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ESTIMATING GROUNDWATER RECHARGE IN THE DRY ZONE OF SRI LANKA WITH A SOIL WATER BUDGET MODEL II. APPLICATION OF THE MODEL TO ESTIMATE RECHARGE IN DIFFERENT LOCATIONS IN THE DRY ZONE

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ABSTRACT

An attempt to estimate recharge with a simple soil water balance at 7 locations in the dry zone of Sri Lanka shows that with the presently available hydrological data, the estimates are likely to be wide ranges rather than single values, with limited use. The reasons behind these short comings in the application of the soil water budgeting method in the dry zone are discussed and measures are identified if a soil water budgeting method is to yield more meaningful estimates of recharge.

Abbreviations :The meanings of symbols and abbreviations used in this paper are as given in Appendix 1.

Introduction

A simple soil water budgeting model to estimate recharge is described by de Silva (xxxx). The application of the model to estimate recharge at different locations in the dry zone are described in this paper. Also the results obtained are analysed and discussed in order to arrive at suitable conclusions.

Determination of suitable values for model parameters for the dry zone

To estimate recharge with the soil water budget model formulated, data and values for model parameters are required. The data required are rain, potential evapotranspiration and available water capacity of soil in the root zone and the model parameters required are interception storage capacity, runoff threshold, runoff coefficient, preferential flow threshold, preferential flow coefficient and root constant. Rainfall and potential evapotranspiration data are usually available and available water capacity data can be experimentally determined (Table 1) if they are not available. However, model parameters need to be determined for each site from hydrogeological information of the area.

One way of determining the values for model parameters is by calibrating the soil water budget with soil moisture data, stream flow data or water table data (if the water table is shallow and actual recharge is similar to potential recharge). However, for the model parameters to be realistic these calibration data must cover at least a wet, dry an average year (with respect to rainfall). Since such data are not available for the present study, a different approach is to test the sensitivity of each model parameter, identify the important parameters and attempt to determine these important parameters only. However, for the sensitivity analysis approximate values for model parameters are still required.

Table 1
Details of climate, vegetation, plant type and soil and experimentally obtained soil parameters required for the Soil Water Budget

Location	*Number of sampling points*	*Mean Annual Rain*[1] *(mm/y)*	*Mean Annual Pan Evaporation*[1] *(mm/y)*	*Vegetation*	*Major Plant type*	*Top soil*	*Field capacity (%)*	*Permanent wilting point (%)*	*Depth of root zone (m)*
Embilipitiya	8	1397	1729[2]	Shrub jungle	Maana (Grass about 30 cm tall)	Loamy Sand	21.40	15.71	0.69
Middeniya	16	1484	1729[2]	Mango and Teak Plantation	Eluk (Grass about 30 cm tall)	Sandy Loam	21.48	13.27	1.09
Buweliara	12	1041	1868	Shrub jungle	-	Sandy clay Loam	26.00	15.56	0.84
Angunakola-pellessa	12	1041	1868	Shrub jungle	Eraminiya (Bush about 1.5 m tall)	Sandy Clay Loam	19.80	11.92	0.94
Maha Illup-pallama	8	1305	1579	Jungle	-	Loamy Sand	20.86	10.99	1.17
Anamaduwa	1	1117	1958[4]	Jungle	-	Sandy loam	18.12	9.66	1.52
Kalpitiya	7	955	1958[4]	Sparse Jungle	Bolpana (Tree about 3m tall)	Sand	14.00[5]	4.00[5]	1.5[5]

[1] 6 year mean value except for Angunakolapellessa and Buweliara where the mean values are 17 year ones.

[2] Pan evaporation values are from the climate station at Sevanagala.

[3] Since no rainfall or pan evaporation data are available for Buweliara, data from the nearest climatic station (Angunakolapellessa) is used for Buweliara.

[4] Pan evaporation value are from climate station at Vanathavillu.

[5] Field capacity and permanent wilting point values are assumed as 14% and 4% by volume respectively for Kalpitiya as no experimental data are available (Booker tropical soil manual, 1984). Also the depth of root zone is considered as 1.5 m.

The last 6 cols. of Table 2 show the likely values for model parameters (and also how they were arrived at using Figs. 1, 2 (a), (b), (c), (d), (e), (f) and also using information given in first 7 cols. of Table 2) for each site in the dry zone of Sri Lanka.

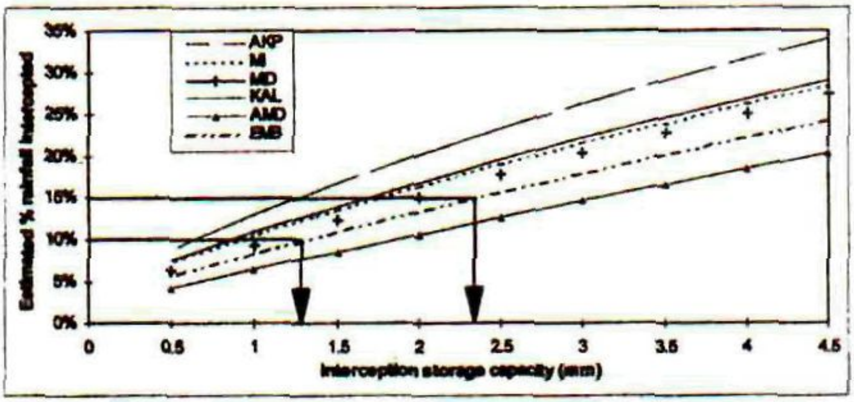


Fig. 1 Percentage rainfall intercepted by different values of interception storage capacity for the different sites in Sri Lanka (using interception model in equation 9 in de Silva (xxxx); arrows show the determination of interception storage capacity values for Embilipitiya)

Sensitivity Of Model Parameters

In determining the sensitivity of model parameters, two possible problems need to be addressed. They are:

(a). The sensitivity of recharge to a particular parameter varying for a different combination set of other model parameters (i.e., the sensitivity of recharge for a particular model parameter is obtained by keeping the other parameters constant and varying the particular parameter within its possible range). However, the sensitivity obtained this way may be different for a different set of other parameters combination). Fig. 3 shows the sensitivity of recharge to interception storage capacity at the site Angunakolapellessa for three model parameter combinations.

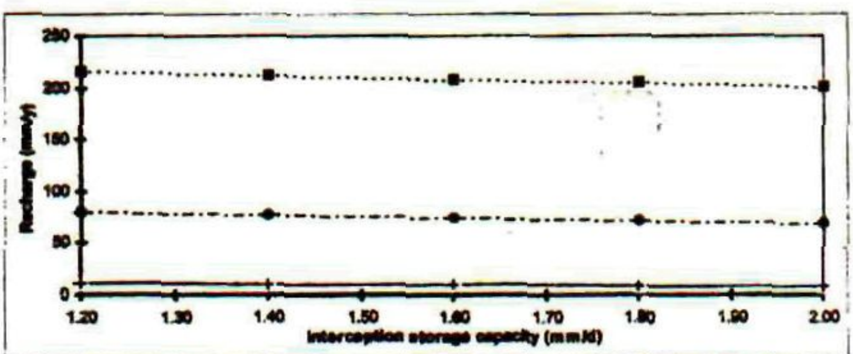


Fig. 3 Sensitivity of recharge to interception storage capacity at Angunakolapellessa for different model parameter combinations.

[In Fig. 3, AWC=101 mm which is the average AWC for site AKP. Lines with ■, • and + as markers has model parameter combination as *(0.5, 20, 0.15, 5 and 0.15), (0.65, 12.5, 0.32, 12.5 and 0.05) and (0.8, 5, 0.5, 15 and 0.01) for (RC, ROt,* ROc, PFt and PFc)]

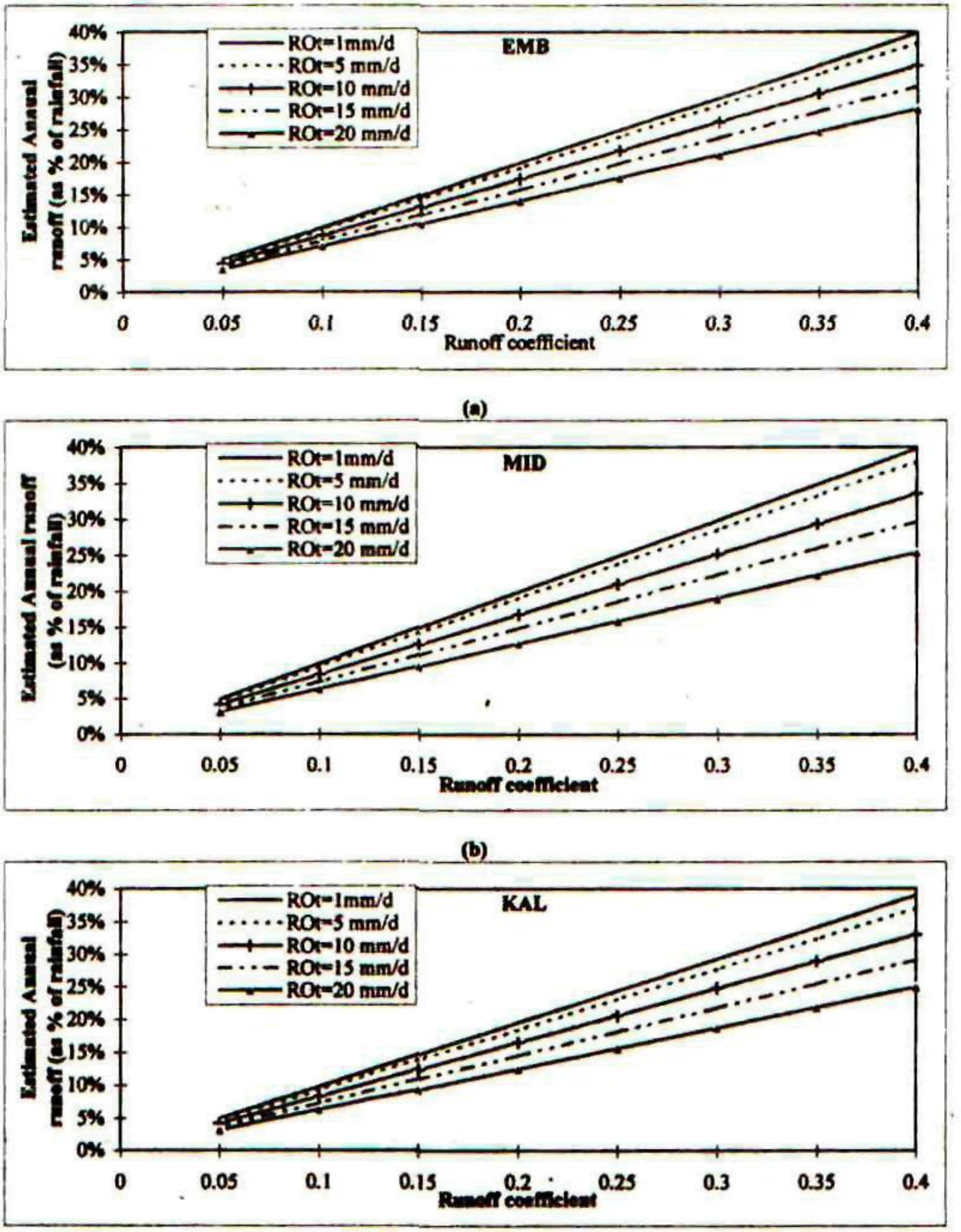
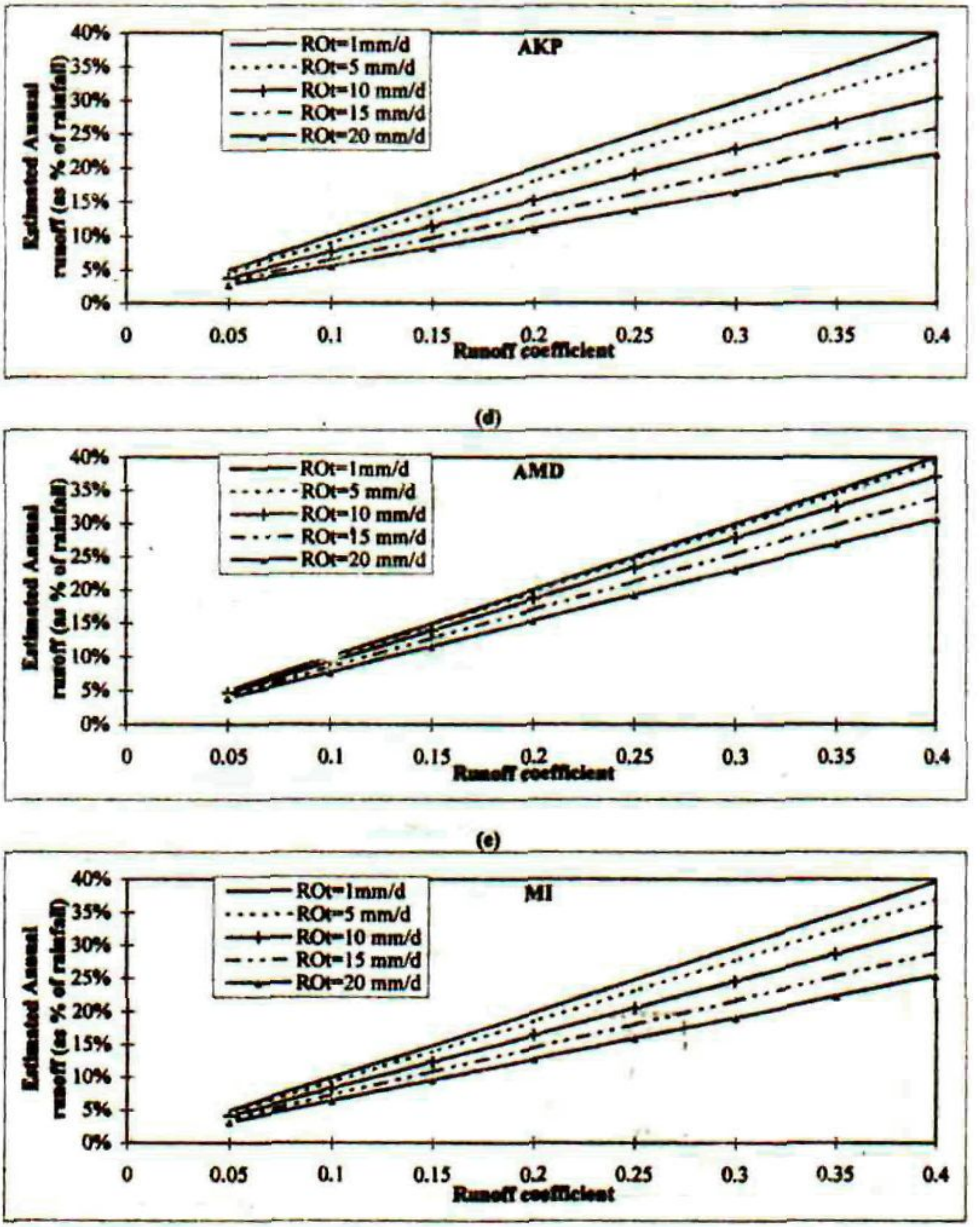


Fig. 2(a), (b) and (c) Different percentages of annual runoff for different runoff thresholds and coefficients for sites Embilipitiya (EMB), Middeniya (MID) and Kalpitiya (KAL). Runoff as calculated *from equation 10 in de Silva (xxxx)*



(f)

Fig. 2(d), (e) and (f) Different % of annual runoff for different runoff thresholds and coefficients for sites at Angunakolapellessa (AKP), Anamaduwa (AMD) and Maha Illuppallama (MI). Runoff as calculated from equation 10 in de Silva (xxxx)

Table 2 Likely model parameters for different sites in Sri Lanka

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12	Col. 13	Col. 14
Site	**% daily Rain with amount > 8 mm/d**[1]	**Soil**	**Vegetation**	**Topography**	**Likely Interception (% of rain)**[2]	**Likely Runoff (% of rain)**[3]	**Likely Pref. Flow (% of rain)**[4]	**Isc**[5] **(mm/d)**	**ROt**[6] **(mm/d)**	**ROc**[7]	**PFt**[8] **(mm/d)**	**PFc**[9]	**Critical Deficit**[10] **(%AWC)**
EMB	45%	Sandy Loam	Shrub jungle	Flat	10% - 15%	15% - 25%	1% - 10%	1.2 - 2.5	5 - 20	0.15 - 0.35	5 - 15	1% - 15%	50% - 80%
MID	45%	Sandy Loam	Mango, Teak and grass	Flat-undulating	10% - 15%	15% - 30%	1% - 10%	1.2 - 2.0	5 - 20	0.15 - 0.4	5 - 15	1% - 15%	50% - 80%
BWA	30%	Sandy clay Loam	Dense Shrub jungle	Flat-undulating	15%-20%	15%-30%	1% - 10%	1.2 - 2.0	5 - 20	0.15 - 0.5	5 - 15	1% - 15%	50% - 80%
AKP	30%	Sandy Clay Loam	Dense Shrub jungle	Flat-undulating	15%-20%	15%-30%	1% - 10%	1.2 - 2.0	5 - 20	0.15 - 0.5	5 - 15	1% - 15%	50% - 80%
MI	30%	Loamy Sand	jungle	Flat	15%-20%	15% - 25%	1% - 10%	1.5 - 2.5	5 - 20	0.15 - 0.4	5 - 15	1% - 15%	50% - 80%
AMD	70%	Sandy loam	Jungle	Flat-undulating	15%-20%	20%-30%	1% - 10%	3.0 - 4.0	5 - 20	0.2 - 0.3	5 - 15	1% - 15%	50% - 80%
KAL	30%	Sand	Sparse Jungle	Flat	10%-15%	0%	1% - 10%	0.8 - 1.8	5 - 20	0.0	5 - 15	1% - 15%	50% - 80%

[1] From Fig. 6 in de Silva (xxxx) (amount of rain is not an indication of intensity, but since most storms in the dry zone are short duration, these figures serve as a rough guide to decide on the % runoff likely in Col. 7 in this Table. Amount of rain of 8 mm/d is used as an arbitrary indicator).

[2] Considering information in this Table, Table 1 of de Silva (xxxx) and information on interception in de Silva (xxxx) & this paper

[3] Considering information in this Table and information on runoff in de Silva (xxxx) & this paper and that stream flows are generally 37.5% of annual rain in the dry zone

[4] Considering information in this Table and information on preferential flow in de Silva (xxxx) & this paper.

[5] Considering information in this Table and Fig. 1.

[6,7] Considering information in this Table and Fig. 2 (a), (b), (c), (d), (e) and (f).

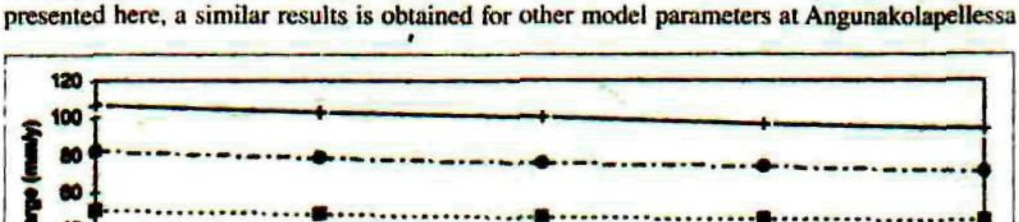
[8,9] Considering information in this Table and Fig. 2 (a), (b), (c), (d), (e) and (f), since the model used is basically same for both runoff and preferential flow.

[10] From Table 3 in de Silva (xxxx).

From Fig. 3 it is evident that for the 3 model parameter combinations considered (chosen to give a high, average and low value of recharge) the sensitivity of recharge is the same whatever the model parameter combination. Though not presented, a similar result was obtained for other model parameters at Angunakolapellessa and for all other parameters at all other sites as well. Therefore, it is concluded that to obtain the sensitivity of a particular model parameter, it is sufficient to consider only a single combination of other parameters. Hence, in this study only the parameter combination yielding an average recharge value for each site is considered to obtain the sensitivity of a particular parameter to recharge.

(b) The sensitivity of recharge to a particular model parameter varying for different values of available water capacity. This will not be important if the available water capacity for the site does not vary much, but if they do, this factor also needs consideration.

Fig. 4 shows the sensitivity of recharge to different available water capacity values of 75 mm, 101 mm and 175 mm (being the minimum, average and maximum value of available water capacity respectively) at Angunakolapellessa. Fig. 4 suggests that the sensitivity of recharge to a model parameter is similar for the different values of available water capacity. Though not presented here, a similar results is obtained for other model parameters at Angunakolapellessa



and for all other parameters at other sites as well.

Fig. 4 Sensitivity of recharge to different values of available water capacity at Angunakolapellessa

[In Fig. 4, model parameter combination is 0.65, 12.5, 0.32, 12.5 and 0.05 respectively for RC, ROt, ROc, PFt and PFc]

Therefore, to obtain the sensitivity of recharge to a model parameter at a site, only one parameter combination is considered using the average available water capacity value for the site, in the present study.

Fig. 5 (a), (b) and (c) show the sensitivity of recharge to model parameters for Angunakolapellessa, Embilipitiya and Maha Illuppallama respectively. Table 3 shows a summary of the sensitivity analysis for each site (i.e., the % change in recharge by changing a particular parameter by ± 10%).

From Figs. 5 (a), (b) and (c) and Table 3, it is evident that the runoff coefficient (ROc) is the most sensitive parameter affecting recharge at all the sites except at Kalpitiya (because runoff was considered to be negligible at Kalpitiya). The least sensitive parameter is the preferential flow threshold (PFt) at all the sites. The other parameters are sensitive in some sites but not in the other sites (as seen from Table 3).

Table 3
The sensitivity of recharge to different model parameters at different sites

Site	Interception storage capacity Isc(mm/d)	Root constant RC	Runoff threshold ROt (mm/d)	Runoff coefficient ROc	Pref.l flow threshold PFt (mm/d)	Pref flow coefficient PFc
Embilipitiya	2.3%	1.3%	1.3%	7.3%	0.2%	0.7%
Angunakolapellessa	2.9%	2.3%	1.9%	11.5%	1.6%	3.9%
Buweliara	3.1%	4.4%	2.0%	11.0%	1.7%	3.9%
Middeniya	3.8%	3.5%	4.4%	13.0%	0.9%	2.9%
Maha Illuppallama	5.2%	1.3%	3.1%	11.8%	0.7%	1.5%
Anamaduwa	2.4%	0.7%	0.5%	5.8%	0.9%	4.4%
Kalpitiya	2.0%	2.0%	0.0%	0.0%	0.7%	1.8%

[Note: The sensitivity values shown are the change of recharge (%) obtained by changing the particular model parameter by ± 10.0% (e.g., at Embilipitiya, a ± 10.0% change in Isc results in a change of recharge of 2.3%)].

Considering the model parameters that cause a change in recharge value by more than 2% (in Table 3) when the parameters themselves are changed by ± 10% as sensitive, model parameter ranges in Table 2 can be narrowed down to those shown in Table 4. [e.g., since the sensitivity of recharge to runoff threshold (in Table 3) is less than 2% at Angunakolapellessa, it is not necessary to consider the range from 5.0 mm/d - 20.0 mm/d for runoff threshold in Table 2, but is sufficient to consider only the mid point (12.5 mm/d) as in Table 4].

Table 4
Values for model parameters obtained from sensitivity analysis for different sites in Sri Lanka

Site	Isc (mm/d)	ROt (mm/d)	ROc	PFt (mm/d)	PFc	RC
Embilipitiya	1.2 - 2.5	12.5	0.15 - 0.35	10	7.5%	0.65
Angunakolapellessa	1.2 - 2.0	12.5	0.15 - 0.50	10	1% - 15%	0.5 - 0.8
Buweliara	1.2 - 2.0	5 - 20	0.15 - 0.50	10	1% - 15%	0.5 - 0.8
Middeniya	1.2 - 2.0	5 - 20	0.15 - 0.4	10	1% - 15%	0.5 - 0.8
Maha Illuppallama	1-5 - 2.5	5 - 20	0.15 - 0.2	10	7.5%	0.65
Anamaduwa	3.0 - 4.0	12.5	0.20 - 0.30	10	1% - 15%	0.65
Kalpitiya	0.8 - 1.8	5 - 20	0	10	7.5%	0.65

Therefore, it is concluded that from the sensitivity analysis, the model parameter ranges required to consider are as shown in Table 4 for all the sites in the dry zone for the present study.

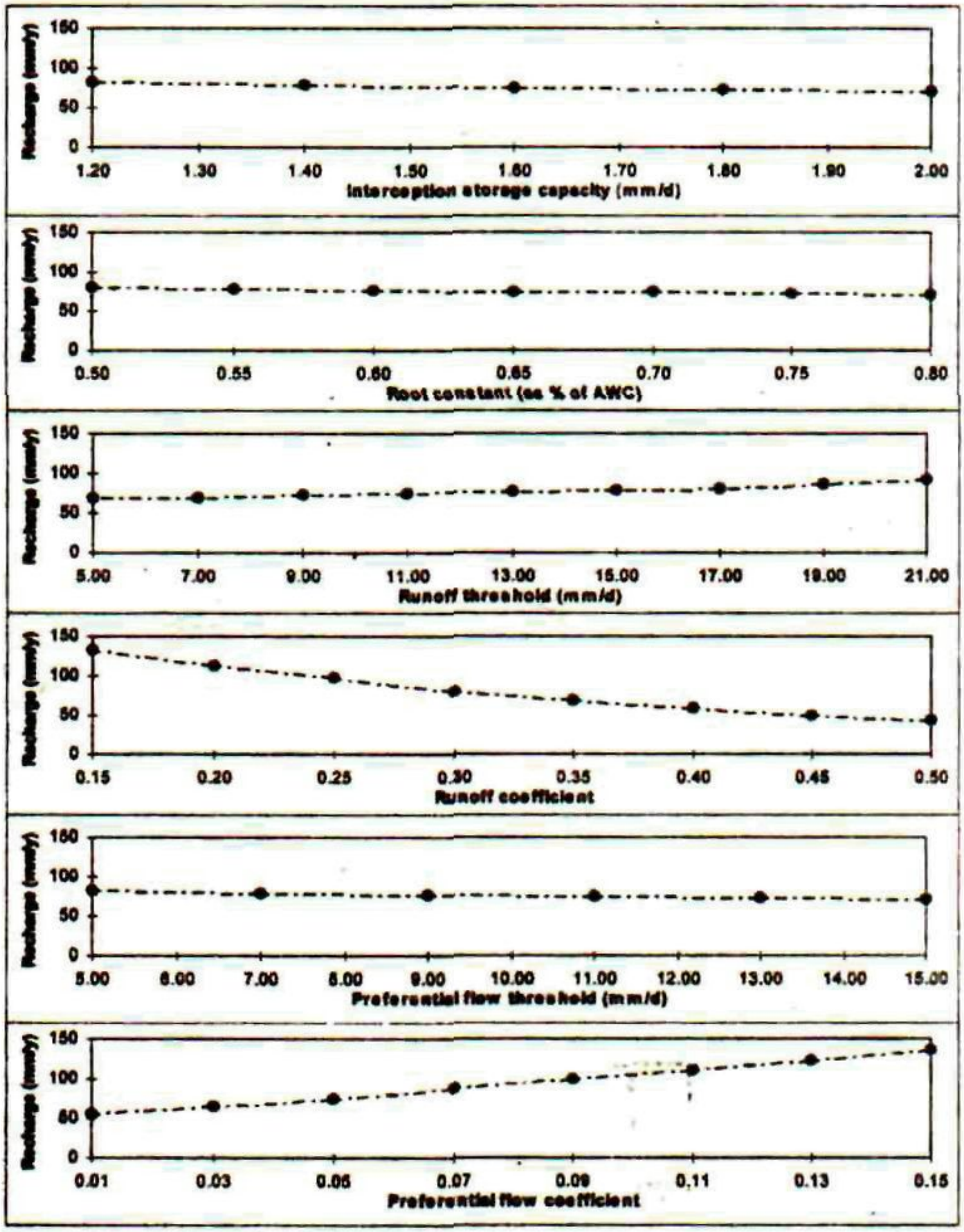


Fig. 5 (a) Sensitivity of potential recharge to model parameters at Angunakolapellessa

[In Fig. 5 (a), AWC=101 mm which is the average AWC for site AKP. The model parameter combination is 0.65, 1.6, 12.5, 0.32, 12.5 and 0.05 for RC, Isc, ROt, ROc, PFt and PFc respectively unless the particular parameter is varied over the ranges shown].

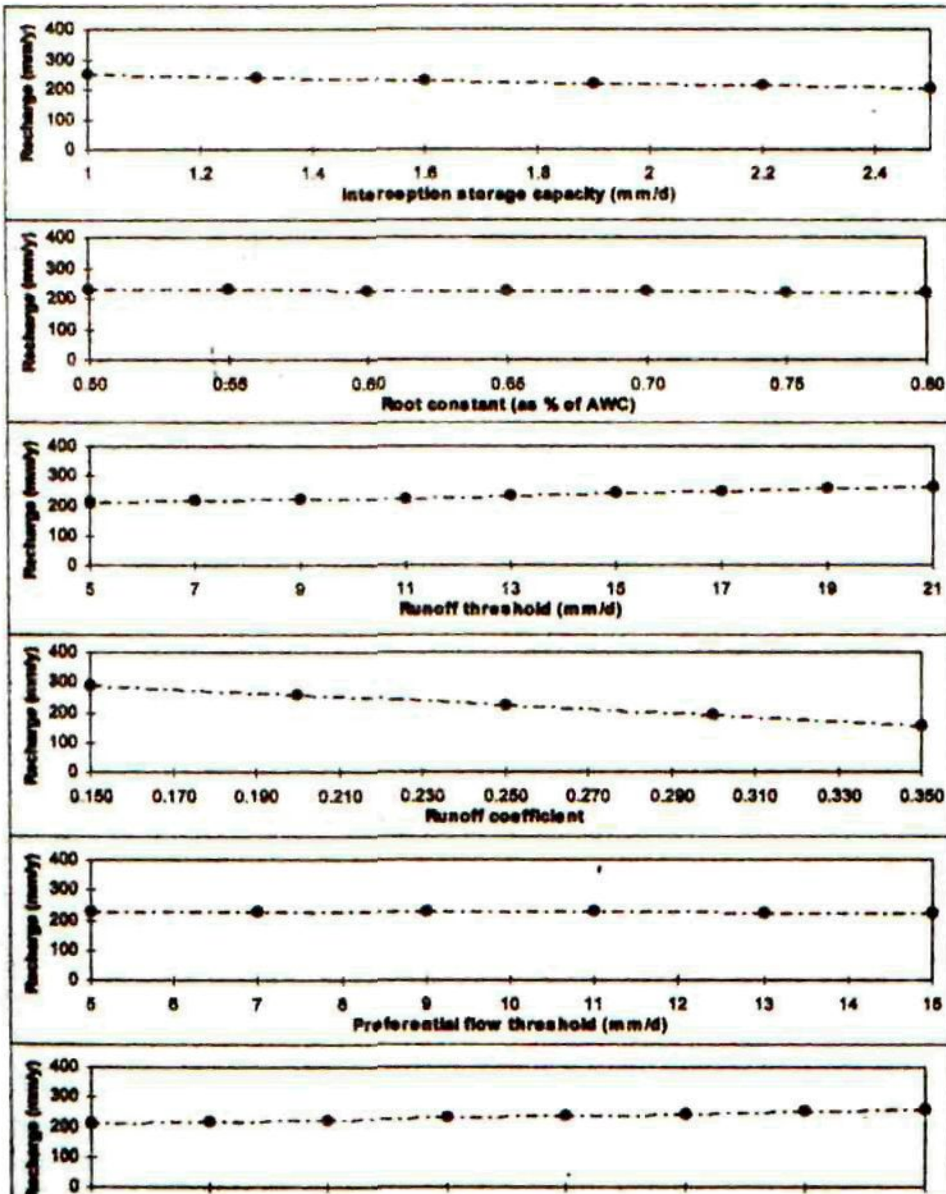


Fig. 5 (b) Sensitivity of potential recharge to model parameters at Embilipitiya

(In Fig. 5 (b), AWC=51 mm which is the average AWC for site EMB. The model parameter combination is 0.65, 1.8, 12.5, 0.25, 10 and 0.05 for RC, Isc, ROt, ROc, PFt and PFc respectively unless the particular parameter is varied over the ranges shown)

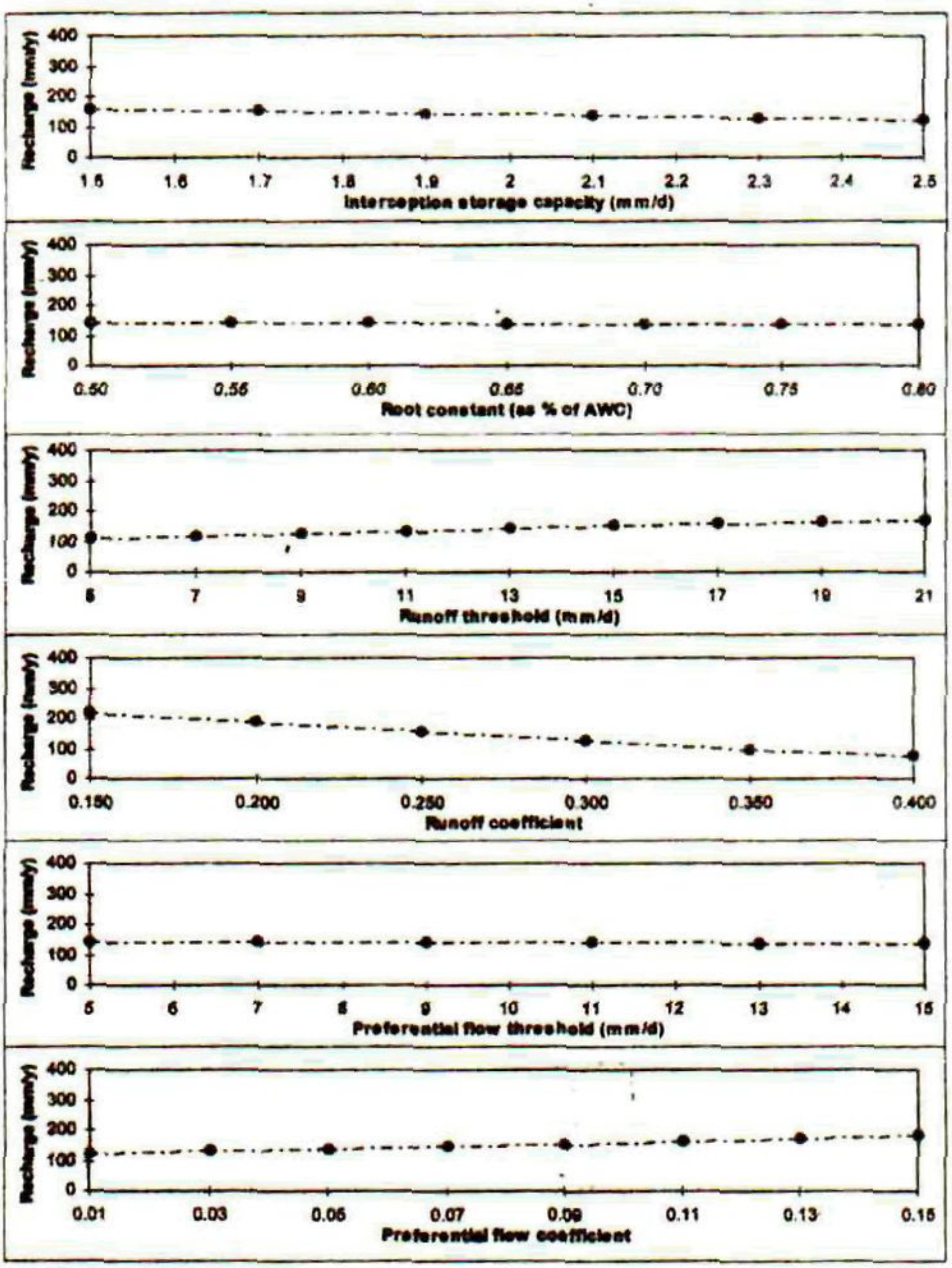


Fig. 5 (c) Sensitivity of potential recharge to model parameters at Maha Illuppallama

[In Fig. 5 (c), AWC=173 mm which is the average AWC for site ML The model parameter combination is 0.65, 2, 12.5, 0.28, 12.5 and 0.05 for RC, Isc, ROt, ROc, PFt and PFc respectively unless the particular parameter is varied over the ranges shown]

Estimates of recharge with the limited data available

With the model parameter combinations in Table 4, the range of estimate of recharge at each site in the dry zone of Sri Lanka is shown in Table 5.

Table 5
Range of recharge values possible from the soil water budget with combinations of model parameters in Table 4 for sites in Sri Lanka

Site	*Minimum Recharge (mm/y)*	*Maximum Recharge (mm/y)*
Embilipitiya	80	391
Angunakolapellessa	7	244
Anamaduwa	46	237
Buweliara	7	235
Maha Illuppallama	16	340
Middeniya	12	348
Kalpitiya[1]	94	195

(Note: Soil water budgets with an accounting period of one day were carried out for durations of 6, 5, 5, 5, 10, 7 and 6 years for Embilipitiya, Angunakolapellessa, Anamaduwa, Buweliara, Kalpitiya, Maha Illuppallama and Middeniya respectively in Table 5)

1 Field capacity and permanent wilting point values are assumed as 14% and 4% by volume respectively for Kalpitiya as no experimental data are available (Booker tropical soil manual, 1984). Also the depth of root zone is considered as 1.5 m.

From Table 5, it is evident that the range of recharge values for a site, obtainable with the data available with the soil water budgeting method is rather wide and hence will be of little practical use. This result however, demonstrates the importance of estimating the model parameters accurately as even the narrow ranges of model parameters used in the soil water budget model (Table 5), result in a rather wide ranges of estimates for recharge. Therefore, it is concluded that for the use of a soil water budgeting model to estimate recharge in the dry zone of Sri Lanka, it is necessary to be able to use accurate model parameters. These results also suggest that more research work on runoff, preferential flow and interception is needed in order to obtain meaningful results from a soil water budget.

Concluding discussion

The two papers describe an attempt to develop a simple, yet sufficiently detailed soil water budgeting model to estimate recharge in the dry zone of Sri Lanka and also the application of the model to 62 sampling points at 7 locations in the dry zone to estimate recharge.

From this study, the conclusions that can be arrived at are as follows.

1. To obtain the sensitivity of a particular model parameter in the SWB model, it is sufficient to consider only a single combination of other parameters.
2. Even if the AWC at a location varies, it is sufficient to consider the sensitivity of one model parameter combination using the average available water capacity value for the location.
3. Interception of rainfall by vegetation, surface runoff of rainwater to streams, and preferential flow appear to be the important components of the hydrological balance of the dry

zone (apart from the usual components of rainfall and actual evapotranspiration). However, with the simple model formulated in this study and for the ranges of model parameters considered most suitable for each site, runoff coefficient above a threshold appear to be the model parameter to which estimated recharge is most sensitive. Therefore, accurate estimation of runoff is necessary if the SWB model is to yield realistic estimates of recharge. Also interception is more sensitive than preferential flow.

4. With uncertainties in the components of runoff, interception and preferential flow, the estimates of recharge obtainable with the present model are far from useful as a wide range of recharge (e.g. for Embilipitiya the recharge range is from 80 mm/y to 391 mm/y) is obtained than a more narrow, useful range. By using a more sophisticated model, these ranges will be even wider (as the uncertainties will be even more). Also it will not be possible to use a model which is simpler than the present model as the processes of interception, runoff and preferential flow were shown to be important.
5. Therefore, if this method is to be used successfully, more research work on the process of interception, runoff and preferential flow are needed. Also maintaining records of groundwater levels, river and stream flow hydrographs at strategic locations is necessary, which will enable some of these processes to be estimated realistically enabling useful estimates of recharge.

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Appendix 1

The meanings of symbols and abbreviations used in this paper are as follows. Where relevant the usual units of measurement of parameters are also given.

Δs	-	Change in soil moisture storage (mm/d or mm/y)
AKP	-	Angunakolapellessa
AMD	-	Anamaduwa
AWC	-	Available water capacity in the root zone (mm)

BWA - Buweliara
EMB - Embilipitiya
ETa - Actual evapotranspiration (mm/d or mm/y)
ETp - Potential evapotranspiration (mm/d or mm/y)
F - Ratio of ETa/ETp when Soil moisture deficit > Root Constant (see below for definition of Root constant)
I - Interception of rain by vegetation (mm/d)
Isc - Interception storage capacity (mm/d)
KAL - Kalpitiya
MF - Flow through the soil matrix (mm/d)
MI - Maha Illuppallama
MID - Middeniya
PF - Flow through preferred pathways (mm/d)
PFc - Preferential flow coefficient
PFt - Preferential flow threshold (the amount of rain in a day above which preferential flow is assumed to occur) (mm/d)
R - Rain (mm/d or mm/y)
RC - Root constant (i.e., SMD at which ETa fall below ETp)
Re - Groundwater recharge (mm/y)
RO - Runoff (i.e., overland flow of rain falling on the ground) (mm/d)
ROc - Runoff coefficient
ROt - Runoff threshold (the amount of rain in a day above which runoff is assumed to occur) (mm/d)
SMD - Soil moisture deficit (mm)
SWB model - Soil water budgeting model