RAINFALL INTERCEPTION AND PARTITIONING IN AFROMONTANE RAIN FORESTS OF THE EASTERN ARC MOUNTAINS, TANZANIA: IMPLICATIONS FOR WATER CONSERVATION

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MUNISHI, P. K. T. & SHEAR, T. H. 2005. Rainfall interception and partitioning in afromontane rain forests of the Eastern Arc Mountains, Tanzania: implications for water conservation. The aboveground components of the hydrologic cycle of rain forest are important processes that determine the hydrologic behaviour and dynamics of these ecosystems. Precipitation, throughfall, stem flow, canopy interception and streamflow were measured and modelled in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Measurements were made daily for 50 months in the Ulugurus and 56 months in the Usambaras. Throughfall was 76% of the gross rainfall in the Usambaras and 79% in the Ulugurus. Stemflow was less than 2% of rainfall. Both parameters were correlated with gross rainfall (r^2 = 0.97, 0.99, 0.86 and 0.94). Canopy interception was 22% of rainfall for the Usambaras and 20% for the Ulugurus. Streamflow was best modelled using five months running mean rainfall in the Ulugurus (r = 0.67) and three to four months in the Usambaras (r = 0.72). A high proportion of the gross rainfall is delivered as net precipitation. There is effective partitioning of rainfall on the forest canopy providing reasonable dumping effect of rainstorms. The slow response in streamflow to rainfall events shows the efficiency of the forests to mitigate storm water impacts and thus ensuring continuous water supply. Further studies in effects of forest harvesting on water yield are pertinent to enable adequate planning of forest utilization.

Key words: Throughfall – stemflow – interception – streamflow – afromontane – rain forest – eastern arc mountains

MUNISHI, P. K. T. & SHEAR, T. H. 2005. Pemintasan hujan dan pemetakan di hutan hujan hujan gunung Afrika di Pergunungan Ark Timur, Tanzania: implikasi bagi pemuliharaan air. Komponen atas tanah kitar hidrologi hutan hujan merupakan proses penting yang menentukan sifat serta dinamik hidrologi ekosistem ini. Curahan, jatuh telus, aliran batang, pemintasan kanopi dan aliran sungai di dua hutan hujan gunung

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Afrika yang terletak di Pergunungan Ark Timur, Tanzania disukat dan dibuat model. Bacaan diambil setiap hari selama 50 bulan di Uluguru dan 56 bulan di Usambara. Di Usambara, jatuh telus adalah 76% daripada jumlah hujan kasar sementara di Uluguru, jumlahnya ialah 79%. Aliran batang adalah kurang daripada 2% jumlah hujan. Kedua-dua parameter ini berkorelasikan dengan jumlah hujan kasar (r^2 = 0.97, 0.99, 0.86 dan 0.94). Pemintasan kanopi ialah 22% daripada jumlah hujan di Usambara dan di Uluguru, jumlahnya ialah 20%. Di Uluguru aliran sungai paling baik dimodel menggunakan purata hujan untuk lima bulan berturut-turut, tetapi memadai bagi tiga hingga empat bulan di Usambara (r = 0.72). Sebahagian besar jumlah hujan kasar turun sebagai curahan bersih. Terdapat pemetakan hujan yang berkesan di atas kanopi hutan dan ini memberi kesan campakan yang agak baik terhadap hujan ribut. Tindak balas aliran sungai yang perlahan terhadap hujan menunjukkan keberkesanan hutan mengurangkan impak air hujan ribut lantas memastikan bekalan air yang berterusan. Kajian lanjut tentang kesan penebangan hutan terhadap penghasilan air adalah penting untuk membolehkan rancangan bagi penggunaan hutan dibuat dengan baik.

Introduction

In Tanzania there is a general view that forest vegetation on mountains (montane forests) secure continuous supply of water. In other words presence of montane forests means constant supply of water during the dry season. This is contrary to many studies of the influence of forests on water yield (e.g. Bosch 1982, Bosch & Hewlett 1982, Shiklomanov & Krestovsky 1988). These studies showed an increase in water yield when forest was removed. Mountains are of vital importance to the globe as a source of water, typically having higher rates of precipitation than surrounding lowlands. Montane forests play an important role in the water cycle including the capture of atmospheric moisture, storage of water in and beneath canopies, and release to streams (Price & Butt 2000). In semiarid and arid regions, more than 90% of river flow comes from forested mountains (Price & Butt 2000).

To argue for forest conservation for water protection, one should be able to demonstrate the positive effects of a forest on streamflow as opposed to other landuses or non-forested lands. One approach is a paired watershed experiment in which runoff and rainfall are monitored in selected catchments for specific periods around a planned alteration in landuse. Alternatively, long-term monitoring of a deforested watershed and the effects of forest regrowth on water flow can also be used. Estimates of runoff coefficients of forested and non-forested land can be used to assess the effects of forests on surface runoff generation. High runoff coefficients mean larger amounts of surface runoff and lower base flows.

The hydrology of a forest ecosystem is complex, and several processes determine the paths of water movement before it reaches the streams. These processes include precipitation, interception, throughfall, stemflow, evaporation and runoff. In most of the tropics, rainfall is the major water input into a catchment. Fog condensation and horizontal precipitation may contribute considerable amount of water input in mountain forest ecosystems and coastal environments.

The amount of interception depends on the ability of the forest to collect and retain rainfall (interception capacity), storm size and intensity, evaporation rate, vegetation type and density, and canopy height, form and age (e.g. Shiklomanov & Krestovsky 1988). Although interception is not a major factor in most hydrologic calculations, it is believed to affect the water balance of montane forest ecosystems. On the other hand, throughfall and stemflow form the net precipitation that has a potential to enter the soil, recharge the ground water and generate stream flow (Owens 2002).

The Eastern Arc Mountains harbour hydrologically important vegetation in Tanzania. Most of these forests are gazetted forest reserves in mountainous areas that are managed for their role as major sources of water. We are developing an evaluation of the hydrologic values of the Eastern Arc mountain forests. This work will ultimately include intensive long-term assessments of streamflow and effects of forest management, reforestation and partial harvesting in these areas. The major objectives of this study were to evaluate the aboveground processes of the hydrologic cycle of these catchments, namely, precipitation, throughfall, stemflow, canopy interception and streamflow, and to analyse their relationships in two forests.

Materials and methods

Study sites

The Eastern Arc Mountains from southern Tanzania to southern Kenya run as a range of crystalline mountains near the Indian Ocean coast of Tanzania and Kenya (8° 51' S, 34° 49' E to 3° 2' S, 38° 20' E). The ancient crystalline rocks are part of the Pre-Cambrian Mozambique belt composed of highly metamorphosed sediments and minor intrusive igneous bodies that originated from block faulting dating back to the Karoo period approximately 300 million years ago (Lovett 1996).

The western Usambara Mountains (Figure 1) are in the northern part of the range (4° 25'–5° 07' S, 38° 10'–38° 35' E). The climate of the Usambaras is oceanic with bimodal rainfall partly determined by their proximity to the Indian Ocean and the equator. Rainfall peaks in April and November. The mean annual rainfall maximum is 2000 mm in the wettest areas falling to less than 600 mm in the rain shadow areas. The study site, Mazumbai forest reserve, is on the wetter side of this range. The monthly rainfall averages > 50 mm and the mean annual rainfall is 1300 mm. The Usambara Mountains are composed of late Pre-Cambrian rocks of the Usagara system, metamorphic rocks of the gneiss type. The area contains two highland soil types, namely, the Humic Ferrisols in the drier areas and Humic Ferralitic soils in the more humid and wet areas. Moist forests occur from 150 to 2285 m elevation, on the wetter eastern, southern and northern sides of the mountains.

The Uluguru north forest reserve (Figure 1) covers a steep summit ridge and the northern half of the Uluguru Mountains between Morogoro town and the Mgeta–Bunduki depression, within an altitude range of 1000 to 2340 m. The soils are acidic lithosols and ferralitic red, yellow and brown latosols that have developed over Pre-Cambrian granulite, gneiss and migmatite rocks. In the study area, a north-west to north-east facing slope (on the Bondwa summit at 2200 m), hornblende-pyroxene granulites are dominant with injections of granite and gneiss as well as some basic intrusions. Mean annual rainfall ranges from 1200–4000 mm year^{-1}, and temperatures range from 15–22 °C. Rainfall and temperature are

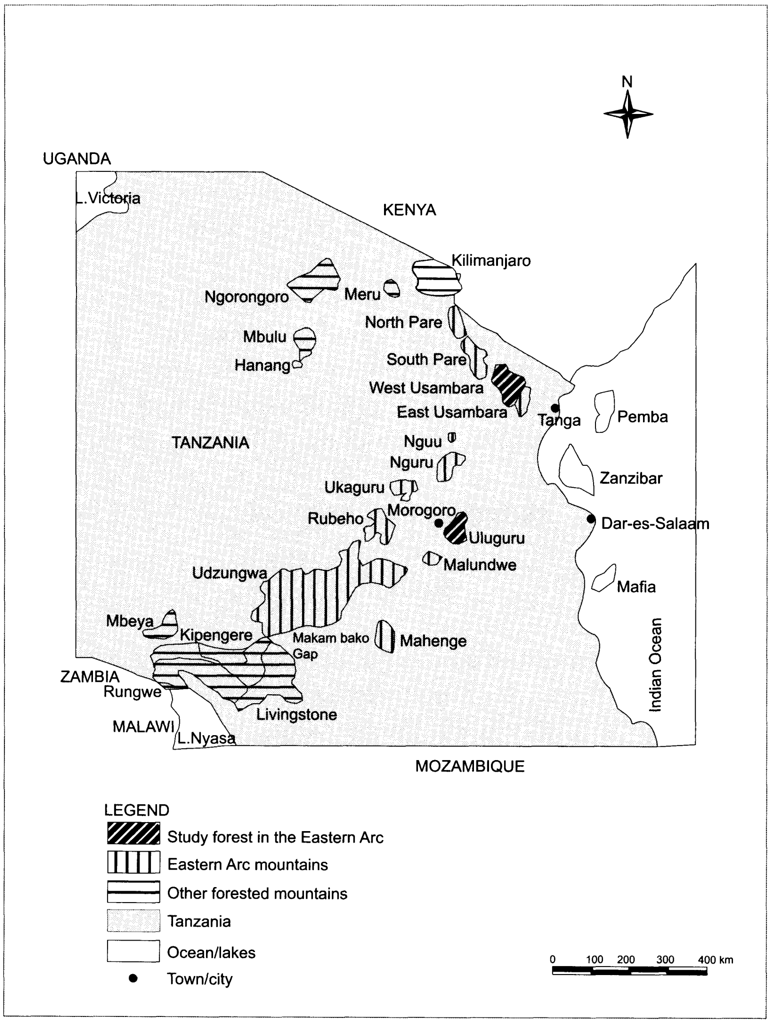

Figure 1 A map of Tanzania showing the Eastern Arc Mountains and the forests in which the study was conducted

oceanic with no marked dry season though short dry periods occur with rainfall peaking in April and November. With the exception of rock outcrops the forest reserve is entirely covered with moist submontane and montane forests. The study area falls within the montane evergreen forest zones that form a broad belt around both sides of the mountain.

Data collection

The methods used were designed for long-term monitoring of internal catchment hydrologic processes and water budget studies in the catchment forests of Tanzania (Norden & Munishi 1995). Three sampling points were established in the Uluguru mountain forests in April 1995 and in the Usambara mountain forests in April 1999. Though subjectively selected, the sites were established to represent as much as possible the different parts of the forests with respect to altitude forest structure and exposure. The distance between sites in the same forest was at least one kilometer.

In evaluating the relationship between rainfall and streamflow in the Usambaras, a longer period rainfall and streamflow data set (1990–1993) was used in order to avoid possible errors that may result from short period measurements. The rainfall data in these analyses were from ordinary standard rain gauge, 13 cm orifice, diameter and a circumference of 40 cm, installed within the watershed. This data set did not have corresponding throughfall and stemflow measurements.

A total of 30 troughs were placed under the forest canopy in three selected sites in each forest. The size of trough used in the Ulugurus was 100 × 25 cm, with a collecting area of 2500 cm^2 while in the Usambaras, the size was 75 × 20 cm and collecting area, 1500 cm^2.

In each area, two troughs similar to those inside the forests were placed in open areas outside the forests to measure gross rainfall. All troughs were placed in fixed positions, 75 cm above the soil surface with their long axis perpendicular to the slope direction (Hutjes *et al.* 1990). They were attached to supporting wooden frames and installed at a slanting angle to enable water to flow into funnels that led into sealed plastic containers.

Stemflow was collected from 10 (five at each site) randomly selected trees with diameters of 18–60 cm at breast height (dbh) in the Ulugurus, and nine trees (three at each site) in the Usambaras (25–56 cm dbh). Split plastic tubing was spirally wrapped firmly at about 1.3 m height of each tree to collect water flowing down the stem. One end of the tube was attached to the lid of a plastic container, allowing water to drain into the container. Both throughfall and stemflow were measured daily. The projected crown areas were estimated for each tree with stem flow measurements. The mean crown area for all trees in each forest was used to represent the collecting area for stemflow.

Stage heights (water levels) were measured at stream gauging stations with v-shaped 90° weirs established about 1000 m downstream of a stream that drains the forests at the experimental sites. In the Ulugurus, stage heights were recorded by an automatic water level (chart type) recorder that gave continuous recording of water levels. In the Usambaras stage heights were measured from a graduated staff installed in the measuring dam and read three times daily, i.e. in the morning, afternoon, and evening at approximately six-hour intervals. The daily water level was the average of the three readings.

Data analyses

The average daily gross precipitation, throughfall and stemflow volumes were computed as the total rainfall collected by all troughs or trees divided by the number of troughs or trees at each site. The monthly totals were computed as the sum of the daily averages. These monthly totals were divided by the collecting areas (trough areas for precipitation and throughfall, and crown area for stemflow) to convert them into precipitation, throughfall, and stemflow per month (in mm). Stage heights (cm) were averaged on monthly basis. Throughfall, stemflow and streamflow sample events were regressed against gross rainfall to evaluate their relationships and develop prediction models for throughfall, stemflow and streamflow from gross rainfall. Paired *t*-tests were used to evaluate any difference in throughfall and stemflow between experimental sites in the same forest.

Results

In the Usambaras, throughfall was 76.9% of the gross rainfall, stemflow was 1% of the gross rainfall, and canopy interception was 22.9% of the gross rainfall (Table 1). Throughfall for the Ulugurus was 79.3% of the gross rainfall (Table 1). The mean proportion of monthly rainfall partitioned as stemflow was 1.2% of the incident rainfall. Canopy interception was 19.7% of the gross rainfall. Though stemflow constitutes a relatively small proportion of the gross rainfall delivered as net rainfall compared with throughfall, the two showed similar trend (distribution) when compared with gross rainfall.

The monthly mean rainfall was higher in the Ulugurus than in the Usambaras. The proportions of rainfall partitioned as throughfall, net rainfall and interception

Table 1 Mean monthly throughfall, stemflow, interception, and net rainfall as a percentage of gross precipitation in the afromontane rain forests of the Eastern Arc Mountains, Tanzania

Forest	Parameter	Range	Mean ± SE (mm)	% Gross rainfall
Usambara	Gross rainfall	1.9–429.3	122.7 ± 24.6	
	Throughfall	67.9–183.9	94.4 ± 21.3	76.9
	Stemflow	0.1–2.1	1.2 ± 0.1	1.0
	Net rainfall	67.9–184.2	95.6 ± 21.4	77.9
	Interception	15.8–32.1	27.1 ± 3.8	22.1
Uluguru	Gross rainfall	3.1–916.9	247.9 ± 32.2	
	Throughfall	37.0–266.9	196.6 ± 29.2	79.3
	Stemflow	0.1–4.4	3.2 ± 0.5	1.2
	Net rainfall	37.6–302.3	199.8 ± 29.6	80.5
	Interception	0.0–62.4	48.8 ± 5.5	19.7

did not differ much between the two forests (Table 1). Stemflow contributes relatively small amounts of water (about 1%) to the forest floors in both forests. Table 2 shows that generally, all sites within the same forest had significant differences in throughfall and stemflow ($p < 0.05$). Both throughfall and stemflow showed similar increasing trends with increasing amount of monthly precipitation. Throughfall and stemflow were relatively more variable with low rainfall events. Low rainfall events were also among those with relatively high amounts of throughfall.

Net rainfall is the remainder of the gross rainfall delivered to the forest floor after canopy interception. This proportion was higher in the Ulugurus than in the Usambaras (Table 1). Canopy interception was higher in the Usambaras despite lower stem density (988 ± 376 stems per ha^{-1}) than in the Ulugurus (1164 ± 397 stems per ha^{-1}). Both forests had similar diameter distribution (25 ± 6 cm dbh in the Usambaras and 22 ± 2 cm in the Ulugurus).

Regression of monthly throughfall and stemflow against gross precipitation showed a significant linear relationship in both forests (Table 3). Individual monthly mean rainfall events showed no correlation with streamflow. Streamflow was best modelled using five year running average rainfall in the Ulugurus and three to four years in the Usambaras. Both gross rainfall and net rainfall showed significant linear relationship with streamflow ($p < 0.01$) (Table 3). In the Usambaras, the prediction model for streamflow from rainfall developed from a short period of seven months data set was almost identical to the one developed from a longer period of three years (Table 3).

Discussion

The distribution of precipitation followed the long-term distribution patterns typical of the study sites with bimodal annual rainfall patterns. The average proportions of the incident rainfall partitioned as throughfall, 79.3% for the Ulugurus and 76.9% for the Usambaras, are close to those given by other studies for montane and lowland tropical rain forests; e.g. in a study long enough to account for seasonal variations in storm patterns and/or vegetation status, Bruijnzeel (1990) reported

Table 2 Paired *t*-test (p-values) showing within forest differences in throughfall and stemflow in two afromontane rain forests of the Eastern Arc Mountains, Tanzania

Forest	Site	Throughfall	Stemflow
Usambara	1 & 2	0.009	0.009
	1 & 3	0.020	0.010
	2 & 3	0.004	0.003
Uluguru	1 & 2	0.030	< 0.001
	1 & 3	0.050	< 0.001
	2 & 3	0.410	0.040

Table 3 Prediction models for throughfall (mm), stemflow (mm), and streamflow (m) from gross rainfall (mm) and net rainfall (mm) in two afromontane rain forests of the Eastern Arc Mountains, Tanzania

Forest	Model	r^2	Period
Uluguru	Throughfall = 0.893 Rainfall – 3.94	0.97	50
	Stemflow = 0.014 Rainfall – 0.30	0.86	50
	Streamflow = 0.00093 Rainfall + 0.23	0.67	37
	Streamflow = 0.00099 Net Rainfall + 0.25	0.69	37
Usambara	Throughfall = 0.86 Rainfall – 8.5	0.99	8
	Stemflow = 0.002 Rainfall – 0.09	0.94	8
	Streamflow = 0.00091 Rainfall + 0.20	0.72	7
	Streamflow = 0.0009 Net Rainfall + 0.20	0.72	7
	1Streamflow = 0.0006 Rainfall + 0.20	0.73	46

Note: Streamflow was measured as stage height (m). The p-values for every model are < 0.01.
[1]This model was developed using a longer data set from the Usambaras (March 1990–December 1993). The models for the short and long data sets were almost identical.

a mean 81% for tropical montane rain forest while Uebel (1997) reported a 96% throughfall when using a shorter data set (three months) from the Ulugurus. Studies in tropical rain forests have all shown that less than 1% of annual rainfall was partitioned as stemflow (e.g. Uebel 1997). Stemflow in this study was a little higher than those given in other studies from tropical rain forests but similar to that of hypermaritime forests of different climatic conditions in the north coast of British Columbia, Canada (Anonymous 2002). On the other hand, it was lower than that of some urban forests also in different climatic conditions (Xiao *et al.* 1998). Both throughfall and stemflow increased with increasing amount of monthly rainfall as has been shown in other studies of tropical rain forests (e.g. Richards *et al.* 1996). Small rain events of less than 5 mm gave high percentages of throughfall. The minimum measurable amount of rainfall that can be detected by the rain gauge used in this study was 1 mm and all amounts below this were not quantified and were recorded as trace. High percentages of throughfall may result from rain events that occur when the canopy is fully saturated such that very small amount of rainfall is required for water to start dripping from the forest canopy. Such small rain events may not be recorded in meteorological stations but the rain produces substantially measurable amounts of throughfall. In addition, fog condensation (occult precipitation and horizontal precipitation) in the forest canopy may also be sufficient to cause measurable amounts of throughfall without any rainfall being recorded in meteorological stations outside the forest. Uebel (1997) found that in several occasions rainfall measured inside the forest was higher than that measured outside the forest in the Ulugurus. This is common in montane cloud forests such as the sites in this study.

Net rainfall was higher in the Ulugurus but canopy interception was higher in the Usambaras. Since both forests have similar diameter, the differences may be accounted for by storm characteristics, seasonality and probably tree architecture rather than forest structure. Species composition in the Usambaras was different from the Ulugurus and this may account for tree architectural differences.

Due to their close proximity, the differences in stemflow and throughfall between different experimental sites within the same forest (vegetation type) as observed in this study cannot be explained by differences in rainfall. A relevant explanation is likely to be variations in forest structure, such as number of stem density and diameter distribution (Spittlehouse 1998, Anonymous 2002). This means that there were wide site variations in forest structure within individual forests that can greatly influence variations in throughfall and stemflow between different sites. Other possible causes may be tree structural and geometrical differences, e.g. vertical stratification and branching geometry. Horizontal precipitation may also account for the differences since the study sites are at an elevation where horizontal precipitation is likely to augment the amount of rainfall. Some investigators have reported less stemflow in large diameter trees compared with small diameter trees in tropical rain forests (e.g. Uebel 1997).

The interception figures observed in this study are higher than those reported in other studies for tropical rain forests (e.g. Lu & Tang 1995, Asdak *et al.* 1998a, b), but are similar to those of a hypermaritime forest in north coast of British Columbia (Anonymous 2002) and a mature poplar-pasture vegetation (Guevara-Escobar *et al.* 2000).

Monthly rainfall ranged from 1.9–429.3 mm and 3.1–916.9 mm in the Usambaras and Ulugurus respectively. In our analysis the daily rainfall data were lumped into monthly means, which may cause inconsistency in the results and conclusions thereof. The characteristics of individual rain events (peak, intensity and intensity profiles) are likely to be very different in a 'dry' month compared with a 'wet' month and this has a bearing on the mean monthly rainfall. However, such inconsistencies may be reduced if a long-term data set was used. This study used data from observations of over 36 months; we considered this to be long enough to account for seasonal variations in the parameters though longer period data would increase the precision. The short data set used in the Usambaras helped to confirm the consistency of rainfall patterns in the region. The similarities between the model from short and long data sets in the Usambaras confirmed the strength of the correlation between rainfall and streamflow in these forests, irrespective of rainfall duration. The strong correlation between rainfall, throughfall and stemflow in the two sites indicated that streamflow can adequately be predicted from measurements of rainfall where costs for establishment of stream gauging stations are prohibitive. Such relationships are enhanced by the presence of the forest vegetation. Interception and the manner in which rainfall is partitioned on the forest canopy is a measure to determine the efficiency of a forest ecosystem to mitigate storm water impacts through reduction of runoff volume and delay peak flows. This is an important characteristic of vegetation biomes managed for water/soil conservation and this is true for the Eastern Arc forests.

Conclusions

Canopy interception accounted for at least 20% of the rainfall in the Eastern Arc forests. On average, more than 70% of the incident rainfall is delivered to the forest floor by throughfall. Stemflow delivered about 1%. The slow response of streamflow with storm events is an indication of the potential of these forests to mitigate storm water impacts by reducing runoff volumes and delaying onset of peak flows. The prediction models for throughfall, stemflow, and streamflow are the first to be developed for the forests of the Eastern Arc Mountains of East Africa. The present description and modelling of these processes given here, though preliminary are important for future development and testing of water balance models, which can help in resource management planning, especially that related to changes in landuse and conservation of water resource. The models may also be useful in similar forest ecosystems elsewhere in the region. Though variations may exist, the models developed in this study are good approximations where resource constraints prevent extensive studies of the aboveground components of the hydrologic cycle.

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References

ANONYMOUS. 2002. Canopy interception in a hypermaritime forest on the north coast of British Columbia. Extension Note No. 49. *http//www.for.gov.bc.ca.rni/Research/Extension_Notes/Enote49.pdf.*

ASDAK, C., JARVIS, P. G. & GARDINGEN, P. V. 1998a. Modeling rainfall interception in unlogged and logged forest areas of Central Kalimantan, Indonesia. *Hydrologic and Earth Systems Sciences* 2(2–3): 211–220.

ASDAK, C., JARVIS, P. G., GARDINGEN, P. V. & FRASER, A. 1998b. Rainfall interception loss in unlogged and logged forest areas of Central Kalimantan, Indonesia. *Journal of Hydrology* 206: 237–244.

BOSCH, J. M. 1982. Stream flow response to catchment management in South Africa. Pp. 279–254 in *Proceedings of Symposium on Hydrological Research Basin and Their Use in Water Resource Planning.* Sonderh Landeshydrologic, Bern.

BOSCH, J. M. & HEWLETT, J. D. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* 55: 3–23.

BRUIJNZEEL, L. A. 1990. *Hydrology of Moist Tropical Forests and Effects of Their Conversion: A State of Knowledge Review.* UNESCO International Hydrological Programs: Amsterdam.

GUEVARA-ESCOBAR, A., EDWARDS, N. R. W., MORTON, H. R., KEMP, D. P. & MACKAY, A.D. 2000. Tree water use and rainfall partitioning in a mature poplar-pasture system. *Tree Physiology* 20: 97–106.

HUTJES, R. W. A., WIERDA, A. & VEEN, A. W. L. 1990. Rainfall interception in the Tai forest Ivory Coast: application of two simulation models to humid tropical system. *Journal of Hydrology* 114: 259–275.

LOVETT, J. C. 1996. Elevational and latitudinal changes in tree associations and diversity in the eastern arc mountains of Tanzania. *Journal of Tropical Ecology* 12: 629–650.

LU, S. & TANG, K. 1995. Study of rainfall interception characteristics of natural hardwood forests in Central Taiwan. *Bulletin of Taiwan Forest Research Institute New Series* 10(4): 447–457.

NORDEN, G. L. & MUNISHI, P. K. T. 1995. *The Catchment Forest Project Report.* Sokoine University of Agriculture, Morogoro.

OWENS, K. M. 2002. Rainfall partitioning within Juniper Communities. Final Report to the Texas Water Resources Institute. Texas Agriculture Experiment Station, Uvalde Research and extension Center. *http//www. Uvalde.tamu.edu/staff/keith/TWRI2002% 20 Report. pdf.*

PRICE, M. F. & BUTT, N. (EDS.) 2000. *Forests in Sustainable Mountain Development: A State-of-Knowledge Report for 2000.* CAB International, Wallingford.

RICHARDS, P. W., WALSH, R. P. D., BAILLIE, I. C. & GREIG-SMITH, P. 1996. *The Tropical Rain Forests.* 2nd edition. Cambridge University Press, Cambridge.

SHIKLOMANOV, A. I. & KRESTOVSKY, I. O. 1988. The influence of forests on reclamation practice on stream flow and water balance. Pp. 78–82 in Reynolds R. C., & Thompson, B. F. (Eds.) *Forests, Climate, and Hydrology; Regional Impacts.* United Nations University, Tokyo.

SPITTLEHOUSE, D. L. 1998. Rainfall interception in young and mature coastal conifer forests. Pp. 40–44 in Alila, Y. (Ed.) *Mountains to Sea: Human Interaction with the Hydrological Cycle.* Canadian Water Resources Association, Cambridge.

UEBEL, J. 1997. *Throughfall and Stemflow in a Montane East African Rainforest.* Minor Field Study No 16. Swedish University of Agricultural Sciences, Uppsala.

XIAO, Q., MCPHERSON, G. E. SIMMPSON, R. J. & USTIN, S. 1998. Rainfall interception in Sacramento's urban forest. *http//www.Cstars.ucdavis.edu/papers/html/xiaoetal1998a paperfr.html.*