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Effect of Climate Change on Potential Groundwater Recharge in the Dry Zone of Sri Lanka

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Groundwater is still an important water source for many parts of the world, especially in countries such as Sri Lanka, because, despite a huge government investment to divert some of the rivers to dry areas, there are many areas which this river water cannot reach, and hence a large number of people depend on groundwater for their basic water requirements. The effects of climate change are evident in all parts of the world which include significant weather pattern changes, effect on fauna and flora, see level changes etc. Groundwater recharge, which results mostly from rainfall in many areas of the dry zone, will therefore be different from what they are now. This study looks at the possible effects of climate change on the estimates of potential groundwater recharge in the dry zone of Sri Lanka.

The study locations chosen were Angunakolapellessa, Mahalllupallama and Kalpitiya, where estimates of recharge were obtained with a soil water balance model, programmed on a spreadsheet. The model was validated with estimates of recharge obtained by different workers at different locations including Sri Lanka. Parameters of (rainfall and evapotranspiration) generated from a Regional Climate Model (PRECIS)were inputted to the model both for the 1961-89 (baseline) as well as for the 2071-99 (generated) periods, giving estimates of recharge for the periods 1961-89 and 2071-99.

The results show that the current estimates of recharge are likely to be reduced by 20 – 40% in the three study locations. The possible effects of such changes in recharge estimates and possible action to mitigate these possible effects of high/low estimates of recharge are also discussed.

Keywords: Groundwater recharge; climate change; dry zone of Sri Lanka.

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1. INTRODUCTION

The importance of groundwater for a country like Sri Lanka is well documented and well known [1,2]. As piped water supply is not available in many parts of the country except for a few cities and towns, people in most areas, especially in the dry zone, depend on dug wells, agro wells or occasionally a bored deep well (locally known as a tube well) for their water requirements, unless a canal (which might not be flowing at all times) or a reservoir is available in the near vicinity. As at 2005, about 70% of the population in the country depended on groundwater for their water needs and more than 25% of the piped water supply came from groundwater [3]. To harness the groundwater resource sustainably, one of the most important parameters which cannot be overlooked is the rate at which the water table is replenished (mostly from precipitation) known as the groundwater recharge rate.

Due to the overwhelming evidence like global temperature increase, extreme climatic conditions including heavy bursts of precipitation in a shorter time and desertification in many parts of the world, melting of ice caps in the arctic and extinction of many animal and plant species, most people now believe that the climate change is real. In the last century, the temperature of the earth rose by about 0.6°C [4] and it is expected to rise between 1.4 to 5.8°C by 2100 due to the emission of greenhouse gasses [5] and the temperature in Sri Lanka is said to increase by 0.9 – 4.0°C by 2100 over the baseline period (1961-1990) temperature [6]. Worldwide, there have been many studies related to various aspects of climate change on groundwater [7,8,9,10] and a relatively fair number of studies on the effect of climate change on the groundwater recharge [11,12,13,14,15,16,17,18]. However, the 4th report of IPCC [19] states that "*there has been very little research on the impact of climate change on groundwater and that the few studies of climatic impacts on groundwater for various aquifers show very site specific results*". This may be because, instinctively, one might tend to think that these groundwater resources are hidden and hence protected from the vagaries of weather, but, a little thought will enable anyone to imagine the scary effects of such a scenario. Studies on the effects of climate change on any of the aspects of groundwater in Sri Lankan have been scarce [6,20,21] and almost non-existent in reporting the effects on the estimates of groundwater recharge. In fact, one of the important research areas identified at the National Seminar on Groundwater Governance in Sri Lanka [22] is the "*Effects on groundwater due to climate changes*".

Most of the work reported on the effect of climate change on groundwater recharge suggests a decline in recharge rates over the coming years. Eckhardt and Ulbrich [12] from their study on the Dill catchment in south east Germany, suggest that recharge rates could be as low as 50% of the existing values, whereas Herrera-Pantoja and Hiscock [13] from their study in three locations (Coltishall, Gatwick and Paisley)in UK conclude that recharge rates could be as low as 88% of the existing rates at least for Paisley and in general it will be declining with the increase of temperatures. Thampi and Raneesh [18], from their study in Chaliyar river basin in Kerala, South India forecast a reduction of recharge by 4 - 7% by 2071- 2100. They have used the regional climate model (RCM) PRECIS to predict the future climate and then fed these into a hydrologic model to estimate the recharge. Dawes et al. [17], have used a general climate model (GCM) and MODFLOW respectively to estimate climate and recharge and concludes that recharge estimates could be as low as 60-99% in the Swan coastal plain in South West Australia. Jackson et al. [16] have used 13 GCMs to estimate the climate in 2080 in Central Southern England and have concluded that the recharge estimates could be decreased by 26% or increase by 31% depending the GCM used. However ten of the GCMs predict an increase in recharge and they are of the view that where possible as many climate models must be used to arrive at the climate in order to get realistic results. However, Nyenje and Batelaan [15] found the estimates of recharge to increase by 20-100% for the period 2020-2080 for the Upper Ssezibawa catchment in Uganda and Jyrkama and Sykes [11] from their study in the Grand River watershed in south western Ontario in Canada, predict that recharge rates could be increasing by as much as 100 mm/year over the next 40 years, as warmer winter temperatures reduce the amount of ground frost and allows more water to infiltrate resulting in increased groundwater recharge rates.

The studies of climate change on any aspects of groundwater in Sri Lanka include the study by Ranjan et al. [20] where they have estimated the effects of salt water intrusion due to climate change on coastal aquifers in Sri Lanka assuming a sharp interface of sea and fresh water model. Eriygama et al. [6] have looked at the climate change effects on water resources with special emphasis on agriculture and developed a climate change vulnerability index (CCVI) and concludes that this index is high in the typical farming districts such as Anurdhapura, Badulla and NuwaraEliya resulting in adverse effects of climate change in these districts. In their study, de Silva et al. [21] have estimated that the average annual paddy water requirement is likely to go up by about 23% in 2050 due to the climate change effects as they estimate from a global climate model (HadCM3) that the rainfall is likely to reduce by 9 – 17% and potential evapotranspiration is likely to increase by 3.5%. It is noted here that unlike in the global scenario where some studies have found an increase in groundwater (recharge) whilst others show a decrease, in the Sri Lankan studies, all point towards a decrease in the groundwater resource. However, none of the above studies for Sri Lanka have directly attempted to see the effects of climate change on estimates of groundwater recharge.

In this context, this study was carried out to investigate the possible effect of climate change on the estimates of groundwater recharge rates in the dry zone of Sri Lanka, which as said before is very important for a country like Sri Lanka as 70% people depend on it and also because groundwater recharge rate is possibly the most important parameter one needs to know to develop / use the groundwater without any adverse effects.

2. MATERIALS AND METHODS

The locations chosen for this study were Angunakolapellessa, MahaIlluppallama and Kalpitiya in the dry zone of Sri Lanka (Fig. 1). These locations were chosen because of the readily availability of required data as some of the research centres for dry zone agriculture are situated in these locations.

Tables 1 and 2 below show the climatic, vegetation and soil data for the study area.

The methodology adopted in this study is as follows:

1. A simple soil water balance model (Fig. 2) was developed to estimate groundwater recharge in the dry zone of Sri Lanka after considering all the important processes of the hydrological cycle which are likely to be important in this zone. The model was converted to a spreadsheet model on a computer so that daily calculations and estimate for daily recharge is done quickly and easily. Processes such as interception of rainfall by vegetation and runoff as well as flow through cracks in the clayey soil (ie preferential flow) were included along with rainfall, run off and evapotranspiration in the model formed and programmed on a spreadsheet. Full details of the module and explanations as to why a particular sub model was used for a particular process are given in de Silva [23]. The time step for this model was one day as is recommended for optimum use of soil water balances [24,25]. Rainfall and pan evaporation data were obtained from the Department of Meteorology in Colombo, Sri Lanka and from the Regional Dry Zone Research Centres at Angunakolapellessa and MahaIllupallama. Pan evaporation data were converted to evapotranspiration data by multiplying with an appropriate pan coefficient.
2. By careful consideration of the climate, vegetation and soils the required variables and parameters for the soil water balance was obtained. Full details of this analysis and the procedure involved are available in de Silva [23].
3. Laboratory work was carried out to determine the field capacity and permanent wilting point of the root zone soils as these two parameters were inputs in the said soil water balance model.
4. This model was tested for accuracy using data and recharge estimates and experimentally determined soil moisture deficit data as explained in de Silva [23].
5. The validated model was then used to estimate recharge with both baseline data of rainfall and potential evapotranspiration for the baseline period (1961-89) and for the generated data period (2071-99). This generated data was obtained by courtesy of the PRECIS [26] Regional Climate Modelling System through Dr (Mrs) Savita Patwardhan, Indian Institute of Tropical Meteorology, Pashan Rd, Panchawati, Pashan, Pune, Maharashtra 411008, India and Dr. R. Jagannathan, Professor of Agronomy, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore-641003 (personal communication, 2011-2012). Figs. 3 & 4 show the baseline and generated rainfall and evapotranspiration respectively for the three study locations.

6. The estimated recharge both for the baseline period and generated period was then compared to see the effect of climate change on estimates of recharge.

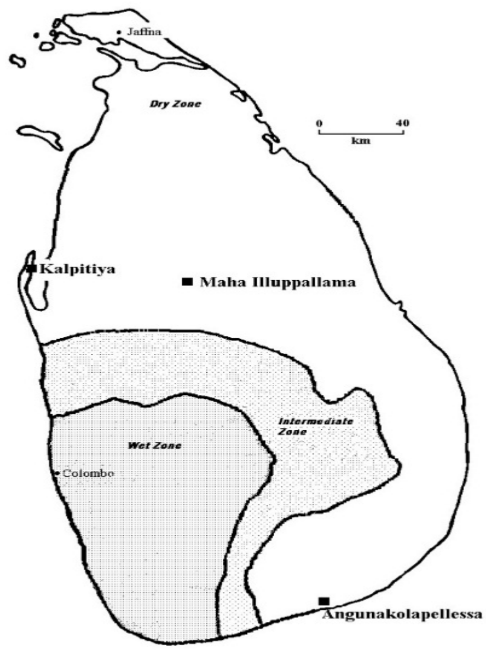

Fig. 1. Study locations in the dry zone of Sri Lanka

Table 1. Climate data for study locations

Study location	1961-89 (Baseline)		2071-99 (Generated)	
	Mean annual rain (mm/y)	Mean annual pan evaporation (mm/y)	Mean annual rain (mm/y)	Mean annual pan evaporation (mm/y)
Angunakolapellessa (LAT: 6.164, LON: 80.898)	951	1547	1121	1613
MahaIlluppallama (LAT: 8.233, LON: 79.767)	1195	1682	1265	1858
Kalpitiya (LAT: 6.249, LON: 80.767)	955	1823	916	2052

Table 2. Soil and vegetation data for study locations

Study location	Root zone depth(m)	Field capacity (%)	Permanent wilting point (%)	Soil	Vegetation	Topography
Angunakolapellessa (LAT: 6.164, LON: 80.898)	0.95	20.2	12	Sandy Clay Loam	Dense Shrub jungle	Flat-undulating
MahaIlluppallama (LAT: 8.233, LON: 79.767)	1.17	20.9	11	Loamy Sand	jungle	Flat
Kalpitiya (LAT: 6.249, LON: 80.767)	1.5	14	4	Sand	Sparse Jungle	Flat

3. RESULTS AND DISCUSSION

The Soil Water Balance model developed, was validated with data from different locations around the world as shown in Table 3.

The SWB model was also validated with recharge estimated for Angunakolapellessa for the period 1961 – 1989 which is 98 mm/year and this compares well with other published results for the same area by different methods (e.g. Dharmasiri and Dharmawardena, [31], estimates a recharge of 59 mm/year using tritium profiling for this study area; Seneviratne [32] estimates recharge in the Walave basin to vary between 20 – 450 mm/year from chloride profiling).

The estimates of recharge for the baseline period (1961-89) and for the period 2071-99 for the three study location are shown in Tables 4 and 5 shows the yearly estimates of recharge for the three locations both for the baseline and generated periods.

Fig. 6 shows the daily distribution of estimates of groundwater recharge for the three locations both for the baseline and generated periods.

Fig. 7 shows the estimates of annual recharge for the three locations both for the baseline and generated periods.

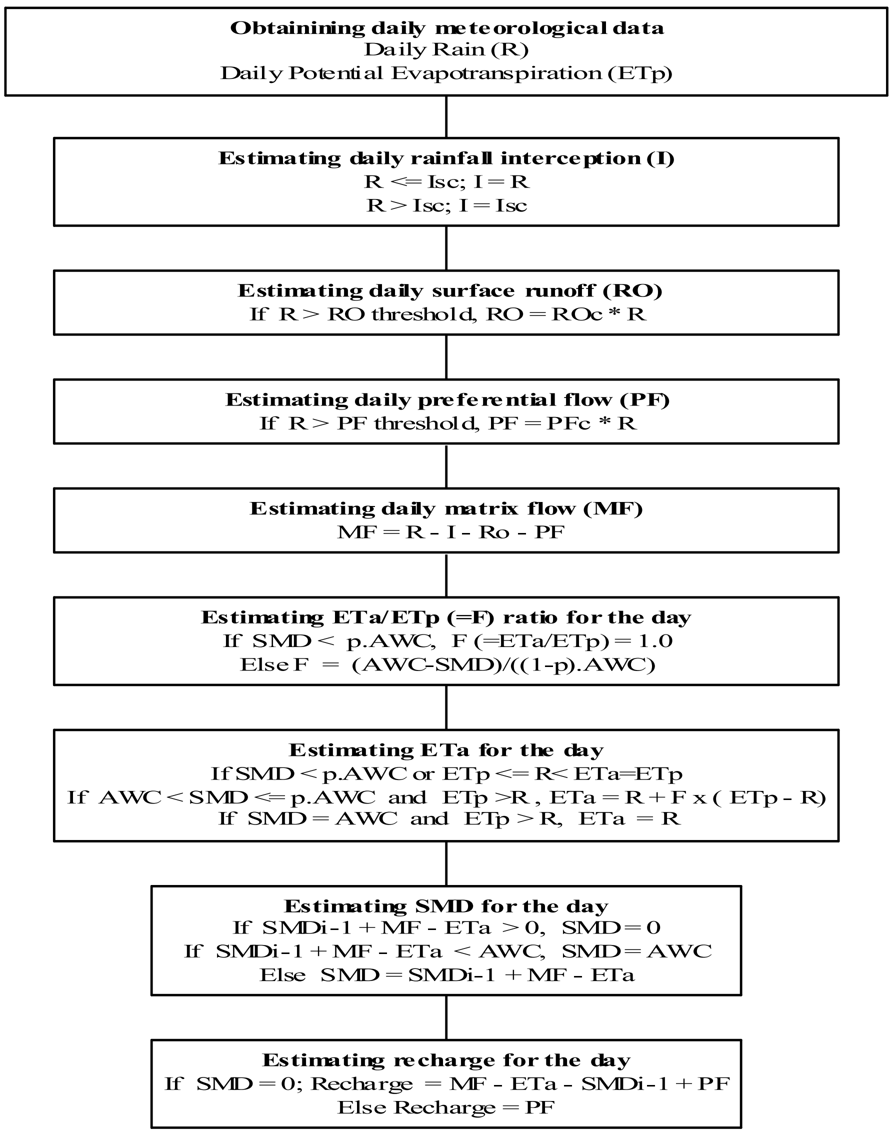

Fig. 2. Flow chart of the soil water balance model suitable for the dry zone of Sri Lanka

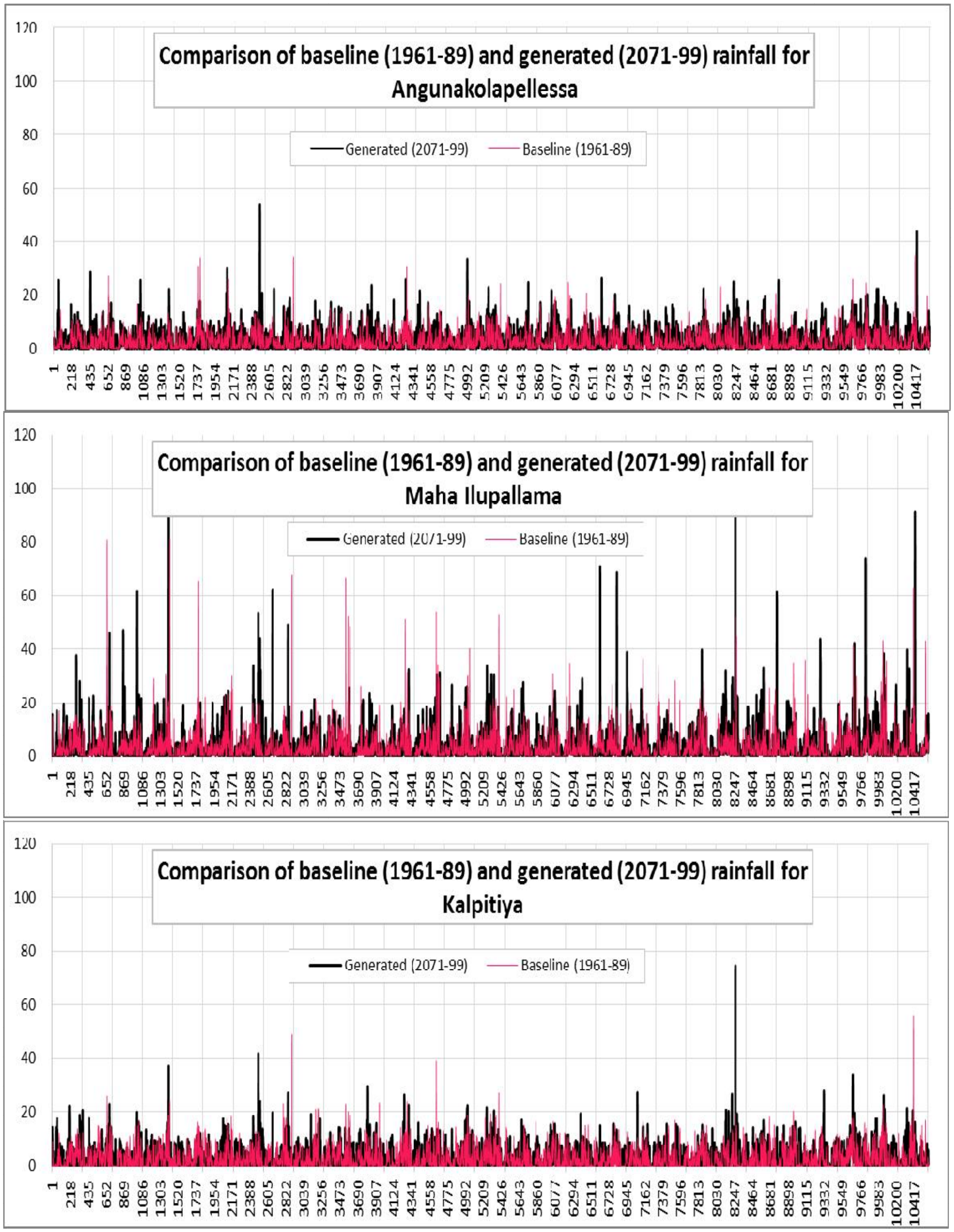

Fig. 3. A graphical illustration of baseline (1961-89) and generated (2071-99) rainfall for the three study locations (NOTE: Vertical axis – Rainfall (mm) and horizontal axis – Time (days)

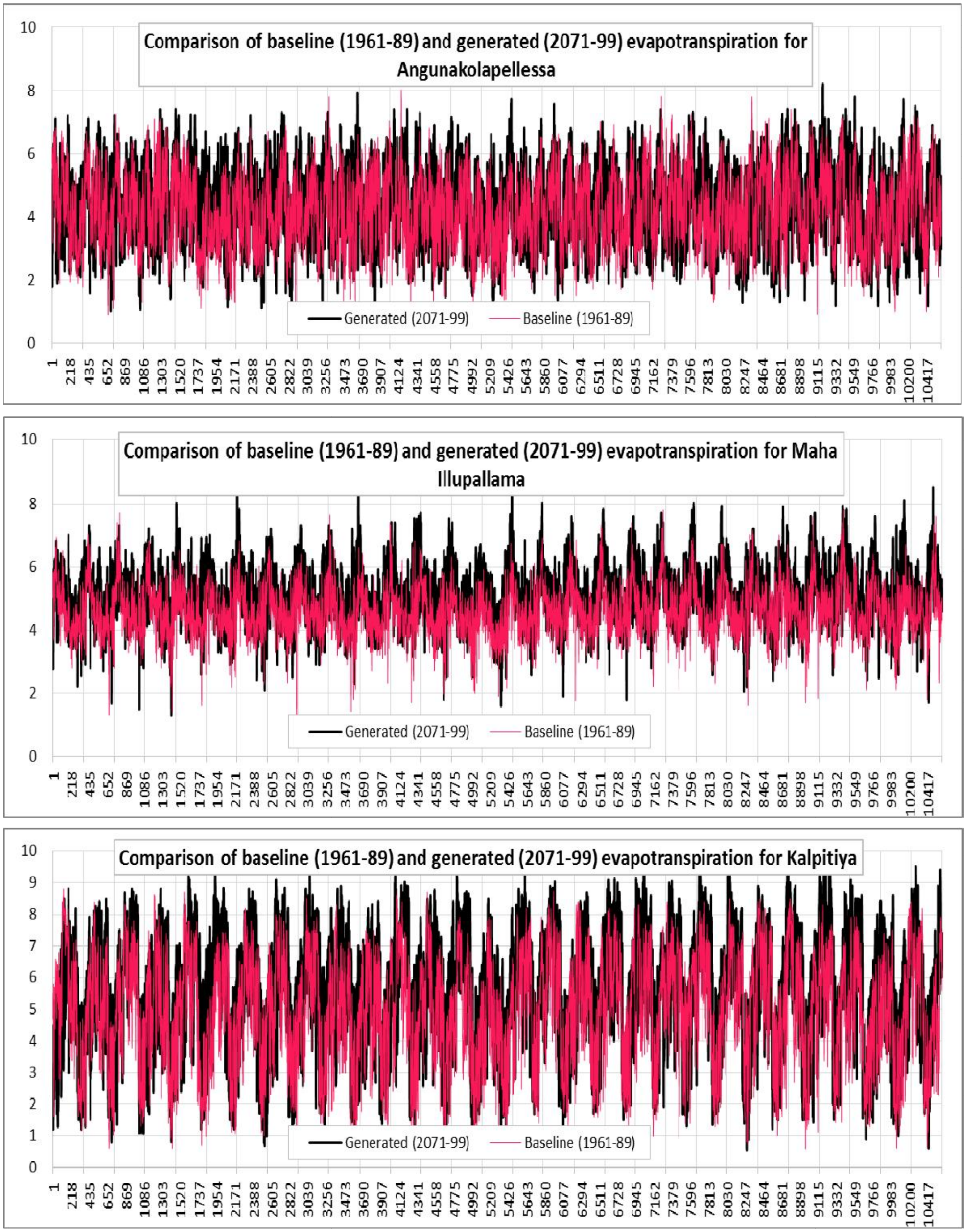

Fig. 4. A graphical illustration of baseline (1961-89) and generated (2071-99) evapotranspiration for the three study locations (NOTE: Vertical axis – Rainfall (mm) and horizontal axis – Time (days)

Table 3. Validation of the soil water balance model developed

Location	Mean annual Precipitation (mm/y)	Mean annual ETp (mm/y)	Available estimate and method this estimate was obtained	Source	Soil water balance model(used in this study) estimate	Time steps and duration of SWB
Ngwazi, Tanzania	630	1397	Soil moisture deficit (see Fig. 6) from field measurement (on 15 Nov the SMD measured was 338 mm)	[27]	See Fig. 5 (on 15 Nov 1989 the SMD predicted was 335 mm)	Daily for 245 days (1 Apr 89 - 1 Dec 89, both days inclusive)
Nguru, Nigeria	463	2090	Recharge, 30-60 mm/y from groundwater flow modelling and chloride method	[28] and Carter (1996) personal communication	29 mm/y	Daily for 11 years (1965 - 1975, both years inclusive)
Silsoe, UK	560	721	Recharge, 94-183 mm/y from a SWB and Recharge, 168 mm/y from chloride method	[29] [30]	121 mm/y	Daily for 30 years (1962 - 1991, both years inclusive)

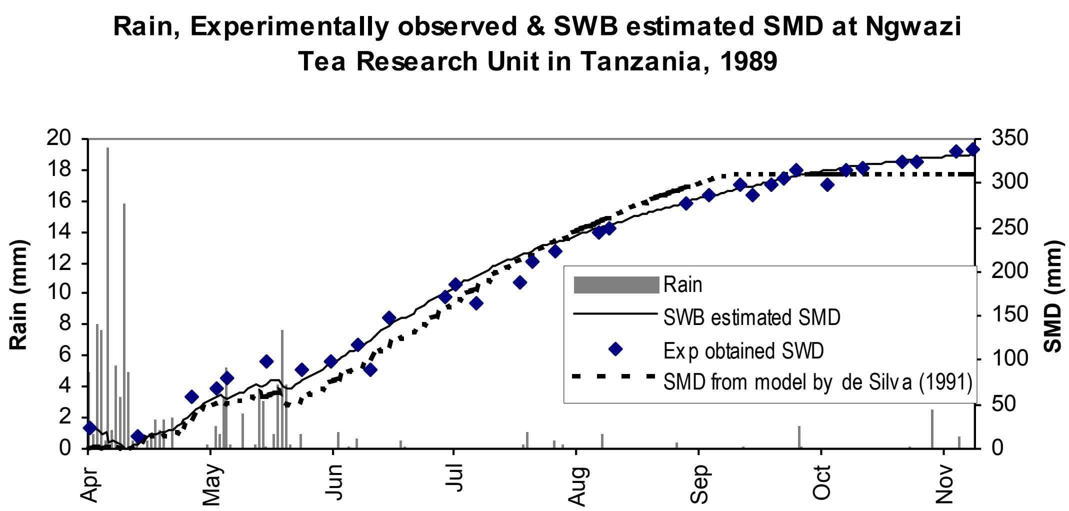

Fig. 5. Experimental soil moisture deficit and soil water budget model estimated soil moisture deficit

Table 4. Estimates of average annual recharge for the baseline (1961-89) and generated (2071-99) periods for the three study locations

	Angunakolapellessa	Mahallluppallama	Kalpitiya
1961-89	98	126	79
2071-99	80	78	65
% change from 1961-89 to 2071-99	-18%	-38%	-18%

Table 5. Estimates of yearly recharge for the baseline (1961-89) and generated (2071-99) periods for the three study locations

Year	Recharge (mm/y)					
	Angunakolapellessa		Mahallluppallama		Kalpitiya	
	1961-89	2071-99	1961-89	2071-99	1961-89	2071-99
1	88	52	120	37	86	34
2	80	18	179	50	71	29
3	49	27	79	69	35	38
4	45	6	106	163	73	77
5	221	9	184	29	168	1
6	120	29	131	75	107	47
7	108	128	118	82	15	101
8	86	52	123	42	66	67
9	76	5	83	35	116	3
10	113	30	230	42	112	11
11	56	83	68	39	17	38
12	126	57	105	27	85	22
13	68	14	159	81	91	5
14	71	166	110	40	84	195
15	148	85	136	152	77	8
16	73	42	111	56	13	4
17	102	190	79	97	71	86
18	97	6	92	75	25	1
19	84	167	112	95	12	101
20	67	39	95	75	21	3
21	39	6	142	19	18	3
22	118	110	179	45	136	103
23	104	154	116	157	26	227
24	82	159	109	106	20	139
25	58	55	109	48	91	48
26	73	97	80	34	89	69
27	304	392	171	120	144	306
28	98	100	210	239	193	74
29	94	50	134	119	226	49

From the results presented, it can be seen that the estimated recharge rates are likely to decrease in the dry zone during the period 2071-99, compared to the baseline period (1961-99). On average, the decreases are about 20% for Angunakolapellessa and Kalpitiya and about 40% for Mahalllupallama. Also the yearly values show significant differences for the two periods (as seen in Table 5 above) and in certain periods (eg. years 4, 5 and 6 for Angunakolapellessa) the recharge values are significantly low for few consecutive years in the 2071-99 period and these very low recharge values will have drastic effects on humans, animals and agriculture, as the amount of water reaching the water table will be minimal for a few consecutive years, compounding the problems. The reduced estimates of recharge are in agreement with most of the studies for different parts of the world [12,13]. They are also in agreement with the reported studies of climate change on rainfall / groundwater in Sri Lanka where all the documented literature points to a decrease in rainfall / recharge [6,20,21].

However, there are certain years (eg years 4 and 28 for Angunakolapellessa) where the estimates of recharge for the generated period are higher, compared with that of the baseline period. The effects of increased recharge include increased availability of groundwater for consumption, but, for most parts of the dry zone of Sri Lanka, this is not likely to be of much benefit as most of the dry zone is underlain by crystalline hard rock and storage of this increased recharge will not be possible in most areas except where cracks and fissures are available in the hard rock. Undesirable effects of increased recharge include increased salinity rendering the area not suitable for agriculture, upwards movement of the water table affecting crops/ forests with deep roots and possible increase in landslides especially in hilly areas. However, as pointed out, it is more likely for the recharge to decrease and the effects of decreasing recharge rates include, water tables lowering with associated ground subsidence, drying of wells and desertification.

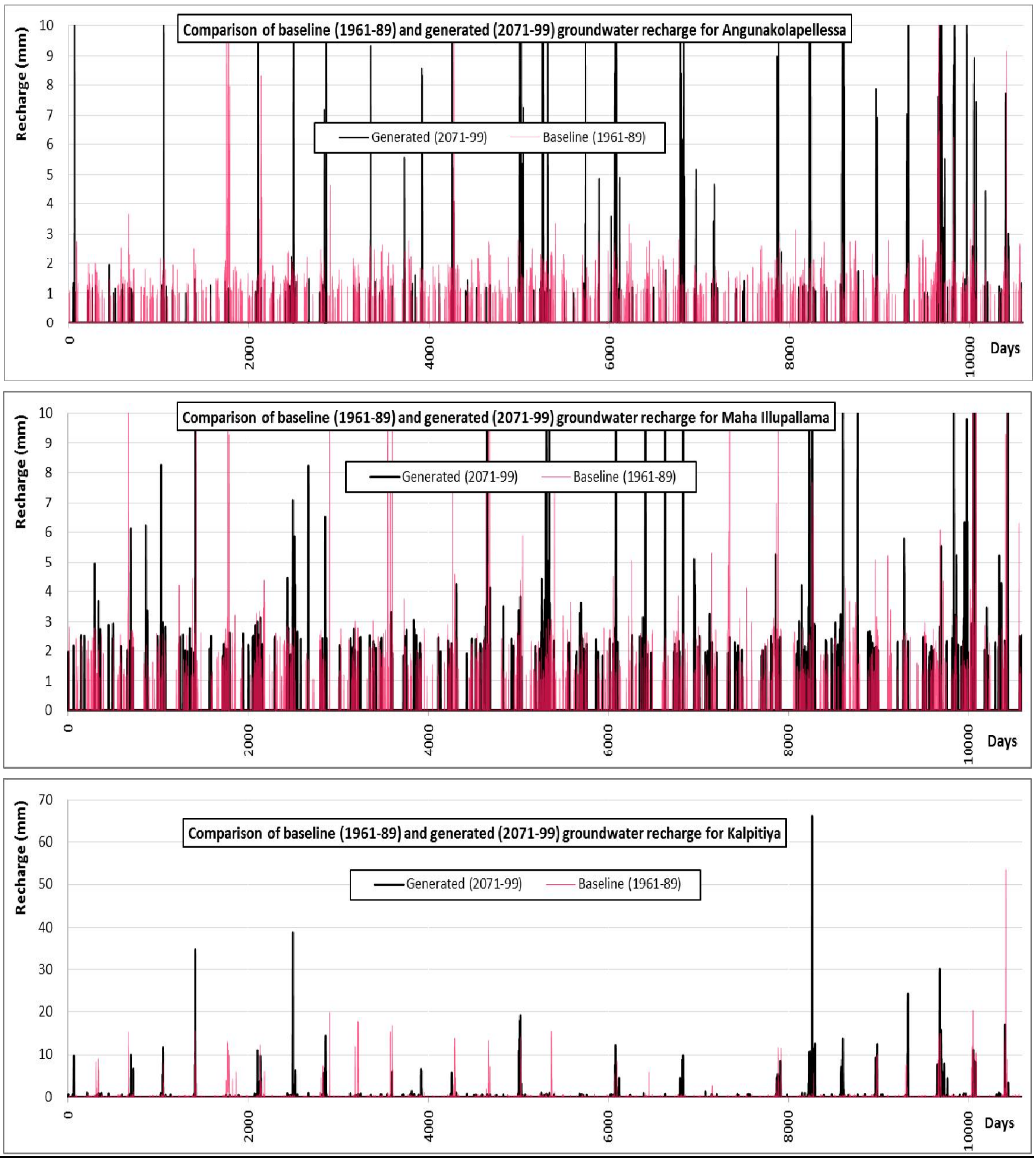

Fig. 6. Graphical representation of estimates of daily recharge for the baseline and generated periods for the three study locations

The approach used in the study may be improved by using more accurate models for estimating recharge. However, it is very likely that similar results are obtained, whatever models are used as the primary parameters that govern the recharge process (rainfall and evapotranspiration) are similar for all models which includes the model used in this study. However as Jackson et al. [16] have shown, its best if the climate forecasts can be obtained with many RCMs and /or GCMs, which unfortunately was not possible in this study.

Another important consideration is the variation of rainfall / ET with time which is possible with climate change. It can be easily shown that even if the average annual values for rain / ET remain the same, the different variations of them throughout the year can cause significant effects on estimates of recharge. As daily values for rainfall, evapotranspiration and all other varying parameters were used, it is likely that the estimates of recharge from this study are closer to the true values compared to most studies where the time step has been a month or even some cases an year.

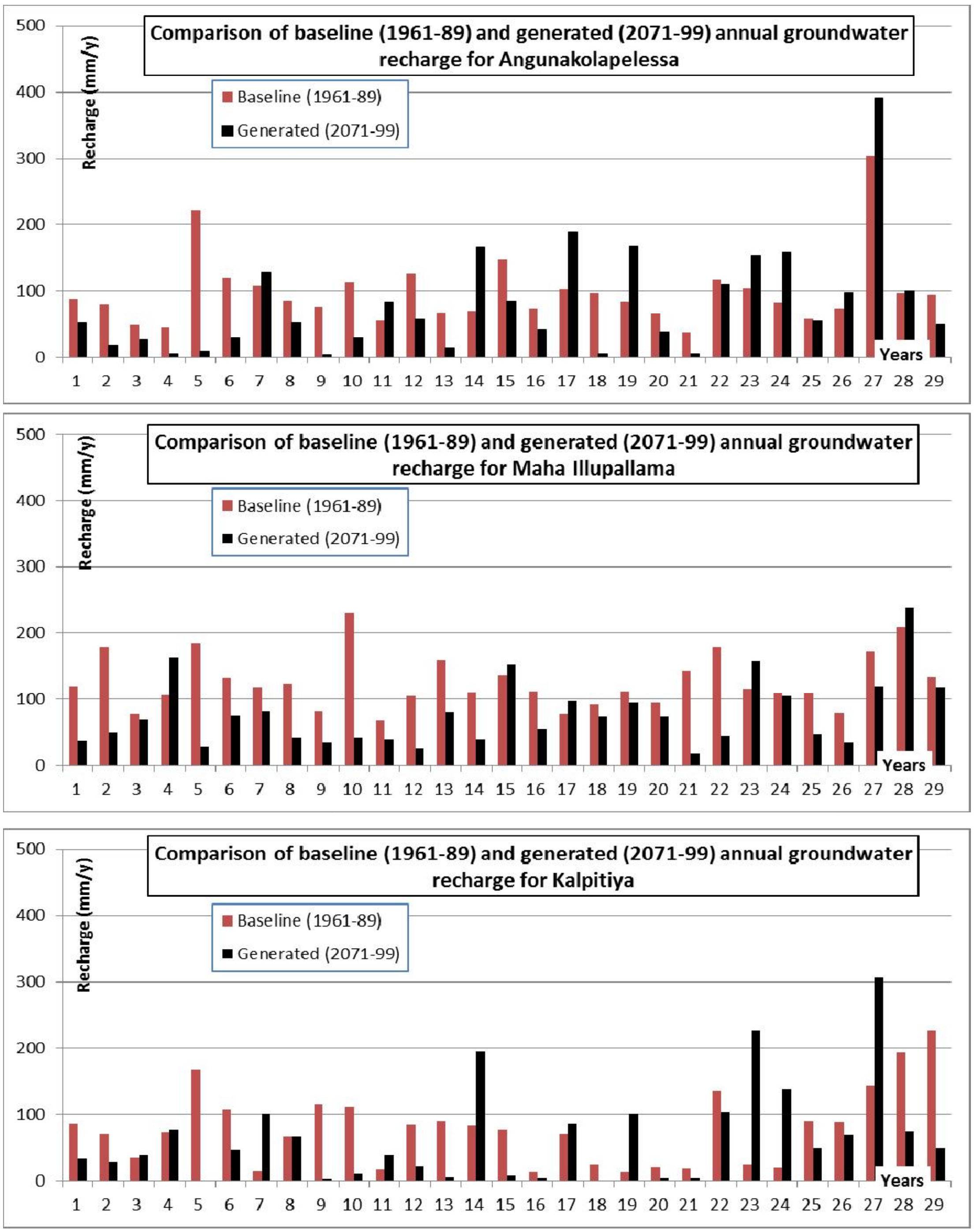

Fig. 7. Graphical representation of estimates of annual recharge for the baseline and generated periods for the three study locations

This work, as most of the other work reported; assume that there is no change with any of the soil and vegetation parameters with climate change. However, as Holmann [33] indicated, it is very likely that this is unlikely to be the case as soils of the future may not have the same water infiltration properties. Other parameters considered for the model (ie, interception, runoff and preferential flow parameters) are likely to change as well as a result of climate change. If the results are to be more accurate, these effects also need to be considered and built into the model.

Due to the availability of resources, the present study was carried out only for three locations in the dry zone, but, need to be extended to a few other locations to arrive at a general conclusion for the dry zone. As Jackson et al. [16], from there study of 13 global climate forecasting models in UK found out, the potential groundwater recharge can vary from – 20% to + 31% depending on the climate forecasting model used. This is also supported by the work of Holmann et al. [34]. Further, it is also recommended that more accurate climate prediction models and a combination of such models be used in obtaining at least the two most important input variables of the model (i.e. rainfall and ET) in order to get more accurate estimates of recharge.

4. CONCLUSION

This study looked at the possibility of using climate data generated by a regional climate model (PRECIS) for the period 2071 – 99, in a simple soil water balance model to estimate the potential recharge rates for the same period in three locations in the dry zone of Sri Lanka. The following specific conclusions are arrived at, from this study.

(i) The forecasted estimates of recharge for the period 2071 – 99 are very likely to be reduced by an amount 20 – 40% compared to those of 1961 – 99 in the dry zone of Sri Lanka. However, as said before carrying out a similar study in more locations will enable in increasing the accuracy of this estimates as the above figures have been arrived at by studying only 3 locations (nevertheless they being representative of the average conditions in the dry zone of Sri Lanka).

(ii) The reduction in forecasted recharge is in good agreement with other studies which have looked at effects of climate change in groundwater / water resources in the dry zone of Sri Lanka.

(iii) This study is able to show the daily variations of forecasted groundwater recharge estimates in the dry zone of Sri Lanka, which has not been shown in any of the studies the author is aware.

(IV) The reduction of recharge is very likely due to the reduction in rainfall and increase in evapotranspiration as has been shown in other studies as well (de Silva et al. [21]).

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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