria *i* compered to criteria *j*, then the reciprocal value is assigned to the criteria *j* compared to the criteria *i*. For example, if intensity value of 3 is assigned for slope compared to soil, then the intensity value of soil compared to slope is considered as 1/3. However, the judgement on assigning values in this study is subjective and based on the knowledge gathered from similar studies.

	Slope	Soil	Land Use	Population
Slope	1	3	5	7
Soil	1/3	1	3	5
Land Use	1/5	1/3	1	3
Population	1/7	1/5	1/3	1
Total	**1.6762**	**4.5333**	**9.3333**	**16**

Table 12: Comparison matrix

Step3: Weight determination

Once the comparison matrix is completed, the weights of each criterion are calculated as follows:

Equation 1: Calculation of weight (Saaty 1977)

$$W_i = \frac{\sum_{j=1}^{n} P_{ij}}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} P_{ij}\right)} \text{-----------------------------} (1)$$

Where:
W = Weight
i = Criteria i
j = Criteria j
n = Number of criteria
P_{ij} = Pairwise comparison of criteria i compared to criteria j

The final weight of each criteria is calculated by averaging each row as per the **Table 13** (Saaty 1977).

	Slope	Soil	Land Use	Population	Weight	Weight as a %
Slope	0.5966	0.6618	0.5357	0.4375	**0.55789**	**56**
Soil	0.1989	0.2206	0.3214	0.3125	**0.26334**	**26**
Land Use	0.1193	0.0735	0.1071	0.1875	**0.12187**	**12**
Population	0.0852	0.0441	0.0357	0.0625	**0.05688**	**6**
Total	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**1.0000**	**100**

Table 13: Weight determination

Step4: Assessment of the consistency by calculating the CR

Consistency ratio is calculated in order to check the consistency of the pairwise comparison matrix.

Equation 2: Calculation of consistency ratio (Saaty 1977)

$$CR = \frac{CI}{RI} \text{-----------------------------------} (2)$$

Where:
CI = Consistency index
RI = Random consistency index

Equation 3: Calculation of consistency index CI (Saaty 1977)

$CI = (\lambda_{max} - n) / (n - 1)$ – (3)

Where:
n = Number of criteria = 4
λ_{max} = Total of the products between each element of the weight (**Table 13)** and the column totals of the comparison matrix (**Table 12**).

λ_{max} = (1.6762 × 0.55789) + (4.5333 × 0.26334) + (9.3333 × 0.12187) + (16 × 0.05688) = **4.1766**

From the equation 3,

$$CI = \frac{(4.1766-4)}{4-1} = \mathbf{0.0588}$$

As proposed by Saaty (1977), the RI value depends on the number of criteria used in the analysis. Saaty (1977) has introduced a range of RI values based on the number of criteria used.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.32	1.32	1.41	1.45

As this study considered 4 criterions,

$$RI = \mathbf{0.90}$$

From the equation 2,

$$CR = \frac{0.0588}{0.90} = \mathbf{0.0653}$$

As the consistency ratio (CR) calculated is less than 0.1 which is the maximum CR value acceptable for pairwise comparison recommended in AHP, the consistency of the comparison matrix of this study is acceptable.

3.3.2 Weighted overlay

Based on the above factors, the suitability of preliminary locations were delineated using the equation below.

$$S = \sum_{i=1}^{n} W_i R_i$$

Where:

S = Suitable preliminary locations
W = Weight for each criterion based on the importance in the analysis
R = Rank for the individual features of a criteria
i = Criteria i
n = Number of criteria

Weights and ranks were assigned for each criterion as per the **Table 14**. Ranks was assigned from 1 to 10, where 1 represent the least suitability and 10 represents the highest suitability. Weights were assigned based on the **Table 13.** The higher weight represents the higher influencing factors in the analysis.

The data preparation and analysis were carried out using the model builder tool available in the ArcMap (**Figure 16**). This model is compatible with customizing any numbers of data sets with different file formats over different geographical locations.

Criteria	Rank	Weight Assigned
Soil		
• Alluvial soils of variable drainage and texture; flat terrain	1	26
• Bog and Half-Bog soils; flat terrain	8	
• Erosional remnants steep rock land and various lithosols	1	
• Grumusols; flat terrain	8	
• Immature Brown Loams; steeply dissected, hilly and rolling terrain	1	
• Latosols and Regosols on old red and yellow sands; flat terrain	2	
• Major Tanks	1	
• Noncalcic Brown soils & Low Humic Gley soils; undulating terrain	6	
• Reddish Brown Earths & Immature Brown Looms; rolling, hilly and steep terrain	1	
• Reddish Brown Earths & Low Humic Gley soils; undulating terrain	6	
• Reddish Brown Latosolic soils; steeply dissected, hilly and rolling terrain	1	
• Red-Yellow Latosols; flat to slightly undulating terrain	8	

• Red-Yellow Pdzolic soils with dark B horizon & RedYellow Podzolic soils with prominent A1	8	
• Red-Yellow podzolic soils with prominent A1 or semi-prominent A1	8	
• Red-Yellow podzolic soils with soft or hard laterite,rolling and undulating terrain	6	
• Red-Yellow Podzolic soils with strongly mottled subsoil & Low Humic Gley soils; rolling and undulating terrain	6	
• Red-Yellow Podzolic soils; steeply dissected, hilly and rolling terrain	1	
• Regosols on Recent beach and dune sands; flat terrain	2	
• Regosols on Recent beach sands; flat terrain	2	
• Rendzina soils; undulating to rolling terrain	6	
• Soils on Old Alluviam;	8	
• Solodized Solonetz Solonchaks and Soils on recent marine calcareo	3	
Land Use		
• Coconut	3	
• Dense Forest	2	
• Garden	6	
• Open Forest	2	
• Other Land	8	12
• Paddy	3	
• Rubber	3	
• Tea	3	
• Undefined	8	
• Water Bodies	1	
Slope (%)		
• 0-0.5	9	
• 0.5 - 1	8	
• 1 - 2	6	56
• 2 - 3	4	
• 3 - 5	3	
• > 5	1	
Population (per pixel)		
• 0 - 300	8	6
• 300 - 600	7	

• 600 - 900	5
• 900 - 1200	2
• > 1200	1

Table 14: Weights assigned to classes of each theme based on their influence on primary selection for water storage system.

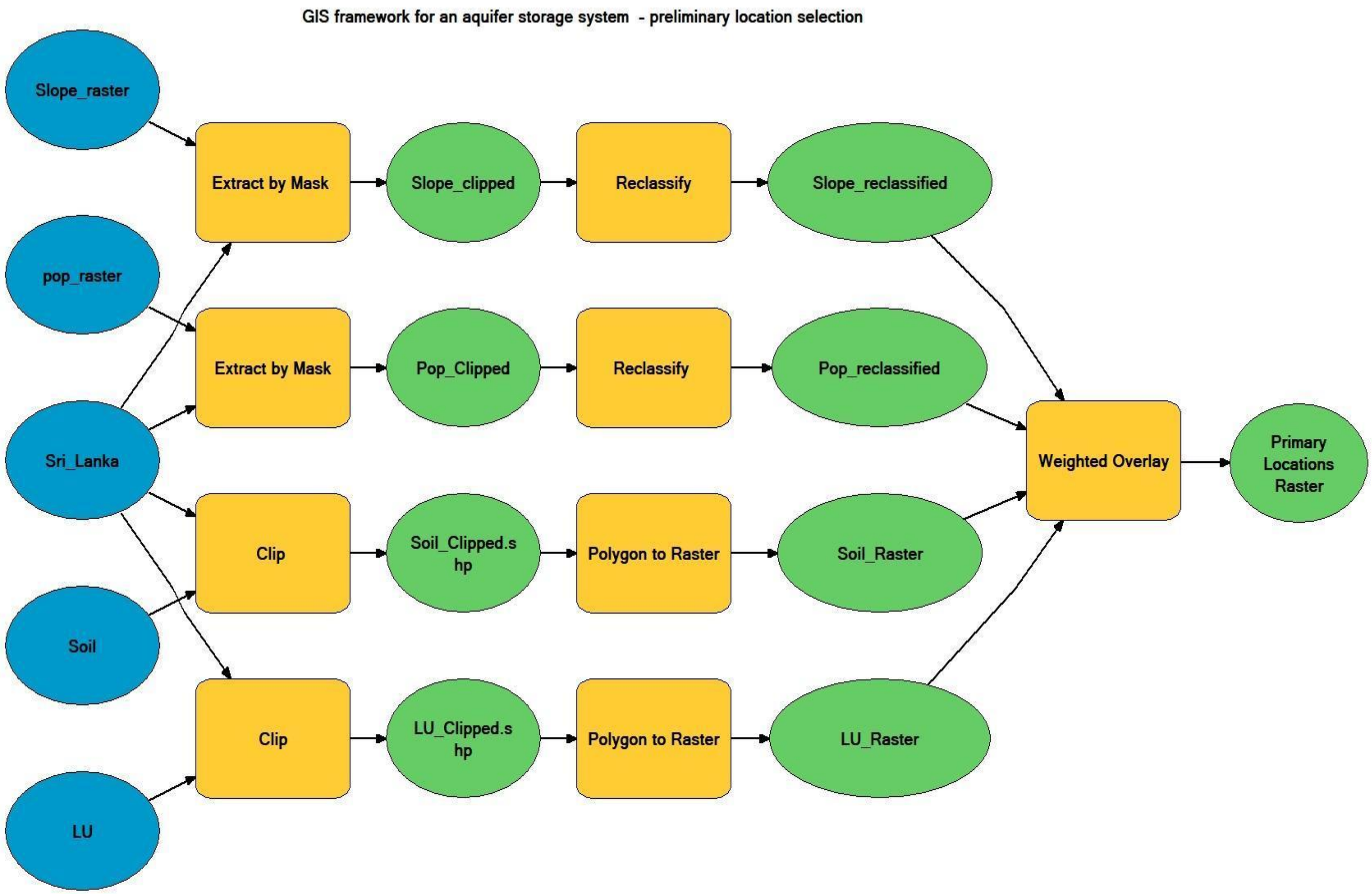

Figure 16:GIS model for the preliminary location selection

The result indicates the suitability of locations under 9 different levels (**Figure 17 (a)**). Number 1 represents the least suitability and number 9 represents the highest suitability. In order to maintain the highest possible accuracy in the study, suitability levels 8-9 were considered in the study (**Figure 17 (b)).**

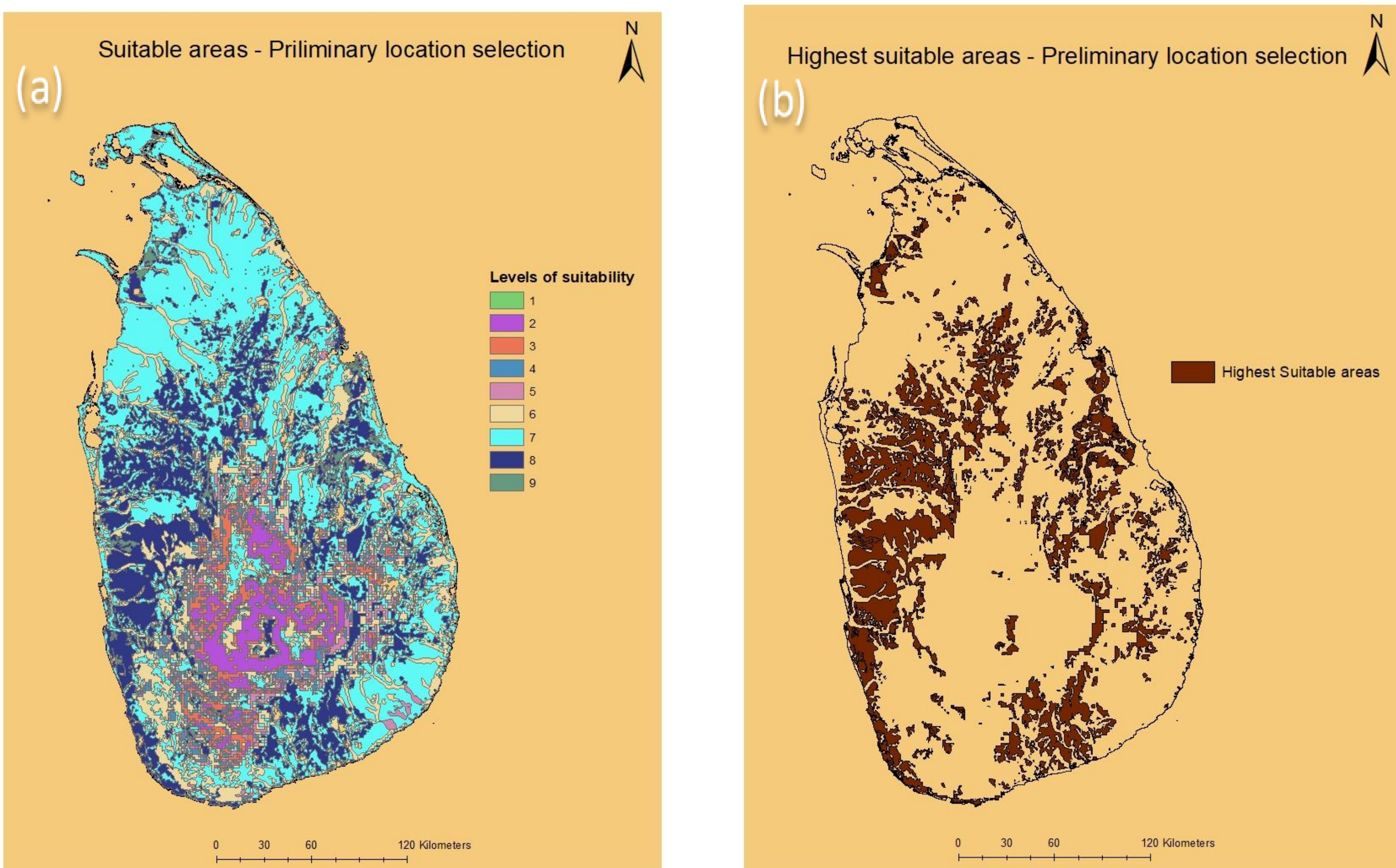

Figure 17:(a) Levels of suitability – Preliminary selection (b) Most suitable areas

3.4 Selection of precipitation suitability - Secondary selection

Both present and future predicted precipitation data were analyzed in this step.

The future precipitation prediction data consists of 12 files that depict the average monthly precipitation for each month for the year 2050. This data set has been generated by averaging the monthly precipitation prediction data from the year 2041 to 2060 (**Figure 18** (**b**))**.** As the study does not focus on the monthly rainfall, the annual precipitation for the year 2050 was calculated by summing up the monthly precipitation data as follows.

$$P = \sum_{n=1}^{12} R_n$$

Where:

P = Average annual precipitation
R = Average predicted monthly precipitation
n = Month

The data set was then clipped to the country boundary in order to extract the precipitation values over Sri Lanka.

Present precipitation data was also used in the study. The original data set presents the average monthly precipitation from 1970 to 2000 (**Figure 18** (**a**)) over the world. The same procedures were followed to extract the annual mean rainfall within the 30 years over Sri Lanka.

Considering the fact that the mean annual precipitation over Sri Lanka varies from 900 mm to 5000 mm, the average future and present precipitations values were reclassified to exclude the areas reporting the low precipitation values in both present and future scenarios. Including the areas with only the higher precipitation values are expected to be provided optimal results in the study (**Table 15**).

The study considers 2000 m annual precipitation value as the minimum precipitation requirement for a new water storage project. The study focuses on rainwater harvesting and storing the excess water volume during the discharge. Country receives majority of water input through precipitation. Contributions from mist, dew, hail and frost to surface waters are relatively insignificant except in the central highlands (Madduma Bandara 2000). Evaporation and infiltration are identified as the main water outputs in the country. In order to have a positive rainwater excess based on both the present and future scenarios, the selected areas should record a higher water input than an output.

The mean annual rainfall over the intermediate and wet zones are 1,750 mm to 2,500 mm and over 2,500 mm respectively (Punyawardena 2010). The dry zone records less than 1750 mm mean annual rainfall. Based on the studies conducted on future climatic projections in Sri Lanka, almost all the projections agree on an increase of annual mean precipitation over the wet zone of the country (Eriyagama et al. 2010). Besides, De Silva (2006) projects enhanced rainfall in the wet zone, northwestern and southwestern dry zones; reduced rainfall in other dry zone areas (such as Anuradhapura, Batticaloa and Trincomalee), and increased rainfall (2%) in the intermediate zone by the 2050. This explains that the country expects approximately less than 2000 mm precipitation over dry zone and approximately over 2000 m rainfall over wet and intermediate zones in the future.

The dry zone records the highest evaporation rate within the country. The annual average evaporation within the dry zone is estimated to between 1700 mm to 1900 mm, which exceeds the average annual rainfall of the area (Panabokke et al. 2002). This value is projected to be higher in the future parallel to the predicted increment of temperature in the dry zone by 2050 (De Silva 2006). Further, mean annual rainfall values and pan evaporation values recorded over 21 rainfall stations (**Table 16**) reveal a pattern that the majority of the areas that exceed 2000 mm mean annual precipitation record positive rainfall excess (Weerasinghe 1991). Apart from these, 2000 mm is calculated as the closest rounded up value of the country's average mean annual rainfall based on the lowest and highest mean annual rainfalls of 900 mm and 5000 mm respectively.

Considering these factors, the minimum precipitation requirement for a water reservoir was set as 2000 mm for this analysis (**Figure 19**). This will allow to select the areas that records only the positive rainfall excess values within the country considering present and future precipitations and evaporation data.

Precipitation Ranges (mm)	Suitability	Reclassified values	
		Future precipitation	Present precipitation
900-1000	Not suitable	0	0
1000-2000	Not suitable	0	0
2000-4000	Suitable	2	1
4000-6000	Suitable	2	1

Table 15:Reclassification for the precipitation values

Zone	District	Rainfall (mm)	Pan Evaporation (mm)	Rainfall Excess (mm)
Wet	Colombo	2345	1722	623
Wet	Gall	2513	1969	544
Intermediate	Kurunegala	2125	2140	-15
Wet	Nuwara Eliya	2328	1382	946
Wet	Mapalana	2354	1874	480
Intermediate	Hambanthota	1075	2229	-1154
Intermediate	Ugunakolapalessa	1092	2426	-1334
Dry	Batticaloa	1704	2087	-383
Dry	Puttalam	1110	2104	-994
Dry	Mahailuppallama	1379	2157	-778
Dry	Trincomalee	1649	2470	-821
Dry	Vavuniya	1488	2039	-551
Dry	Mannar	967	2135	-1168
Dry	Jafna	1329	2236	-907
Intermediate	Badulla	2384	1523	861
Intermediate	Diyatalawa	1732	1484	248
Wet	Kandy	3171	1983	1188
Wet	Ratnapura	3596	1642	1954
Dry	Anuradhapura	1203	2020	-817
Wet	Watawala	5245	1500	3745
Dry	Amparai	1538	2300	-762

Table 16:Annual precipitation and pan evaporation of 21 rain gauge stations
Source: Weerasinghe 1991

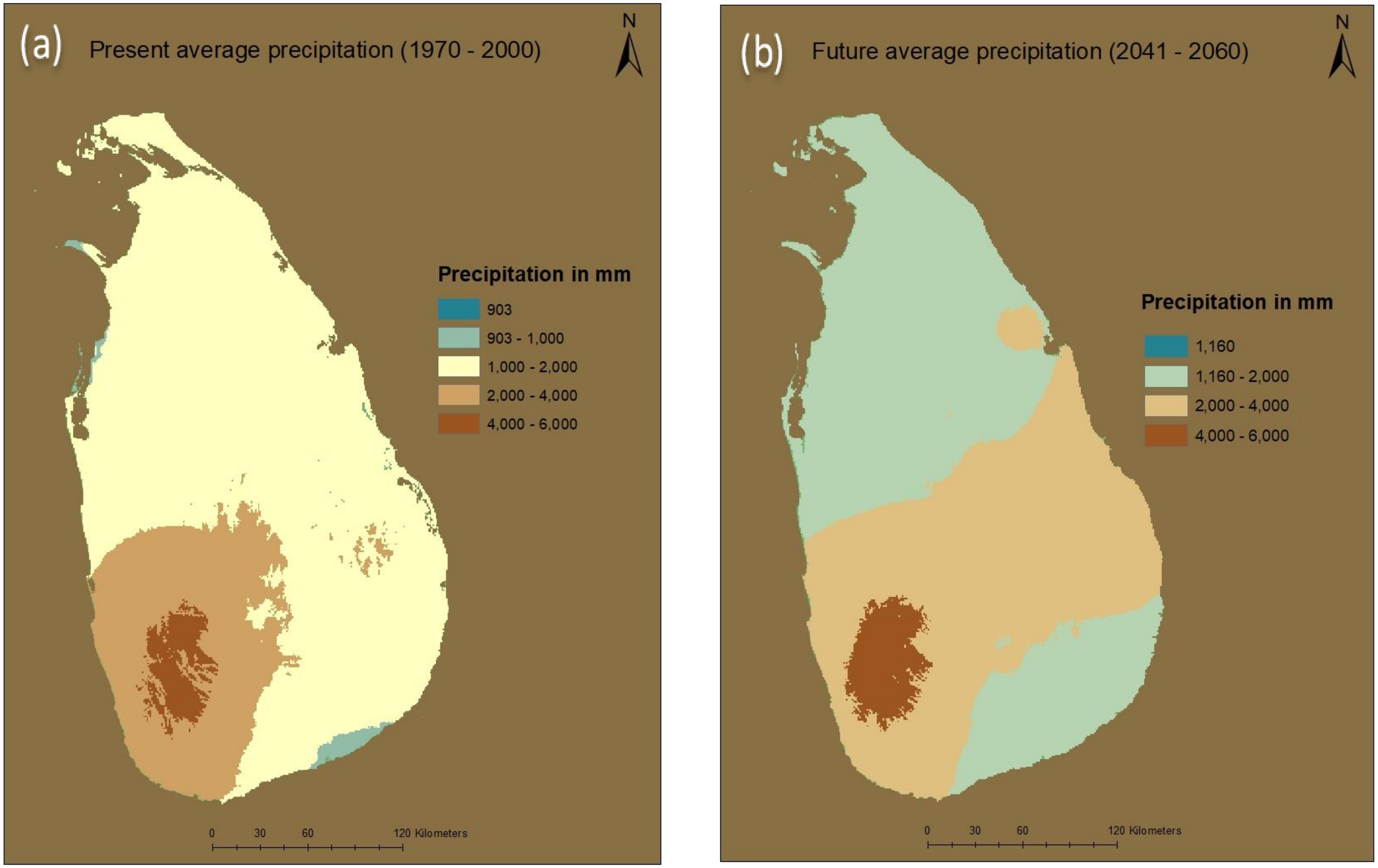

Figure 18:(a) Present average precipitation and (b) Future average precipitation

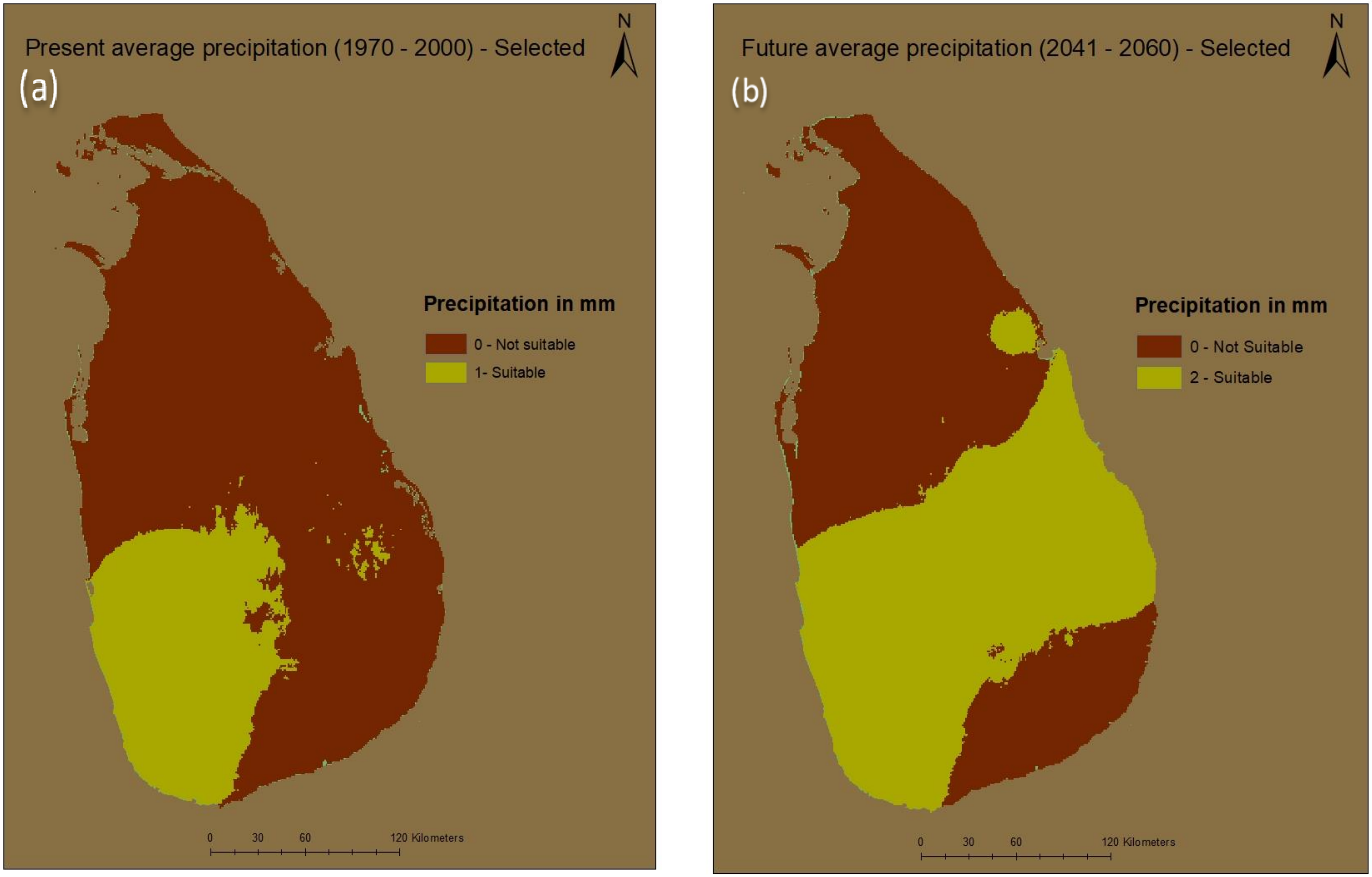

Figure 19:Selected precipitation suitability areas in (a) present and (b) future scenarios

The most favorable precipitation scenarios during the present and future conditions were joined to extract the areas with the adequate precipitation conditions during both time frames (Future average precipitation - Present average precipitation). Although the result divided the study area into four categories (**Table 17**), study focuses only on the suitable areas based on both the present and future precipitation (**Figure 20**). This will allow to achieve the optimal results based on both present and future scenarios.

The areas not suitable based on either of the time frames and not suitable based on both time frames were excluded from the study. Although the study could consider the areas that are only suitable based on the future precipitation (result = 2), the final results generated with this scenario would not be sempiternal. All the delineated locations which are not suitable based on the future precipitation scenario are considered to be vulnerable locations for being dried out in the future.

Result	Suitability based on the future precipitation	Suitability based on the present precipitation
-1	No	Yes
0	No	No
1	Yes	Yes
2	Yes	No

Table 17: Suitability table

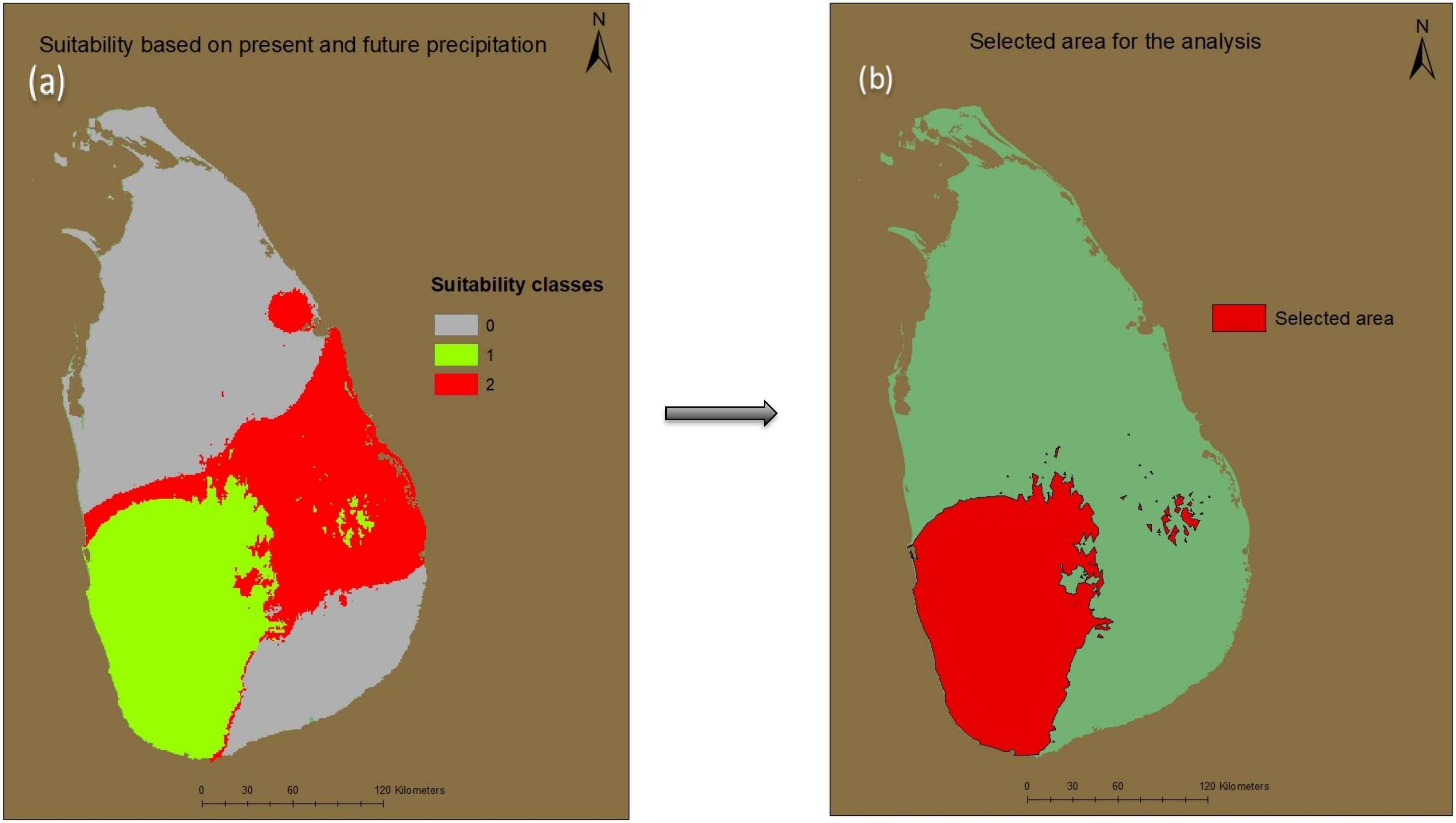

Figure 20:(a) Precipitation suitability – classification and (b) Precipitation suitability – Selected

Final location selection for water storage system was executed by joining the preliminary locations and the final precipitation suitability data by following the data analysis workflow as illustrated in the **Figure 21**. This outputs the best fitted locations for water storage system based on the precipitation, geographical, environmental scenarios, and socio-economic scenarios. The resultant layer (**Figure 22**) was then overlaid with the existing tank layer (**Figure 23**) of the country in order to avoid the overlapping areas (**Figure 24**).

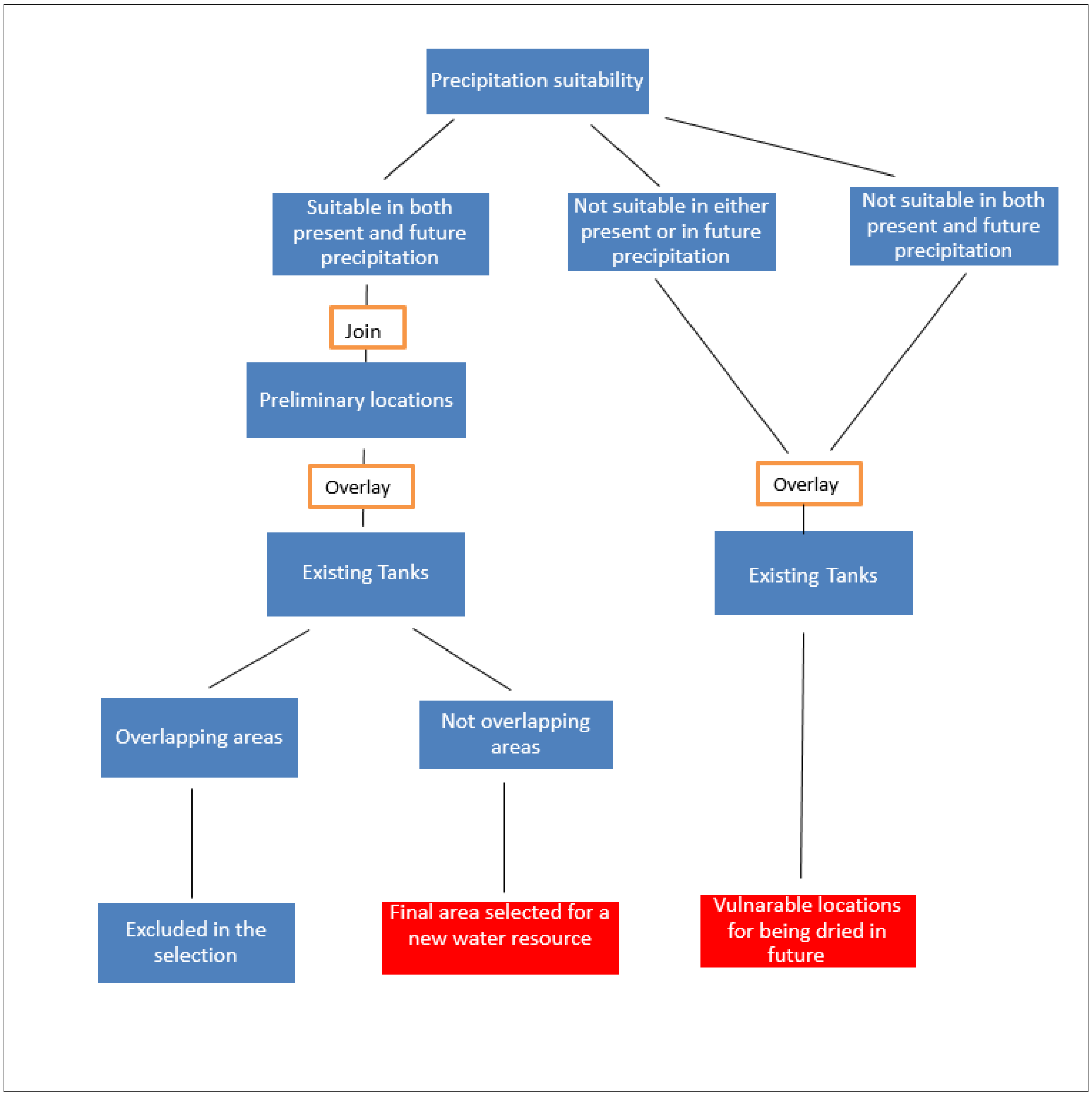

Figure 21:Delineating location for water storage system - Work flow

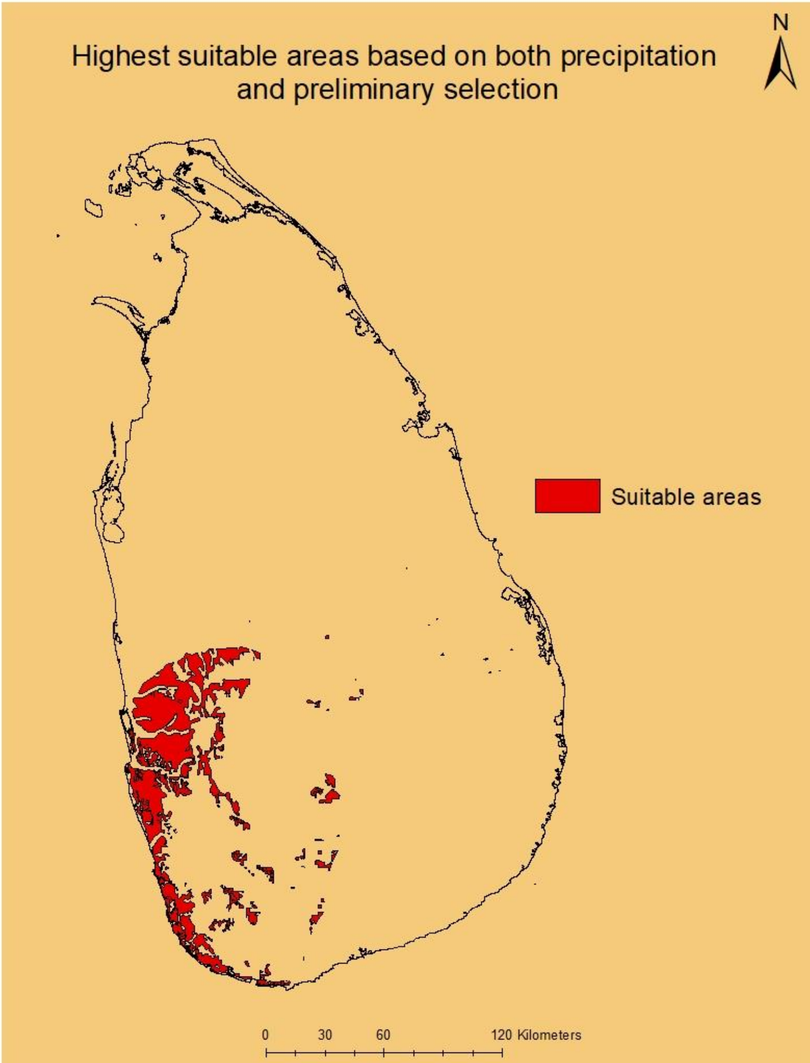

Figure 22:Suitable areas

Overlay

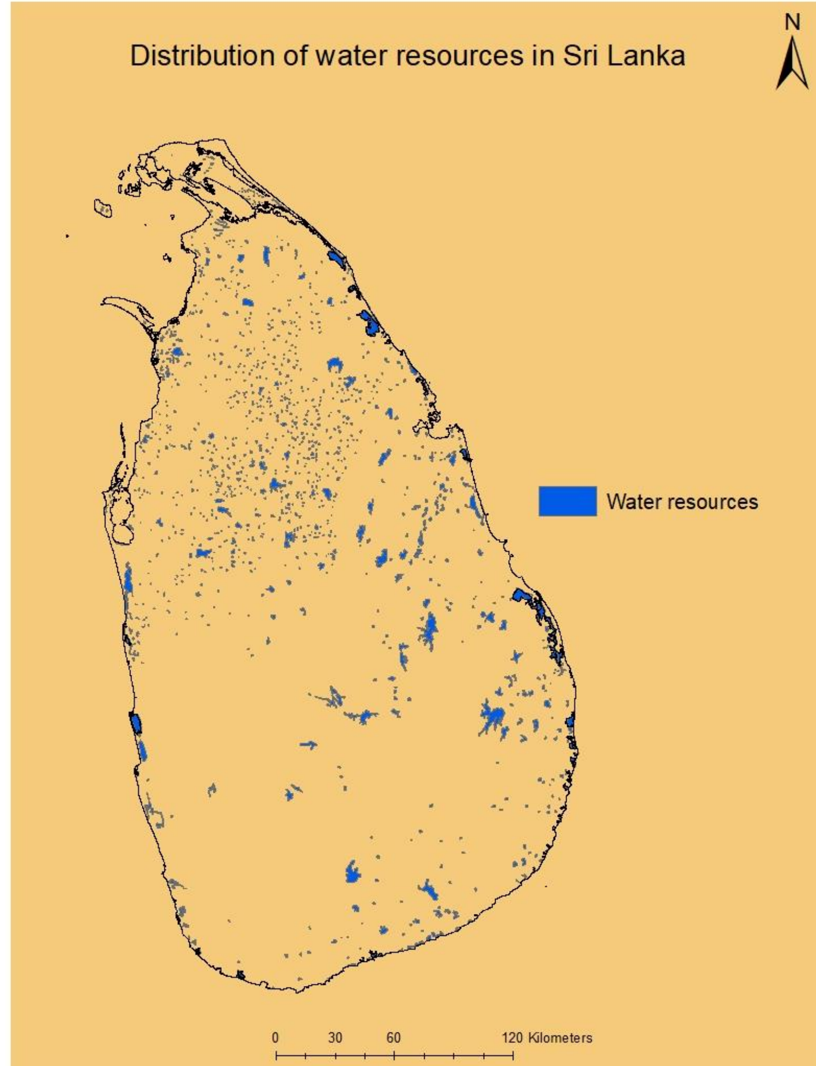

Figure 23:Distribution of water resources

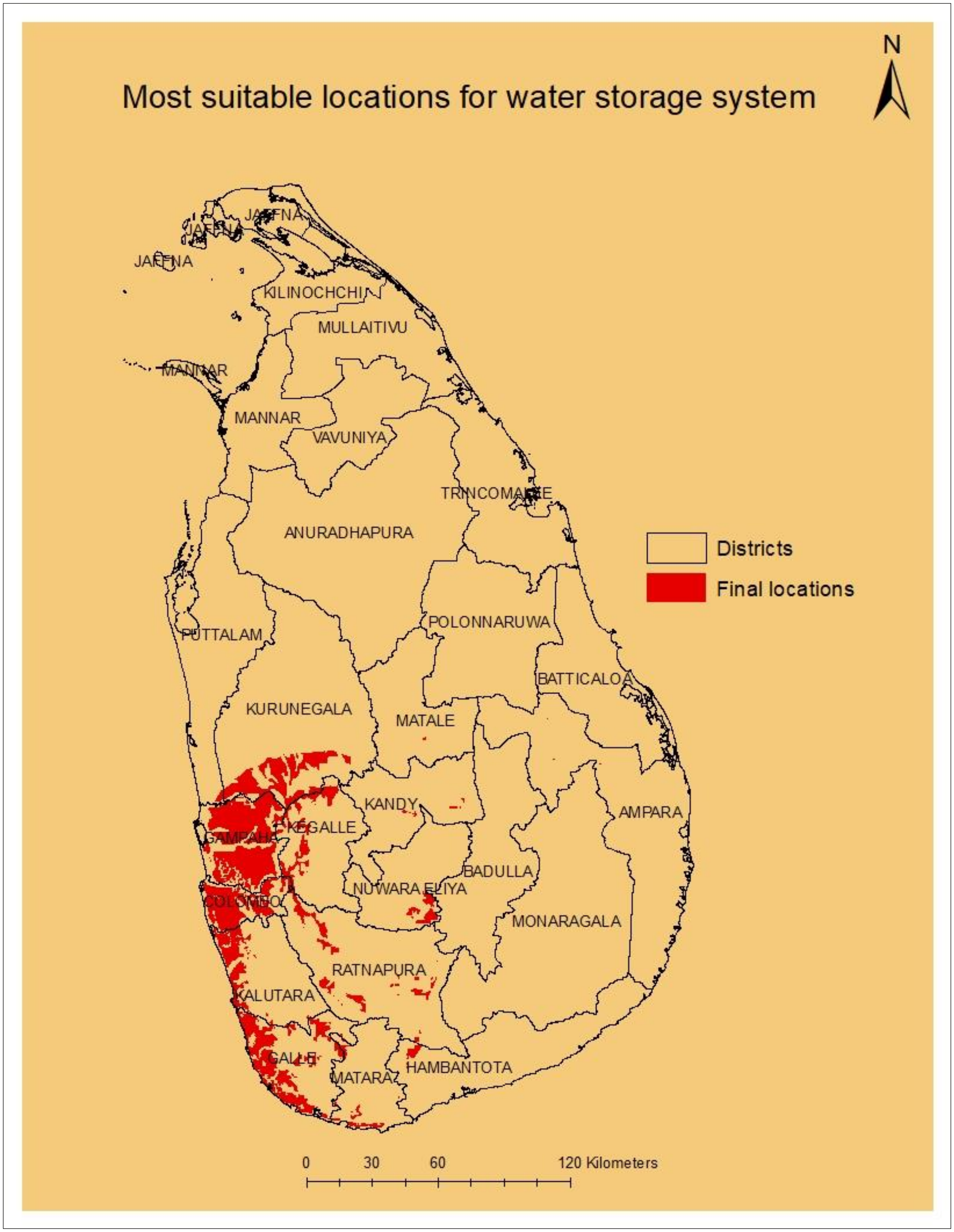

Figure 24:Final locations selected for water storage system

4. Results

The resultant map (**Figure 25**) depicts the most favorable locations for water storage systems which are compatible with expected changes in the future precipitation pattern in the year 2050.

Majority of the locations have scattered within the districts of Colombo, Gampaha, Kurunegala and Gall. Districts Kalutara, Rathnapura and Kagall also show a moderate number of locations while Nuwara Eliya, Matara, Hambanthota and Kandy districts show lower number of locations based on the analysis. These locations have distributed within the wet zone where the annual precipitation is about 2500 mm in the present scenario. Besides, the surrounding areas of the selected locations demonstrate either minimum or no active water storage systems in the present scenario (**Figure 26**)

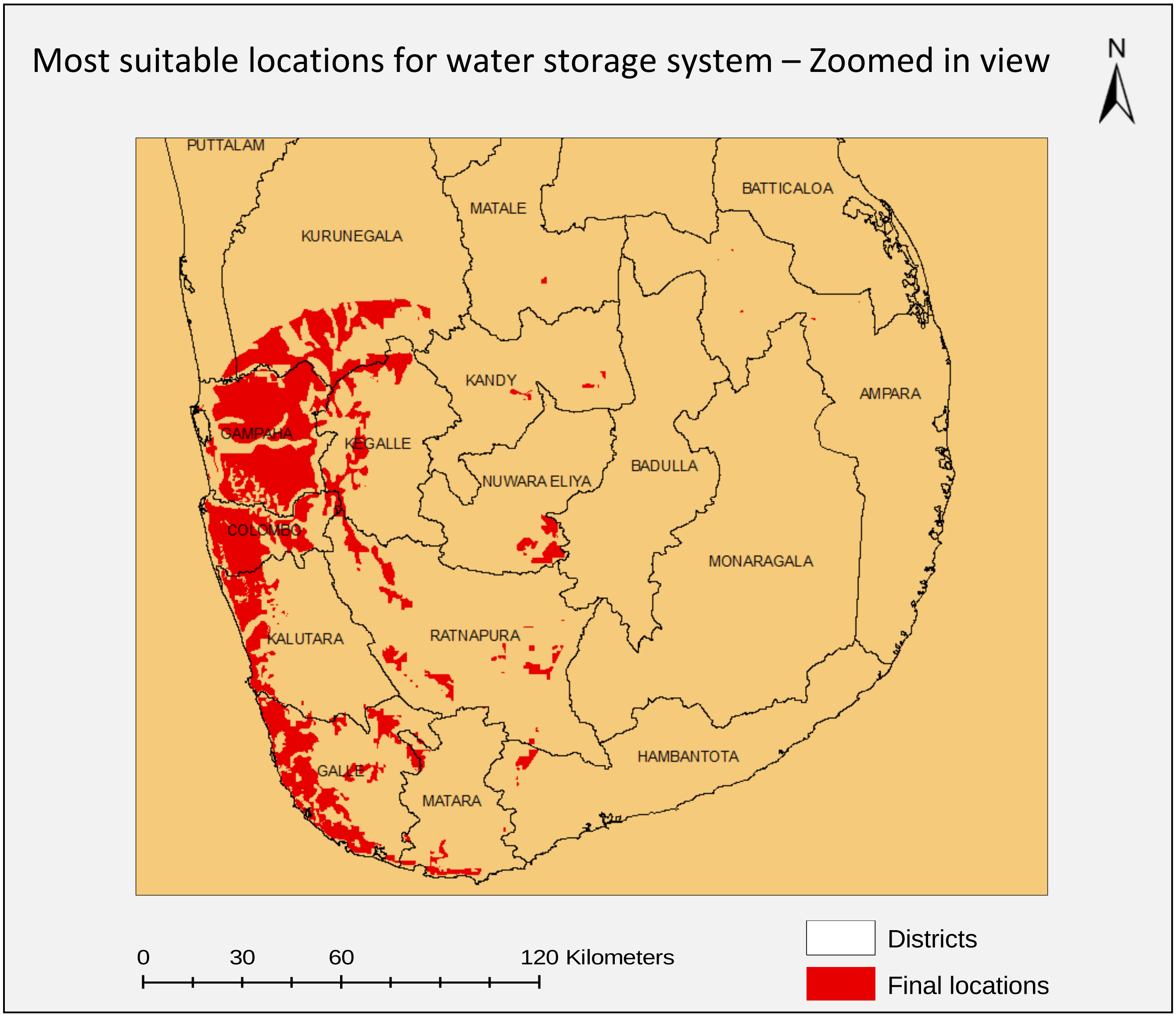

Figure 25:Selected areas for water storage system

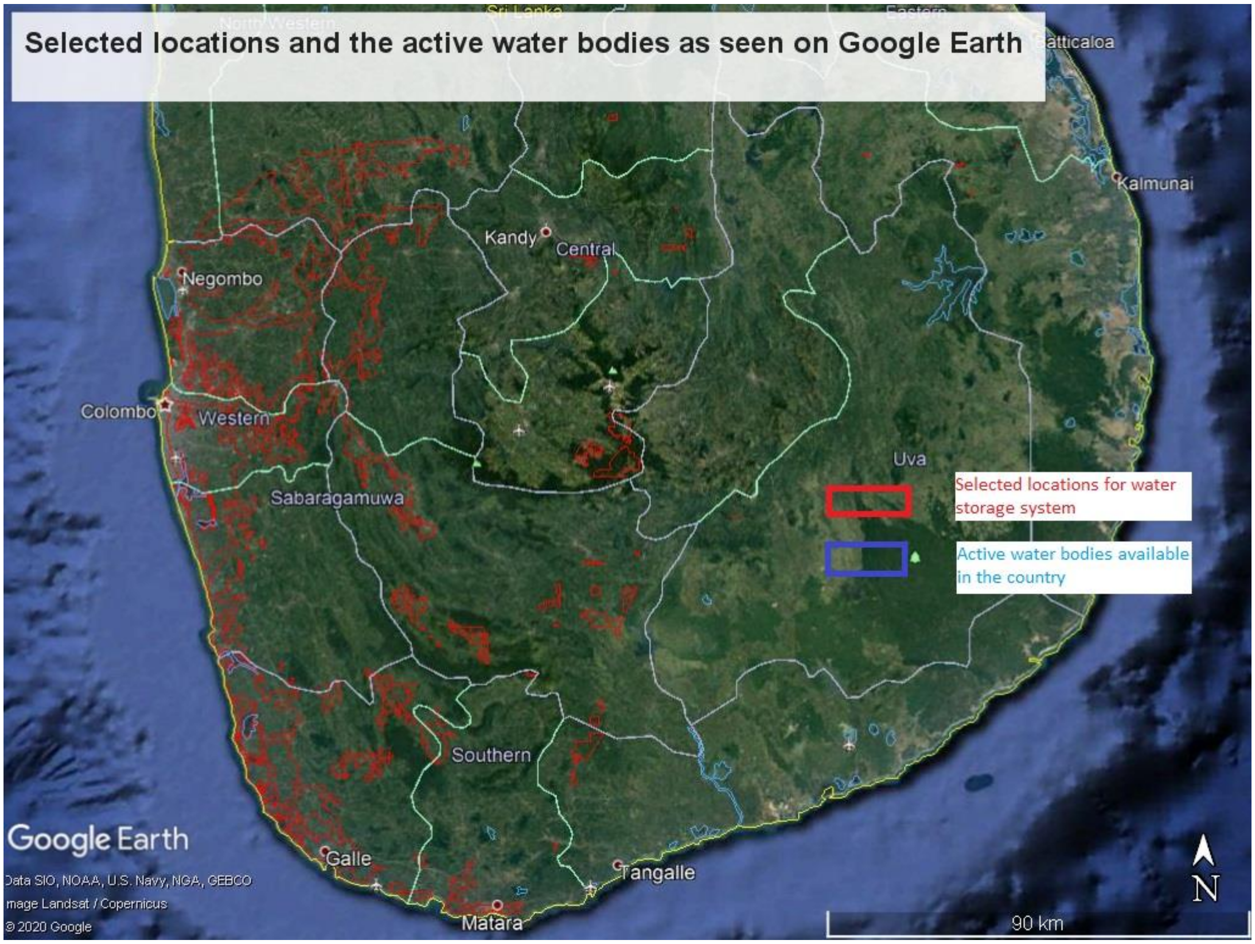

Figure 26:Selected locations and the active water bodies as seen on Google Earth
Source: Google Earth - https://www.google.com/earth/versions/ accessed on 17 October 2019

Despite the suitable locations for water storage system, the study also points out the list of existing water resources that will be vulnerable to being dried out due to the changes in the future precipitation pattern (**Figure 27**). As per the results, 1160 out of the 1,202 tanks considered in the study are under the risk of being dried in the future (**Table 18)**. This is 74% of the existing tanks in the country. Among them, 34 tanks extended over 10 km^2 area (**Table 19**). About 90% of these endangered tanks have located within the dry zone where the annual average rainfall is about 1450 mm in the present.

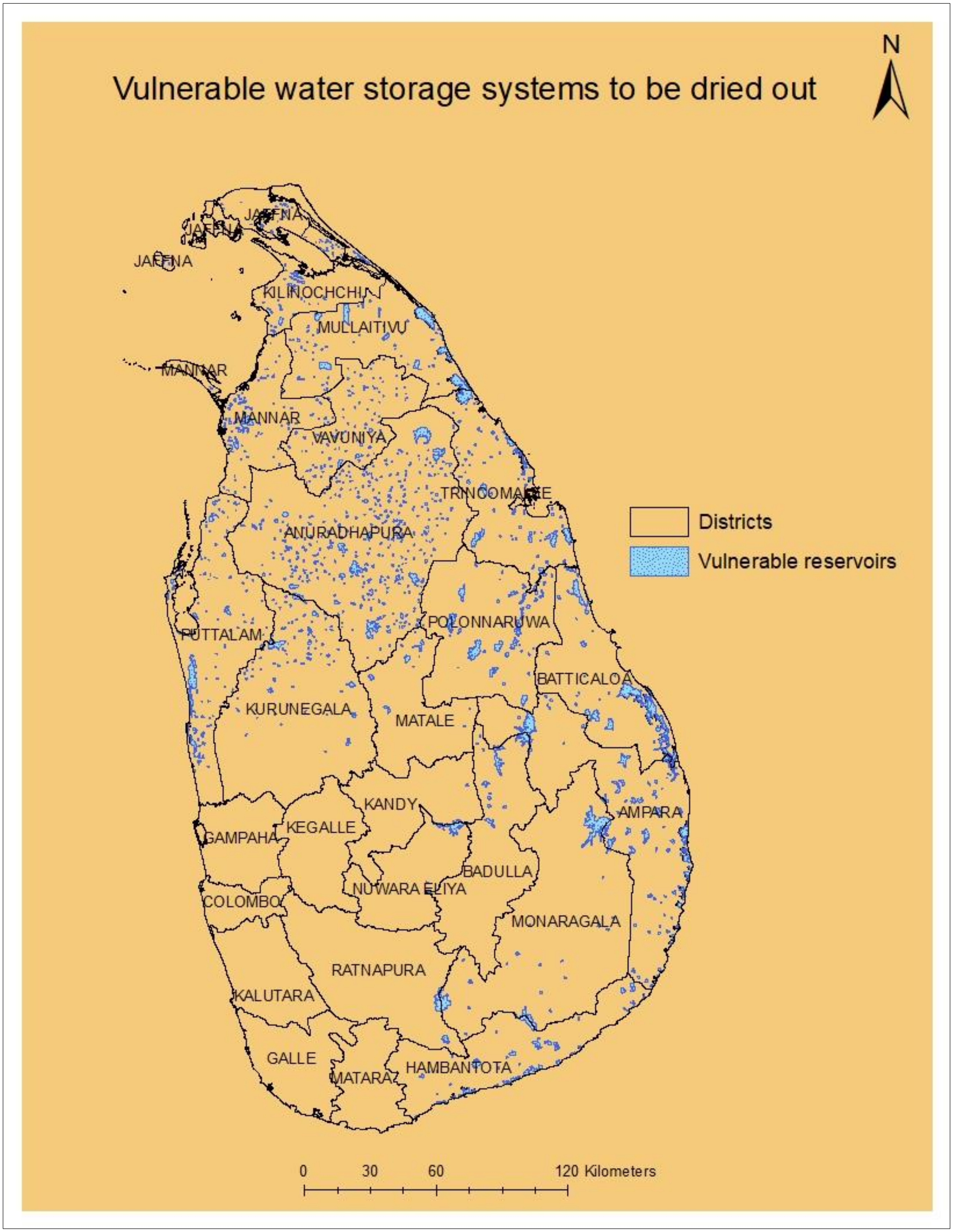

Figure 27:Vulnerable tank locations to be dried out in the future

District	Climatic Zone	Total Nu of available tanks	Vulnerable tanks	% of Vulnerable tanks
Ampara	Dry Zone	59	59	100
Anuradhapura	Dry Zone	360	360	100
Badulla	Intermediate Zone	11	11	100
Batticaloa	Dry Zone	30	28	93
Colombo	Wet Zone	4	0	0
Galle	Wet Zone	18	0	0
Gampaha	Wet Zone	1	0	0
Hambantota	Dry Zone	30	29	97
Jaffna	Dry Zone	37	37	100
Kalutara	Wet Zone	5	0	0
Kandy	Wet Zone	2	1	50
Kegalle	Wet Zone	0	0	0
Kilinochchi	Dry Zone	66	66	100
Kurunegala	Intermediate Zone	75	74	99
Mannar	Dry Zone	93	93	100
Matale	Intermediate Zone	14	14	100
Matara	Wet Zone	5	0	0
Monaragala	Dry Zone	16	16	100
Mullaitivu	Dry Zone	54	54	100
Nuwara Eliya	Wet Zone	5	1	20
Polonnaruwa	Dry Zone	48	48	100
Puttalam	Dry Zone	103	103	100
Ratnapura	Wet Zone	1	1	100
Trincomalee	Dry Zone	63	63	100
Vavuniya	Dry Zone	102	102	100
Total		**1202**	**1160**	

Table 18: Percentage of vulnerable water reservoirs within each district

NAME	Area2	X	Y
Lagoon	123.2	81.70331	7.631005
Senanayake Samudra	79.96	81.48157	7.185914
Maduru Oya Reservoir	62.42	81.195685	7.582576
Kokkilai Lagoon	56.16	80.926245	8.986583
Uda Walawe Reservoir	43.35	80.839611	6.464607
Nanthi Kadal Lagoon	36.01	80.770939	9.287284
Mundal Lake	30.55	79.808732	7.798556
Lunuganwehera Reservoir	30.32	81.194471	6.38758
Padawiya Wewa	29.18	80.761084	8.80368
Upaar Lagoon	29.04	81.408547	8.140534
Randenigala Reservoir	28.27	80.882132	7.186366
Parakrama Samudra	27.4	80.977348	7.909511
Kala Wewa / Balalu Wewa	21.72	80.550514	8.000747
Nachchaduwa Tank	19.99	80.487343	8.24879
Inginimitiya Reservoir	19.65	80.153156	7.935461
Iranamadu Tank	18.9	80.444141	9.299877
Periya Kalapuwa	18.67	81.843833	7.159757
Minneriya Wewa	18.22	80.879339	8.028256
Wahalkada Wewa	14.93	80.827943	8.722338
Ullackalie Lagoon	14.9	81.36306	8.38283
Vavuni Kulam	14.5	80.357459	9.084039
Nayaru Lagoon	14.16	80.855536	9.139
Ulhitiya Reservoir	14.12	81.073636	7.443066
Giant's Tank	14.04	80.035454	8.856926
Hurulu Wewa	12.69	80.725394	8.209982
Kantale Wewa	12.61	80.980124	8.366752
Rajangane Reservoir	11.91	80.248706	8.130062
Rukam Wewa	11.81	81.475267	7.640049
Allai Wewa	11.59	81.304456	8.36769
Navakiri Aru Tank	11.29	81.593071	7.458649
Jayanthi Wewa	10.9	81.537594	7.112385
Kalapuwa	10.9	81.851231	7.060904
Chilaw Lake	10.79	79.812652	7.527985
Mora Wewa	10.3	81.014402	8.577136

Table 19:List of the vulnerable tanks cover over 10 km^2 area

5. Discussion

5.1 Locations for new water reservoir

As per the results, the selected locations for new water reservoirs are located within the wet zone where about 60% of the total population is living (**Table 20**). In the high rainfall areas of the wet zone, the river discharge accounts for 50-70 % of rainfall (Pathmarajah 2016) due to the fact that the surface over the wet zone is mostly covered by buildings, cement floor or asphalt surfaces due to the higher population density. Consequently, a higher surface runoff rate within the wet zone can be identified due to the low infiltration capability over the non-natural surfaces. In parallel, the surface runoff drops to less than 30 % in the dry zone, even during high rainfall seasons due to a high infiltration rate over a large bare surface (Pathmarajah 2016). Locating new water storage systems over higher runoff areas is expected to achieve the project purpose of maximizing the rainwater harvesting by minimizing the surface runoff in the country.

Further, the selected areas for new water reservoirs are mainly located within the directly hit zone by the longest SWM rainfall. Besides, this area receives moderate to higher rainfall during the other three monsoonal seasons as well. The SWM receives from May to September, rainfall varying from about 100 mm to over 3000 mm based on the present precipitation data (DOM 2019). According to a study conducted by Sri Lankan scientists on the impacts of the climate change up until 2050, an increasing rainfall for the wet zone and a significant drying up in the dry zone of Sri Lanka have been identified. It further highlights that unexpected high rainfall in the wet zone areas and the extreme dry conditions in the dry zone will be experienced by 2050. Basnayake et al. (2004c), predict an increase in rainfall during the SWM for a range of IPCC scenarios (A1, A1FI, B1, A2 and B2) while a decrease in NEM rainfall (the season when the majority of the dry zone receives rainfall) for the same IPCC scenarios. Ashfaq et al. (2009) also projected increased rainfall during the SWM in western Sri Lanka and decreased rainfall in the east part. This spatial trend has also been noted by De Silva (2006) and Basnayake (2004a) (**Figure 28**). It is seen that almost all available projections agree on increased mean annual precipitation in the wet zone of the country (Eriyagama et al. 2010) where the majority of the selected locations for new water reservoir are located.

The average per capita availability of freshwater amounting to 2,592 m^3/year, is adequate for the country's needs. However, water availability in several major cities within the wet zone has dropped below 1000 m^3/year, well below the required limit. With the projected population increase by 2025, many populated areas within the wet zone are expected to record equally low per capita water levels in the future (MOE 2010). The share of water used by the urban population living within the wet zone in Sri Lanka is projected to increase to 45% by 2015 and to 65% by 2030 (MOE 2010). This indicates that water demand of the wet zone is projected to increase in future. Considering the fact that there is an increase of precipitation over the wet zone is expected in future (Eriyagama et al. 2010), commencing new water reservoir projects within the wet zone is viewed as the most efficient and the cost-effective solution of fulfilling the projected water demand within the zone in the future. This will expect to reduce the cost of transferring water from the dry zone through channels and pipes while minimizing the water waste through evaporation and pollution during the transferring process.

District	Total Population in 2012
Colombo	2,324,349
Gampaha	2,304,833
Kaluthara	1,221,948
Kegalla	840,648
Kandy	1,375,382
Matale	484,531
Nuwara-eliya	711,644
Galle	1,063,334
Matara	814,048
Rathnapura	1,088,007
Total Population in aforementioned districts	12,228,724
Total population of Sri Lanka	20,359,439

Table 20:Populations in 2012 in the districts that fall mainly within the wet zone of Sri Lanka
Source: DCS 2012

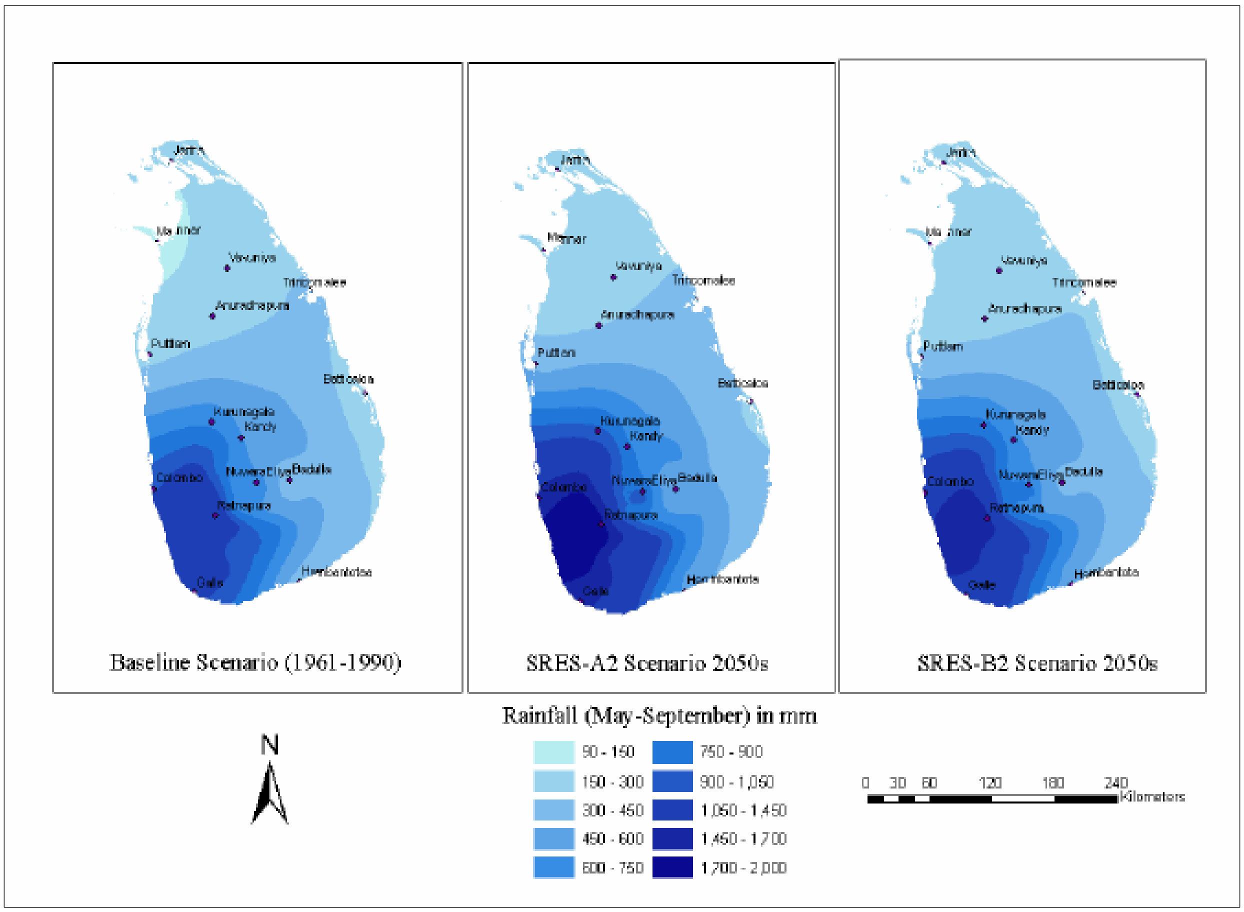

Figure 28: South-West Monsoon Rainfall Scenarios in 2050s
Source : De Silva 2006

The dry zone accounts for more than 90% of current water withdrawals, mainly due to the higher share of irrigation demand. Demand projections for 2025 show that the dry zone will continue to absorb over 90% of total water withdrawals (IWMI 2007). With the expected low rainfall and higher temperature in the dry zone, the present water volume within the dry zone is projected to further decrease in future. This implies that the existing water storage systems within the dry zone will not be sufficient or will be barely sustained within the dry zone in the future. The expected water demand in the wet zone will no longer be fulfilled by the water volume contributed by the dry zone in future. It is recommended that the water requirement of the wet zone should be fulfilled within the wet zone and should rely less on the water transferred from dry zone in the future. In addition, the excess water stored within the wet zone during the higher rainy season can be reserved and transferred to the dry zone in order to fulfil the projected water demand in the future.

Considering the expected lower rainfall over the dry zone in future, the existing water storage systems within the dry zone will be adequate to provide the sufficient storage capacity in the future. Adding new water reservoirs focusing on maximizing the water storage capacity within the dry zone is visibly a less effective solution. In addition, expansion and renovation of the existing reservoirs will be a cost-effective solution and will also provide the additional capacity if required. Considering the fact that, present irregularity of the spatial distribution of water reservoirs within the dry zone has not been able to fulfil the water requirement of the country, deviation from the existing distribution pattern is recommended in the study.

Climatic Zone	Falkenmark		UN		IWMI
	1991	2025	1991	2025	2025
Wet Zone	N	N	N	M	M
Dry Zone	N	M	S	S	S

Table 21:Water scarcity criteria in 1991 and 2025
Source : Amarasinghe et al. 1999
(N: No water scarcity, M: Moderate water scarcity, S: Severe water scarcity)

From the water scarcity criteria indicated by three studies (Falkenmark 1989, UN 1995, IWMI 1997), two of concluded that the dry zone of the country will be in a severe water scarcity condition in 2025. However, all three studies agreed that there will be “no” to “moderate” water scarcity conditions over the wet zone in 2025 (**Table 21**). This implies that locating water storage facilities over the low water scarcity areas and transferring the excess water to the higher water scarcity areas will be an adequate solution in mitigating the water scarcity issue in the future.

Being located within the highest rainfall recorded zone in both present and future precipitation scenarios, the proposed areas for new water reservoirs should be prioritized in water facility development projects. Although the commercial value of the selected areas are comparatively high, well distributed small-scale water reservoirs are proposed in order to minimize the high economical land utilization. With the year-round rainfall, maintaining an adequate water level over the newly proposed locations will not be a challenge during both present and future climatic scenarios.

5.2 Vulnerable water storage systems

The majority of vulnerable water storage systems have located within the north and north east parts of the country, specifically within the districts categorized under the dry zone illustrated in earlier section in the paper. Water reservoirs located within the wet zone show minimal to no vulnerability to being dried out based on the anticipated changes in the future precipitation pattern.

Many studies on the future precipitation patterns in the country project a decrement of annual rainfall in the dry zone. De Silva (2006) projects reduced rainfall in dry zone areas such as Anuradhapura, Batticaloa and Trincomalee by the 2050s for scenario A2. Specifically, NEM, the season when the majority of the dry zone receives rainfall from December to February, is predicted to decrease by 34% (A2) and 26 % (B2) for 2050s. The districts Trincomalee and Batticaloa will report the highest decrease of rainfall as 27% (A2) 29 %(B2) respectively (De Silva 2006) considering the overall rainfall. The projected rainfall over the district Jaffna, Mannar, Vavuniya, Anuradhapura, Batticaloa, Trincomalee and Hambantota are also projected to decrease due to the predicted decrease in NEM during January and February months according to the A2 and B2 scenarios for 2050s compared to the baseline (1961-1990) scenario (De Silva et al. 2006). Rain being the only source of water of the reservoirs located within the dry zone, this clearly indicates that the area comprised with the vulnerable water reservoirs will be directly affected by the expected low rainfall based on the future climatic change scenario.

Although the reduction of rainfall is measured as the main factor, expected changes in the evaporation will also provide a higher contribution to the low water level within the zone in the future. An increment of temperature has been identified over the north and north east parts of the country during the NEM, mainly over the north, north east and north west regions of the country based on the future climatic change scenarios. The highest increase in temperature is predicted in Anuradhapura by 2.1° C (A2) and 1.6° C (B2) by 2050 (De Silva 2006) where about 29% of the water reservoirs are located. Increment of temperature will parallelly result the increment of surface evaporation over these areas. Besides, the north and north east regions of Sri Lanka is expected to have a 2% increment of evaporation in 2050 as per the A2 and B2 scenarios (De Silva 2006). This reflects the fact that the negative impact of climate change is severe in the north and north east areas where the majority of the vulnerable water resources are concentrated.

An increase of water demand within the dry zone for irrigational purposes has also been identified in the future. As per Amarasinghe et al. (1999), the dry zone districts will require more than 80% of the total water demand in 2025 based on the current irrigation sector efficiency. This is due to its substantial share in irrigation. The available water resources within many districts in the dry zone may not be adequate even to meet their projected demand in the future (Amarasinghe et al. 1999). Specifically, districts Ampara, Anuradhapura, Batticaloa, Hambantota, Jaffna, Killinochchi, Kurunegala, Mullaitiv, Polonnaruwa, Puttalam, Trincomalee, and Vavunia will face severe seasonal or year-round absolute water-scarce conditions due to the higher water withdrawal for agriculture.

These factors clearly imply that dry zone of the country is highly prone to a low water input based on the expected low rainfall and higher evaporation rate in the future. Besides, the zone is projected to have a higher water withdrawal due to the high intensity of the irrigational activities in the future. This discrepancy will lead the water reservoirs located within this zone to a higher vulnerability of being dried out in the future.

Beside the future projections on water availability within the dry zone, different reports pointed out that the contributed water volume by many water reservoirs within the dry zone have already getting low over recent years.

As reported on the Dailynews on 19/07/2018, Anuradhapura District Irrigation Director, Prasanna Silva has pointed out 13 major water reservoirs which are having less than 50% water capacity within the district of Anuradhapura (**Table 22**) (Wijesinghe 2018). Among them Padaviya Wahalkada and Mahawilachchiya reservoirs reported the least water capacities. Cultivation under these major water reservoirs has already been abandoned due the higher water scarcity. As per the results generated in the study, 9 out of the 13 major water reservoirs mentioned in the above report overlapped with the study results.

Reservoir	Normal capacity (af)	Present capacity (af)	Irrigable landscape (acres)	Landscape cultivated during Yala season - 2018
Padaviya	85,000	6,190	13,800	Nil
Wahalkada	43,000	1,917	2,000	Nil
Wilachchiya	32,500	1523	2,660	Nil
Nuwara Wewa	36,050	9,170	2,600	2,600
Tissa Wewa	3,500	1,700	902	902
Nachchaduwa	45,150	1,7320	7,000	7,000
Abhaya Wewa	1,675	5,90	385	385
Mahakanadarawa	36,250	8,850	2,000	1,035
Thuruwila	8,157	6,420	465	415
Rajanganaya	81600	7,0910	19,500	15,000
Angamuwa	14,400	7,600	-	-
Hurulu Wewa	55,000	17,265	10,400	3,000
Manankattiya	4,879	7,58	1,050	170

Table 22:List of tanks with less than 50% water capacity in present in the district Anuradhapura
Source: Wijesinghe 2018

Despite, Lunugamwehera reservoir, one of the 10 largest water resources that will be vulnerable to being dried out in future based on the study results, has reported a gradual water decrease over the years. Based on the report published by IWMI on the Water Scarcity and Managing Seasonal Water Crisis, the estimated average annual flow into the Lunugamwehera reservoir shows a decreasing trend over the time due to the variability of the rainfall over the catchment area. **Table 23** shows the average inflow of the Lunugamwehera reservoir collected by different agencies for a range of years (Sakthivadivel et al. 2001).

Estimates of flow into the Lunugamwehera reservoir.

Year	Agency	Data Used	Average Inflow (MCM)	Average Inflow (ac. ft)	75 % Probable Inflow (MCM)	Remarks
1977	Asian Development Bank Appraisal (ADB 1977)	-	392	318,000	-	-
1986	Asian Development Bank Restudy (ADB 1986)	-	315	255,000	-	-
1994	ID in collaboration with IWMI (IWMI 1994)	1986–1992	290	235,000	181	Monthly data
2000	IWMI present study	1989–1999	279	226,000	166	Monthly data

Note: 1 hectare-meter (ha-m) = 8.1 acre-feet (ac.ft.), approximately.

Table 23:Water levels of Lunugamwehera reservoir
Source: Sakthivadivel et al. 2001

The study also categorized Inginimitiya reservoir as a vulnerable water resource that will be dried out based on the expected precipitation in 2050. As per the Irrigation Management Improvement project report in 1992, general public living within the Inginimitiya catchment area claims that the rainfall has significantly reduced ever since the reservoir was constructed. As a result, the area is experiencing severe recurrent drought seasons. Water level of the Inginimitiya reservoir has been highly affected by this reason (IIMI 1992)**.**

These factors clearly imply that the some of the major water reservoirs within the dry zone are already in the process of getting to dry out based on the continuous reduction of water input and increment of water output over the years. These water resources are expected to be further dried out in the future based on the projected low precipitation, higher evaporation and increased water withdrawal within the zone.

The districts that report zero number of vulnerable water reservoirs, namely Colombo, Gall, Gampaha, Kalutara, Matara, Kandy, Nuwara Eliya and Kegalle overlap with the districts that comprise the suitable locations for new water storage projects based on the study results.

6. Conclusion

The study focused on the need for consideration of future precipitation changes in delineating new locations for water storage system in Sri Lanka. The study was further extended towards delineating suitable locations for water storage systems by taking the future precipitation predication data of the year 2050 into the consideration. The future precipitation data set has been generated by averaging the predicted precipitation data from 2041 to 2060. Besides delineating the locations, the study also pointed out the most vulnerable water features that will be completely dried out due to the changes of the precipitation pattern in the future.

Despite the future precipitation data, other relevant geographical and socio environmental data were utilized in the analysis in order to make the end results more realistic. The analysis was carried out by utilizing the GIS techniques. The primary analysis was carried out by integrating the data on GIS platform employing the weighted linear combination method.

The results generated in the study demonstrate that a majority of the adequate locations for new water storage system are located within the district of Colombo, Kalutara, Gampaha and Gall. Despite the geographical advisability preserved, these areas overlap with the highest rainfall zone in the present scenario as well as with the highest rainfall zone considering the expected future rainfall scenario in the year 2050. Further, the inevitable rainfall received during the SWM, from May to September over these areas, is highly favorable in maintaining a good water storage within these areas.

The study also pointed out that about 96% of the existing tanks in the country will be dried out in future due to the changes in the future precipitation pattern. Among them, the majority of tanks are located within the dry zone. The effect will be mainly driven by the reduction of water input due to the projected low precipitation, high temperature and evaporation in the future. Besides, a higher water withdrawal is also projected within the dry zone mainly by the irrigational activities. Many of the large water reservoirs that overlap with the study results within the dry zone are already in the process of being dried out based on their water levels reported over the years. There reservoirs are expected to be further dried out in the future.

Implicating the importance of the content in this project to the concern entities in Sri Lanka is expected to be challenging. Together with the lack of qualified professionals in the field and the shortage of up-to-date technology, less interest on deviating from the traditional methods can be shown by the stakeholders. Presenting the proposal in public forums on the related fields, arranging face to face meetings with the project managers and publishing the paper on the internet for free access are identified as few strategies in maximizing the awareness of the approach presented in this project.

Accuracy of the results generated in the study depends on the accuracy of raw data used in the analysis. Due to the unavailability of a proper data management within the country, the study was unable to gather up-to-date data for the analysis. Despite the data collection date, accuracy of the data is also controversial due to the preliminary data collection methods utilized in the country.

Even though the accuracies of the climatic predictions are debatable, the consequences of climatic changes are serious and should be mitigated with no delay.

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