# A comparison of actual and potential recharge of water table in the dry zone of Sri Lanka

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## ABSTRACT

**The actual rate of replenishment of water table (actual recharge) was compared with the rate of deep percolation leaving the root zone (potential recharge) in six study locations in the dry zone of Sri Lanka. There was a significant difference between the two rates suggesting significant amounts of interflow in the upper soil layers as the most likely reason for this difference. This finding is in agreement with the available evidence.**

***Key words:*** Actual recharge, Potential recharge, Estimating recharge, Dry zone of Sri Lanka

## INTRODUCTION

As the population increases, the demand for water increases and there is a felt need to develop the groundwater resource, especially in the dry zone of Sri Lanka. In developing this groundwater resource, the most important, yet the most difficult parameter to estimate is the rate of recharge or the rate at which the water table in the aquifers is replenished.

There are a number of methods of estimating recharge (Lerner *et al.* 1990; de Silva, 1996). Details of these methods have been described by Lerner *et al.* (1990). Of these, the soil water budget method and tracer techniques have been used widely in different parts of the world.

More often than not, the rate of water reaching the water table (actual recharge) is less than the rate at which water leaving the root zone (potential recharge). The main reasons for this difference are significant amounts of horizontal interflow (i.e., horizontal flow through the upper layers of the soil profile), upward movement of water during severe dry weather periods and in some cases the extraction of moisture by the deep penetrating roots of some species of trees.

The objective of this study is to determine whether actual recharge is significantly different to potential recharge in the dry zone of Sri Lanka.

## MATERIALS AND METHODS

Suitable locations were chosen, depending on the availability of facilities to conduct the study, ease of accessibility and most of all the suitability of using the recharge estimation methods to be adopted. The methods of estimation of actual recharge and potential recharge were chosen. Climatic, soil and vegetation data required to estimate recharge with the chosen methods were either collected or experimentally determined (de Silva, 1996). Then estimates of actual and potential recharge were obtained for each study location. These actual and potential recharge estimates were then compared and finally the reasons for the difference in two types of estimates at each location were identified.

### Study locations

Study locations are shown in Fig. 1 and Fig. 2 shows the mean monthly rainfall and mean monthly evapotranspiration for study locations. The locations were selected by considering the availability of data and availability of facilities to experimentally obtain soil and vegetation parameters. Table 1 and Table 2 summarise the climatic, vegetation and soil data for each study location [details of experimental determination of soil parameters are given in de Silva (1996)].

### Estimating Recharge to the Dry Zone Aquifers in Sri Lanka

De Silva (1998a) compared the most commonly used methods of estimating recharge for the conditions in the dry zone of Sri Lanka.(Table 3). From Table 3 it is evident that for dry zone conditions (including the special equipment requirement, data requirement, time required and cost), the soil water budgeting method was the most appropriate method of estimating the potential recharge and the chloride profiling method was the most appropriate method for estimating the actual recharge.

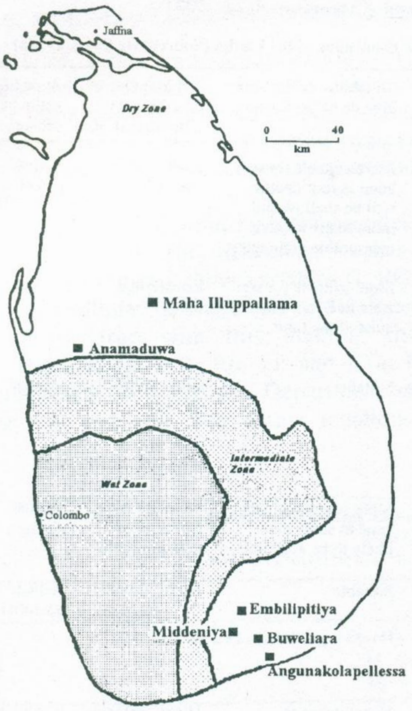


**Fig. 1. Study locations in the dry zone of Sri Lanka (Study locations are shown as dark squares)**

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More often than not, the rate of water reaching the water table (actual recharge) is less than the rate at which water leaving the root zone (potential recharge). The main reasons for this difference are

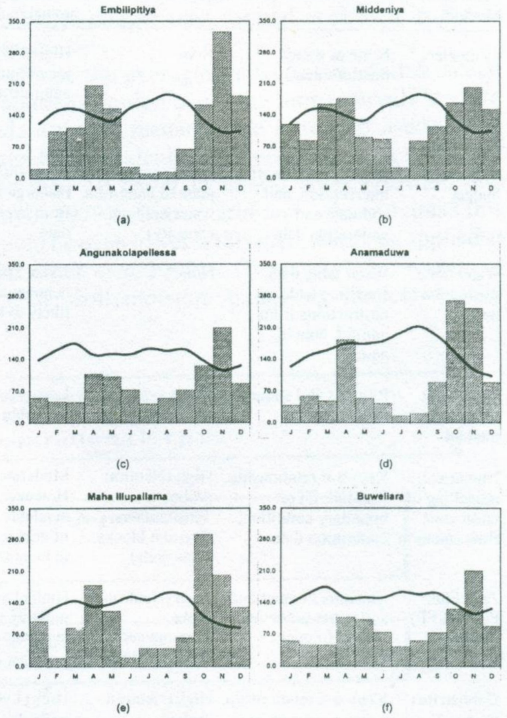


**Fig. 2. Mean monthly rainfall (shown as hatched bars) and mean monthly pan evaporation (shown as the dark continuous line) for all study locations (the number on the Y axis are in mm)**

**Table 2. Soil properties, root zone depth and depth to water table at each study location**

| Study location | Field Capacity (%) | Permanant Wilting Point (%) | Depth to water table (m) | Root zone depth (m) |
|---|---|---|---|---|
| Embilipitiya | 21.4 | 15.7 | >2.9 | 0.69 |
| Middeniya | 21.48 | 13.27 | >18 | 1.09 |
| Buweliara | 26.00 | 15.56 | >4.0 | 0.84 |
| Angunakolapellessa | 20.2 | 12.0 | >4.1 | 0.95 |
| Maha Illuppallama | 20.9 | 11.0 | >3.2 | 1.17 |
| Anamaduwa | 18.12 | 9.66 | >3.8 | 1.52 |

**Table 1. Soil, climatic and vegetation details of study locations in Sri Lanka**

| Study Location | Mean Annual Rain[1] (mm/y) | Mean Annual pan Eveporation[1] (mm/y) | Vegetation | Major Plant Type | Top Soil |
|---|---|---|---|---|---|
| Embilipitiya | 1397 | 1729[2] | Shrub jungle | *Maana* (Grass about 30 cm tall) | Loamy Sand |
| Middeniya | 1484 | 1729[2] | Mango and Teak Plantation | *Eluk* (Grass about 30 cm tall) | Sandy loam |
| Buweliara[3] | 1041 | 1868 | Shrub jungle | - | Sandy Clay Loam |
| Angunakolapellessa | 1041 | 1868 | Shrub jungle | *Eraminiya* (Bush about 1.5m tall) | Sandy Clay Loam |
| Maha Illuppallama | 1305 | 1579 | Jungle | - | Loamy Sand |
| Anamaduwa | 1117 | 1958[4] | Jungle | - | Sandy Loam |

[1] 6 year mean value except for Angunakolapellessa and Buweliara where the mean value are 17 year ones.
[2] Pan evaporation values are from the climate station at Sevenagala (i.e., the nearest agro-climatic station).
[3] Since no rainfall or pan evaporation data are available for Buweliara, data from the nearest climatic station (Angunakolapellessa is used for Buweliara)

**Table 3.Comparison of recharge estimation methods in relation to the dry zone conditions of Sri Lanka (Source: De Silva, 1998a)**

| Recharge Estimation Method | Data required | Special equipment required | Approximate time required to estimate annual recharges | Suitability of dry zone climate of Sri Lanka | Approximate cost for 20 point estimates(SL Rs ) | Type of estimate of recharge | Remarks |
|---|---|---|---|---|---|---|---|
| Lysimeters | None as direct measurement | None | High (>2 years) as time required for naturalization | More suitable for wet zone as root depths will be shallow and more likely to have measurable drainage | High (100,000 - 500,000) | Actual/ potential | |
| Soil water budget | Rain, ETp, Runoff, interception, and soil data and calibration data | Low (pressure plate to determine water holding capacity) | Low (about 4 weeks) as recharge is determined from available climatic data | More suitable for wet zone as ETa = ETp most of the time | Low (2,000 - 6,000) | Potential | |
| Water table fluctuation method | Water table data, specific yield, abstractions from aquifer, area of aquifer | None | 1 year (if water table data is not available which is likely to be the case) | Suitable | Low (5,000-10,000) | Actual | |
| Catchment water balance method | Rain, Et and stream flow data | None | Low (4 weeks) if data available, 1 yr otherwise | More suitable in wet zone as some data likely to be available | No point est Low cost if data available | Actual . | |
| Numerical modelling of unsat zone flow equation | K(ϕ)-ϕ-θ relationship, Rainfall, ETp, boundary condition, calibration data | High (Neutron probe, Tensiometers, Gypsum blocks, Flow cells) | Moderate (6 months). However, low if data available, but the type of data required is likely to be not available | Suitable | High( >80,000) | Actual/ potential | Availability of resources limited |
| Zero Flux Plane (ZFP) method | Moisture content and soil water potential data at frequent intervals | High (Neutron probe, Tensiometers, Gypsum blocks) | High (1 year) as data unlikely to be available | Not suitable as periods of no ZFP likely | High( >80,000) | Potential | Availability of resources limited |
| Darcian flux [K(ϕ)-ϕ] method | K(ϕ)-ϕ-θ relationship, soil water potential data | High (Neutron probe, Tensiometers, Gypsum blocks, Flow cells) | High (1 year) as data unlikely to be available | Suitable | High( >80,000) | Actual/ potential | Availability of resources limited |
| Tritium profiling | Tritium input, diffusion coefficients | High (Liquid scintillation, coincidence counting machine) | High (1 year) | More suitable in wet zone as less evaporation | moderate (>50,000) | Actual | Availability of resources limited to analyze for Tritium |
| Chloride profiling | Chloride input, diffusion coefficient, rain, soil chloride data | Low (spectrophotometer) | High (1 year) but 3 months if work is done between Oct-Jan (rainy period). However, if annual variability of chloride level in rainfall are high, a number of years of chloride data in rain are required | Suitable | Low (10,000-30,000) | Actual | |

Note: Costs involved in each method are very approximate and are based on the information from various sources and also from the experience gained during field work in Sri Lanka.

storage. If the balance is carried out annually (especially from the end of rainy season to the same time the following year), the change in soil moisture storage is negligible.

Therefore equation 1 reduces to;

$$Re = P - I - RO - ETa \;\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In equation 2, the importance of preferential flow is not immediately clear as there is no such term in it. However, the same equation can be written as in equation 3, where the first term within brackets is the matrix flow (MF) and the second term within brackets is the preferential flow (PF).

$$Re = (P - I - RO - PF - ETa) + (PF) \ldots (3)$$

Now, the estimation of actual evapotranspiration is affected by matrix flow, which in turn is affected by the amount of preferential flow. Therefore, estimates of recharge (which are affected by estimates of actual evapotranspiration), are affected as a result of preferential flow (i.e., for estimates of recharge to be affected by preferential flow, it is not necessary for preferential flow paths to be effective for deeper depths, but depths just around root zone are sufficient).

The basis for most soil water budgeting models is shown in equation 3. The differences in these models result from the way other variables (I, RO, PF and ETa) are estimated. Therefore, to obtain an estimate for recharge with this method, the parameters required are P, I, Ro, PF and ETa. P (rainfall) measured daily by the Department of Meteorology is available for many locations. Simple, yet sufficiently accurate methods were used to estimate I, RO, PF and ETa. Details of these methods are found in de Silva (1996). The simple soil water budget thus formed is shown in Fig. 3 below.

Since the averaging effect of rainfall & actual evapotranspiration over long time intervals tends to underestimate recharge, the time step used in soil water budget calculations must be one day (certainly less than 10 days) in humid areas (Howard and Lloyd, 1979) while in arid and semiarid areas this should be even lower if this method can be applied at all (Lerner *et al.* 1990).

The soil moisture budgeting models usually

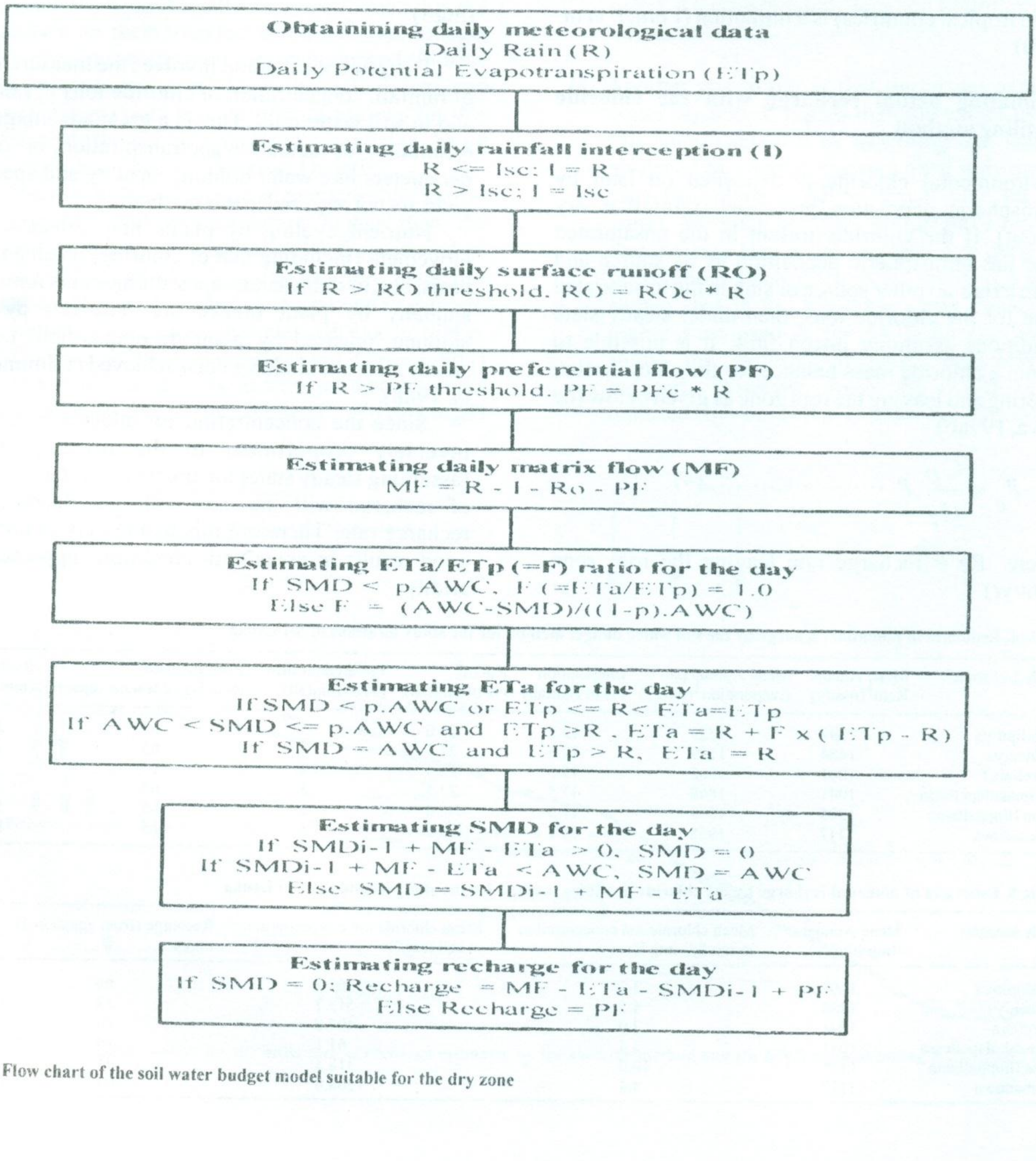


**Fig. 3. Flow chart of the soil water budget model suitable for the dry zone**

need to be calibrated with results from a lysimeter, from soils moisture measurements or any other estimate of recharge. Rushton and Ward (1979) and Senerath (1990) reported instances of using soil water budgeting methods. The advantages of these methods are that they use readily available data, rapid to apply and account for all water entering the system.

Major disadvantages of a soil water budget include the fact that recharge is estimated as the residual of large numbers of parameters which could produce large errors if actual evapotranspiration is numerically close to rainfall. With errors in other fluxes accumulating the error in the residual can be high. Also the difficulties of measuring the other fluxes especially where the number of fluxes is high (as in tropical countries) is a limitation (Lerner *et al.* 1990).

### Estimating actual recharge with the chloride profiling method

Environmental chloride is deposited on land by atmospheric deposition processes (rainfall + dry fallout). If the chloride present in the unsaturated zone has atmospheric deposition as its source and there exists no other source or sink in the unsaturated zone for the chloride ions, then under steady state conditions assuming piston flow, it is possible to obtain a chloride mass balance for the chloride flux entering and leaving the root zone as given below (de Silva, 1998b).

$$R_e = \frac{C_p}{C_z} . P \qquad \text{.....................(4)}$$

where Re = recharge rate leaving the root zone (mm/yr)

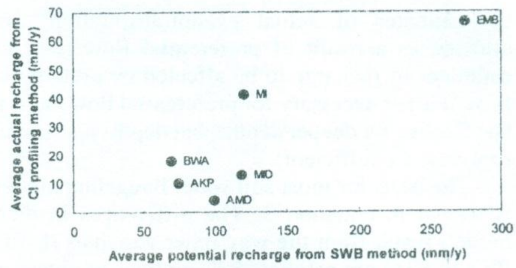


Fig. 4. Comparison of recharge estimates by SWB method and chloride method at the 6 locations in the dry zone.

$C_z$ = mean chloride ion concentration in soil water (mg/l)

P = precipitation (mm/yr)

$C_p$ = chloride ion concentration in rainfall (mg/l)

Therefore the method involves the measurement of rainfall, concentration of chloride ions in rainfall and in soil water only. This is a great advantage, as estimation of actual evapotranspiration or other parameters like water holding capacity and specific yield are not required in this method.

Nutrient cycling by plants may affect solute movement (including that of chloride) on an annual basis, but, in stable landscapes, the amounts removed annually by plant uptake are balanced by the amounts released by plant decomposition, i.e., a steady state should have been achieved (Edmunds *et al.* 1988).

Since the concentration of chloride in soil is inversely proportional to the recharge rates (assuming steady state) the precision of the estimate of recharge will increase with the decrease in recharge rate. Therefore this method could provide good results in areas with conditions approaching aridity.

**Table 4. Estimates of potential recharge by the soil water budget method for the study locations in Sri Lanka**

| Study Location | Mean Annual Rain[1] (mm/y) | Mean Annual pan Eveporation[1] (mm/y) | Interception (% of rainfall) | Runoff (% of rainfall) | Preferential flow (% of rainfall) | Root constant (% of available water capacity) | Recharge (mm/y) |
|---|---|---|---|---|---|---|---|
| Embilipitiya | 1397 | 1729 | 12.5 | 20.0 | 5 | 65 | 275 |
| Middeniya | 1484 | 1729 | 12.5 | 22.5 | 5 | 65 | 119 |
| Buweliara[3] | 1041 | 1868 | 17.5 | 22.5 | 5 | 65 | 70 |
| Angunakolapellessa | 1041 | 1868 | 17.5 | 22.5 | 5 | 65 | 75 |
| Maha Illuppallama | 1305 | 1579 | 17.5 | 20..0 | 5 | 65 | 120 |
| Anamaduwa | 1117 | 1958 | 17.5 | 25.0 | 5 | 65 | 100 |

**Table 5. Estimates of potential recharge by the chloride profilling method for the study location on Sri Lanka**

| Study location | Mean Annual Rain (mm/y) | Mean chloride ion concentration in rainfall (mg/l) | Mean chloride ion concentration in soil (mg/l) | Recharge (from equation 2) mm/y |
|---|---|---|---|---|
| Embilipitiya | 1397 | 3.2 | 67.7 | 66 |
| Middeniya | 1484 | 4.5 | 513.7 | 13 |
| Buweliara | 1041 | 7.0 | 404.8 | 18 |
| Angunakolapellessa | 1041 | 4.4 | 61.1 | 10 |
| Maha Illuppallama | 1305 | 10.0 | 318.3 | 41 |
| Anamaduwa | 1117 | 5.4 | 1508.0 | 04 |

The method requires a knowledge of historical input of the chloride for a number of years. Also the method is unlikely to work in areas with a shallow water table and in areas where an artificial application of chloride has taken place.

## RESULTS AND DISCUSSION

Tables 4 and 5 summerise the calculations for estimating potential recharge with the soil water budget method and for estimating actual recharge by the chloride profiling method respectively.

Fig. 3 shows the comparison of the average recharge estimate for the 6 locations by the chloride profiling method and the SWB method.

As seen from Fig. 3, the agreement between the two methods is poor in all locations (though it is not necessary for them to agree as the soil water budget method estimates the potential recharge and chloride method estimates are nearer the actual recharge value). There could be a number of reasons for this apparent difference in actual and potential recharge which are described and discussed below.

(a) The possibility of long term average chloride ion concentration in rain being higher than the values obtained experimentally for a period of about 8 months for the study locations in the dry zone. (If the chloride concentrations in rain are higher, the recharge estimates will also be higher from equation 4. Edmunds and Gaye (1994) reported from a study in Senegal that the mean chloride concentration of rain in 1990 (9.3 mg/l) was about 6 times that in 1989 (1.6 mg/l). Therefore, it is possible that the chloride method has under estimated the actual recharge in the dry zone due to the non availability of long term chloride data in rainfall.

(b) The possibility of having a high amount of interflow (or horizontal flow of water in the shallow layers of the soil) suggesting that estimates by both methods are correct. (It must be noted that the soil water budget estimates the potential recharge and the chloride method estimates deep percolation into the deeper unsaturated zone). Ward and Robinson (1990) cites a similar case where 80% of the infiltrating water is carried to the streams as interflow in a soil with uniform texture. This theory is shown in Fig. 4 taking the study location Embilipitiya as an example.

(c) Another possibility is that the actual available water capacity is higher than the values used in this study (obtained by assuming that water is absorbed by roots in the root zone only and the zero flux plane is never deeper than the root zone). Wellings and Bell (1980) have reported that the zero flux plane can be 5-6 m deep with grass (about 80 cm deep roots) in UK. It is easily shown that if the available water capacity is higher than used in the SWB for the present study, the resulting recharge estimates are reduced. However, from the SWB results reported by de Silva (1996) for Ngwazi in

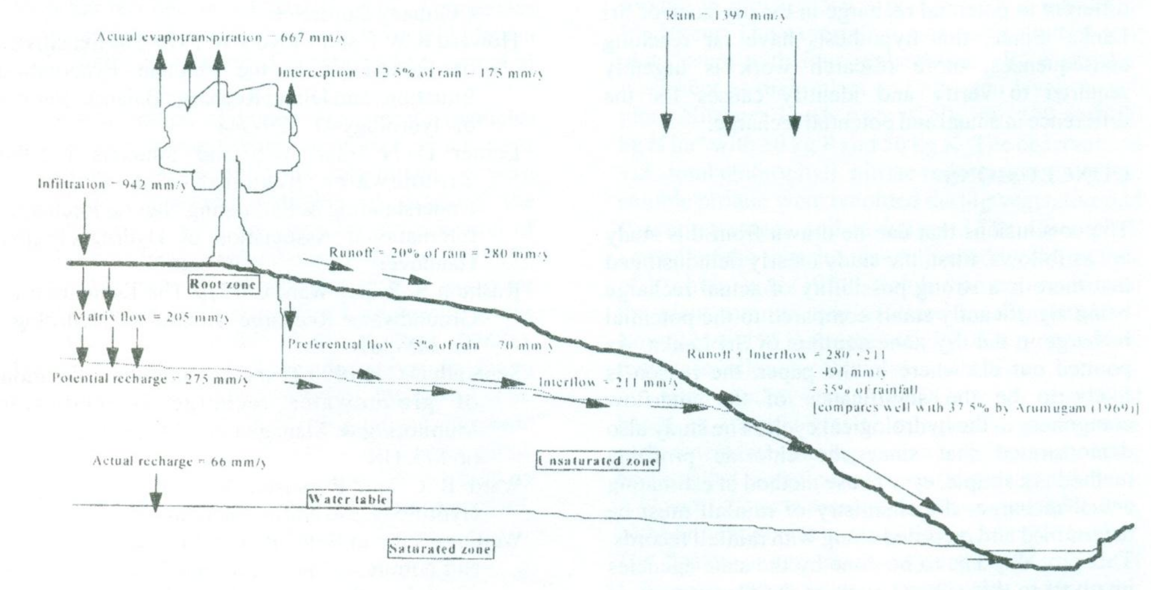


**Fig. 5. A possible explanation for the difference of recharge estimates by the chloride method and the SWB method taking Embilipitiya as an example**

Tanzania and Nguru in Nigeria, the SWB yielded reasonable results which agreed with estimates of recharge by chloride method and groundwater flow modelling. Also in Silsoe, UK the soil moisture deficit predicted by the SWB method agreed well with those obtained experimentally by the neutron probe. Therefore, it is unlikely to be the reason for the disagreement of recharge estimates by the chloride method and the SWB method. However, more research work on the effect of the zero flux plane being significantly deeper than the root zone on estimating recharge with the SWB is certainly necessary, which will enable a better understanding of the hydro-geology of the dry zone. The absorption of water by deeper tree roots is also a possible reason for the estimates by the two methods to differ, but since the effect is similar to a deeper zero flux plane (as discussed above), it will not be separately treated here.

The fact that the streams and rivers flow immediately after rains also support the theory of significant runoff or runoff and interflow. The non availability of significant amounts of underground water (as evident by the dropping of water tables with even small abstractions) and insignificant baseflow (i.e., the contribution of groundwater from the aquifers to the streams and rivers) also support the theory of less actual recharge.

Therefore, considering the evidence, it is very likely that the actual recharge is significantly different to potential recharge in the dry zone of Sri Lanka. Since, this hypothesis have far reaching consequences, more research work is urgently required to verify and identify causes for the difference in actual and potential recharge.

## CONCLUSIONS

The conclusions that can be drawn from this study are as follows. First, the study clearly demonstrated that there is a strong possibility of actual recharge being significantly small compared to the potential recharge in the dry zone aquifers of Sri Lanka. As pointed out elsewhere in the paper, the reason is likely to be the significance of the interflow component in the hydrological cycle. The study also demonstrated that since the chloride profiling method is a simple, easy to use method of estimating actual recharge, the chemistry of rainfall must be determined and recorded along with rainfall records. This probably has to be done by the state agencies involved in this subject such as the Department of Meterology.

Finally it is concluded that since the economic implications of the different actual and potential recharge rates are significant, more research work (spanning possibly over a number of years) is necessary to confirm the preliminary findings of this study.

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