INFLUENCE OF DEFORESTATION & AFFORESTATION ON VARIOUS HYDROLOGICAL PARAMETERS

1989-90

NATIONAL INSTITUTE OF HYDROLOGY
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PREFACE

The history of forest influences on hydrological parameters dates back to thirteenth century which led to the evolution of the specific field of forest hydrology. Interest in forest influences on hydrological parameters increased rapidly during nineteenth century and has continued since then. However, the efforts in this direction in India have been somewhat limited. From the studies conducted so far, no specific inferences can be drawn regarding forest influences on hydrologic parameters like floods and soil moisture. It has, however, been realised that forest vegetation management in upland watersheds can improve the water budget of a catchment. The studies are in progress at various places in the country and elsewhere to understand the influence of forest and its manipulations on hydrological regime.

In view of the existing gap in defining exact role of forests in relation to their effects on hydrological parameters, the Institute took up work of compiling results of related studies done in the country and abroad. The literature available was critically scanned and based on these efforts, following three status reports were prepared:

(i) Forest influences on hydrological parameters

(ii) Status of hydrological studies in forested catchments

(iii) Sediment yield from different land uses

Later, using available information, a paper entitled 'Hydrological Responses of Land Uses' was also prepared. The Institute has taken up a programme to study the relationship between land, soil, water and vegetation and their inter-relationship. The present note gives a summary of findings of the reports and the paper. It may be mentioned that most of the results reported pertain to small watersheds and may not be applicable to large catchments directly. Dr. K.K.S. Bhatia, Sri A.K. Sikka, Sri V.K. Lohani and Sri N.S. Raghuvanshi have contributed to the compilation of various studies and preparation of this report.

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Director

INFLUENCE OF DEFORESTATION & AFFORESTATION ON VARIOUS HYDROLOGICAL PARAMETERS

The influence of forests on their environment forms part of a complex relationship between environment and forest vegetation. Investigators have investigated for past several decades to ascertain the influences of forests on hydrological parameters and water availability. In this direction, forest influences on various hydrological parameters viz. rainfall, interception, infiltration, soil moisture, evapotranspiration, groundwater, water yield, soil loss and floods etc. forms an important area of hydrological studies. A summary of results of studies done in this regard in the country and elsewhere is given in following sections.

1.0 RAINFALL

In India, limited studies have been directed towards the effects of forests on rainfall. In 1906, a committee was set-up by Govt. of India to find the relationship among forests, atmosphere and soil; which concluded that the effects of forest on rainfall were probably small (Hill, 1916). Voeleker (Lohani, 1985) had conducted studies on small plots for about 52 years on rainfall and forest data in Nilgiris and had concluded that the planting of trees increased the number of rainy days on local scale. Another study indicated that there was no increase in rainy days during monsoon period (Ranganathan, 1948). Bhattacharya (1956) after conducting intensive studies in Pathri, Ranipur and Ratmau (in U.P. hills) concluded that planned deforestation did not have any effect on rainfall. Pisharot opined that local changes due to deforestation are less likely to affect the meteorological aspects and quoted experiments done in Germany and England in support of his opinion (quoted from Mistry, 1987). Biswas (1980) has related percentage of forest cover with total rainfall in A & N Group of Islands and concluded that rainfall seems to increase with forest cover. However, India Meteorological Department (IMD) denies any correlation between deforestation and rainfall (Agarwal et. at., 1987). In a detailed study conducted in Western Karnataka and part of Kerala, Mehar Homji (1986) concluded that forest clearance did not seem to reduce the total number of rainy days. Dutt and Manikiam (1987) have concluded based on results of several studies that deforestation has effects on rainfall on local scale but on regional or global scales these effects are not significant.

Regarding studies done abroad, there are two schools of thought, one claiming that forests do influence rainfall although on a small and local scale and other strongly claiming that forests in general do not have significant effect on rainfall. Lee (1980) has strongly refuted the claim that forests increase rainfall. Pereira (1973) has also stated that there is no corresponding evidence as to any effects of forests on the occurrence of rainfall. Zon (1927) and Hursh (1948) have opined that forests influence the rainfall in the area but these claims can be challenged because of local and small scale conditions. In coastal fog belts or mountainous area characterized by frequent or persistent cloud, forests could capture and condense atmospheric moisture which in some cases might form a significant portion of rainfall as reported by Hamilton & King (1983), Lee (1980).

Based on the limited studies done in India and abroad it may be concluded, that the results are generally inconclusive in nature, indicating that forests do not effect rainfall on a regional scale. However, in coastal forests the precipitation may be more because of interception and then condensation of fog by forests.

2.0 INTERCEPTION

The results obtained in various interception studies carried out in India and abroad by Dabral et. al. (1963), Dabral and Subbarao (1969), Mathur et. al. (1975), Lull (1964) and others (as given in Appendix-I) indicate that the canopy interception varies from 15% to 35% of rainfall for different species of forests. There is evidence that interception varies not only with type of species, canopy density etc. but also with intensity of rainfall, as is evident from Appendix-II (Mathur et. al. 1975, Kittredge, 1962). It indicates that interception reduces with increase in rainfall amount and beyond 60 mm rainfall/storm, the interception loss reduces to significantly low values.

It can be concluded that the interception is a function of forest type, density, composition, structure and rainfall amount/intensity. It may be inferred that the average total interception by a dense forest cover (including canopy interception 20%, undergrowth 10% and litter interception 5%) appears to be around 35%. It has also been observed that the interception is higher from needle leaved trees as compared to broad leaved trees. The interception in forested catchments does not have significant effect during heavy storm (100 mm or so). However, this is important from soil conservation view point.

3.0 INFILTRATION

Results obtained from some studies done in the country and abroad regarding infiltration rates under various land uses are presented in Appendix-III. In a study conducted at Bellary (semi-arid region) and Ootacamund (Nilgiri hills) under different vegetative covers, the results indicated maximum infiltration rates for woodlands as 17 cm/hr and for Shola forest (miscellaneous vegetation) as 12.5-16.8 cm/hr. In Bihar, Mistry and Chatterjee (1965) recorded average infiltration rates as 26, 12 and 9 cm/hr under forests, grasslands and crop lands, respectively. A comparative study of infiltration rates conducted in Dehradun (North-Western Himalayan region) under Eucalyptus, Sal, Chir, Teak, Bamboo and grassland gave initial infiltration rates as 54.0, 21.4, 12.0, 9.6, 9.6 and 7.6 cm/hr, respectively. In the same study, effects of fire on infiltration in Chir plantation was studied and infiltration was found to reduce to a value of 3.6 cm/hr. The analysis of infiltration data from small forests and agriculture watershed in Doon valley indicated that the rate of infiltration was twice in forest watershed (Shorea Robusta) as compared to agriculture watershed(Dhruvanarayana and Shastri, 1983). Dunford (1954) reported reduced infiltration capacity of soil devoid of leaf litter in ponderosa pine forests of Colorado, USA.

In general, it can be inferred that the infiltration rates are relatively more in forested soils as compared to agricultural areas & grasslands. Based on the results of some of the infiltration studies carried out, it could be inferred that infiltration rates from arable crop land and grasslands are nearly 30 to 35% and 40-50% respectively of that from forest lands. However, it is drastically affected due to biotic interferences like forest fires, tampling by cattles, removal of leaf litter etc. The studies conducted abroad also confirm these results (Molchanov, 1963).

4.0 SOIL MOISTURE

A limited number of studies have been conducted to observe the effects of forest on soil moisture regime. In a study conducted at Dehradun, it has been observed that soil moisture (in mm of soil depth) remains at higher level under forest than grass, e.g. bamboo (14-102), teak (30-73). Results of soil moisture studies conducted in Nilgiris in latritic soil under various land uses are given in Appendix IV. It can be observed that soil moisture always remains higher in forested lands as compared to agricultural lands.

In general, it can be concluded that much efforts have not been made to quantify soil-moisture storages under forested lands. However, forested soils have a better soil moisture retention capacity due to improved soil structure because of more humus and organic content.

5.0 EVAPOTRANSPIRATION

As for the effects of forests on evaporation, the presence of forests may provide shade to ground, thereby reducing both air and soil temperatures and also wind velocity which finally reduces evaporation. One of the measures to reduce reservoir evaporation is by growing thick forest along the periphery of the reservoir. As a result the wind velocity at the reservoir surface gets reduced which reduces evaporation from reservoirs. The presence of forests also affects temperature in terms of having effects on surface albedo. As stated by Pereria (1973) the reflection ranges from 12% for pine forest to 40% for deserts. Obviously lower the albedo and more will be the energy available for evaporation losses in case of forested areas.

Studies leading to computation of forest transpiration have indicated that forests generally absorb more radiant energy which is available for transpiration. A limited number of studies done, have indicated that forest have generally high evapotranspiration (ET) requirement as compared to other land uses. Results of few such studies have been summarized in Appendix V. Gupta (undated) has cited Engler's observation as the transpiration of forest compared with crop land and meadows could be indicated as 100 : 43 : 22.

The studies conducted in India and abroad indicate that forests have higher ET requirements as compared to other land uses. However, more studies are required to be done for systematic computation of ET by forests.

6.0 GROUNDWATER

There exist some data that show higher water tables follow forest clearing (Boughton, 1970; Melzer, 1962). This effect is apparently due to the replacement of deep rooted trees, which are able to use soil moisture at depth, by shallow-rooted annuals with a lower water use. In Northern Thailand, Chunkao (as cited in Hamilton & King, 1983) reported a decrease in well levels in dry seasons following reforestation. In Southern Australia, Cassells (quoted by Hamilton & King, 1983) reported that some areas under grass, about 10 percent of the annual 632 mm rainfall reached the underground aquifer, but under nearby pine plantations no recharge at all occurred. The small watershed cutting experiments have yielded in a general conclusion that total water yield over the year increases with the greatest increases in the low flow months. Boughton (1970) has also indicated that most cutting experiments have shown rise in groundwater levels. In the studies conducted for Nilgiris in India, Samraj (1984) observed that plantation of Eucalyptus trees has resulted in significant lowering of base flows.

The effects of forests on groundwater have not been studied on large scale. A limited number of studies done abroad in this regard have indicated non-coherent results. The American studies claim that water table collapsed as a result of deforestation or forest fire while Swiss studies seem to indicate no effects on water table by forests cover changing to grass (Hamilton & King 1983).

7.0 WATER YIELD

Trees through their root system allow a definite volume of percolation and subsequent movement of percolated water. The roots also extract soil moisture regularly to provide necesary nutrients to super-structure above the ground. Thus, when forest is cut, this system gets snapped all of a sudden and thereby water gets stored in to the soil profile and its subsequent utilisation or deposition by plant body gets disturbed. This results in sudden increase in water yield in the from of surface runoff. The results of experimental studies conducted in USA and elsewhere have shown increased stream flow following forest cutting in a watershed. In Japan and Kenya also a large increase in water yield was observed following clearing of forests (Hibbert, 1965). It has also been observed at places that removing 30% or less of the forest cover would not produce a significant change in stream-flow. In India, Subbarao et.al (1985) did not record any significant increase in fortnightly water yield after imposing 20% of forest thinning in coppice sal forest at Dehradun. It has also been observed that reforestation of a small brushwood watershed (1.45 ha) by Eucalyptus species (replacing brushwood) reduced water yield by 28%. Results of some such studies are summarized in Appendix-VI.

Based on studies reported above, it can be inferred that substantial reduction of densities of forest overstories and thinning (more than 30%) increase water yield and establishment of forest overstories on sparsely vegetated land and/or changing to fast growing species like Eucalyptus decrease water yield. This decrease is more significant in first few years of growth. Besides, the type of land cover, the size of watershed have also important bearing on water yield. Based on various studies, it appears that in small watersheds forests tend to decrease the water yield (i.e. due to decreased surface runoff) while in large watersheds, the subsurface component of total water yield (delayed yield) gets increased.

8.0 SOIL LOSS

The soil loss in a catchment would largely depend upon the land use pattern. Bhatia (1986) presented the results of various experimental studies conducted by researchers in India for soil loss from different land uses. The results were presented for various land uses e.g. forests, grass-lands, agricultural lands, fallow lands, ravine lands, bare rocks etc. From the results of various studies, a summary table (Appendix-VII) was derived to give specific ranged of soil loss for each land use. In Kenya, replacement of rainforest by contour planted tea estates resulted in no significant increase in soil loss (Edwards and Blackie, 1981). However, varied experiences have been there in this regard (Gintings; 1981, Drysdale and Manner, 1981).

From the limited studies, it can be concluded that soil loss is less from dense, well managed forests in comparison to ill managed (denuded) forest. However, soil loss is very less from well managed grass lands. Soil conservation is an effective answer to soil loss problems.

9.0 FLOODS

The occurrence and frequency of floods can not be conclusively linked with deforestation or afforestation in absence of factual data. Studies conducted by Bhattacharya (1956) indicated that the planned and limited deforestation did not have any untoward consequence with regard to floods in Pathri and Ranipur catchments (U.P., India). However, some effects were found on the frequency (not intensity) of floods in Ratmau catchment. Hewlett (1982) has recently examined the evidence worldwide from Forest Watershed Research and reported that there was no cause-effect relationship between forest cutting in the head waters and floods in the lower basins.

It is important to note that afforestation measures basically minimize soil loss and reduce sediment load in streams and rivers thus moderating flash floods. The effect of forestation may be insignificant for large floods.

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Appendix - I

Effect of Forest Species on Interception

Forest Type	Interception as % of rainfall	Reference
Babul	26.0	Mathur et. al. 1975
Khair	28.5	Dabral et al. 1963
Teak	20.8	Dabral and Subba Rao, 1969
Chir	22.1	-do-
Sal	25.3	Dabral et. al. 1963
Eucalyptus (Bluegum)	21.9	Samraj et. al. 1982
Natural Shola Forest	33.3	Singh and Prajapati, 1974
Northern U.S. Harwoods	15.0	Lull, 1964
Spruce Fir	32.0	-do-
White Pine	26.0	-do-
Hemlock	28.0	-do-
Acacia	25.1	
E.Hybrid	11.56	
Shisham	6.5	
Cybress	36.0	
Shorea Robusta	25.3	
Bamboo	20.0	
N.Carolina Hardwoods	23.0	
Conifers (Rain)	22.0	
Conifers (Rain snow)	28.0	
Deciduous forest	13.0	

Appendix - II

Effect of Rainfall Amount/Intensity on Interception

Rainfall (mm)	Interception as Percentage of Rainfall (%)	
	Sal Forest (India, Mathur et. al, 1975)	Cryptomeria (Japan Kittredge, 1962)
0-1	-	83.0
1-3	-	61.0
3-6	37.3	51.0
6-10	-	35.0
10-20	24.5	18.0
20-40	13.0	-
40-60	5.9	12.0
60-100	4.1	11.0
100 & above	4.1	-

Effect of Forest Species on Infiltration

Land Use	Infiltration Rate (cm/hr)	Reference
Shola Forest	16.84	Tejwani et. al, 1975
Bluegum	20.69	-do-
Grazed Grassland	5.13	-do-
Forest Land	26.00	Cited from Gupta, 1980
Grass Land	12.00	-do-
Crop Land	9.00	-do-
Oak forest	66.00	Molchanov, 1963
Ash forest	124.2	-do-
Meadow	36.00	-do-
Cultivated land	7.2	-do-
Pasture	1.8	-do-
Sal	2.2-8.95	
Ash	16.8	

Appendix - IV

Effect of Forests on Soil Moisture (Soil Type - Lateritic, Nilgiris, India)

Forest type/land use (India)	Soil Moisture (cm/mt depth)											
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
Cultivated Branch/Terrace	23.5	19.0	20.5	20.0	19.5	22.0	17.5	17.5	17.5	17.5	20.0	16.0
Shola	30.5	27.0	23.0	28.5	26.0	31.0	22.5	22.5	22.0	24.0	25.0	20.0
Bare (Earlier Grassland)	30.0	25.0	22.0	28.0	17.5	27.0	18.0	21.0	20.0	23.0	25.0	24.0
Grassland	38.0	30.0	27.0	30.0	18.5	32.6	17.0	24.0	20.0	22.0	22.5	23.0

Source : Derived from Anon (1982)

Appendix - V

Effect of Forests on Evapotranspiration

Forest type/ land use	Evapotranspiration (mm)	Transpiration	Reference
Chir	840	-	Dabral et. al. (1965)
Teak	840	-	-do-
Sal	560	-	-do-
Eucalyptus	268-5526	-	-do-
Forest	50% of precipitation	100	Kunlcle (1975)
Grasslands	38% of precipitation	22	Gupta (undated)
Cropland	-	43	
Eucalyptus Globulees	38% of precipitation	-	Thomas (1972)
Dry Deciduous Forest	560	-	Mishra (1968)
Pinus	536	-	Dabral et. al. (1965)
Radiata	760-885	-	
Pinaster	149	-	
Macarthuri	268	-	
Stuartiana	1200	-	
Diversi Colour	1248	-	

Appendix - VI

Water Yield as Affected by Land use

Region/Place	Cover conditions	Runoff as percentage of Rainfall (%)	References
N-W Himalayas	Coppice Sal forest	35-45	Lal and Subba Rao, 1981
	High Sal forest	14-23	Mathur, 1980
	Agril. Watershed		
	Untreated	9	Dhruvanarayana et.al. 1985
	Treated	6	
	Grass cover	21-27 (monsoon) 4-11 (winter)	Tejwani et.al. 1975
Southern Hills	Forest watershed		
	Well managed	25-43	Chinnamanni, 1985
	Ill managed	10-30	
	Agril. Water		
	Well managed	6-30	
	Ill managed	10-30	
	Grassland Watershed	10-30	
U.S.A at various regions	Forested Watershed	4-18 (surface runoff)	Hamilton and King, 1983
The Philippines	Primary Forest	0.25	
	Logged over forest (Plots of 8 m^2)	1.75	
	Imperata grassland		
Malaysia	Natural Forest Watershed (15 ha.)	16.0	
	Eucalyptus (15 ha.)	20.0	

Appendix - VII

Land Use and Soil Loss Ranges*

Sl.No	Land Use	Soil Loss (t/ha/year)
1.	Forest	
	a) Dense, Well Managed	0.5 to 0.90
	b) Ill Managed (denuded lands)	20.0 to 60.0
2.	Agricultural Lands	
	a) Without soil conservation	
	i) Hilly areas	20.0 to 40.0
	ii) Plain areas	5.0 to 20.0
	b) With Soil conservation (varying from simple agronomic practices to engineering measures)	
	i) Hilly areas	1.0 to 19.0
	ii) Plain areas	0.0 to 3.0
3.	Cultivated Fallow Lands (1% to 9% slope)	4.0 to 70.7
4.	Ravine Lands	
	i) Denuded lands	10.0 to 20.0
	ii) Treated lands	0.5 to 5.0
5.	Grass Lands	
	i) Well Managed	0.0 to 1.0
	ii) Ill managed	20.0 to 40.0

* This table has been derived from results of various studies conducted in India at various places for various slopes for different rainfalls for different soils etc. Ranges are being presented here to give a general idea of the soil loss from a particular land use.

Source : Bhatia (1986)

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