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# ROLE OF SHOLA FORESTS IN MAINTAINING WATER COURSES IN THE HIGH RANGES OF THE WESTERN GHATS OF KERALA

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(Final report of the research project KFRI 312/98)

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# ABSTRACT

Shola-grassland ecosystems restricted to the high ranges of the Western Ghats are peculiar in vegetation, soil microclimate etc., due to its location. They conserve soil and water and thus feed the streams even during the lean periods. An investigation was carried out in one of the shoal regions in South Wayabad, namely Chembra to estimate runoff from two adjacent shoal-grassland catchments which differed in morphometry and extent. The first catchment ($C_1$) was larger (1.52km$^2$) and steeper (65% slope) with longer than broader shape compared to the second catchment ($C_2$) with 0.79 km$^2$ area and 50% slop and thus was more conducive to runoff and soil erosion. But it was blessed with greater coverage of 0.61 km$^2$ (40.13%) of shoal forest. The second catchment had a shoal cover of 0.27 km$^2$ (34.17%) only. Streamflow (runoff) was quantified by velocity-area method along with stage level recorder to obtain stage of flow.

The site received 1673.9 mm rainfall in the water year June 1999-May 2000 of which 85 per cent fell during the South West monsoon. Runoff from $C_1$ amounted to 1056.6 mm (63.1%) while that from $C_2$ amounted to 1133.17 mm (67.7%). Runoff coefficient was higher in $C_2$ in all the months showing that it could not retain as much water as $C_1$ in any of the seasons. The climate, soil and type of vegetation in both these catchments were similar, the morphometry and extent of area occupied by shoal vegetation alone differed. Drainage density did not vary much but form factor, circularity ratio and elongation ratio were higher in the second catchment, which show that $C_1$ is comparatively more prone to runoff and erosion. But the study revealed the contrary – runoff percentage was lesser in this catchment while sediment load did not differ between catchments. The microclimate and the soil properties within the shoal have been found to be very conducive to retention of water and is reflected in the soil moisture status in different seasons. Thus, it is concluded within the limits of a single water year observation that shoal forests do play a positive role in maintaining the water courses in the high ranges of Kerala Western Ghats. Long-term observations to substantiate the present findings are warranted.

# 1. INTRODUCTION

The term ‘shola’ derived from Tamil 'Cholai' meaning stream as well as shade (Swarupanandan *et al.,* 1998) later on became synonymous with both mountain streams and the forests associated with them. No better word could have been thought of because these forests and streams are inseparable and each owes its existence to the presence of the other. They occur together in the mountain folds and depressions where there is abundant moisture holding soil and water most efficiently even on very steep slopes. The location of these Tropical Montane Forests (Meher Homji, 1965) in the high ranges of the Western Ghats above 1500 m altitude also adds to their water conserving efficiency due to low evapo-transpiration demand.

Shola species are mostly of the tropical stock with temperate species predominating the forest fringes (Balasubramanian and Kishorekumar, 1999). Many of these are endemic to the Western Ghats and some come under the category, 'rare' and 'threatened'. Though, large tracts of shola -grasslands have already been converted to plantations of tea, wattle, eucalypt, pine, silver oak etc. in the past, the growing awareness of the importance of this precious resource has led to management and conservation of existing patches.

It is a common belief that forests conserve water and maintain the streams perennial. Some consider that forests regulate and increase stream flow and removal results in reduction of streamflow. Others argue that forests consume huge amounts of water for their growth and thus reduce streamflow, though they redistribute the flow during water deficient periods. Both theories accept the water-regulating role of forests but are opposed on the question of the influence of forests on streamflow.

The present study, 'Role of shola forests in maintaining watercourses in the high ranges of the Western Ghats of Kerala' was taken up to reveal the relevance of shola forest in maintaining the streams perennially. The specific objectives of the project were to study the rainfall, runoff and sediment yield in selected micro-watersheds and relate these to the land and vegetation differences. But no locality with comparable watersheds of typical shola vs. degraded shola could be selected because the degree of disturbance in adjacent watersheds was never different. The study, carried out at Chembra, in South Wayanad had to be restricted to assessing the difference in the influence of two adjacent grassland-shola watersheds which differed in their morphometry but not in the land, vegetation, climate and soil characteristics. The study was also limited in time; data could be gathered for one and a quarter water year (June 1999 - September 2000) only, limiting rigorous analysis of data.

# 2. REVIEW OF LITERATURE

Exploitation of tropical rain forests resulting in degradation of their status is known to cause harm to the environment including the hydrological aspects though the estimates of the rates at which these forests are disappearing vary considerably between workers (FAO & UNEP, 1982; Myers, 1984 and Lanly, 1989). Realising the gravity of the situation the international colloquium on the development of hydrologic and water management strategies in the humid tropics conducted by UNESCO expressed strong concern regarding the hydrological impacts of the rapid rate of exploitation of forests (UNESCO, 1989).

Several paired catchment studies had been initiated in French guyana (Roche, 1981); Indonesia (Bruijnzeel, 1986) and Malaysia (Rahim, 1987, 1988 and 1989) and India (James *et al*., 1987and 2000, Santhoshkumar, 1998) to look into the hydrological behaviour of forests. Increases in water yield were reported on conversion and removal of forest cover to other land uses in Australia (Gilmour, 1977); Tanzania (Edwards, 1979), Kenya (Blackie, 1972) French Guyana (Fritsch, 1983) and Taiwan (Hsia and Koh, 1983). Average increase of 220mm $y^{-1}$ was obtained in Tanzania after converting montane evergreen forest to agriculture. Most of the increase occurred during the dry season while overland flow contributed very little due to high infiltrability of the volcanic soil. Mumeka (1986) reported increased water yield (194-230 mm $y^{-1}$) on converting *Brachystegia* woodland to agricultural use from a high rainfall region of Zambia (c. 1400 mm). Another study conducted in Taiwan on clear cutting mixed evergreen hill forest also yielded an increase of 448 mm $y^{-1}$ of water (Hsia and Koh, 1983). It was also reported by Gilmour (1977) that clearing of a lowland rainforest in Babinda, Queensland with high mean annual rainfall (c. 4035 mm) resulted in 264 and 323 mm (7% & 13.4%) increase in runoff in the first and second year respectively following clearing. Soil moisture levels were observed to remain higher because of reduced transpiration. Similarly Fritsch (1983)  an increase of 408 mm was also by in the first year on clear-cutting a primary low land rainforest in French Guyana. Rainforest clear cutting at Sg. Tekan, Malaysia (1730 mm $y^{-1}$ rain) resulted in very high increase in water yield of 822 mm $y^{-1}$ in the first year following clear cutting, but the average annual increase over a four-year period amounted to 314 mm $y^{-1}$ only (Rahim, 1988; DID, 1989).

Water balance studies carried out in the U.S.S.R, U.S.A, Switzerland, England, Germany, Japan and other countries also reported high evapo transpiration from forests, stream flow decreases with the growth of forests and stream flow increases due to cutting and burning of forests (Hibbert, 1967; Molchanov, 1970).

But there are opposing results which support the water-conserving role of forests. Results of standard network design observations in large catchments in the U.S.S.R revealed that annual stream flow increases under the influence of forests (Sokolovsky, 1952; Bochkov, 1959; Budyko, 1974). Rakhmanov (1951) reported 12-17 mm increase in runoff with each 10% increase in forest cover. Ya Pashinsky in Poland got high correlation coefficient between percent forest cover and runoff. He reported 16mm increase in precipitation and augmentation of stream-flow with 10% increase of forest cover.  Accelerated runoff and sediment loss due to developmental activities in forest areas has been reported also Sankar (1989) and Thomas *et al.* (1996) from Kerala.  James *et al*. (1987 and 2000) monitored 2 $km^2$ watersheds with different canopy cover in the southern Western Ghats for five years. Exploited forests with <30% cover, 30-60% cover and dense forest were compared. Stream-flow from dense forest lasted till February while that from fully exploited lasted only till November. Unit hydrographs showed that the lag time of dense forest was 36 % more than that of partially exploited and 58 % more than that of the fully exploited. Evapo - transpiration and infiltration was found to be more in the case of exploited forest. Sediment transport during the Southwest monsoon from the exploited forest was 5 to 6 times more than that from the dense forest. Kumar (1998) reported higher values of lean flow and lower values of runoff per unit area from protected watersheds in Kerala. He also observed higher erosion from less protected catchments while high soil moisture and low temperature were obtained in protected watersheds. Yadupathiputty and Pradeep (2000) after detailed hydrological investigations in the Western Ghats concluded that the CWC method of establishing unit hydrographs fails completely in the Western Ghats catchments. They also added that runoff processes in this region are different from the commonly known mechanisms of infiltration excess over land flow.

# 3. STUDY AREA AND METHODS

## Study area

The study was carried out at Chembra Peak area in Meppadi Forest Range of South Wayanad Forest Division (Figs. 1&2 and Pls. 1-6). Chembra peak and surroundings at an altitude of more than 1000 m record a mean maximum of 33$^{o}$C during summer days and a mean minimum of 15$^{o}$C during winter nights. On an average the annual rainfall in this region is around 2000 mm.

The relevant region was extracted from resampled RGB composite image from IRS 1C satellite (Feb.1997). The RGB image was subjected to an unsupervised classification (clustering) to arrive at broad land use. The extracted image ranged from 76.0750046 to 76.1083374 E and 11.5290003 to 11.5543337 N (100 X 76 cells). The study area and streams were digitised from scanned and resampled Survey of India 1:50,000 toposheets. The watersheds for both streams were traced along the drainage boundary. They were marked off from the classified image and area under evergreen forests and grassland was calculated.

## Methods

The following methods were used to characterise the watersheds and measure the rainfall, runoff and sediment yield from them. Watershed is defined as "a unit of area which covers all land and water which contribute runoff to a common point" (Ullah *et al.*, 1972). Runoff is that portion of the precipitation, which finds its way into stream, lake or ocean as surface or subsurface flow. The excess rainfall flowing over the land surface is termed as overland flow, whereas water flowing in a defined channel is termed as stream flow. The terms runoff and stream-flow are often used synonymously.

The terms used in stream morphometry are given below:

*Stream order*

Finger tip channels are specified as order one and where two first order tributaries join a channel segment of second order is formed and so on (Strahler, 1952).

*Drainage density*

Drainage density, $$D = \frac{\sum_{i=1}^{N} Lu}{Au}$$ (Strahler, 1952)

Where Lu = Length of stream (km)
Au = Basin area ($km^2$)

*Form factor*

Form factor, $$Rf = \frac{Au}{Lb^2}$$ (Horton, 1945)

Where Lb =Maximum basin length

*Circularity ratio*

Circularity ratio, $$Rc = \frac{Au}{Ap}$$ (Miller, 1953)

Where $A_P$ = Area of a circle with same basin perimeter ($km^2$)

*Elongation ratio*

Elongation ratio, $$Re = \frac{D}{Lb}$$ (Schumm, 1956)

Where D = Diameter of circle of basin area (km)

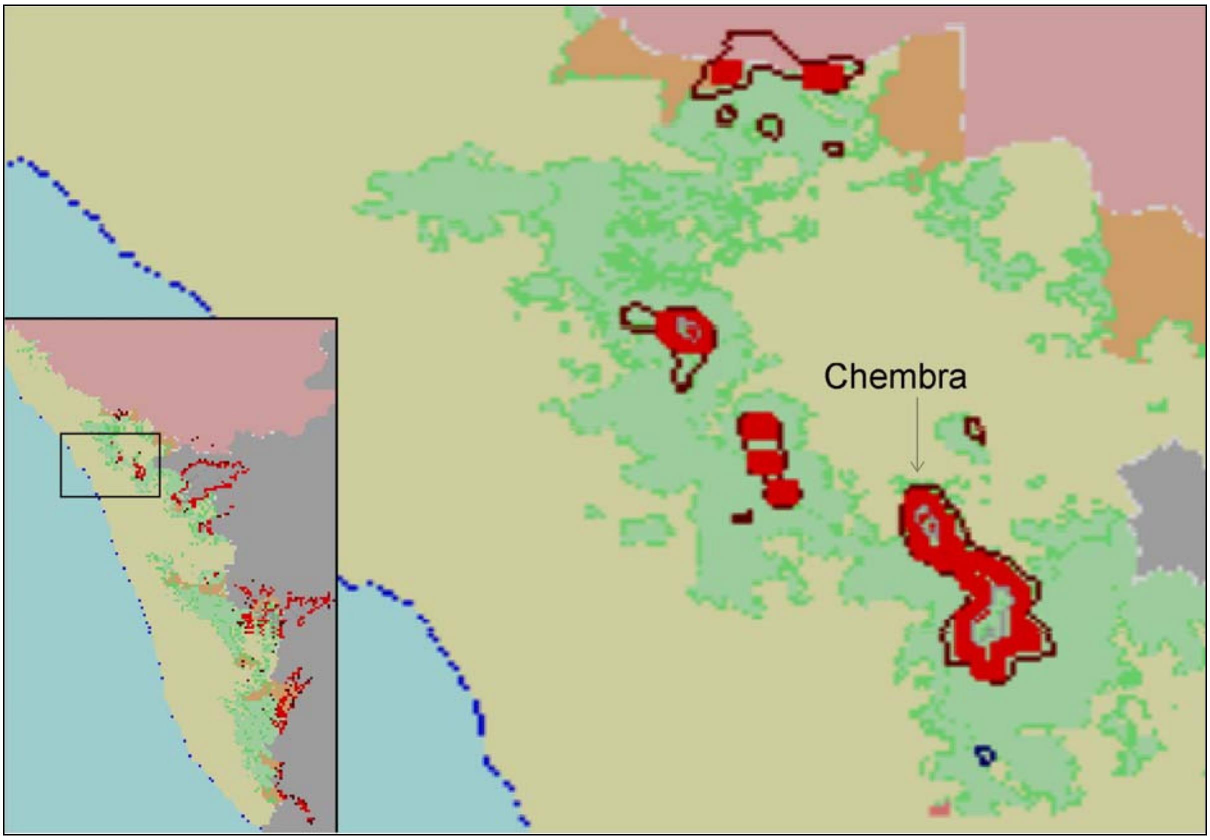



Fig. 1 Study area showing Chembra located in Wayanad region of Kerala. Green is forest area, brown line 1200m contour and red line 1500 m contour.

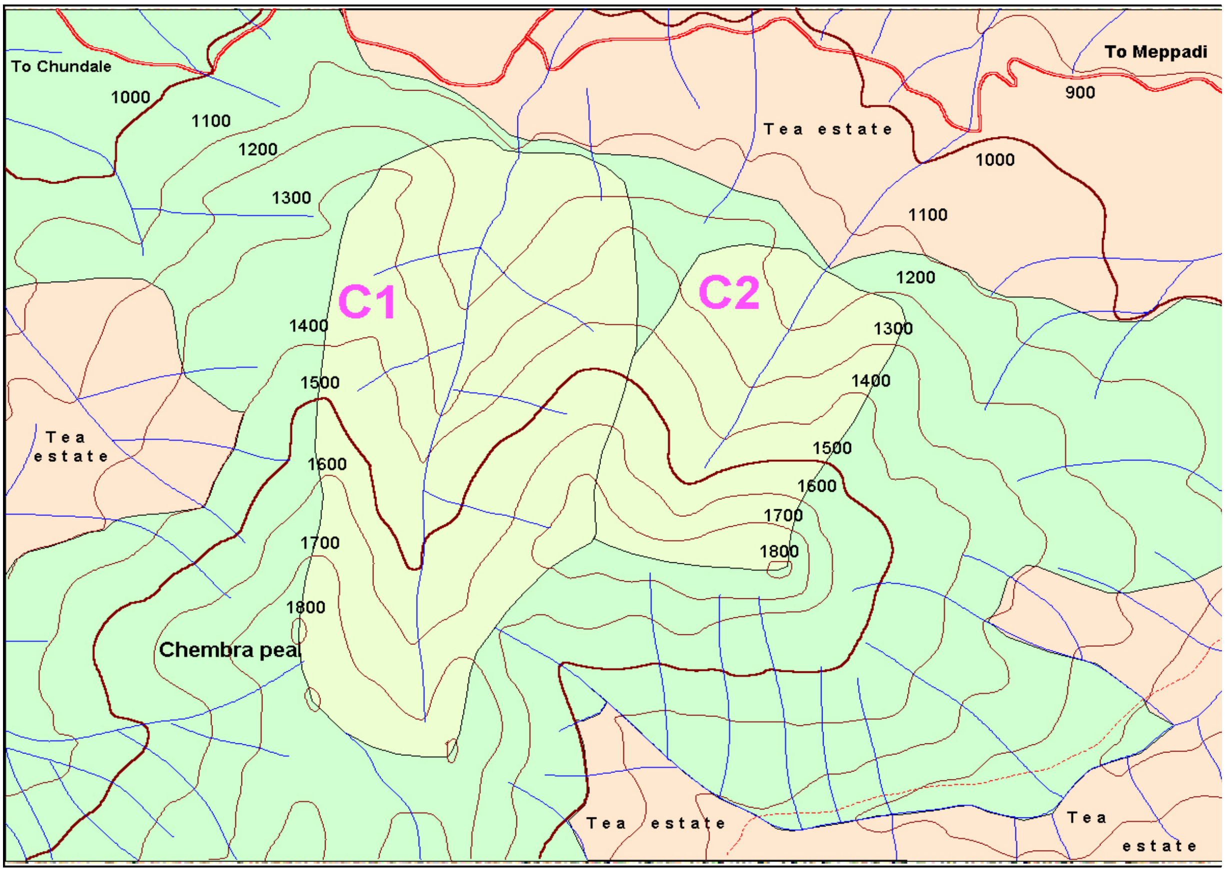



Fig. 2 Detailed map of Chembra region showing catchments C1 and C2 with streams. Reddish areas are non forest, green forest and light green catchments.

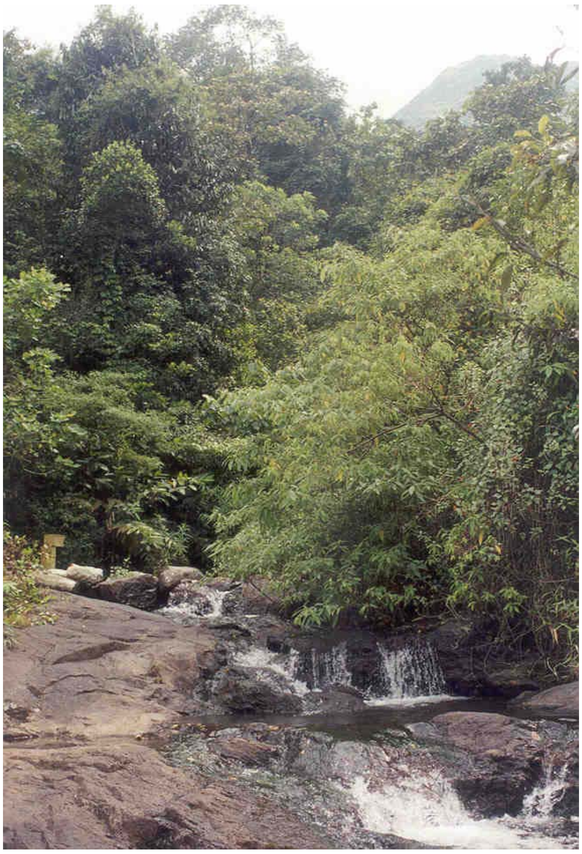
Pl. 1. A general view of catchment 1

Pl. 2.  A general view of catchment 2

Pl. 3. A general view of the shola forest

Pl. 4. The shola – A closer view

Pl.5.A view of the stream section in catchment 1 showing the stage level recorder and stilling well



Pl. 6. A view of the stream section in catchment 2 with the stage level recorder and stilling well.

*Rainfall*

Rainfall was measured with the help of a standard raingauge of Indian Meteorological Department specification which has a 127 mm diameter receiver opening made of gun metal finely finished knife edge top. The rain falling in the receiver is funnelled into 175 mm capacity container and measured with the help of specially calibrated graduated cylinder of 25 mm capacity.

*Atmospheric Temperature and Relative Humidity*

Atmospheric temperature and relative humidity were obtained from charts of a hygrothermograph installed within the shola forest.

*Streamflow or runoff*

Streamflow or runoff is expressed in terms of both rates of flow and also as volume. Rate is often expressed in cubic metre per second (cumec) units and volume in cubic metre. The depth of runoff is expressed in millimetres and the area in kilometres. Stream discharge is computed using the equation Q=av, where Q is the discharge in cumecs, a - is the area of cross section at the point of measurement and v is the mean velocity of flow.

The cross sectional area of the stream at the selected site was calculated and the velocity of flow measured twice a day with the help of float. Staff gauges were fixed in the stream and the depth of flow noted. A Stage level recorder was installed in a stilling well fabricated for the purpose along side a weir, which was constructed to regulate water flow. Discharge measurements at different stages of flow obtained from stage graphs were used to develop a station rating curve which was subsequently used to obtain the runoff values for the measured depths. Runoff coefficient was calculated using the formula:

$$\text{Runoff coefficient} = \frac{\text{Runoff}}{\text{Rainfall}}$$

*Sediment yield*

Water samples were collected twice daily and the sediments made to settle by adding alum (aluminium sulphate). The supernatant water was decanted, the sediment collected, oven dried and weighed. Sediment load per unit volume was multiplied by volume of runoff to obtain sediment yield.

*Soil sampling and analyses*

Soil samples were collected at random from the surface. One profile each was also studied in the shola and the adjacent grassland. The collected samples were air dried in shade, processed and analysed following the procedures given in ASA Monograph (1965) and Jackson (1958). Sand, silt and clay (0.02-2 mm, 0.002-0.02 mm and <0.002 mm) were determined by the hydrometer method; pH in 20:40 soil water suspension; organic carbon (OC) by potassium dichromate-sulphuric acid wet digestion; exchangeable bases (EB) by 0.1 N HCl method; particle density (PD) using standard flask technique; bulk density (BD) by core sampling, maximum water holding capacity (MWHC) gravimetrically and porosity by calculation. Available nitrogen (N) was estimated by alkaline permanganate method, exchangeable potassium (K) by colorimeter and exchangeable calcium (Ca) and magnesium (Mg) by EDTA titrimetry. Soil samples were collected separately from the surface once a month and soil moisture content of the samples estimated gravimetrically.

# 4. RESULTS

Data collected on morphometry, climate, vegetation, soil, runoff and sediment yield are presented in Tables 1-14 and described below:

*Catchment morphometry*

The morphometric properties of the two catchments $C_1$ and $C_2$ are presented in Table 1. The stream of order 3 in $C_1$ had a length of 1.889 km. and the stream in $C_2$ of order 2 was 0.9887 km long. Both the hilly watersheds had northern aspects and started from 1150m altitude. Catchment $C_1$ went up to 1860 m with an average slope of 65% while catchment $C_2$ had maximum altitude of 1800m only and it was less steep with 50% slope on an average. $C_1$ had an area of 1.52 $km^2$, drainage density of 1.243 $km/km^2$, form factor of 0.426, circularity ratio of 0.6759 and elongation ratio of 0.7366 while $C_2$ had corresponding values of 0.79 $km^2$, 1.252 $km/km^2$, 0.808, 0.808 and 1.0147 respectively.

**Table 1. Morphometric properties of the two catchments**

| Morphometry | Catchments | |
|---|---|---|
| | **C1** | **C2** |
| A. Linear aspects | | |
| Length of main stream (km) | 1.8890 | 0.9887 |
| Stream order | 3 | 2 |
| Aspect | N | N |
| B. Areal aspects | | |
| Catchment area ($km^2$) | 1.52 | 0.79 |
| Shola area ($km^2$) | 0.61 | 0.27 |
| Drainage density ($km/ km^2$) | 1.243 | 1.252 |
| Form factor | 0.426 | 0.808 |
| Circularity ratio | 0.6759 | 0.808 |
| Elongation ratio | 0.7366 | 1.0147 |
| C. Relief aspects | | |
| Elevation (amsl) | | |
| Max. | 1860 | 1800 |
| Min. | 1150 | 1150 |
| Mean slope (%) | 65 | 50 |

### *Rainfall*

Rainfall pattern depicted in Table 2 and Figure 3 are described below. Rain occurred in all the months except January and February 2000 during the study period and most of it fell during the Southwest monsoon period of June-August, as is the normal pattern in Kerala State. July was the month with maximum rainfall. Most of the rain (83.65%) fell during June-August 1999 when we take into consideration the water year June 1999 - May 2000. Northeast monsoon period comes next with 12.11% as its contribution. All the other months together provided only 2.65 per cent. The month of July 1999 had 28 rainy days giving 656.7 mm rainfall while July 2000 could contribute even higher quantity

(720.3mm) though the number of rainy days were only twenty five. Maximum rainfall of 73 mm was recorded on 9th July in the year 1999 and 96mm rain fell on 12th July 2000. There were 64 days with more than 10mm rainfall in the water year June 1999 - May 2000 and 115 such days when the whole study period was taken into account.

**Table 2. Rainfall distribution during the study period**

| Year | Month | No. of rainy days | Rainfall (mm) | Maximum in a day (mm) | No. of days with > 10 mm rain |
|---|---|---|---|---|---|
| 1999 | June | 22 | 416.4 | 54 | 17 |
| | July | 28 | 656.7 | 73 | 24 |
| | August | 21 | 327.2 | 28 | 16 |
| | September | 11 | 26.4 | 4.7 | - |
| | October | 19 | 123.5 | 34 | 5 |
| | November | 7 | 74.2 | 26 | 2 |
| | December | 3 | 5.1 | 2.5 | - |
| 2000 | January | - | - | - | - |
| | February | - | - | - | - |
| | March | 4 | 14.8 | 4 | - |
| | April | 3 | 12 | 5 | - |
| | May | 5 | 17.6 | 6 | - |
| | Total during water year June 1999 – May 2000 | 123 | 1673.9 | | |
| | June | 13 | 421.1 | 64 | 10 |
| | July | 25 | 720.3 | 96 | 23 |
| | August | 20 | 353.2 | 30 | 17 |
| | September | 7 | 34.5 | 8 | 1 |

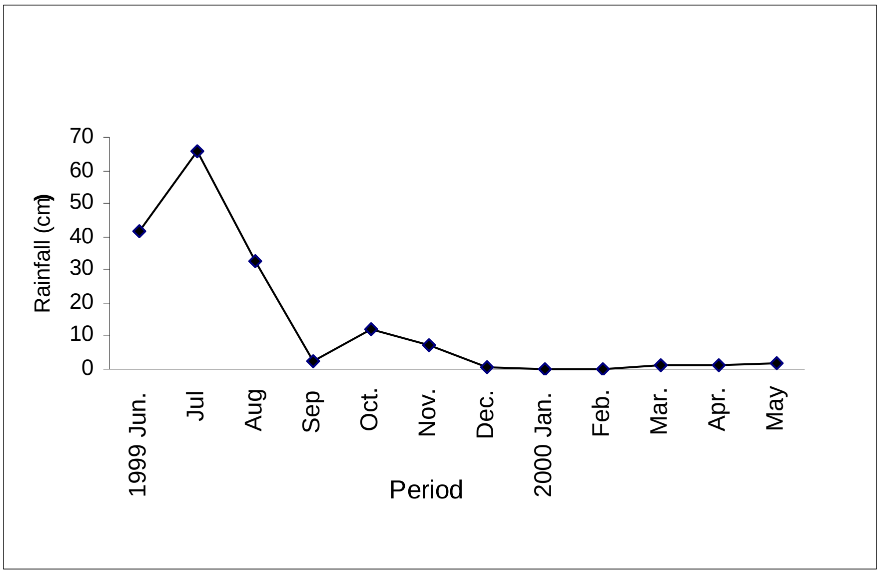



Fig. 3. Rainfall during water year 1999-2000

*Microclimate within the shola*

The microclimate within shola forest is shown in Table 3 and Figures 4, 5 and 6 and described below. During the Southwest monsoon season the day temperature recorded a mean maximum of 29°C and mean minimum of 24°C while during night the respective values were 25 and 22° Celsius. Relative humidity during this season was found to range from 95 to 100 per cent mean maximum and 70 to 90 per cent mean minimum values. The winter season was colder with mean maximum values of 27°C during the day and 21°C during the night while the mean minimum was found to be 20°C and 16°C respectively. Relative humidity remained steady at 100 per cent in December and January both during day and night. Summer season recorded mean maximum day temperature of 31°C during day and 25° C during night; the mean minimum were 25°C and 21°C respectively. The mean maximum relative humidity was 95 per cent and mean minimum 50 per cent in this season. On the whole it was observed that the variation in temperature between months is not much and the relative humidity was high in most of the months except the summer when lower mean minimum values were recorded.

**Table 3. Microclimate within shola**

| Year | Month | Temperature | | | | Relative humidity | |
|---|---|---|---|---|---|---|---|
| | | Day | | Night | | | |
| | | Mean Max. | Mean Min. | Mean Max. | Mean Min. | Mean Max. | Mean Min. |
| 1999 | June | 25 | 24 | 24 | 23 | 95 | 70 |
| | July | 27 | 25 | 25 | 24 | 100 | 90 |
| | August | 28 | 26 | 25 | 24 | 95 | 70 |
| | September | 29 | 25 | 25 | 22 | 95 | 60 |
| | October | 28 | 27 | 27 | 27 | 100 | 90 |
| | November | 25 | 20 | 20 | 20 | 95 | 90 |
| | December | 27 | 21 | 21 | 18 | Steady at 100 | |
| 2000 | January | 25 | 20 | 20 | 16 | | |
| | February | 27 | 25 | 25 | 24 | 95 | 50 |
| | March | 31 | 26 | 25 | 22 | 95 | 50 |
| | April | 30 | 25 | 24 | 21 | 95 | 50 |
| | May | 30 | 26 | 26 | 23 | 95 | 55 |
| | June | 25 | 24 | 24 | 23 | 100 | 80 |
| | July | 29 | 27 | 26 | 24 | 95 | 60 |
| | August | 28 | 25 | 25 | 24 | 95 | 75 |
| | September | 30 | 26 | 26 | 25 | 100 | 78 |

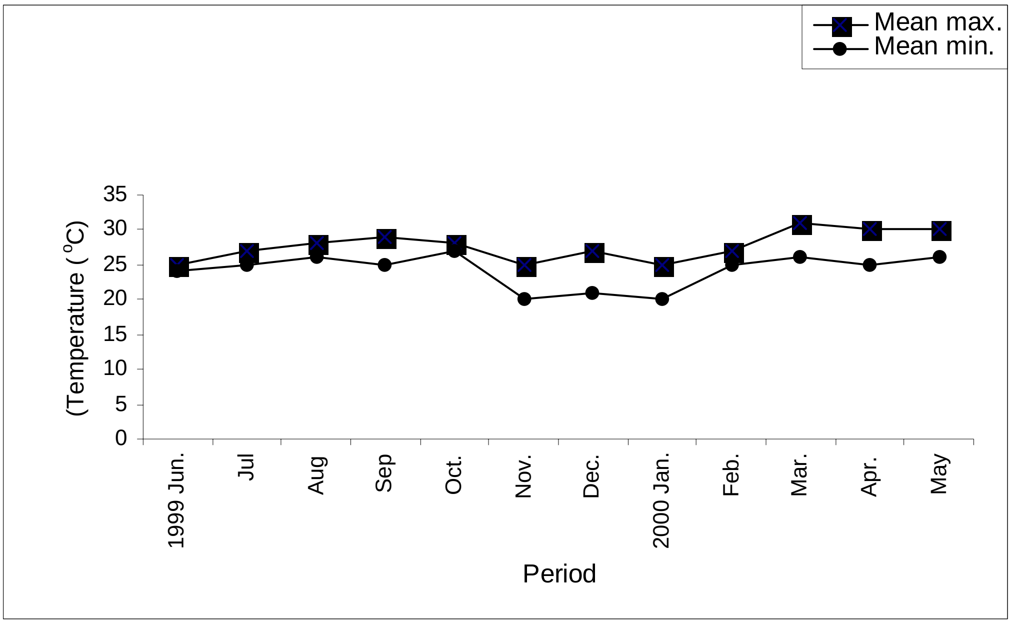



Fig 4. Monthly variation in day temperature within shola

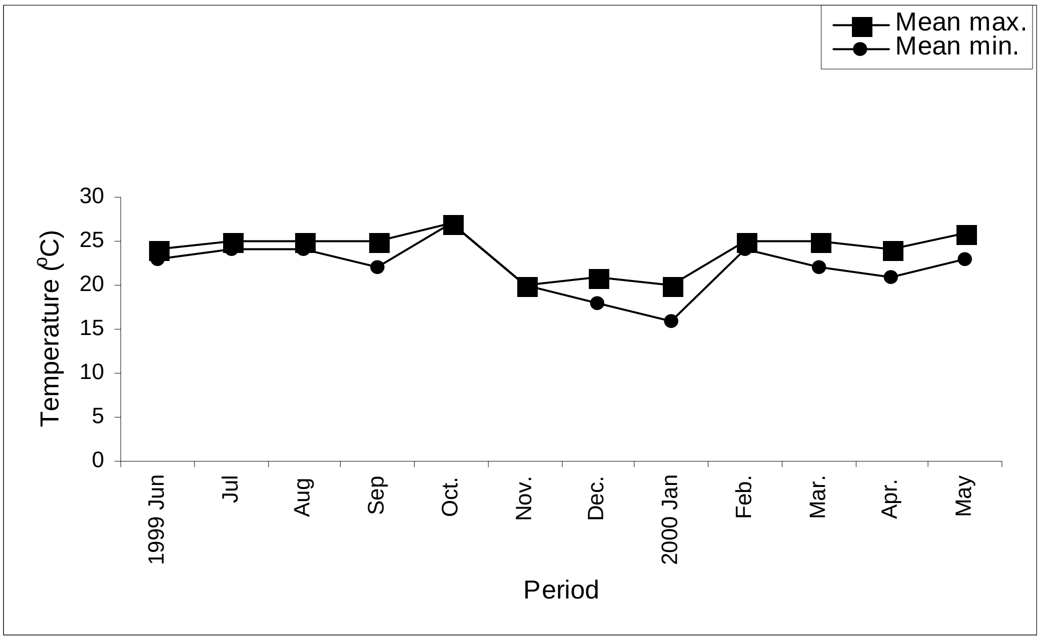



Fig. 5. Monthly variation in night temperature within shola

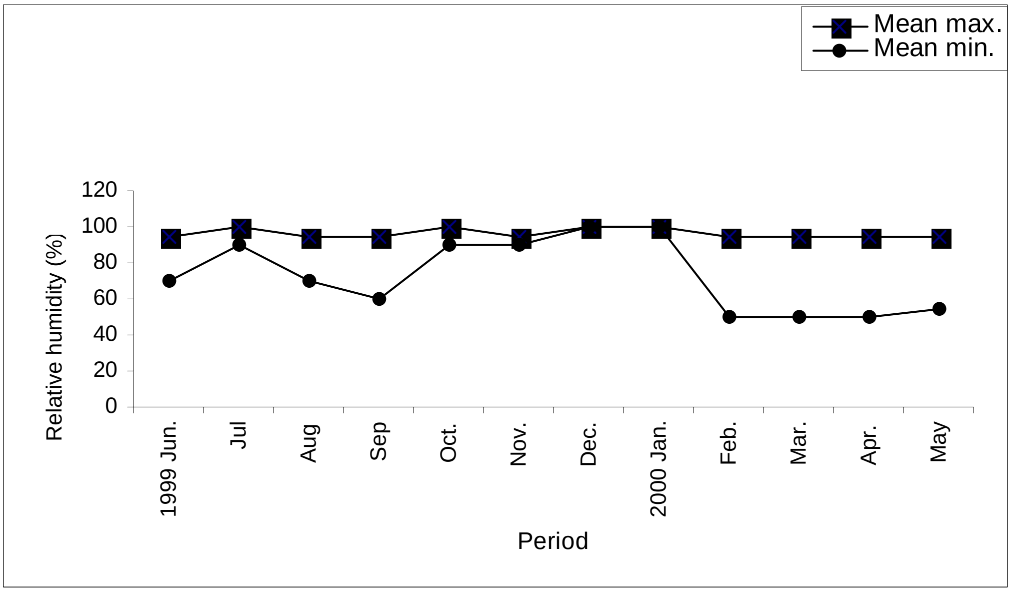



Fig. 6. Monthly variation in relative humidity with in shola

*Soil moisture*

Soil moisture measured in the surface soil is presented in Table 4 and Figure 7. It can be seen from the table that soil moisture in shola didn't fluctuate much between months in a particular season. Soil moisture values of 32-34% on an average were recorded during the S.W. monsoon, 29-30% during the N.E. Monsoon, 28-29% during the winter and 13-16% during the summer. The grassland could not retain as much soil moisture as the shola especially during the non monsoon days. The values during the corresponding seasons were 30-33%, 22-26%, 14-19% and 6-7 per cent.

It can be seen from Fig. 7 that the values for soil moisture did not differ much between shola forest and grassland during the period June-September. But shola forest soil stored higher quantity of moisture from the month of October till May when compared to grassland. During the winter and summer season the shola soil contained double the percentage of moisture as that of grassland. The surface soil with well developed stable macro aggregates permits easy infiltration and the deeper soil has more effective volume per unit area for greater moisture storage.

**Table 4. Soil moisture status in shola and in grassland**

| Year | Month | Soil moisture (%) | |
|---|---|---|---|
| | | Shola | Grassland |
| 1999 | June | 32±7 | 31±5 |
| | July | 34±4 | 33±4 |
| | August | 33±5 | 30±4 |
| | September | 28±4 | 28±4 |
| | October | 30±2 | 26±3 |
| | November | 29±2 | 22±2 |
| | December | 29±3 | 19±5 |
| 2000 | January | 28±4 | 14±4 |
| | February | 26±4 | 12±3 |
| | March | 25±5 | 7±3 |
| | April | 16±2 | 7±3 |
| | May | 13±2 | 6±3 |
| | June | 33±7 | 31±2 |
| | July | 35±4 | 32±4 |
| | August | 33±5 | 30±4 |
| | September | 28±4 | 26±4 |

± Denotes standard deviation

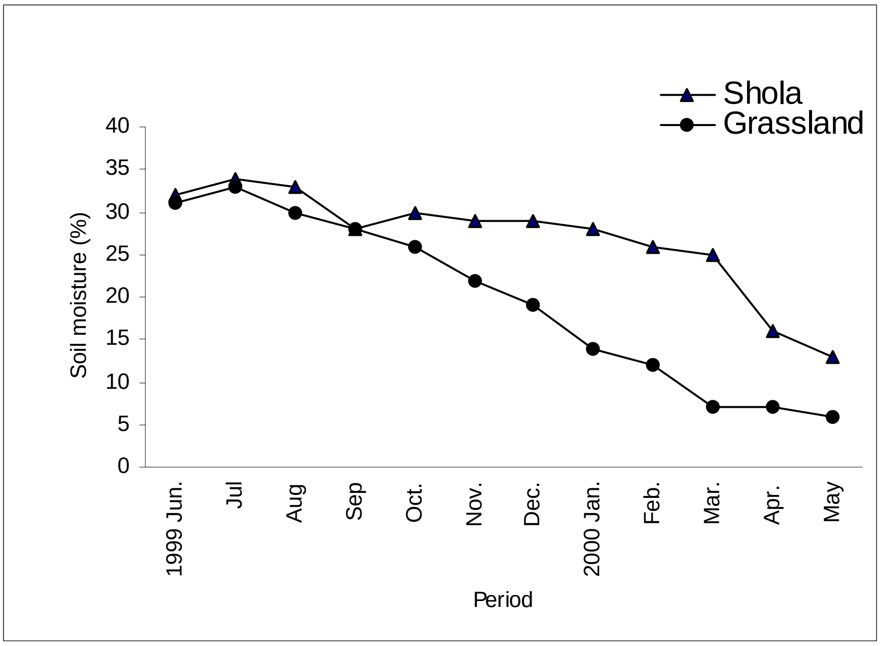



Fig. 7. Soil moisture status in shola and grassland

## *Vegetation*

The shola vegetation is characteristic and peculiar. The trees are stunted with umbrella shaped canopy and crooked branches that are covered with mosses, ferns, lichens and orchids. The leaves are coriaceous and curved. Fire resistant temperate species dominate the fringes which act as a natural fire belt (Balasubramanian and Kishore Kumar, 1999). Table.5 provides a list of common shola trees found in the study area.

**Table. 5. List of trees found in the shola**

| Sl.No. | Name of species | Sl.No. | Name of species |
|---|---|---|---|
| 1. | *Agrostistachys indica,* Dalz. | 11. | *Ligustrum* sp. |
| 2. | *Antidesma menasu*, Miq. | 12. | *Litsea* sp. |
| 3. | *Ardissia pauciflora*, Heyne | 13. | *Myristica dactyloides*, Merr. |
| 4. | *Cinnamomum* sp., | 14. | *Neolitsea zeylanica* |
| 5. | *Dillenia bracteata* W. | 15. | *Rapanea* sp. |
| 6. | *Elaeocarpus* sp. | 16. | *Symplocos* sp. |
| 7. | *Elaeocarpus munroii*, Mast. | 17. | *Symplocos laurina* |
| 8. | *Euriya nitida* | 18. | *Syzygium* sp. |
| 9. | *Garcinia* sp. | 19. | *Ternstroemia japonica*, L. |
| 10. | *Hydnocarpus alpina*, W. | | |

*Soil*

Soils of shola and grassland characterised by studying profiles as well as several surface samples (Tables 6,7,8,9 & 10 and Plates 7 & 8) are presented below. The morphology reveals that the shola soil is deep (>150cm) with abundant litter cover. It was dark reddish brown in colour throughout, though the surface horizons were darker than those below. Very friable, loose, crumb structure was found in the top soil while the subsoil horizons had loose massive structure. Roots were found to be present even beyond 100 cm depth, though most of the roots were concentrated within the top 40cm section. It was sandy loam in texture with very low bulk density (1.0g $cm^{-3}$), high porosity (56.5%) and water holding capacity (60%) in the top layers. Soil was acidic with a pH of 5.6 in the surface layers which decreased downwards up to 5.0 below 110 cm depth. Organic carbon was very high in the topsoil with the topmost horizon recording as high as 6.56 per cent. It decreased drastically down the soil to 0.94 per cent beyond 110 cm. Exchangeable bases of 15 cmol $^{(+)}kg^{-1}$ in the surface 0-15 cm layer also had a decreasing trend down the profile. There was 0.20% nitrogen, 230 ppm potassium, 0.16% calcium and 0.32% magnesium in the top soil. The concentration of all these elements were also highest in the surface and the values decreased down the soil surface.

The grassland soil was very dark brown in the surface turning dark brown and dark reddish brown to yellowish red down the soil horizons. It had crumb and granular structure in the surface and massive structure in the subsurface. The soil was loose in the surface but firm in the subsurface. Roots were present only up to 85 cm and most of them were restricted to the top 60 cm layer. It was also found to have a sandy loam texture with lower bulk density (1.05g $cm^{-3}$), high porosity (54.3%) and water holding capacity (53%) in the surface. Bulk density increased with depth to even 1.2 g $cm^{-3}$ , porosity decreased to 48.9% in the layers beyond 85 cm. The soil was very acidic with 4.7 pH in the

Pl. 7. A soil profile in the shola
(The spots are 20 cm apart)

Pl. 8. A soil profile in the grassland
(The spots are 20 cm apart)

top soil which decreased to 4.5 in lowest layers. Organic carbon was high recording values of 4.63% in the surface, which fell to 0.35% beyond 85-cm depth. Exchangeable bases decreased from 14 cmol $^{(+)}$kg$^{-1}$ to 10 cmol $^{(+)}$kg$^{-1}$ nitrogen from 0.15% to 0.04%, potassium from 140 ppm to 74 ppm, calcium from 0.24% to 0.26% and magnesium from 0.19% to 0.011 per cent down the profile.

**Table 6. Properties of surface soil (0-15 cm)**

| Property | Shola | Grassland |
|---|---|---|
| Sand (%) | 76.0±**4** | 78.0±**5** |
| Silt (%) | 9.0±**2** | 9.0±**2** |
| Clay (%) | 15.0±**1** | 13.0±**1** |
| BD (g cm$^{-3}$) | 1.05±**.05** | 1.15±**.03** |
| PD (g cm$^{-3}$) | 2.3±**.4** | 2.3±**0.4** |
| Po (%) | 54.0±**4** | 50.0±**4** |
| WHC (%) | 60.0±**8** | 50.0±**6** |
| pH | 5.6±**.4** | 5.0±**0.3** |
| OC (%) | 2.8±**1.0** | 2.4±**0.6** |
| EB cmol$^{(+)}$kg$^{-1}$ | 18.0±**.03** | 8.0±**2** |
| N (%) | 0.18±**.03** | 0.04±**0.04** |
| K (ppm) | 220.0±**80** | 120.0±**60** |
| Ca (%) | 0.14±**.08** | 0.03±**0.01** |
| Mg(%) | 0.022±**.01** | 0.020±**0.004** |

n=40 ± denotes standard deviation

*Shola soil profile and properties*

Shola forest, 1600 m asl, steep slope, full canopy cover, thick litter cover, well drained, no rocks, few stones.

0-10 cm Dark reddish brown (5 YR 2.5/2) loose, friable, crumb structure, abundant roots
10-20 cm Dark reddish brown (5 YR 3/2) loose, friable, crumb structure, abundant roots.
20-28 cm Dark reddish brown (5 YR 3/3) loose friable, granular structure, plentiful roots.
28-40 cm Dark reddish brown (5 YR 3/3) loose, massive, plentiful roots.
40-70 cm Dark reddish brown (5 YR 3/4) loose, massive, few roots.
70-110 cm Dark reddish brown (5 YR 3/4) loose, massive, few roots.
> 110 cm Dark reddish brown (5 YR 3/4) loose, massive few roots.

**Table 7. Physical properties of soil profile in shola**

| Soil depth | Gravel | Sand | Silt | Clay | B.D | P.D | Po | MWHC |
|---|---|---|---|---|---|---|---|---|
| | --------- % --------- | | | | ----- $gcm^{-3}$ ----- | | ------ % ------ | |
| 0-10 cm | 1 | 76 | 9 | 15 | 1.0 | 2.3 | 56.5 | 60 |
| 10-20 cm | 1 | 78 | 9 | 13 | 1.0 | 2.3 | 56.5 | 60 |
| 20-28 cm | 14 | 77 | 9 | 14 | 1.05 | 2.3 | 54.3 | 57 |
| 28-40 cm | 17 | 78 | 10 | 12 | 1.10 | 2.35 | 53.2 | 53 |
| 40-70 cm | 7 | 78 | 8 | 14 | 1.05 | 2.3 | 54.3 | 53 |
| 70-110 cm | 21 | 76 | 9 | 15 | 1.10 | 2.35 | 53.2 | 53 |
| > 110 cm | 0.7 | 77 | 11 | 12 | 1.10 | 2.35 | 53.2 | 52 |

**Table 8. Chemical properties of soil profile in shola**

| Soil depth | pH | OC (%) | E.B ($cmol^{(+)}kg^{-1}$) | N (%) | K (ppm) | Ca (%) | Mg (%) |
|---|---|---|---|---|---|---|---|
| 0-10 cm | 5.6 | 6.56 | 15 | 0.20 | 220 | 0.160 | 0.032 |
| 10-20 cm | 5.7 | 4.68 | 14 | 0.17 | 224 | 0.104 | 0.023 |
| 20-28 cm | 5.6 | 1.68 | 11 | 0.09 | 190 | 0.052 | 0.011 |
| 28-40 cm | 5.5 | 1.23 | 10 | 0.07 | 140 | 0.040 | 0.008 |
| 40-70 cm | 5.3 | 1.08 | 12 | 0.06 | 120 | 0.020 | 0.010 |
| 70-110 cm | 5.2 | 1.13 | 12 | 0.08 | 120 | 0.018 | 0.008 |
| > 110 cm | 5.0 | 0.94 | 10 | 0.07 | 105 | 0.020 | 0.014 |

### *Grassland soil profile and properties*

Grassland, 1600 m asl, steep slope, thick grass growth, well drained, few rock exposures

0-20 cm Very dark brown (10 YR 2/2), loose, friable, crumb structure, abundant roots.
20-40 cm Dark brown (7.5 YR 3/4), loose, friable, granular structure, abundant roots.
40-60 cm Dark brown (7.5 YR 3/4) loose to firm, massive structure, plentiful roots.
60-85 cm Dark reddish brown (5 YR 3/4) firm, massive structure, few roots.
> 85 cm Yellowish red (5 YR 5/6) firm, massive structure, no roots.

**Table 9. Physical properties of soil profile in grassland**

| Soil depth | Gravel | Sand | Silt | Clay | B.D | P.D | Po | MWHC |
|---|---|---|---|---|---|---|---|---|
| | --------- % --------- | | | | ----- $gcm^{-3}$ ----- | | ------ % ------ | |
| 0-20 cm | 3 | 78 | 16 | 6 | 1.05 | 2.3 | 54.3 | 53 |
| 20-40 cm | 7 | 76 | 17 | 7 | 1.10 | 2.35 | 53.2 | 52 |
| 40-60 cm | 3 | 79 | 9 | 12 | 1.15 | 2.3 | 50 | 48 |
| 60-85 cm | 18 | 75 | 9 | 16 | 1.2 | 2.35 | 48.9 | 46 |
| > 85 cm | 10 | 76 | 7 | 17 | 1.2 | 2.35 | 48.9 | 43 |

**Table 10. Chemical properties of soil profile in grassland**

| Soil Depth | pH | O.C (%) | E.B ($cmol^{(+)}kg^{-1}$) | N (%) | K (ppm) | Ca (%) | Mg (%) |
|---|---|---|---|---|---|---|---|
| 0-20 cm | 4.7 | 4.63 | 14 | 0.15 | 140 | .024 | .019 |
| 20-40 cm | 4.7 | 2.89 | 12 | 0.08 | 120 | .018 | .010 |
| 40-60 cm | 4.6 | 1.28 | 13 | 0.07 | 104 | .020 | .005 |
| 60-85 cm | 4.5 | 0.84 | 11 | 0.04 | 86 | .022 | .005 |
| > 85 cm | 4.5 | 0.35 | 10 | 0.04 | 74 | .026 | .011 |

*Runoff*

Runoff from the two shola catchments are depicted in Table 11 and Figure 8. It can be seen that during the water year 1999-2000, 16,06,059 $m^3$ water flowed down the stream draining the first catchment ($C_1$) and 8,95,242 $m^3$ water through the stream in the second catchment ($C_2$). Runoff was concentrated in the S.W. monsoon season. A quantity of 14,49,016 $m^3$ ran off from $C_1$ while the runoff from $C_2$ amounted to 8,12, 294 $m^3$ during this season. These were 90.62% and 90.7% respectively of the total runoff. Maximum runoff occurred during the month of July corresponding to maximum rainfall. Contribution during this month alone was 45.4% and 45.7% of the total runoff from the catchments $C_1$ and $C_2$ respectively. Runoff tapered down to 3520 $m^3$ and 1393 $m^3$ in the month of May. Peak runoff was recorded on a few days in June, July and August , the highest peak being on 09-07-1999 with 52 mm from $C_1$ and 51.2 mm from $C_2$ (Table. 13) which is equivalent to 79040 $m^3$ and 40448 $m^3$ respectively.

Runoff coefficient, an index of runoff - rainfall relationship was seen to be above 0.5 during the S.W. monsoon season showing that more than half the rainfall ran off the catchments (Table 12.). In July with highest rainfall, the runoff coefficient was more than 0.70 and in September the values rose to 1.37 in $C_1$ and 1.43 in $C_2$. This means that runoff was greater than rainfall in this particular month. All other months had lower than 0.5 values with the lowest value of around 0.1 in the month of May. Similar pattern was repeated in the S.W. monsoon of the next water year also.

**Table 11. Runoff from the catchments during the study period**

| Year | Month | Runoff ($m^3$) $C_1$ | Runoff ($m^3$) $C_2$ |
|---|---|---|---|
| 1999 | June | 367080 | 206032 |
| | July | 728384 | 408825 |
| | August | 298680 | 167654 |
| | September | 54872 | 29783 |
| | October | 72656 | 40029 |
| | November | 33744 | 17617 |
| | December | 19912 | 9954 |
| 2000 | January | 7904 | 3871 |
| | February | 5016 | 2449 |
| | March | 8168 | 4620 |
| | April | 6123 | 3015 |
| | May | 3520 | 1393 |
| | Total runoff during the water year 1999-2000 | 1606059 | 895242 |
| | Total runoff during S.W. monsoon | 1449016 (90.2%) | 812294(90.7%) |
| | June | 353248 | 198290 |
| | July | 821712 | 458674 |
| | August | 271016 | 153497 |
| | September | 61104 | 33022 |

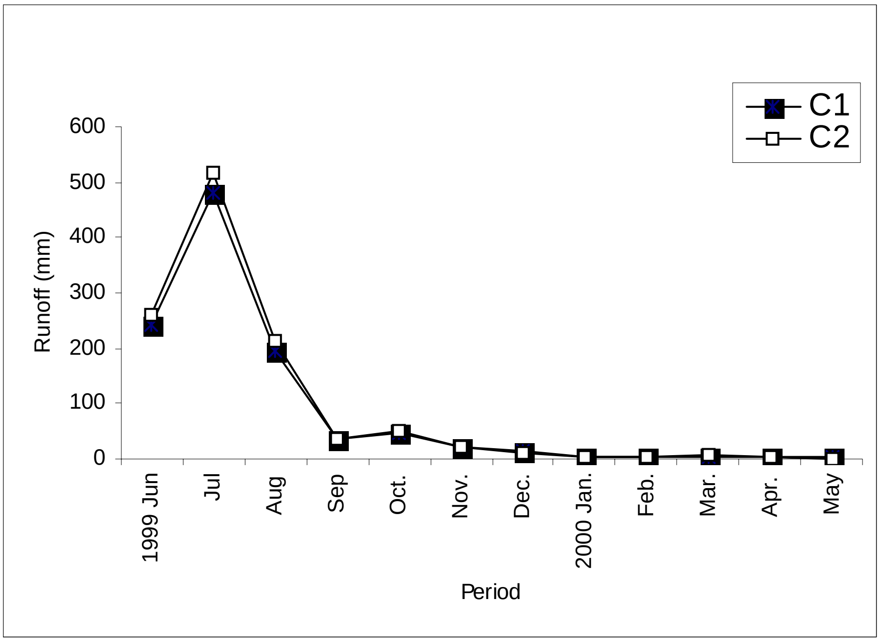



Fig. 8. Runoff from the catchments $C_1$ and $C_2$ during the water year June 1999-May 2000

**Table 12. Rainfall-runoff relationship of the catchments**

| Year | Month | Rainfall (mm) | Runoff (mm) C1 | Runoff (mm) C2 | Runoff coefficient C1 | Runoff coefficient C2 |
|---|---|---|---|---|---|---|
| 1999 | June | 416.4 | 241.5 | 260.8 | 0.58 | 0.63 |
| | July | 656.7 | 479.2 | 517.5 | 0.73 | 0.79 |
| | August | 327.2 | 196.5 | 212.2 | 0.60 | 0.65 |
| | September | 26.4 | 36.1 | 37.7 | 1.37 | 1.43 |
| | October | 123.5 | 47.8 | 50.67 | 0.39 | 0.41 |
| | November | 74.2 | 22.2 | 22.3 | 0.30 | 0.30 |
| | December | 5.1 | 13.1 | 12.6 | 2.6 | 2.5 |
| 2000 | January | - | 5.2 | 4.9 | - | - |
| | February | - | 3.3 | 3.1 | - | - |
| | March | 14.8 | 5.4 | 5.8 | 0.36 | 0.39 |
| | April | 12 | 4.0 | 3.8 | 0.33 | 0.32 |
| | May | 17.6 | 2.3 | 1.8 | 0.13 | 0.10 |
| | Total during water year June 1999 – May 2000 | 1673.9 | 1056.6 | 1133.17 | | |
| | June | 421.1 | 212.4 | 251.0 | 0.55 | 0.60 |
| | July | 720.3 | 540.6 | 580.6 | 0.75 | 0.81 |
| | August | 353.2 | 178.3 | 194.3 | 0.50 | 0.55 |
| | September | 34.5 | 40.2 | 41.8 | 1.16 | 1.21 |

**Table 13. Peak runoff from the catchments**

| Date | Runoff (mm) C1 | C2 |
|---|---|---|
| 13-06-1999 | 38.4 | 39.3 |
| 28-06-1999 | 30.5 | 36.7 |
| 09-07-1999 | 52.0 | 51.2 |
| 08-08-1999 | 22.0 | 12.6 |
| 18-08-1999 | 26.0 | 28.0 |
| 07-06-2000 | 23.6 | 23.2 |
| 12-07-2000 | 42.7 | 24.6 |
| 23-08-2000 | 36.8 | 20.0 |
| 24-08-2000 | 34.5 | 16.7 |
| 25-08-2000 | 35.3 | 18.0 |

*Sediment yield*

Table. 14 shows the suspended sediment yield from the two catchments. Measurable amounts of sediments were present in stream water only during the months of June and July when the streams did overflow their banks. Water was clear during all other months. In the month of June 1999, 0.021 kg/m$^{-3}$ was the sediment load in the stream from catchment $C_1$, while that through the stream from $C_2$ was 0.020 kg m$^{-3}$. The sediment load was 0.019 kg m$^{-3}$ and 0.017 kg m$^{-3}$ respectively from $C_1$ and $C_2$ during the next month. The corresponding figures during June and July 2000 were 0.018, 0.018, 0.019 and 0.018 respectively. It could be inferred that on an average 0.1431 tonne/ha. soil was being lost from $C_1$ and 0.1448 tonne/ha from $C_2$ annually.

**Table 14. Sediment yield**

| Year | Month | Catchment | Suspended sediment load ($kg/m^3$) | Runoff ($m^3$) | Soil loss (kg) |
|---|---|---|---|---|---|
| 1999 | June | $C_1$ | 0.021 | 367080 | 7708.7 |
| | | $C_2$ | 0.020 | 206032 | 4120.6 |
| | July | $C_1$ | 0.019 | 728384 | 13839.3 |
| | | $C_2$ | 0.017 | 408825 | 6950.0 |
| | **Total** | $\mathbf{C_1}$ | | | **21548.0** |
| | | $\mathbf{C_2}$ | | | **11070.6** |
| 2000 | June | $C_1$ | 0.018 | 353248 | 6358.5 |
| | | $C_2$ | 0.018 | 198290 | 3569.2 |
| | July | $C_1$ | 0.019 | 821712 | 1561.5 |
| | | $C_2$ | 0.018 | 458674 | 8256.1 |
| | **Total** | $\mathbf{C_1}$ | | | **21971.0** |
| | | $\mathbf{C_2}$ | | | **11825.3** |

# 5. DISCUSSION

The results obtained could not lead to definite conclusions due to inherent limitations imposed by the duration of the study but still are indicatory of the role of shola forests in maintaining watercourses in the high ranges of the Western Ghats. The study area located at Chembra was hilly with steep slopes and received a total of 1673.9 mm rainfall in the water year June 1999 – May 2000 most of which was concentrated (85%) in the South West monsoon season (Fig. 3). The total runoff (Fig. 8) was 63.1% of the total rainfall in $C_1$ and 67.7% in $C_2$. The runoff coefficient was always higher in C2 showing that it could not retain as much water as $C_1$ in any of the rainy months. Runoff coefficient values greater than unity recorded in the month of September shows that discharge exceeded rainfall, in both C1 and C2 during this month.

The two shola-grassland catchments (C1 and C2) being adjacent did not differ in climate, microclimate soil and type of vegetation. The only notable differences were with respect to slope and proportion of shola forest (Table 1). The catchment $C_1$ was steeper with greater percentage of shola cover (40.13%) compared to catchment $C_2$ which had 34.17% under shola cover. Drainage density did not differ much between the catchments while the form factor, circularity ratio and elongation ratio were more in the case of $C_2$. This shows that $C_1$ was more longer than broader and also that it was more conical with steeper side slopes. These features render it more liable to runoff losses. But, runoff percentage had been found to be comparatively lower from this catchment. The sediment load did not differ much between the two catchments (Table 14).

The only reason that can be deduced is the impact of shola forest, which efficiently conserve soil and water. The microclimate within shola and its soil moisture status lends credence to this view. It can be seen from the figures 4 and 5 that the temperature was low and steady within the shola. It was never seen to rise above 31$^{o}$C even during the hottest summer day nor to fall below 16$^{o}$C during the coldest winter night. The relative humidity values (Fig. 6) were high (70-100%) except in summer when it goes down to 50% during the day but bounce back to 95% in the night. This microclimate reduces the evapo-transpiration demand of shola vegetation permitting extended storage and release from the soil. The soil moisture status (Fig.7) during various months of the water year in the shola compared to grassland shows that during the non monsoon months shola soil holds much more water than the grassland. The absolute amount stored will be much more because the shola soil is spongy in the top layers on the one hand and it is deeper on the other hand creating more volume of storage per unit surface area. These facts explain the greater efficiency of the first catchment in reducing run off in spite of its morphological weakness.

Both the catchments, though small in extent has been found to feed the streams originating from them throughout the year. And the shola forests can be seen to be mainly behind this benevolence. Thus, it can be concluded that shola forests are capable of giving birth to and maintaining streams in the high ranges, though this conclusion arrived at from a single year study has to be supported by further detailed longterm studies. Establishment of permanent, full fledged, automatic stream gauging stations in all the important shola regions is suggested.

## 5. CONCLUSION

Hydrological data collected from two adjacent shola-grassland catchments at Chembra in South Wayanad during the limited period of one water year (1999-2000) revealed the importance of shola forests in conserving water and thus maintaining the streams perennial. The first catchment prone to easy runoff compared to the second by virtue of its morphometry was found on the contrary to contain runoff more efficiently that could only be attributed to the role of larger shola forest cover in that catchment. Thus shola forests play an important role in watershed management especially in the upper reaches of the Western Ghats.

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