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Forest hydrological studies in different agro-climatic conditions in India

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ABSTRACT

Forests are essential to both development and preservation of global environment. A review of the results on runoff, peak discharge and soil loss from small forest watersheds in various agro-climatic regions of the country has been attempted. Based on various studies conducted in India, it appears that in small watersheds, forest tend to decrease the surface runoff and peak discharge. Contrary to this, in larger watershed, the surface runoff component of total water yield gets increased. Soil loss was observed less from dense and well managed forests in comparison to ill managed (denuded) forests. However, soil loss is observed even lesser than forest from well managed grassland. Soil conservation measures are found effective in reducing the runoff and soil loss. Hydrological research on small forest watersheds carried out in various regions is scattered and scanty for up-scaling to predict hydrological responses on large heterogeneous watersheds and land-uses. Hydrological investigations on different forest species/cover, topographic, physiographic, climatic and edaphic conditions employing uniform methodology and instrumentation are required. Most of this work need to be of an inter-disciplinary nature and should take full advantage of locally available environmental knowledge.

1. INTRODUCTION

Forest hydrology deals with the role of forest over precipitation (rainfall) and water yield (runoff) generating potential of the forest in conjunction with other parameters namely soil, topography, vegetation management and land management practices (Lee, 1980). The runoff is a function of rainfall, soil, topography, vegetation and its management, and land management practices. It can thus be manipulated by modifying the parameters influencing it. Bruijnzeel and Bremmer (1989) after examining the published work on hydrology summarized that (i) vegetation and land use practices do exert clear influences on total water yield and timing (peak flows and dry season flows) of steam flow areas of less than 500 sq km, beyond which the effect tends to disappear; (ii) conversion of forest land to agricultural uses (cropping, grazing) will increase total water yield as a result of reduction in evapo- transpiration; and (iii) reforesting degraded grassland or crop lands with fast growing trees will generally lead to reduced total and dry season flows as the associated increase in water consumption will override the effect of improved rainfall infiltration. They raised the basic question; 'what is the forest and land use in the uplands with respect to flooding, dry season flows and sedimentation in low lands?' Alternatively, what downstream benefits can be expected in this regard from upland reforestation? They found that at a local level (micro-level), sediment load is strongly affected by human activities and stream discharge characteristics much less. At the medium level, downstream of the catchment is being impacted. At the micro-level, in large basins, human impact in the upper watersheds is but one factor and is considered to have insignificant impact on lowland floods, low flows and sediment. Hydrological research in Indian Himalayan mountains was reviewed by Negi (2002). Monograph 7 on 'Accounting for ecological services of India's forest soil conservation, water augmentation and flood prevention' published by TERI (Kumar *et al.,* 2006) also reviewed the work on forest hydrology in various parts of country. They suggested that there is a strong need to undertake systematic and more studies to strengthen soil and water conservation and flood prevention efforts in the country.

Studies in India on forest hydrology have been carried out on a modest scale in scattered form and largely limited to small watershed scales only. Further, most of the studies were conducted at plot or small watershed scale with study period ranging from few storms to few years. The information to define the entire hydrological system and water budgeting of a particular forest type is lacking. The current knowledge in forest hydrology science provides the general magnitudes and directions of direct hydrologic responses to changes in forests over short time scale in small areas. However, today's forest and water managers need forest hydrology science to predict or indicate the hydrologic responses in forest landscape that are changing over large areas or long time scales. Predictions are needed to understand the indirect and interacting hydrologic responses to change in forested landscapes associated with climate change, forest disturbances, forest species composition and structure, and land development, and how these changes will affect water quantity and quality downstream and over long time scales. A sound knowledge base supported by the findings of research studies in the area of forest hydrology science would help to support forest and water management decisions in many ways. In this direction, forest influences on various hydrological parameters *viz.*, rainfall, interception, soil moisture, water yield, soil loss, nutrient loss and flood *etc.* form an important area of hydrological studies.

In this study, the literature in forest hydrology in various parts of India (except studies in glaciers) during last four decades has been reviewed to understand the behavior of hydrological responses on forest cover such as runoff, peak discharge and sediment loss and analyse the results from the standpoint of our ability to make decisions regarding soil and water conservation, water augmentation, flood prevention and environmental protection programmes in the country.

2. FOREST HYDROLOGICAL STUDIES IN INDIA

Western Himalayas

A micro watershed (14 ha) in Sirsa catchment, Himachal Pradesh having 92% area under open scrubs and remaining 8% agriculture, recorded 24.3% runoff (rainfall-1206 mm) and sediment loss of 12 t $ha^{-1}yr^{-1}$ (Rana and Subehia, 1996). In the following year, higher rainfall (1724 mm) increased both runoff (36.6%) and soil loss (59.3 t $ha^{-1}yr^{-1}$). A highly denuded watershed (21 ha) in Sukhna catchment of Shiwalik hills near Chandigarh yielded an annual runoff of 30% and sediment loss of 150 t $ha^{-1}yr^{-1}$. When watershed was planted with *Acacia catechu* and *Dalbergia sissoo* and soil conservation measures adopted, the runoff reduced to 4% and sediment loss to almost negligible (0.2 t $ha^{-1}yr^{-1}$) after a period of 30 years due to development of dense forest (Bansal,1994). Two identical small steep, rugged and sparshly vegetated watersheds (one control and another treated with conservation measures and planting of *Eucalyptus* and *A. catechu*) was taken in lower Shiwalik hills having 20% slope to measure runoff and soil loss. There was reduction of 54.3% in runoff and 53.9% in peak discharge from treated watershed. Further, soil loss in treated watershed always remained at lower level (<30%) as compared to control watershed (Panwar *et al.,* 2012). Panwar *et al.* (2011) compared four small watersheds (area-0.81 to 4.75 ha) for their vegetation diversity, light intensity, runoff and soil in Shivalik Himalayas. They reported that where shurbs and trees were maximum, the soil loss (1 kg ha^{-1}) and runoff (0.2%) were minimum. They observed that shrubs contributed more towards reducing runoff and soil loss compared to trees. A long term study on forest watershed concludes that hilly protected forest watershed can provide water yield to the tune of 10-20% of rainfall in Shivalik. Hydrological behaviour does not change significantly upto 1000-1200 mm rainfall. For rainfall more than 1200 mm, hilly watershed would contribute more runoff and become more vulnerable to soil erosion (Tiwari *et al.,* 2013). 12-year data (1981-92) of daily discharge and sediment yield of Giri river (tributary of Yamuna) in Shiwalik hills of H.P. were analysed by Chaudhary and Sharma (1997). They found that the runoff in the catchment was to be 32.2% and sediment load 9.6 t $ha^{-1}yr^{-1}$ (ranging from 2 to 17 t ha^{-1} in different years) and emphasised that large scale deforestation and grazing in the catchment area are the main factors contributing soil erosion problem. The study carried out in five micro watersheds having agriculture and horticulture land uses (area: 829-1233 ha; slope 5-35%) in the Jhelam Basin of Dal catchment of Kashmir (altitude varying from 1500-1583 m) produced mean runoff from 55.1 to 59.8% and soil loss more than 15 t $ha^{-1}yr^{-1}$ (Bhatt *et al.,* 2015).

Central Himalayas

At CSWCRTI (now Indian Institute of Soil & Water Conservation), Dehradun, experiments conducted on the effect of landuse and land cover change revealed that runoff and peak discharge reduced by 28 and 73%, respectively after five years of treatment from scrub land to *Eucalyptus* plantation compared to control. Further, due to *Eucalyptus* plantation, the soil loss reduced from 11.5 to 7.2 t ha^{-1} (Vishwanatham *et al.,* 1994). In another study, *D.sissoo* watershed (open for grazing) produced 9.5% runoff and 4.3 t ha^{-1} soil loss. When the watershed was treated with brushwood check dam, 6.3% runoff and 2.8 t ha^{-1} soil loss was observed after 5 years of treatment (Shastry and Narayana, 1985). When a cultivated watershed (54 ha) treated with soil conservation measures (field bunding) in Doon Valley was compared with forested watershed control, 76% reduction in storm flow and 94% reduction in soil loss (0.2 from 2.4 t ha^{-1}) was recorded after 14 years in the cultivated watershed (Ram Babu *et al.,* 1978). In a paired catchment approach and treating a mini watershed (4.8 ha) dominated by *D. sissoo* near Rajpur, outer Himalayas, 20% thinning could not detect any change in watershed after two years (Subbarao *et al.,* 1985). However, in the first year, the peak flow has been increased by 8.6% after thinning.

A study in Himalayan foot hills (Kumar *et al.,* 2006) suggests that a micro watershed fully treated with particular forest type (soil loss-14.8 t $ha^{-1}yr^{-1}$) significantly reduced soil loss of 31.7 t $ha^{-1}yr^{-1}$ (46.5-14.8) as compared to untreated bare land watershed (soil loss -46.5 t $ha^{-1}yr^{-1}$). The bare land watershed gave highest runoff (29.4%) as compared to forest watershed.

At Fakot, Garhwal Himalayas, a 370 ha watershed (forest 22%, civil soyam land-56% and cultivated land-22%) produced 42% runoff and 11 t $ha^{-1}yr^{-1}$ soil loss; after treatment with various conservation measures, it gave 14% runoff and 2 t $ha^{-1}yr^{-1}$ of soil loss after 15 years (Dhyani *et al.,* 1997). At Almas near Mussoorie hills, 535 ha mixed watershed (forest + grassland + agriculture) yielded 9% mean annual runoff; 268 ha Oak forest; 21.6% and 105 ha mixed forest watershed gave about 5% runoff. (Tripathi *et al.,* 2000-2010). In another study, agriculture and forest watershed (240 ha) produced 3% surface runoff and 43.5% sub-surface runoff, scrub forest watershed yielded 4.8% surface runoff and 38.8% sub surface runoff while Oak forest watershed (163 ha) gave 2.4% surface runoff and 47.3% sub surface runoff at Sainji, Garhwal Himalayas (Sharda *et al.,* 2000-2010). After soil conservation intervention, surface runoff was recorded 2.0, 2.6 and 1.6% and sub surface runoff 51.5, 46.8 and 56%, respectively (Table 1). An attempt was made to assess runoff, soil and nutrient losses under different land use practices and Oak forest of Rawanganga watershed (1384 ha) in Rudraprayag district of Garhwal Himalayas (Bagwari *et al.,* 2010). The elevation ranges between 800-3190 m above msl and mean annual rainfall of the area is 2120 mm. They observed that runoff was four times higher in agricultural land than Oak forest at lower altitude (800-1200 m) and lowest for forest land at higher altitude (>1600 m). The soil loss was recorded maximum (137 kg $ha^{-1}day^{-1}$) for agriculture at lower altitude and minimum for forest at higher altitude (4 kg $ha^{-1}day^{-1}$). Runoff values suggested that agriculture watershed loose more water as compared to forest.

The effect on runoff and sediment movement in three types of Sal (*Shorea robusta*) (dense, moderately dense and low density forest) at different locations at lower Himalayas was studied by Chaturvedi *et al.* (2014). The soil loss 11.1, 14.9 and 17.8 t $ha^{-1}yr^{-1}$ was observed under dense forest, moderate dense forest and low dense forest, respectively. No significant change (varying from 25.7 to 27.5%) was observed on runoff values. A study on bamboo (*Dendrocalamus strictus*) (>25 slope) in Kalsi Forest Division in N. Himalayan foot hills recorded 13.8% runoff and 6.6 t $ha^{-1}yr^{-1}$ soil loss (Kaushal *et al.,* 2014).

In two micro watersheds at Srikot and Dugar of Garhwal Himalayas, one with 10% area under pure forests and 53% area under wastelands and another with 50% area under Oak forest and smaller wasteland area of 12%, stream flow was recorded 41.5 and 18.1% and mean suspended sediment loss was 9.13 and 4.69 t $ha^{-1}yr^{-1}$, respectively (Joshi *et al.,* 1989). Similarly, in a paired watershed (WS) dominated by Oak and pine forest in Binsar (Central Himalayas), the annual water yield from Oak WS was 3.5 times more than pine WS (Kumar and Verma, 1991). The annual discharge in pine and Oak was 14 and 50%, respectively. The recession of peak flow was rapid in pine WS as compared to Oak WS (Table 1).

In Kumaun Himalaya, studies carried out by Rawat and Rawat (1994a and 1994b) at Nana Koshi reported 33.8% stream flow for a watershed with agricultural land use and 62.3% for a watershed with Oak pine forest. The soil loss was estimated to be 2 t $ha^{-1}yr^{-1}$. They concluded that deforestation and agricultural activities have reduced the water yield by 50% in this watershed. In Khulgad WS (Kumaun Himalaya) having 61% area under agriculture and 39% area covered by pine and Oak forest, sediment loss ranged from 0.4 to 5.0 t $ha^{-1}yr^{-1}$ (average 1.9 t $ha^{-1}yr^{-1}$) for Oak forest and denuded land and stream flow varied from 9.7 to 36.2% (Rawat and Rai, 1997). Similarly, Bhetagad WS (Kumaun Hills) having 2290 ha area (56% under open pine forest and 42.3% terraced agriculture land and rest under tea and pasture) recorded 16% runoff (varying from 136 to 359 mm and annual rainfall ranging from 1004 to 1800 mm) and soil loss of 3.3 t $ha^{-1}yr^{-1}$ (ranging from 0.9 to 4.35 t $ha^{-1}yr^{-1}$) from open pine forest, whereas 3% runoff and 0.1 t $ha^{-1}yr^{-1}$ soil loss was recorded from well-maintained agricultural land. Pasture (grazing land) recorded 9.2% runoff and 1.1 t $ha^{-1}yr^{-1}$ of soil loss (Joshi *et al.,* 2004). In a small micro watershed in the hills of Bhetagad (elevation-1620 m and slope-21%) in Uttarakhand, four years study on soil erosion activity of watershed and compared with another erosion plots study covered with broad leafed forest (Kumar *et al.,* 2006) inferred that soil loss prevented by the forest is quite substantial (12.29 t $ha^{-1}yr^{-1}$).

Jhum (Shifting Cultivation) in Eastern Himalayas

This type of land use is most fragile mountains with regard to soil loss and runoff. In Meghalaya, a *jhum* cycle of 10 years when compared with 5 years *jhum* cycle and terraced agriculture indicated that the loss of sediment, water and nutrients is greater under latter (Misra and Ramakrishna, 1983). Soil loss was found in the range of 34 to 56 t $ha^{-1}yr^{-1}$ for terraced agriculture and 5 years *jhum* cycle. Experiments conducted in Shillong, Meghalaya

Table: 1
Hydrological studies on micro watershed scale in different regions of India

Study Area	Major Land use	Watershed area (ha)	Altitute range (m)	Slope (degree)	Annual rainfall (mm)	Annual runoff (%)	Sediment (t ha^{-1})	Reference
Western Himalayas								
Shiwalik Hills, Sukhna catchment	Highly denuded	21	350-370	9%	1150	30	150	Bansal, 1994
Sirsa Micro WS, HP	Mixed (Ag/For)	14	500-600	10%	1200-1700	24.3-36.6	12-59.3	Rana and Subehia, 1996
Palampur, HP	Mixed (Ag/For)	26	1300	1-10	3000	33-65	3.6-22.5	Bahadur, 1996
Giri Catchment, Shiwalik hills, HP	Mixed (For/Agri)	260000	440-3600	50-60	1675	23.2	9.6	Chaudhary and Sharma, 1999
Manimajra, Lower Shiwalik Hills	Forest/Denuded	2	370	19-21%	1100	4.0 to 8.6	<10	Panwar *et al.,* 2012
Dal Catchment, Kashmir	Agri/Horticulture	829-1233	1583	5-35%	937	55-60	>15	Bhatt *et al.,*2015
Central Himalayas								
Fakot WS, Garhwal Himalaya	For/Ag	370	650-2015	70%	1900	42	11	Dhyani *et al.,* 1997
Almas WS, Garhwal Himalaya	Mix (Ag+For)	535	1800-2000	40-50%	857-1535	3.7-22.0	-	Tripathi *et al.,* 2000-2010
	Mixed Forest	105	2000-212	55%	860-1424	1.0-11.3	-	
	Oak Forest	267	2100-2250	58%	860-1713	7.5-41.3	-	
Sainji WS, Garhwal Himalaya	Mix (Ag+For)	240	2100	50-60%	1162	3.0 and 43 sub-surface	-	Sharda *et al.,* 2000-2010
	Scrub forest	52	2100	50-60%	1162	4.8 and 39 sub-surface	-	
CSWCRTI, Doon Valley	Forest (Open for Grazing)	4.4	620	3-8%	1680	9.5	4.3	Shastry and Dhruva Narayana, 1985
CSWCRTI, Doon Valley (Paired WS)	Forest (Scrub/brush wood)	0.9 to 1.45	620	5.1-9.2%	1680	8-12%	7.2 to 11.5	Vishwanathan *et al.,* 1994
Srikot Gad, Garhwal Himalaya	Forest/Agri	286	1200-1500	15-25%	2365	18.1	4.7	Joshi and Negi, 1996
Dugar Gad, Garhwal	Wasteland /Agri	306	1200-1500	15 - 25	1697	41.3	9.2	Joshi and Negi, 1996
Binsar, Kumaun Himalayas (Paired WS)	Forest	39-43	1650-2300	48 - 52	1175	14-50	-	Kumar *et al.,* 1991
Nana Kosi, Kumaun Himalaya	Agri/Forest	5500	1200-1900	-	804	33.8-62.3	2.0	Rawat *et al.,* 1994
Khulgad WS, Kumaun Himalaya	Agri/ Forest	3200	1150-2200	-	840	9.7-36.2	1.9	Rawat and Rai,1997
Betagad WS, Kumaun Himalaya	Forest/Agriculture	2290	1060-2000	14-28%	1004-1800	16-3	3.3-0.1	Joshi *et al.,* 2004
Eastern Himalayas								
Jhum	*Jhum* Agriculture	1	200-1140	40	2170	6.5	41	Singh, 1986
Shillong, Meghalaya	*Jhum* Agric (Bench trerrace)	1	200-1140	40	2170	5.9	2.3	
Shillong, Meghalaya	*Jhum* Cultivation	0.5	146-1000	50-60	2240	-	146-170	Singh and Singh, 1981
Mizoram	*Jhum* Paddy	10-20	200-1000	30-45	2450	-	15.0	Satpathy and Bundela, 1999
	Eucalyptus	10-20	200-1000	30-45	2450	-	12.5	
Meghalaya	Mix (For/Agric)	9-389	100-1000	30-53	1600-2550	1.1-1.4	67-246	Singh, 1997

Study Area	Major Land use	Watershed area (ha)	Altitute range (m)	Slope (degree)	Annual rainfall (mm)	Annual runoff (%)	Sediment (t ha^{-1})	Reference
Western and Eastern Ghats								
Nilgiri Hills, Western Ghats (Paired WS)	Grassland/Forest	32	2020-2100	20-25%	1450-1630	23.8-31.4	Negligible	Samra *et al.,* 2001
Nilgiri Hills, Western Ghats	Tea Plantation	Farmers Field	2150	8-12% & 30-35%	1280	19.4-23.0	8.9-12.4	Sahoo *et al.,* 2014
Nilgiri Hills, Western Ghats	Forest/Agriculture	5.7-19.8	2200	8-12%	835 - 1493	4.5-10	0-5.2	Sahoo *et al.,* 2006
Calicut, Kerala, Western Ghats	Plantation Crops	29.5-78.9	1850	10.7-25.2%	1485	35-50	-	Hakkim *et al.,* 2004
Coastal Eco zone of Western Ghats, - Karnataka	Forest	7-23	900-1100	8-17%	3446-4015	34.8-43.8	-	Krishnaswamy *et al.,* 2006
Koraput, Eastern Ghat	Mix (Forest, Hort. & Agri.)	318	880-1330	8-27%	1350-1600	36.8	39	Patnaik *et al.,* 2004
Central India								
Bajni Watershed, Bundelkhand	Mix - Forest/Agri/Pasture	4.26	300-325	3-15%	890	29	14.4	Sharma *et al.,* 2004
Garhkundar- Dabur WS	Mix - Degraded Forest/Agriculture	5.74	340-360	4-18%	815-860	34	5.5	Singh *et al.,* 2014
G.R. Hills, WS Chitradurga, Karnataka	Mix - Agri/Forest	214	725	3-20%	610	17	10.5	MoA, 2004
Joladaragi WS, Bellary, Karnataka	Mix(Agric/forest)	620	420 - 486	7-25%	530	25	12	MoA, 2004
Hingonia WS, Indore, MP	Mix- Agric/ forest+grass	424	550	3-17%	980	30	1.5	MoA, 2004
Khariya Nala WS, Mauranipur, UP	Mix (Agric/ range land)	645-882	150-200	5-28%	830-900	30-70	14-41	MoA, 2004
Tejpura WS, Jhansi, UP	Mix - Agric/forest & range land	776	230-275	3-14%	930	70	18.5	Bharadwaj *et al.,* 2008
Ravine Areas								
Yamuna Ravine, Agra, UP	Mix-Agric/ Forest	22	170-180	2-5%	765	15	3.7	Bharadwaj *et al.,* 2008
Yamuna Ravine, Agra, UP	Mix - Forest/ Grass	0.2-0.3	170-175	9%	550-765	11.6-27.8	2.0-3.4	Sharda *et al.,* 1982
Yamuna Ravine, Agra, UP	Agriculture	8.4 - 9.6	170-175	3-5%	490-625	8.2-8.7	1.4-4.5	Tiwari and Bhushan, 1984
Chambal Ravine, Kota, Rajasthan	Agric/ Forest/ Grass	0.4 - 1.45	257	1-2%	750	1.9-15.1	0.4-3.8	Dhruvanarayana, *et al.,* 1990
Chhajawa WS, Kota, Rajasthan	Mix - Agric/ forest	15.4 - 16. 9	240-245	1-3%	870	7.7-24.7	4.1-15.1	Prasad *et al.,* 1996
Mahi ravine, Vasad Gujrat	Mix - Agri/ forest	139	34	1.5-4%	840	13.4-24.2	11-16	Nema and Kamanvar, 1976
Navamota WS, Sabarkata Gujrat	Mix-Forest/ Agric	313	35-45	3-5%	665	11.7	25	Kurothe *et al.,* 1997

indicated (Singh, 1986) that bench terrace cultivation reduces the runoff and soil loss in agricultural crops (runoff-5.9% and soil loss-2.3 t ha^{-1}) and horticulture crops (runoff-3.1% and soil loss - 2.9 t ha^{-1}) as compared to *jhum* cultivation (runoff - 6.5% and soil loss - 41.0 t ha^{-1}). In another study, it was estimated that soil loss under first year *jhum*, second year and abandoned *jhum* were 146, 170 and 30 t ha^{-1}, respectively (Singh and Singh, 1981). The Department of Agriculture, Mizoram has estimated the soil loss on contour trenching adopted in *Jhum* land for paddy cultivation and *Eucalyptus* plantation as 15 and 12.5 t ha^{-1}, respectively (Satpathy and Bundela, 1999). Therefore, long term strategy for shift in land use practice to plantation and horticulture crops are suggested (Table 1).

Western and Eastern Ghats

In Nilgiri hills, a 32 ha watershed (Shola forest-41% and plantation of *Eucalyptus globulus*-Bluegum-59%) was compared with natural grassland forest watershed (area about 32 ha). An annual reduction in water yield of the order of 16 and 25.4% was observed from Bluegum watershed over natural grassland forest watershed during first and second rotation of *E.globulus* (Bluegum). Maximum reduction in runoff was observed during July to October which is very crucial for sustaining water supply to hydroelectric reservoirs (Samra *et al.,* 2001). Further, three watersheds, W2A treated (agricultural-5.7 ha), WA untreated (agriculture + habitation-5.1 ha) and W2F (Shola forest-19.8 ha) were taken to monitor hydrologic responses. It was observed that Shola forest W2F (under perennial vegetation) reduced the runoff by 55% (52 mm) as compared to WA (115 mm). The base flow of runoff was higher under Shola forest (73.6%) as compared to WA untreated watershed (31.8%). There was a reduction of peak flow of 90.8% of Shola forest as compared to WA. Soil loss under WA untreated watershed was observed to be 5.2 t $ha^{-1}yr^{-1}$ while it was zero under Shola forest (Sahoo *et al.,* 2006). Effect on runoff and soil loss on tea plantation having soil conservation measures as well as no conservation measure (control) was studied on 8-12% and 30-35% slopes. Minimum runoff and soil loss (118 mm runoff and 4.9 t $ha^{-1}yr^{-1}$ soil loss) was observed at 8-12% slope and 152 mm runoff and 6.9 t $ha^{-1}yr^{-1}$ at 30-35% slope on plantations having conservation measures, while 213 mm runoff and 8.95 t $ha^{-1}yr^{-1}$soil loss on 8-12% and 252 mm runoff and 12.37 t $ha^{-1}yr^{-1}$ soil loss under control watershed (Sahoo *et al.,* 2014).

Three years rainfall-runoff data on watersheds (area 29.5 to 78.9 ha) in Western Ghats studied at Calicut and Wynod districts of Kerala indicated that cashew and tea cultivated watersheds produced nearly 50% of total rainfall (1485 mm) as runoff and coffee watershed produced 35% as runoff, whereas dense forested watershed yielded only 30% runoff (Hakkim *et al.,* 2004). The high canopy cover and humus content under dense forest helped in reduction of runoff from forest watershed. The studies conducted on three small watersheds (7 to 23 ha) under various land uses in coastal area of Western Ghats in Uttara Kannada distrct of Karnataka (rainfall: 3450-4015 mm) indicated that maximum runoff was observed in the degraded watershed (44%) and minimum in *Acacia* forested watershed (33%), while natural (defence control over forests) watershed produced 36.6% runoff. The peak flow data indicated that there was an increase in peak flow upto 123% in degraded and 82 % in *Acacia* watershed as compared to natural forest watershed (Krishnaswamy *et al.,* 2006).

A 318 ha watershed (45% under forest, 52% under cultivation and rest under wasteland) in the Eastern Ghats of Korapat district, Odisha was taken up to study the effect of forest and horticulture plantations along with various conservation measures taken in the watershed (Table 1). The runoff reduced from 36.8 to 12.4% and soil loss from 38.8 to 6.6 t $ha^{-1}yr^{-1}$ due to plantations and conservation measures taken in the watershed (Patnaik *et al.,* 2004).

Central India

Under Bajni watershed near Datia, M.P., three micro wasteland watersheds (W2A 5.74 ha treated with conservation measures, W2B 4.90 ha treated with plantations and W2C 4.26 ha unprotected wasteland), were studied for 5 years. The runoff from W2A watershed decreased from 22 to 12.6%, W2B watershed decreased from 29.8 to 15% and unprotected wasteland watershed (W2C) recorded 29%. The soil loss was recorded as 7.7, 9.8 and 14.4 t $ha^{-1}yr^{-1}$ under conservation measures, vegetative measures and unprotected wasteland, respectively. Due to various conservation and vegetative measures implemented in the watershed near Daita, the average runoff reduced from 25.4 to 16.3% and soil loss from 12.1 to 8.3 t ha^{-1} yr^{-1} (Sharma *et al.,* 2004). Garhkundar Dabar watershed in Tikamgarh district of M.P., having an area of 850 ha (< 55% degraded forest and rocky wasteland and rest under rainfed agriculture) was studied for 6 years. Teak plantations on private land, *Aonla* and citrus based agroforestry system on wasteland were carried. Various soil conservation measures were adoped on agricultural land. These measures resulted in reduction of stream flow from 34 to 21% and soil loss to a great extent (1.5 t ha^{-1} *vs.* 5.5 t ha^{-1}) (Singh *et al.,* 2014).

GR Halli WS in Karnataka, having 314 ha area (158 ha agriculture land and rest denuded forest and grazing land) was taken for study. Large scale plantation was carried out in degraded non arable land with various suitable species. Various conservation and gully control measures were also adopted. Due to large scale plantations and adoption of conservation measures in the watershed, the annual runoff and peak discharge reduced from 17 to 2.3%, 15 to 4.4 m^3 sec^{-1} and soil loss from 10.5 to 1.0 t $ha^{-1}yr^{-1}$ (MoA, 2004). Hingonia WS, having an area of 424 ha (mostly rainfed and degraded land) located near Indore in Malwa region was taken for study. Various soil conservation measures in agricultural land and plantations of horticulture and silvi pastoral systems were taken on degraded land. Due to various watershed management programs, the runoff and soil loss have reduced from 30 to 17% and soil loss from 1.5 to 0.35 t $ha^{-1}yr^{-1}$ (MoA, 2004).

Seven micro watersheds, having area ranging from 645 to 882 ha with total area of 5395 ha located at Khariya Nala watershed near Jhansi, were treated by various soil and water conservation measures like small trenching, stone ridging and gully plugging *etc.* The cultivated area accounts for 62% and rest is community range lands (consists of hills, hillocks and plateau) and wasteland. The entire area other than hills and plateau (range land) were treated with appropriate soil and water conservation measures. Major efforts were made for re-vegetation of grazing lands under hills and hillocks by planting fast growing trees, grasses, legumes and shrubs. Hardy tree species like *Acacia nilotica* were planted in gullied and wastelands. The soil loss from barren hillocks was initially 41 t ha^{-1} which reduced to 18.5 t ha^{-1} at a very first year and subsequently to 1.0 t ha^{-1} in the seventh year (Table 1). Similarly, the soil loss to the extent of 20.5 t ha^{-1} from highly degraded wasteland sites was subsequently brought down to 14.5 t ha^{-1} and further to 1.2 t ha^{-1} during third year. The runoff from hillocks, wasteland and arable land reduced from 70 to 19%, 48 to 15% and 30 to 18% respectively (MoA, 2004). Similarly, Tejpura watershed having 776 ha area, 45 km from Jhansi, UP, was treated with various soil conservation measures like gully plugging, afforestation and pasture development in denuded hillocks and wastelands. Due to these measures, the runoff from the wasteland reduced from 70 to 11% and soil loss from 18.5 to 1.1 t ha^{-1} during 10 years period (Bharadwaj *et al.,* 2008).

Ravine Areas

At Agra, a watershed (22 ha) having agriculture, forest and grassland in Yamuna ravine produced 15% runoff and 3.7 t ha^{-1} soil loss, it gave about 1% runoff and 0.1 t ha^{-1} soil loss after field bunding of agricultural land (Bharadwaj *et al.,* 2008). Two small watersheds having comparable size and of different land uses were evaluated in ravineous area at Agra. In one watershed, *Cenchrus ciliaris* grass was planted while in other, plantation of *D.sissoo* was raised and natural grass was allowed to grow. It was observed that watershed having *D.sissoo* + natural grass registered 58 and 41% less runoff and soil loss, respectively as compared to watershed planted with *C.ciliaris* (Sharda *et al.,* 1982). A watershed (81% agriculture + 19% grassland) of 8.4 ha (reclaimed by constructing a grassed way in table land and check dam in ravine bottom) gave a runoff of 3.9% of rainfall and soil loss of 0.8 t ha^{-1} as compared to an untreated watershed (8.7% runoff and 4.5 t ha^{-1} soil loss) in Agra ravine. Another watershed (100% agriculture) of 9.6 ha (leveled and treated with field bunds) yielded a runoff of 3.9% and soil loss of 0.6 t ha^{-1} as compared to an untreated watershed (runoff-8.2% and soil loss-1.4 t ha^{-1}) (Tiwari and Bhushan, 1984).

At Kota, a watershed in Chambal ravine with *A.nilotica* planted on contour trenches along with *Dichathium annualatum* grass in between reduced the runoff and soil loss from 15.1 to 6.8% and 3.83 to 1.15 t ha^{-1} as compared to agricultural watershed (Dhruva Narayana *et al.,* 1990). The ravine watershed, when protected with *D.annualatum* and mechanical measures further reduced runoff and soil loss (1.9% and 0.43 t ha^{-1}). A ravine watershed (15.9 ha) when treated with various conservation measures in arable land as well as plantations of forest trees and *C.ciliaris* grass for rehabilitation of overgrazing wasteland, produced 7.7% runoff and 4.1 t ha^{-1} soil loss, while undisturbed control watershed (16.9 ha) yielded 24.7% runoff and 15.1 t ha^{-1} of soil loss (Prasad *et al.,* 1996).

In Mahi ravines at Vasad, a 139 ha watershed was taken for study. The upper part of watershed (67 ha) was left untreated and open to biotic interference and lower part (72 ha) was treated with soil conservation measures and closed to biotic interferences. The untreated watershed produced runoff varying from 13.4 to 24.2% and soil loss from 4.7 to 33.2 t ha^{-1}, while treated watershed gave runoff from 5.5 to 9.5% and soil loss varied from 0.7 to 8.4 t ha^{-1} (Nema and Kamanvar, 1976) during 5 years of study. Navamota watershed, having an area of 313 ha (105 ha forest and Panchayat land and rest arable land) was taken in Sabarkata district in Gujarat to know about the hydrological behaviour of watershed. 64 ha area was planted with Neem, *Prosopis juliflora* and *Eucalyptus tereticornis*, 26 ha covered with grass and trees and 15 ha bamboo in gullybed while in arable land, several conservation measures were carried out (Kurothe *et al.,* 1997). All these treatements reduced the water loss from 25 to 3.7% and soil loss from 11.7 to 0.5 t ha^{-1} within a period of 9 years. At Vasad, in Khera district of Gujarat, a study on small watershed for reclaiming gullybed with three types of Bamboo based interventions (bamboo plantation with contour trenches, supported by Bori bunds and live check dam) was taken up. In all the three types of interventions, absorption of rainfall is more than 80% and soil loss reduced from 15.6 to 5.2 t ha^{-1} (ICAR, 2013).

3. RESULTS AND DISCUSSION

Looking at small scale hydrological studies conducted in India, we find that only forests have been studied in some detail. Studies on other important land uses such as grassland, grazing land and *jhum* cultivation, and manipulating land use/cover are limited. Most of these studies have observed runoff and soil loss only for rainy season. However, pre-monsoon and winter showers, which may produce sizeable runoff, have not been studied. Further, effect of rainfall intensities and duration on various hydrological parameters has also not been studied, which are also the controlling factor producing runoff and soil loss. Further, some studies in Himalayas were conducted by University departments where facilities for work and proper instrumentation and manpower are a constraint.

Based on various studies reviewed, it appears that in small watersheds, forest land decrease the water yield (due to decreased surface runoff) and peak discharge, while in larger watersheds, the sub-surface component of total water yield, peaks gets increased. Further, soil loss was observed less from dense, well managed forests in comparison to ill managed (denuded) forest. Soil loss was observed very less from well managed grassland. In N-W Himalaya, afforestation with *Eucalyptus* reduced 20% runoff, 30% peak rate and 4 t ha^{-1} of soil loss. In high hills of Kumaun Himalaya, Oak and pine forest watersheds yielded 14 and 49% runoff, respectively. In 92% open scrub watershed in H.P., 36% runoff and 59 t ha^{-1} of soil loss was observed during high rainfall years. In Mussorie hills, the runoff from oak forest and mixed land use (forest, grassland and agriculture) watersheds was observed 21.5 and 10%, respectively. In Siwalik hills, the denuded watershed when planted with *A.catechu* and *D.sissoo* supported by soil conservation measures, the runoff reduced from 30 to 4% and sediment reduced from 150 t ha^{-1} to 0.2 t $ha^{-1}yr^{-1}$ within a period of 30 years. Some studies available in this region have provided simplistic and generalised recommendations such as plantation of broad leaf species, ban on grazing, deforestation and other human activities to curb the problem of soil and water erosion. In NEH region, *jhum* cultivation loses both soil and water in great magnitude (> 40 t ha^{-1} soil loss and 10% runoff), while it gives only 0.3 t ha^{-1} of soil loss and 0.3% runoff under bamboo plantation. In Western Ghats of Kerala, plantation of cashew and tea produces nearly 50% runoff, while coffee and dense forest gives 35 and 30% runoff, respectively. In waste land areas of Bundelkhand region in M.P., the waste land watershed gave about 30% runoff and 15 t ha^{-1} of soil loss, while it gives 20% runoff and 10 t ha^{-1} of soil loss when the plantations are done. In ravine areas, considerable reduction was observed when watershed was planted with various forest species along with conservation measures. The data set reveals that grasslands loses more water, *jhum* cultivation loses both water and soil of greater magnitude and forested land uses smaller quantities of soil and water through runoff. Agricultural land use presents an intermediate situation between these two land uses. Soil conservation measures are found effective in reducing both the runoff and sol loss.

4. CONCLUSIONS

The micro-watershed based studies have proved very useful in studying the influence of forests on various hydrological processes and understanding the hydrological behavior at micro scale. However, research in forest hydrology is still at its infancy and inadequate to predict hydrological responses in forest landscape that are changing over large areas or long time scale. It can be emphasized that hydrological investigations on the effect of different tree species and forest types on interception, soil moisture, water yield, soil loss and ground water are needed. Hydrological models to predict the impacts of changes on forests on large and ungauged watersheds/basins needs to be developed using long term observed data. The developed mathematical models can be utilised for extrapolation. The effect of climate change and water is increasingly evident and future aspects of climate change are likely to have major effect on forest hydrology. More research studies are required to predict indirect effect of climate change including influence of hydrological responses due to change in forests and forest management.

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