"SPACE INPUT FOR FOREST MANAGEMENT: IN SPECIAL REFERENCE TO FOREST HYDROLOGY"

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Abstract:

Water management is an important aspect of forest hydrology and need to be included in forest working plans. Space and GIS technology with its immense potential in forest water management can improve our efficiency and accuracy by providing near real time statistics related to the forest hydrology. Present paper spotlighted the concept of integrating satellite inputs in hydrological model to address the forest management issues and reports the earlier experiences of hydrological experiments in Kanha National park situated in Balaghat district of Madhya Pradesh, India. Paper also focuses on forest biophysical parameters those are governing water budget in a forest ecosystem. It was found that when satellite derived topography (Digital elevation model, slope, aspect etc.), forest biophysical parameters (forest cover, forest type, Leaf area index, evapotranspiration etc.) along with ground based measurement related to the soil characteristics (such as soil moisture, soil texture, soil organic content, soil porosity etc.) and water level, coupled to hydrological models, produces valuable water balance components of the forest ecosystem which can be useful for updating forest working plans.

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Introduction

Water is an important natural resource and facing problem of stress due to increasing demand for drinking and irrigation. The rainfall and snowfall are the basic forms of water input in the earth system. Most of the rainfall input is received by ocean and see. A small fraction of it is received by terrestrial ecosystem includes forest among others. The input received in forest system is partitioned into interception loses, Evaporation loses, stem fall, through fall, surface runoff, base flow and ground water recharge (Krämer and Hölscher, 2010). However, the distribution of rainfall in these components is depends on forest and species type, forest density, forest biophysicochemical parameters, soil type forest floor characteristics etc. among the others. A systematic representation of input and output components of water system on earth is represented in figure 1.

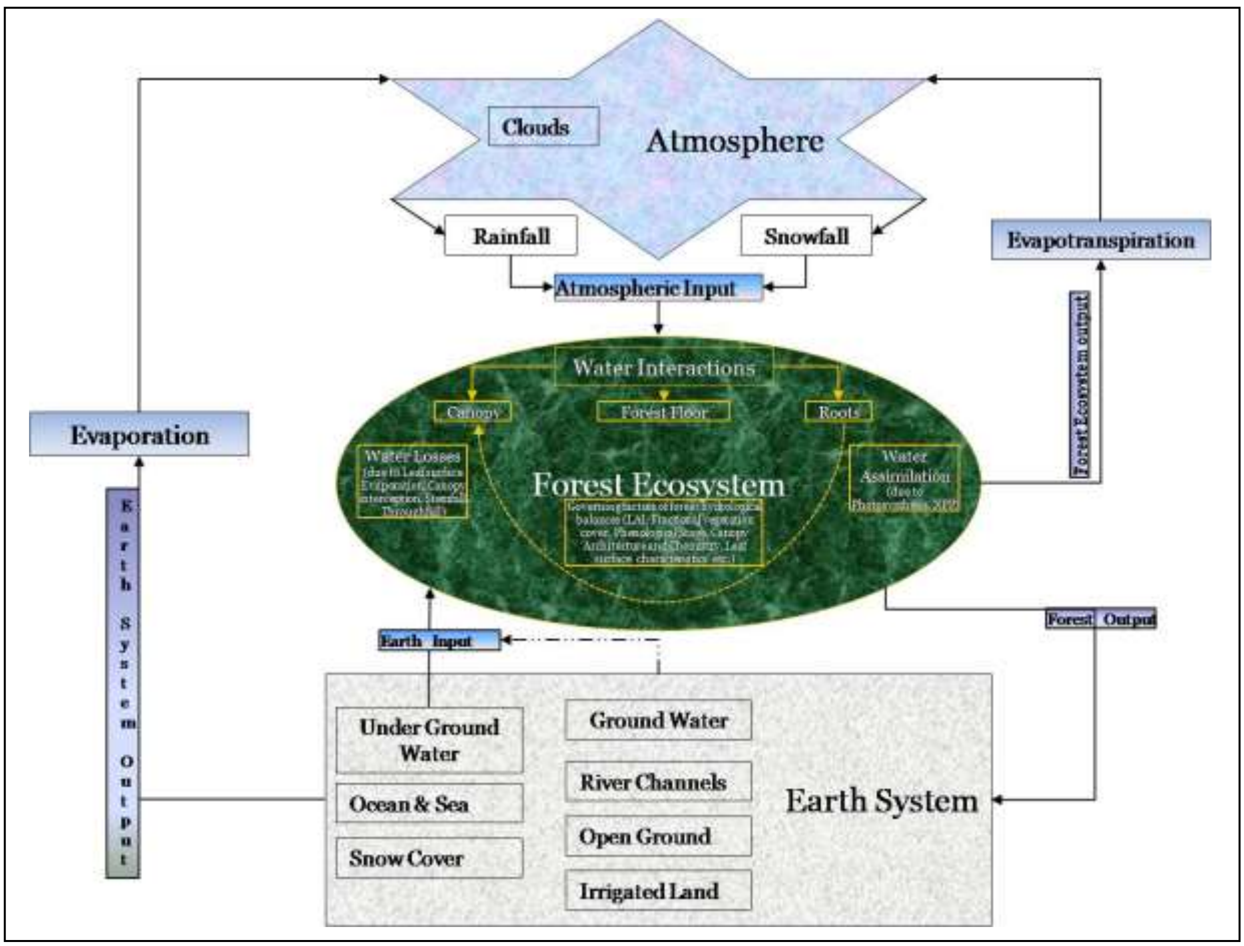

Fig:1 – Scheme showing water input and output in forest ecosystem

Traditional methods based on ground survey for the measurement and estimation of these parameters is not realistic at landscape level. Space-based inputs and GIS models can help in this situation. Space input for forest management includes (a) Targeting, approaching (using Global positioning system i.e. GPS) estimation and attain up-to date statistics of forest resources such as forest cover (FSI), forest type, age etc. (b) Geomorphology of the forest site such as terrain, drainage pattern, soil type, climate, rainfall, temperature, cloudiness, wind, special weather phenomenon etc. (c) Forest fire risk zone models (d) Information about flora and fauna such as species, vegetation form (includes grassland, forest etc.), habitat, niche etc. (e) Encroachments in the form of abandoned and current mines and impacts due to other anthropogenic activities (f) Socio-economic analysis such as no. of villages, illegal cutting, probable site for poachers entry, existing land use and land use changes, sites for NWFPs etc. (g) Disease and insect attack on the forest crop and scenario of the forest health (h) Sites having tourism potential (i) Biodiversity characteristics (j) Road length for estimating carrying capacity and (k)Water resources, its nature (physical and chemical) and distribution in geographic space.

Apart from all these inputs from space technology in the forest management, importance of water resources and its conservation is well known fact to forest managers and forest ecologist especially in a changing paradigm. Despite of this, water resource conservation is not getting appropriate consideration for what it really deserves in forest management both at local and on global scale (Creed et al., 2011). Very few and localized studies have been reported regarding this issue from across the world. The situation is more miserable in Indian context. Study done by Krishnaswamy et al., 2006 in western-ghat region, India was probably the first of its kind study linking forest cover, hydrology and communities especially in watershed regions. A study by ann. (2007) in the same region got existing gaps in the current understanding of both biophysical and social aspects of the forest-water-community linkage. They further provide relevant solutions to fill some of the gaps existing in understanding of forest-water-community interactions using a combined approach of ground survey, geospatial technology and mathematical modeling. However a detailed study specifying linkage between forest biophysical parameters (except percentage forest coverage) and hydrology are still to be explored in detail in Indian context. Kallarackal and Somen (2008) study on transpirational loss of water in five different species touches the subject and require more exploration for better understanding.

Previous studies have reported many issues associated in conducting forest hydrology related research work and real scenario (anno., 2007). For convenience these can be divided in following categories: (a) Lack of appropriate research deign, (b) acceptable methodology, (c) required parameters to be included in forest hydrology related research (Creed et al., 2011), and (d) availability of appropriate data (both ground and RS technology based) for modeling purpose (Anno., 2007; Creed et al., 2011) at landscape level. Availability of long term calibrated records both from ground and remote sensing satellite sensors with appropriate spatial resolution (10-30 m), is the basic limitation of research in forest hydrology (Creed et al., 2011). Calibrated hydrological models applicable for specific type of forest ecosystem is another limiting issue in forest hydrology related research. Lack of modules related to forest hydrology in popular GIS software like ArcGIS, geographic resources analysis support system (GRASS) GIS, MapWindow GIS etc. among others is another important issue that makes this them unexplored. The software present with forest hydrology modules is either very costly or very complex. This generates the need of simple modules having capability to easily integrate remote sensing data and gives a precise output in the form of forest hydrology balance parameters. Taking this in view I proposed a concept which describes (a) the forest biophysicochemical (both biophysical and biochemical) factors and RS data domain valuable in forest hydrological studies, (b) process of coupling *in situ* measurements related to forest biophysical parameters with suitable RS data/model. This followed by similar experiences in hydrological experiments conducted in Kanha National Park during 2010 to 2012.

Materials and Methodology

(i) Study Area

The study was done in a typical central highland and conserved forest area, well known for its tiger reserve the Kanha National Park (KNP) during 2010 to 2012. Kanha National park (KNP) situated in Balaghat district of Madhya Pradesh, India (figure 2) between the geographic extent of Latitude 22˚ 02' 20" N to 22˚ 37' 02" N and Longitude 80˚ 24' 52" E to 81˚ 03' 26" E for the forest hydrology related parameter retrieval during 2010 to 2012.

Fig:2 – Study area (source: http://www.kanhavillage.com/kanha_national_park/kanha-national-park-zones**)**

KNP is typical representative of central Indian Highland geo-physiography with rich biodiversity of both flora and fauna. Minimum temperature varies from 0˚C to 19˚C and maximum from 32˚C to 45˚C with minimum and maximum rainfall of 3.77 mm and 359.52 mm. Elevation ranges from 448 to 913 m. Soil texture is sandy clay to loam. Climate is tropical monsoon type. Forest Type includes moist peninsular Sal forest (3C/C2), Southern tropical moist deciduous forest (3A/C2a), and Southern tropical dry mixed deciduous forest (5A/C3) (Champion and Seth, 1968). Sal (Shorea robusta) is the dominant tree species.

(ii) Methodology

The required parameters for forest hydrology related experiment those to be estimated *in situ* and through remote sensing have been identified with exhaustive review of literature. Biophysicochemical parameters governing water budget in forest ecosystem have been generated/estimated with traditional methodologies and satellite intervention (Singh et a l., 2016 and Singh and Singh 2018). For example Forest cover density (FCD) mapper for vegetation fraction estimation (Singh et al., 2013), Hemi-view observations for leaf area index (LAI) at plot scale and its application for the assessment of landscape level LAI using satellite data (Turner et al., 1999; Goroshi et al., 2011), Remote sensing data derived Vegetation Indices (VIs) for Evapotranspiration (ET) (Loukas et al., 2005), species based information for root architecture and type, thematic maps of soil type from concerned forest departments/sources, SRTM digital elevation models (DEM) for slope, aspects and drainage pattern were used in surface hydrological modeling. The discharge and other ground based parameters were taken from Goroshi et al., 2011. Rainfall input in forest ecosystem was taken from Indian metrological departments (IMD). MIKE-SHE/MIKE-11 hydrological model was used to simulate forest hydrology related parameters and well described in Goroshi et al., 2011.

(iii) Research Gaps and Concept based Discussion

So far several forest biophysical factors such as LAI, ET, NPP etc., have been estimated using methodology coupling *in-situ* measurement and remote sensing in the Kanha national park. Biochemical properties such as canopy chlorophyll content, canopy carbon content, canopy nitrogen content etc. among others, are still to be estimated and need further investigation regarding role of these factors in forest hydrology. Table no. 1 having enlisted biophysicochemical parameters (sub attributes) of importance in relation to the hydrological studies. Simultaneously it is also representing level of interaction which determines fate of water in forest ecosystem falling through rain (column 2 in table no.1).

Extent of interactions between forest biophysicochemical parameters and falling rain is largely depends on level of interactions, type of interactions and time of interactions. Table no. 1 also includes information's related to the remote sensing domain/data which can be used to estimate forest biophysicochemical parameters of interest in forest hydrology along with their mode of applicability. Conceptually we assumed two systems in forest related hydrological budget. First is the input system from where water enters in the forest ecosystem and second is the out system from where water comes out of it. Complete scheme of water input-output system have been given in figure 1.

Table 1

Forest biophysicochemical parameters those govern forest-rain water interaction and various remote sensing domains from where they can be estimated at spatial scale and their mode of applicability

Sl. No.	Level of Interactions	Type of Interaction	Attributes Governing Interaction	Sub Attributes	RS Data Applicable	Mode of Applicability	
						Direct	Indirect
1	Canopy Level Interaction	Leaf and Canopy Interception	Fraction of Vegetation Cover	Shape	ML(VB)/H/M	Direct	NA
		Canopy surface evaporation (Indirect)	Leaf Area Index (LAI)	Leaf Angle	ML(VB)/H/M	Direct	Indirect
			Canopy Architecture	Leaf Orientation Leaf Chemistry	ML(VB$_h$)/H/M	Direct	NA
		Stem fall (Indirect)	Phenology	Leaf Surface property	ML(VB)/H/M	Direct	Indirect
		Throughfall (Indirect)	Species Type	Leaf Shape/Size	ML(VB$_h$)/H/M	Direct	NA
		ET (Indirect)	ET can be measured only by Indirect method from Space input of ML(VB)/H/M sensors				
2	Sub Canopy Level Interaction	Water Retention, Rainfall speed reduction, water storage	LAI	No. of Forest Strata	M	Direct	NA
3	Forest Floor Level Interaction	Herbs & shrubs layer Interaction	Herbs/shrubs layers	Percentage of understory Herbs/shrubs layers	ML/M (minor)	Direct	NA
		Interaction with Litter	Litter	Litter Quantity	NA	NA	Indirect
				Litter Quality (Chemistry and Moisture)	H/M	Direct	NA
		Interaction with Soil	Soil Type	Soil biophysical and biochemical properties	ML(VB)/H/M	Direct	Indirect
4	Root Level Interaction	Root Absorption	Root Architecture	Root orientation, Root morphology, position of root, anatomy of root etc.	RS not applicable	NA	NA
		Root Action on Soil	Root Type				

ML(VB)=multispectral remote sensing data in VNIR region, ML(VB$_h$)= multispectral remote sensing data in VNIR region with high spatial resolution, H=Hyperspectral data, M=Microwave data, NA= not applicable, RS= Remote Sensing

Experience of hydrological experiments in Kanha National Park

Various biophysical parameters (LAI, Forest cover, evapotranspiration etc.) were measured in the KNP premise. Details regarding these forest biophysical factors are discussed in Goroshi et al., 2011. Species types were mapped using high spatial resolution LISS-IV data and location based spectral signatures, showing dominance of Sal species. Water balance study, done in a catchment area of KNP has shown a distribution of total rainfall (4230 mm during 2010 to 2012) into different part. The coupled MIKE SHE/ MIKE 11 MODEL was able to provide information related to various part of water balance component such as the unsaturated flow, saturated flow, overland flow and stream flow etc. among others. Surface water which have been explored in detail and shown 36.6% of it as river water flow, 22.4% as base flow production, 3.6% as water surface evaporation, 12.7% as canopy water storage and 24.9% as transpirational loss (Goroshi et al., 2011) (table 2 and figure 3). Fine agreement (r^2 varies between 0.78 to 0.82) were found between observed and simulated discharge values. For the detail regarding this author may go through in Goroshi et al., 2011.

Table 2

Rain water balance in Forest ecosystem from previous experience

Sl. No.	Parts/components of water balance	Contribution in %
1	River water flow	36.6
2	Base flow production	22.4
3	Water surface evaporation	3.6
4	Canopy water storage	12.7
5	Transpirational loss	24.7
6	**Total**	**100**

Source: Goroshi et al., 2011

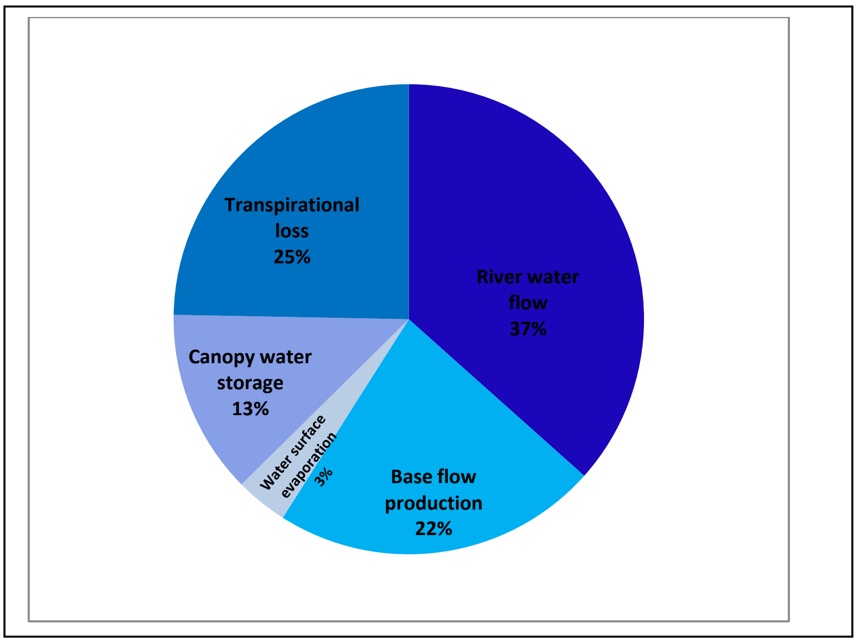

Fig:3 – Scheme showing water input and output in forest ecosystem

Conclusion

Study revealed that the hydrology of the forest ecosystem is the function of forest type, topography, forest biophysicochemical parameters, rainfall intensity and frequency, climate etc. and space technology along with GIS have potential to measure these parameters when coupled with ground observations under the shed of empirical and mathematical models. River water flow and transpirational loses contributes 62 % of total water budget in the forest system. Based flow contributes 22% of total water budget and surface water evaporation contributes 3%. Biophysicochemical properties can directly or indirectly be used to estimate rain water losses in forest-water interaction process. Losses due to canopy intercepted water evaporation can be estimated using LAI as input. From this study we could suggest that the microwave data can be used to estimate under story vegetation cover, herbs, shrubs and litter percentage and water bodies underneath the forest canopies. Microwave data can further be used for the soil moisture estimation and soil surface roughness at landscape scale. These are important parameters to estimate forest water output. Species distribution can be mapped using combined approach of ground truthing and remote sensing data (multispectral/Hyperspectral/Microwave). The intermediate and ultimate outputs of such type of studies would also be helpful in the mitigation of intense hydrological events, maintenance of hydrological flows, protection of soil erosion, retention of sediments, maintenance and purification of water supply, understanding watershed services such as groundwater recharge, flood control, low-flow augmentation etc. within forest ecosystem, role of water in forest productivity, nutrient cycling and biodiversity and insuring climate change related information availability for the global treaties and scientific organizations like UNFCCC, UNDP, FAO, IPCC etc.. Forest Hydrology is the important aspect of forest management strategy and need to be essentially included in forest management plans both at local as well as on global scale as a decisive forest management objective. The space and GIS based analysis can facilitate in the preparation of these plans.

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