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Delineation of Locations for Water Storage Systems Using Future Precipitation Data – A Case Study of Sri Lanka

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ABSTRACT

Paying less attention to the expected precipitation changes when implementing new water-related projects, does not seem supportive in mitigating water crisis arising from climatic changes. Sri Lanka is a country possessing a large number of water storage systems compared to its extent and population. Besides, the year-round rainfall delivers a considerable water input throughout the year. Yet, the country reports frequent water scarcities as a result of spatial and temporal variations in rainfall patterns. In addition, irregular distribution of water storage systems and accumulation of water withdrawal have been identified as the main reasons for the current water crisis. When observing the predicted changes in the precipitation pattern, this issue is expected to accelerate in the future. In order to tackle the issue, this particular study proposes to consider the future precipitation prediction data in delineating locations for new water storage projects in the country.

The preliminary selection of locations was carried out considering the widely used data types. 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. These locations were then filtered by the favorable locations based on the present and future precipitation data. The result of the study reveals that the districts of Colombo, Kalutara, Gampaha and Galle located within the wet zone should be prioritized in large scale water storage projects. The study further reveals that the dry zone can self-sustain with the available water storages. It also points out that 96% of the existing tanks in the country will be dried out mainly due to the reduction of water input and over exploitation in the future.

1 Introduction

At present, the low rainy dry zone, which represents the highest density of water storage facilities, is accountable of fulfilling the water demand of the entire country. However, the water input within the dry zone is significantly decreasing mainly due to reduction of rainfall, increment of evaporation and high-water withdrawal (Imbulana et al., 2006). 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 (Chandrapala, 1996; Jayatillake et al., 2005). The rainfall

data collected for the period of 1949-1980 covering 13 stations, also reveal a decreasing trend in the recent decades (Jayawardene et al., 2005).

Precipitation data recorded from year 2013 to 2018 over 23 rain gauge stations demonstrates a higher rainfall over the wet zone compared to the dry zone (DOS, 2021). The rainfall statics collected over the rain gauge stations within the districts of in Rathnapura, Colombo, Rathmalane, Galle and Kurunegala show the highest annual rainfall during this period Fig. 1). The lowest rainfall values are recorded from the stations located within the dry zone.

This effect is expected to be accelerating within the dry zone based on the predicted precipitation changes by the 2050 under the Intergovernmental Panel on Climate Change (IPCC) A2 scenario (De Silva et al., 2006). According to a study conducted by Sri Lankan scientists on the impacts of the climate change up until 2050, an increment of rainfall over the wet zone and a significant decrease over the dry zone have been identified.

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Fig. 1: Annual rainfall from 2013 to 2018 (Source: DOS, 2021)).

Studies further highlight an unexpected high rainfall in the wet zone areas and extreme dry conditions in the dry zone by 2050. Basnayake and Vithanage (2004), predict an increase in rainfall during the South West Monsoon (SWM) for a range of IPCC scenarios (A1, A1FI, B1, A2 and B2) while a decrease in North East Monsoon (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 et al. (2006) and Basnayake et al. (2004). The annual average evaporation within the dry zone is estimated to be between 1,700 mm to 1,900 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 expected increment of temperature in the dry zone by 2050 (De Silva et al., 2006). The dry zone accounts for more than 90% of current water withdrawals, mainly due to the higher share of irrigation. Demand projections for 2025 show that the dry zone will continue to absorb over 90% of total water withdrawals (IWMI, 2007). However, 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, 2010).

Although this indicates that the dry zone is continued to have a low water input, the zone is still being prioritized for new water storage projects. This is mainly due to the lower attention paid by the stakeholders to the expected precipitation and temperature changes within the country. Being home for more than 80% of the total water storage systems in the country, the dry zone already provides excess room for the present water input within the zone (Panabokke et al., 2002). Besides, as reported by the Department of Agrarian Services, Sri Lanka, 7,753 small tanks have already been abandoned within the dry zone mainly due to the lower regional rainfall. Considering these factors, adding new water storages to dry zone does not seem a tactful approach in mitigating water crisis arising from future climatic changes.

This study proposes locating new water storage projects within high rainy areas by taking the future precipitation pattern into consideration. Harvesting and storing rainwater within the high rainy zones and transferring excess water to the low rainy zones is proposed as an effective water resources adaptation for future climatic change in the country. This approach is particularly applicable for Sri Lanka due to the present irregularity in the distribution of existing water storage systems compared to the present and future rainfall. The cost of transferring water within the country is expected to be reasonable due to the small geographical extent of the country.

2 Methodology

2.1 Overview

Various GIS tools available in the ArcMap (ESRI 2017) software were utilized in the data preparation and the location selection process. Project objectives and the related measures are identified as per the Fig. 2.

Fig. 2: Conceptual model.

Fig. 3: (a) Projected Annual Mean Rainfall in 2050 (Source: WorldClim), (b) Present Annual Rainfall (Source: WorldClim), (c) Soil types of Sri Lanka (Source: IWMI 2014), (d) Slope map of Sri Lanka (Source: Department of Surveying, Sri Lanka), (e) Land use map of Sri Lanka (Source: Department of Surveying, Sri Lanka), and (f) Population map of Sri Lanka – 2015 (Source: WorldPop).

2.2 Data used

The preliminary selection of the locations was carried out based on the widely used data types such as topography, soil type, land use type and population. Most suitable areas based on the future precipitation prediction data were merged with the preliminary locations to extract ideal locations for water features. Moreover, present precipitation data also 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 considered as the most recent climate projection that is used in the Fifth Assessment of the IPCC report. The predicted monthly precipitation data from 2041 to 2060 were averaged in order to generate the predicted average monthly precipitation values in mm for the year 2050 in the study. The data is in 30 seconds resolution and GeoTIFF format (Hijmans et al., 2005).

Current precipitation data were also collected from the WorldClim. This data set has been generated by summarizing the average monthly precipitation data from

1970 to 2000 (Fick and Hijmans, 2017). The study maintains an approximate gap of 40 years between the present and future precipitation data in order to incorporate with the precipitation changes over a long period of time. Selected data set is in 30 second resolution in order to be compatible with the future precipitation data set.

The vector soil layer was extracted from the Water Information System for Sri Lanka. Topography and the land use and land cover data were collected from the Survey Department of, Sri Lanka. Topography map was converted to a Digital Elevation Model (DEM) in order to generate a slope map of the country. Population data were extracted from the WorldPop website (<https://www.worldpop.org>) which provides an open access to archives of demographic data over Sri Lanka. 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 (Fig. 3).

2.3 Preliminary location selection

The suitable locations based on the widely used criteria were delineated as 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 when assigning ranks to the soil data set. Clay, having the lowest infiltration rate, is considered as the best material for building strong, impermeable reservoirs (Weatherhead et al., 2009). Soil types containing clay and clay loam were assigned the highest ranks while the soil types available over the hilly terrain, steep rock land, dunes and the beach areas were assigned low ranks due to their unfavorable geographical and topographical suitability.

The vector contour layer of the country was used to generate the slope map through the DEM, using ArcMap 10.1. The DEM raster layer was re-sampled to 100 m resolution to be compatible with the population raster data set. Steep slopes are rarely economic for water reservoirs and give limited storage, and so, 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. Being not tagged with a specific land cover type, undefined and other land cover types are considered as less important land cover types, and were assigned with a higher rank during 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. Least populated areas were assigned higher ranks in the selection. Less distraction to the human settlements, higher the runoff, and higher the availability of arable lands was considered as the favorable conditions in assigning ranks.

2.3.1 Assigning of weights

Weights were 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 according to the method proposed by Saaty (1977), 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 criteria are analyzed.

A ratio 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 were used for calculating the weights of each criterion. The numbers 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, 1977).

The pairwise comparison method is conducted under the following steps:

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 1:

Table 1: Order of importance(Koswatte et al., 2018)(Koswatte et al., 2018).

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

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 2). The scale contains the values from 1 to 9, which represent the intensity of the importance of one criterion compared to another.

Table 2: The fundamental scale and its description (Source: Saaty, 1977).

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment 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 judgments	When compromise is needed
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Based on the order of importance presented in the Table 1 and the fundamental scale introduced in the Table 2, the pairwise matrix was filled as Table 3. If an intensity value is assigned to the criteria i compared to criteria j , then the reciprocal value is assigned to the criteria j compared to the criteria i . However, the judgment on assigning values in this study is subjective and based on the knowledge gathered from similar studies.

Table 3: Comparison matrix.

	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

Step3: Weight determination.

Equation 1: Calculation of weight (Saaty 1977).

$$W_i = \frac{\sum_{j=1}^n P_{ij}}{(\sum_{i=1}^n \sum_{j=1}^n P_{ij})} \quad (1)$$

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 criterion is calculated by averaging each row as per the Table 4 (Saaty, 1977).

Step4: Assessment of the consistency by calculating the CR. The CR is calculated in order to check the consistency of the pairwise comparison matrix.

Table 4: Weight determination.

	Slope	Soil	Land Use	Population	Weight	Weight as a percentage (%)
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

Equation 2: Calculation of consistency ratio (Saaty, 1977)

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

Where:

CI = Consistency index

RI = Random consistency index

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

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

Where:

n = Number of criteria = 4

λ_{max} = Total of the products between each element of the weight (Table 4) and the column totals of the comparison matrix (Table 3).

From the equation 3,

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

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, from the equation 2,

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

As the 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.

2.3.2 Weighted overlay

Based on the above factors, the suitability of preliminary locations was 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 5. Ranks were assigned from 1 to 10, where 1 represent the least suitability and 10 represent the highest suitability. Weights were assigned based on the Table 4. 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 (Fig. 4).

Table 5: Weights assigned to classes of each theme based on their influence on primary selection for water storage system.

	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	
	Noncalcareous Brown soils & Low Humic Gley soils; undulating terrain	6	
	Reddish Brown Earths & Immature Brown Loams; 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 Podzolic soils with dark B horizon & Red-Yellow 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	
Land Use	Soils on Old Alluvium;	8	12
	Solodized Solonchaks and Soils on recent marine calcareo	3	
	Coconut	3	
	Dense Forest	2	
	Garden	6	
	Open Forest	2	
	Other Land	8	
	Paddy	3	
	Rubber	3	

	Tea	3	
	Undefined	8	
	Water Bodies	1	
Slope (%)	0-0.5	9	56
	0.5 - 1	8	
	1 - 2	6	
	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

Fig. 4: GIS model for the preliminary location selection.

2.4 Selection of precipitation suitability - Secondary selection

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

The future precipitation 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. 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

Present precipitation data were also used in the study. The original data set presents the average monthly precipitation from 1970 to 2000 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 5,000 mm, the average future and present precipitation 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 6).

Table 6: Reclassification for the precipitation values.

Precipitation Ranges (mm)	Suitability	Reclassified values		Precipitation Ranges (mm)
		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	

The study considers 2,000 m annual precipitation value as the minimum precipitation requirement for a new water storage project. 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 1,750 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). De Silva et al. (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 indicates that the country expects approximately less than 2,000 mm precipitation over dry zone and approximately over 2,000 mm rainfall over wet and intermediate zones in the future.

Furthermore, the annual average evaporation within the dry zone is estimated to be between 1,700 mm to 1,900 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 et al., 2006). Besides, mean annual rainfall values and pan evaporation values recorded over 21 rainfall stations reveal a pattern that the majority of the areas that exceed 2,000 mm mean

annual precipitation record positive rainfall excess (Weerasinghe, 1991).

Apart from these, 2,000 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 5,000 mm respectively.

Considering these factors, the minimum precipitation requirement for a water reservoir was set as 2,000 mm for this analysis. This will allow selecting the areas that record only the positive rainfall excess values within the country, considering present and future precipitations and evaporation data.

The most favorable locations based on the present and future precipitation conditions were selected by subtracting the present average precipitation data from future average precipitation data. Although the result divided the study area into four categories (**Error! Reference source not found.**), study focuses only on the suitable areas based on both the present and future precipitation.

Table 7: Suitability table.

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

Fig. 5: Delineating location for water storage system - Work flow.

The areas deemed not suitable based on either one 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. The areas not suitable based on the future precipitation scenario are considered to be vulnerable locations for getting dried out in the future.

Final location selection for water storage system was executed by following the data analysis workflow as illustrated in the Fig. 5.

3 Results

3.1 Preliminary selection:

Based on the preliminary analysis, the country is classified to 9 different suitability levels (Fig. 6(a)). While the number 1 represents the least suitability, number 9 represents the highest suitability based on the widely used data types. In order to maintain the highest accuracy in the study, suitability levels 8-9 were considered in the study (Fig. 6(b)).

3.2 Secondary selection:

The highest suitable locations based on both preliminary and secondary selection criteria were then overlaid with

the existing tank layer of the country in order to avoid the overlapping areas.

The resultant map depicts the most favorable new locations for water storage systems compatible with expected changes in the future precipitation pattern in the year 2050 (Fig. 7).

Majority of the locations are scattered within the districts of Colombo, Gampaha, Kurunegala and Galle. Districts of Kalutara, Rathnapura and Kegalle also show a moderate number of areas while Nuwara Eliya, Matara, Hambanthota and Kandy districts show lower number of areas based on the analysis. These areas are distributed within the wet zone where the annual precipitation is about 2,500 mm in the present scenario. Besides, the surroundings of the selected areas demonstrate either minimum or no active water storage systems in the present scenario.

The study also points out a list of existing water resources that are vulnerable to being dried out due to the changes in the future precipitation pattern Fig. 8. As per the results, 1,160 out of the 1,202 tanks considered in the study are under the risk of being dried in the future (**Error! Reference source not found.**). This is 96% of the existing tanks in the country. Among them, 34 tanks extend over an area of 10 km² (**Error! Reference source not found.**). About 90% of these endangered tanks are located within the dry zone where the annual average rainfall is about 1,450 mm in the present.

Fig. 6: (a) Levels of suitability – Preliminary selection, and (b) Most suitable areas.

Fig. 7: Selected areas for water storage system.

Fig. 8: Vulnerable tank locations to be dried out in the future.

Table 8: Percentage of vulnerable water reservoirs within each district.

District	Climatic Zone	Total No. of available tanks	No. of 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 9: List of the vulnerable tanks cover over 10 km² area.

Name	Area (km ²)	X (Decimal degrees)	Y (Decimal degrees)
Lagoon	123.235	81.70331013	7.631005117
Senanayake Samudra	79.9725	81.48157046	7.185914027
Maduru Oya Reservoir	62.4292	81.19568527	7.582575773
Kokkilai Lagoon	56.1727	80.9262451	8.986583149
Uda Walawe Reservoir	43.3532	80.83961134	6.464606758
Nanthi Kadal Lagoon	36.0198	80.77093911	9.287284488
Negombo Lagoon	34.7434	79.85113577	7.151790254
Mundal Lake	30.5579	79.80873222	7.798556227
Lunuganwehera Reservoir	30.3209	81.19447114	6.387579978
Padawiya Wewa	29.1883	80.7610837	8.803679758
Upaar Lagoon	29.0457	81.40854679	8.140534072
Randenigala Reservoir	28.2737	80.88213166	7.186365838
Victoria Reservoir	27.7226	80.7572273	7.268204082
Parakrama Samudra	27.4056	80.9773484	7.909511321
Kala Wewa / Balalu Wewa	21.7207	80.55051394	8.000747289
Nachchaduwa Tank	19.9913	80.48734323	8.248790037
Inginimitiya Reservoir	19.6578	80.15315558	7.935460868
Iranamadu Tank	18.9052	80.44414138	9.299877406
Periya Kalapuwa	18.6688	81.84383302	7.159756816
Minneriya Wewa	18.2197	80.87933862	8.028256497
Bolgoda Lake	17.7997	79.92534989	6.746223373
Wahalkada Wewa	14.9345	80.82794324	8.722338156
Ullackalie Lagoon	14.9056	81.36306038	8.382830344
Vavuni Kulam	14.5008	80.35745858	9.084038791
Nayaru Lagoon	14.1655	80.85553557	9.139000151
Ulhitiya Reservoir	14.1208	81.07363569	7.443066046
Giant's Tank	14.0381	80.03545393	8.856926189
Hurulu Wewa	12.6973	80.72539357	8.209981972
Kantale Wewa	12.6097	80.98012393	8.366752418
Rajangane Reservoir	11.9099	80.24870554	8.130062111

Rukam Wewa	11.8154	81.47526673	7.640049231
Allai Wewa	11.5928	81.30445616	8.367690495
Navakiri Aru Tank	11.2934	81.59307072	7.458649158
Kalapuwa	10.9044	81.8512315	7.06090388
Jayanthi Wewa	10.8985	81.53759442	7.112385339
Chilaw Lake	10.7957	79.81265242	7.527984843
Kotmale Reservoir	10.7043	80.64185057	7.057595705
Mora Wewa	10.3044	81.01440152	8.57713554

4 Discussion

4.1 Locations for new water reservoir

The study pointed out that the most favorable locations for new water reservoirs are located within the wet zone where about 60% of the total population is living. Within the high rainfall areas of the wet zone, the surface runoff accounts for 50-70% of annual rainfall due to the low infiltration capability over the non-natural cement floor and asphalt surfaces. In parallel, the surface runoff drops to less than 30% in the dry zone, even during high rainfall seasons due to the high infiltration rate over a large bare land (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. During the SWM, from May to September, rainfall varying from about 100 mm to over 3,000 mm based on the present precipitation data is received (DOM, 2019). The SWM trend indicates that the wet zone is continuous to have the highest rainfall in the present and future scenarios (Fig. 9). Besides, this area receives moderate to higher rainfall during the other three monsoonal seasons. As mentioned in the earlier sections of this study, many precipitation 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.

Fig. 9: South-West Monsoon Rainfall Scenarios in 2050s, left to right, baseline scenarios, SRES-A2 scenario, and SRES-B2 scenario (Source: De Silva et al., 2006).

The average per capita availability of freshwater amounting to 2,592 m³/year, is adequate for the country's needs. However, water availability in several major cities within the wet zone has dropped below 1,000 m³/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 expected increment of precipitation over the wet zone 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 to accommodate the water demand 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.

Water 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 capacity 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 fulfill 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.

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 fulfill the water requirement of the country, deviation from the existing distribution pattern is recommended in the study.

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 is comparatively high, well distributed small-scale water reservoirs are proposed in order to minimize the high economical land utilization.

4.2 Vulnerable water storage systems

The majority of vulnerable water storage systems are located within the north and north east parts of the country, specifically within the districts categorized as 'dry'. 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 et al. (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) and 29 % (B2) respectively, considering the overall rainfall. The projected rainfall over the districts 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 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 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 are expected to have a 2% increment of evaporation in 2050 as per the A2 and B2 scenarios (De Silva et al., 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, the 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

Table 10: List of tanks with less than 50% water capacity in present in the district Anuradhapura (Source: Wijesinghe, 2018).

Reservoir	Normal capacity (acre-feet)	Present capacity (acre-feet)	Irrigatable landscape (acres)	Landscape Cultivated during Yala season - 2018 (acres)
Padaviya	85,000	6,190	13,800	Nil
Wahalkada	43,000	1,917	2,000	Nil
Wilachchiya	32,500	1,523	2,660	Nil
Nuwara Wewa	36,050	9,170	2,600	2,600
Tissa Wewa	3,500	1,700	902	902
Nachchaduwa	45,150	17,320	7,000	7,000
Abhaya Wewa	1,675	590	385	385
Mahakanadarawa	36,250	8,850	2,000	1,035
Thuruwila	8,157	6,420	465	415
Rajanganaya	81,600	70,910	19,500	15,000
Angamuwa	14,400	7,600		
Hurulu Wewa	55,000	17,265	10,400	3,000
Manamkettiya	4,879	758	1,050	170

Table 11: Water levels of Lunugamwehera reservoir (Source: Sakthivadivel et al., 2001).

Year	Agency	Data Used	Average Inflow (acre-feet)
1977	Asian Development Bank Appraisal (ADB 1977)		318,000
1986	Asian Development Bank Restudy (ADB 1986)		255,000
1994	ID in collaboration with IWMI (IWMI 1994)	1986-1992	235,000
2000	IWMI present study	1989-1999	226,000

water withdrawal for agriculture. These factors clearly imply that the dry zone of the country is highly prone to a low water excess 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 begun 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 10) (Wijesinghe, 2018). 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.

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, reporting a gradual water decrease over the years, Table 11 shows the average inflow of the Lunugamwehera reservoir collected by

different agencies for a range of years (Sakthivadivel et al., 2001).

The study also categorized Inginiyitiya 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 Inginiyitiya 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 Inginiyitiya 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 drying out due to the imbalance between water input and 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.

5 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. Besides delineating the locations, the study also pointed out the most vulnerable water features that will be dried out due to the changes of the precipitation pattern in the future.

Despite the future precipitation data, the 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 systems are located within the district of Colombo, Kalutara, Gampaha and Galle. 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, is highly favorable in maintaining 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, high temperature and evaporation in the future. Besides, a higher water withdrawal is also projected within the dry zone. 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.

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 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 relies on the accuracy of raw data used in the analysis. Due to the unavailability of a proper water related data management

system in 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.

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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Author Contributions

Conceptualization, methodology, analysis, writing, reviewing and editing by K.N.B. Author has read and agreed to the published version of the manuscript.

Conflict of Interest

The author declares no conflict of interest.

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