Policy Article

Quantitative & Qualitative Perspectives of Forest-Water Interactions at Catchment Scales

ABSTRACT

Forests performs an imperative role in the supply of clean water for variety of uses, and also defending soils from erosion. Factors influencing water use by forests include climate, forest and soil type, among others. In general, forests use more water than shorter types of vegetation because of higher evaporation; they also have lower surface runoff, groundwater recharge and water yield. Much of the world's freshwater are provided through forested catchments only. The qualitative as well as quantitative aspects of forest water has greater influences on variety of far sighted developmental activities for any nation. For example, the water and soils remain two essential drivers of health & growth of forests to protect many dams and even plethora of ground water reserves by tackling siltation & contamination from various pollutants/pollution. With increasing demand for agricultural and urban land (owing to population explosion & more affluent life-styles) majority of forests are put under tremendous pressure (further worsened by climate change). Water and land use policies in tropical countries, like India are often influenced to big extent by many perceived effects from hydrological functioning of forested catchments towards soil erosion control and sediment-reduction benefits. Therefore, hydrological processes become indispensable for any informed discussion of forest-water interactions. This paper offers certain food for thought by summarizing the relevant scientific consensus of key aspects of forest-water relationships; accommodating water quantity, quality & pollution issues in such catchments. It includes couple of wider aspects towards 'forest-water interactions' and 'water quality and pollution facets. Apprehensions and knowledge gaps about hydrological impacts of forest management and also the emerging futuristic R&D issues are elaborated with specified line of sights on effects of forests & forest management on various stream flow parameters, soil erosion, stream sedimentation, water quality, landslides and water use of different vegetation types & species..

Keywords: Forests; Hydrology; Water-Quality; Forest-Water-Interactions; Management; Climate

1. INTRODUCTION

Forests presently cover only about one third of Earth's surfaces (FAO, 2016). Between 2000 to 2012, urban growth, agrarian land adaptations, logging and forest fires resulted in the loss of some 1.5 -1.7 million km2 of tree cover, about 3.2 % of global forest cover (Riitters et al. 2016). Deforestation and anthropogenic land-use alterations have imperative insinuations for climate, ecosystems, water, and thus the sustainability of livelihoods and the survival of species, raises long term concerns. The UN guesstimates that about 1.9 billion people live in water-scarce areas, and if existing tendencies continue, this number will rise to around 3 billion by 2050, with up to 5.7 billion people living in areas suffering water scarcity at least one month per year (WRI, 2018).

Forests always remains an integral constituent to the water cycle: they control stream flow, care ground water recharge, and through evapotranspiration bestow to cloud generation and precipitation. With variety of bio-physical control, they often acts as natural purifiers, filtering water and reducing soil erosion and sedimentation of water bodies. Among these the vital biophysical factors that significantly influence ‘forest-water interactions’ are usually termed as a strong determinant of present days climatic uncertainties. For example, they may include, soil health, gravity, soil pedology, soil wetness and climate change aspects. These determinants of change occur over different scales both temporal and spatial. Some essential determinants of change for forest water use and yield may rarely occur but still have a substantial impact; while others have a more frequent or constant impact on forest hydrology. Certain determinants of change operate on a very small scale, while other determinants of change may impact water resources across basins, regions or even globally. Each of these temporal and spatial scale determinants of change on forest water; are poorly and improperly understood both by policy planners as well as end clients whose livelihood remains solely dependent on forest and agriculture-based earnings. If we talk of water , over 75 % of world’s accessible freshwater comes from forested watersheds; and more than 50% of the Earth’s population is reliant on these areas for meeting their purposes of water use (domestic, agricultural, industrial, and environmental). At global to regional scales, the forest-water-energy cycle connections delivers a true basis for mitigating water scarcity & global warming problems. Moreover, it always requires adequate understanding/considerations of forest-water interactions at catchment scale, where precipitation is recycled by forests/vegetation and transported across terrestrial surfaces. Upward fluxes of moisture, volatile organic compounds and microbes from plant surfaces create precipitation triggers, while the forest-driven air pressure forms may carriage atmospheric moisture toward continental cores. Water fluxes, cools the temperatures and produce clouds that bounce supplementary radiation from earthly surfaces. Similarly, the ‘fog’ and ‘cloud’ interception by trees draws additional moisture out of the atmosphere. This altogether is complemented by processes like ‘infiltration’ and ‘groundwater recharge’ facilitated by trees/forests. All such hydrological processes naturally disperse water, thereby moderating floods. This philosophical configuration is well depicted by Ellison et al (2017).

Maintaining healthy forests always helps improved water and environmental quality, as they interact with water and soil in variety of ways, providing canopy surfaces which trap rain allowing evaporation back into atmosphere. It regulates that how much water reaches forest floor as through fall and pulled water from soil for transpiration. Relationship between forests and water is nowhere simple. Assertions that forests provide water or conversely that they reduce it; are not always factual. Rather the real forest-water relationships remain dependent on multiple factors, including but not limited to scale (spatial and temporal), species, slope, soil, climate, forest management practices, and many locations specific set of conditions. Forest uses water to rise, and therefore fast-growing species will use water more quickly (Filoso et al., 2017). Trees also release water into the atmosphere through evapotranspiration, which often returns as precipitation locally (Ellison et al., 2017). Forest management can therefore have negative as well as positive impacts on water quantity & quality, species, distributions, tree densities and other managerial aspects. It is also important to note that what is true for one context is not necessarily so for others. Present chapter basically seeks to examine evidences about the contribution that forests & water and their stakeholders can make to achieve sustainable development by for regulating forest-water interactions in light of water quantity & quality.

No matter what type the forest is, the plant sizes, canopy density, litter floor and root systems always remain significantly taller, greater, thicker, and deeper than other vegetation types. These are the prime characteristics that make forests able not only to provide & conserve a number of natural resources, but also to perform a variety of favourable functions. Environmental functions performed by forests may include control of water and wind erosion, protection of headwater and reservoir watershed and riparian zone, sand-dune and stream-bank stabilization, landslide and avalanche prevention, preservation of wildlife habitats and gene pools, mitigation of flood damage and wind speed, and sinks for atmospheric carbon dioxide. History and modern studies have well exposed that the misuse of forest resources has caused adverse watershed conditions, depletion of land productivity and water quality, disruption of people's routine actions, conversion of arable lands into semiarid or desert, and destruction of civilizations. Recent mounting interest remains organic sinks of atmospheric carbon dioxide, global warming, and balance between production & protection-based deliveries from forests.

1.1 Issues and Viewpoints Towards Water Resources Anomalies

Under population explosion scenarios, water and forests have emerged as two most important issues of 21st century, where they are concerned not only as essential by cultures & industries, but also as key factors in regulating the environment. Consequently, a study of the interface between these 2 resources (i.e. forest hydrology) becomes an imperative scientific field, offering basic knowledge/foundations for managing water & forested watersheds. Forests usually grow and develop in areas with annual precipitation of 500 mm or higher, and they remain suitable for certain agrarian activities too. Globally the forests cover about 30% land, yet this 30% forested land generates about 60% of total runoff. This altogether remains the reason that why most of our drinking-water supplies originate from forested areas. Any activities, development, and utilization of forested areas will inevitably destroy forest canopies and disturb forest floors to a certain degree, which in turn adversely affect water quantity via their impacts on transpiration, canopy interception losses, infiltration rate, water-holding capacity, and overland flow velocity. It results in increased soil erosion & nutrient losses, raising multiple issues in relation to quantitative & qualitative perspectives of water, whose fundamental knowledge; adequate studies, ample information, and right management still to be attained.

Water resource complications are true hitches to properly regulate quantity, quality, and timings of water. Some regions have too much water (flooding), while others too little (drought). Water may not ensue at the right time and at the right place (timing), or water may not be clean enough for drinking/other-uses (water pollution). Furthermore, the involvedness of water usage in our contemporary society and the necessity of water for economic growth make the right to capture water or its allocation as an imperative issue (water rights). No province in the world is invulnerable from these snags, which stem from the irregular spreading of water, water mobility, disproportion in supply and demand, and steady upsurges in population, economic growth, poor ecological management, and lack of concern by the community. Beside huge gaps in between demands & supplies of water across various regions/localities; it is water quantity which ultimately decides the fate of drought or flood conditions. Forests play a decisive role in both the scenarios. During drought conditions they have sound influences on controlling procedural elements like rainmaking, water translocation, desalination, water reclamation, rain harvesting, household conservation, evaporation reduction, and irrigation efficiency. Similarly, during floods forests suitably regulates basic essentials of floods like its forms, causes, types, nature, damages, inundation (could be a blessing), control measures, flood plain zoning /forecasting.

2. FOREST FUNCTIONS AT CATCHMENT SCALE

Being highly organized natural system, any forest dominated catchment often comprises vegetative constituents (plants, trees, under storied grass/vegetation, other native vegetation) as foremost elements forming a canopy cover and playing the protective character against eroding agents (water, wind, or even the grazing elements). Forests, forest soils and their interactions carry out key functions that contribute to food security and a healthy environment. These functions could be arbitrarily grouped into 3 categories, (i) defensive function offering a stabilizing effect on natural environment (water circulation, precipitation, air circulation, temperature, global & micro-climate, soil erosion prevention), (ii) prolific function to offer raw products/materials (timber, fruits, herbs, mushrooms etc.), and (iii) community function to create favorable environment & ecological conditions favoring health & recreation of society and enhancing livelihoods & markets.

2.1 Hydrologic Functions & Relevant R&D

Hydrological processes in forest dominated catchments are usually found most complex & uncertain, which inevitably invites site specific applications of expert knowledge on predominant conditions in regards to climatic, geological, soil, biological, pastoral, animal/livestock, human systems and their interactions in real field situations. Hamilton (1985) had well quoted some of these myths which have lots of uncertainties on forest hydrological functioning. They clues few questions like, (i) Whether forests increase rainfall (conversely, removal of forests decreases rainfall)?, (ii) Do forests increase water yield (conversely, removal of forests decreases water yield)?, (iii) Do forests reduce floods (conversely, removal of forests increases floods), and (iv) Are base flows always gets increased due to forests (conversely, removal of forests decreases base flows)?, (v) Does the stem flow are always regulated by forests to reduce high flows and increase base flows (conversely, removal of forests results in less well-regulated stream flows)?, (vi) Do forests always reduce erosion (conversely, removal of forests increases erosion)?, and (vii) Do forests always prevent or mitigate landslides (conversely, removal of forests increases landslides). Forest based trees/plants use water by two processes, (i) by transpiration taking water up from soil by roots and evaporating through pores in leaves; and (ii) by interception with direct evaporation from surfaces of leaves/branches/trunks during rainfall. It altogether has greater hydrologic effects on various stream flow parameters (total water yield, low flows, flood flows), soil erosion, stream sedimentation, water quality, landslides and the water use of different vegetation types and species. Though there exists a solid body of scientific information for understanding/interpreting the relationships between forests & water, still there remains parallel and deeply entrenched “popular narratives” which often runs counter to the consensus views of forest hydrologist (Wagener et al., 2010).

Most forest hydrology research until 1970s was carried out in humid temperate forest regions, yielding a more nuanced understanding of basic hydrological processes that apply in forest catchments. Afterward, many researchers (Samraj et al. 1988; Negi 2002; Gaur, 2003) have adopted paired catchments, where after a period of calibration (generally over several years, during which time hydrological performance of selected catchments, in particular their rainfall-runoff relationships are compared); one catchment of the pair is retained as a control, while a treatment (forest harvesting or complete clearing) is applied to other catchment and results were then measured/compared. An illustrative portrait (Fig. 1) deliberates overall hydrological elements at catchment scale with varied influences of such forest elements.

2.2 Environmental Functions

Environmental functions performed by forests may include control of water and wind erosion, defense of headwater and reservoir watershed and riparian zone, sand-dune and stream-bank stabilization, landslide stoppage, protection of wildlife habitats/gene pools, vindication of flood damage & wind speed, and sinks for atmospheric carbon dioxide/soil-carbon. Many established forests have managed to achieve one or more of these environmental functions, while others are preserved to prevent reduction in biodiversity and degradation of ecosystem. Under prevailing situations, use of forests has been shifted from single to multiple purposes; from exploitation into preservation & then conservation usages; from productive into environmental; and then ecological functions. Water based forests eco-systems have ample ability to assimilate many waste products, provides a pleasing environment for recreation, gives a livelihood for communities that depend on water bodies for food, and upholds biodiversity and habitats for the biota to ensure that their offerings/services remain fit for multiple utilities. From water quality stand points there remains varied concerns which are ultimately get influenced or governed by specified sets of ingredients. The matrix of such quality concerns/ ingredients depends upon utility of stakeholders for varied purposes.

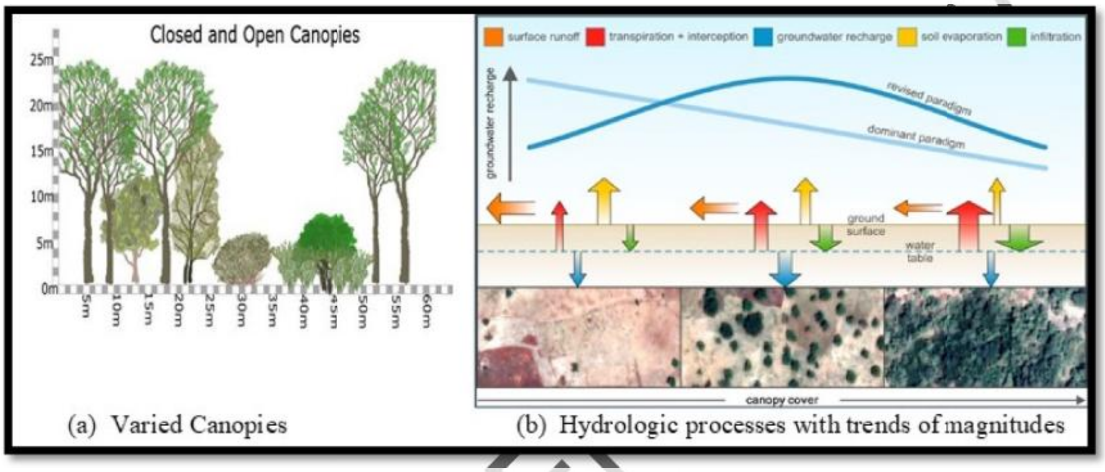

Fig. 1 Varied influences of forest canopies on hydrologic processes

2.3 Supplementary Functions

From other functional point of views there remain enormous roles performed by forests, like (i) protection of water resources via their foliage, craggy bark, and abundant litter, (ii) soil protection by slowing down flow velocity of wind & water, conserving soils & land through dense network of roots/other parts, offering buffering effects to regulate mass erosion/landslides, (iii) sizeable influences on local climate & greenhouse gas emissions, (iv) overall conservation of natural-habitat/biological-diversity, (v) recreational & other social functions in vicinity of cities, tourism and health resorts, (vi) protecting socio-economic & cultural dimensions, (vii) other mechanical/industrial/market-based deliverables for mankind, livestock, and environment. Depending upon the level of management, there could be positive or even some time negative impacts of forests on water environment. Benefits may include, (i) flood moderations/ management, (ii) diffusion/mitigation of pollution & pollutants, (iii) mitigating downstream flooding, (iv) reductions in nutrient & pesticide loss into water, (v) soil protections from regular disturbances, (vi) reducing risks of sediment delivery to watercourses/streams/overland planes, (vii) improvements in health & habitats for humans/animals/aquatic life, (viii) ecological benefits, (ix) recreational gains, and (x) other socio-economic advantages. Similarly if not managed appropriately, negative influences could be (i) adverse impacts from trees planted close to water's edge or non-native monocultures, (ii) excessive high water use freeing heavy evapotranspiration, (iii) adverse impacts on water quality (acidification, eutrophication, siltation, local flooding), (iv) antagonistic biological impacts (damaged spawning areas, clog gills), and (v) other undesired influences (dull drinking water quality, killer conifers).

3. INDIAN FOREST-WATER INTERFACE

Trees have been around for more than 370 million years, and today there are about 80 thousand species of them, occupying 3.5 billion hectares worldwide, including 250 million ha of commercial plantations (UNESCO, 2017). While forests can deliver marvelous ecological, social, and economic benefits to nations, they also disturb the hydrologic cycle in dissimilar ways. It remains more applicable for tropical nations like India, where the demand for water grows sharply and local precipitation patterns changes vastly with shrinking forests. India is tiered 10th in world, with 24.4% of land area under forest & tree cover, even though it accounts for 2.4 % of the world surface area and sustains need of about 17% of human and 18% of livestock population of the world. The total forest cover of the country is reported to be about 708273 Km2 i.e. about 21.54 % of total geographical area of country (ISFR, 2017). It includes variety of fractions/types of forests as illustrated in Fig. 2, which is self-explanatory to depict that the magnitude of dense forests is still very low being hardly 3 % of total geographical extent. Among these forests, some of the specified forests are having enormous high values towards natural resource conservation aspects. One such example is bamboo-based forests or plantations. Country has one of the richest bamboo resources in the World, second only to China in Bamboo production, with total bamboo bearing area as 15.69 million hectare and total number of culms estimated at national level as about 2868 million having equivalent weight of about 17.412 million tones (ISFR, 2017). Bamboo grown areas (forests) remains highly scattered across various states of India, with highest coverage in north-eastern regions. Bamboo has always been known as an enduring, versatile and renewable forest resource, that highly governs and regulate the quantity and quality of runoff from forested watersheds, beside ample support to check soil erosion, sediment control, stream bank stabilizations and other soil and water conservation aspects both at plot and catchment scales (Singh et al. 2014; Rao et al. 2013). There exists vast literature on historical Indian efforts towards hydrological understanding of forests starting from first ever forest hydrological experiment to other important hydrological services, paired catchment studies, & eco-hydrological results on varied forested catchments. Such studies mainly in houses the paired catchment studies across varied regions in India, in particularly the Himalayan region and few other semi-arid locations (Gaur and Kumar, 2018). There persisted couple of ecohydrology based learning lessons for environmental understanding & improvements through bigger interventions like ‘Green India Mission’ and others, putting greater emphasis on forest-water from qualitative and pollution points of view.

Class	Area Km^2	% of TGA
• Very Dense Forests	98158	2.99
• Moderately Dense Forests	308318	9.38
• Open Forests	301797	9.18
• Total Forest Cover (*It includes 4921 Km^2 under Mangrove Cover*)	708273	21.54
• Scrub	45979	1.40
• Non-Forests	2533217	77.06
• Total Geopgraphic Area (TGA)	3287469	100.00

Source: ISFR (2017)

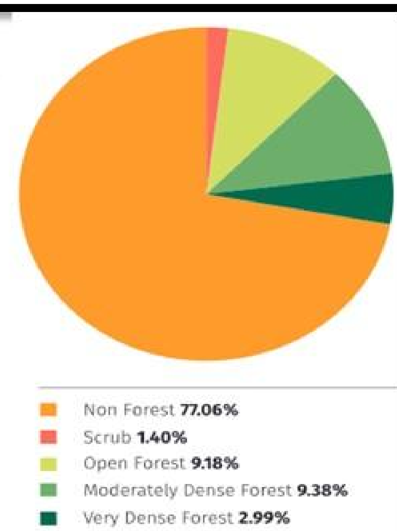

Fig. 2 Updated scenario in regards to Indian forest cover

4. CONTEMPORARY FOREST-WATER RELATIONS & INTERACTIONS

Forest management practices may have a noteworthy effect on potential use/yield of water at micro scale. On smaller catchments (<10 Km2), cutting of forest-trees often increases the peak (flood) flows, specifically during small to medium-sized rainfall events. Here major determinants remain the rainfall amount & intensity, antecedent rainfall, catchment geomorphology, and vegetation type. Forests dominatingly influence low flows to promote baseflows, but its longevity of increase depend upon futuristic conditions of contributing catchment, infiltration capacity in particular. Smaller catchments with small rainfall events often have a limited capacity to regulate stream flows, compared with large catchments, large rainfall events, or well managed vegetation. Forests are equally beneficial for water quantity & quality, which could be further amended by adopting ways like,

- Filtering & cleaning water as leaves & root systems can trap or convert harmful toxins, helping to prevent impurities from entering water systems.
- Controlling sediments by stabilizing sediments & preventing water pollution, habitats, and reservoir siltation.
- Protecting habitats by sheltering breeding grounds for aquatic species, providing nutrients &coolness to water and thus reducing need of chemicals for aquaculture
- Increasing vegetation density, which indeed kills the kinetic energy of falling rainwater and thus preventing splash erosion& high velocities of overland flows.
- Increasing rainfall by enhanced evaporated water-vapors & expanded cloud covers.
- Effectually absorbing rain water preventing erosion and flooding.

A proper understanding of hydrological cycle is obligatory for any informed argument on forest-water interactions. In accordance to general principle of hydrologic cycle, the water moves in a continuous cycle from the atmosphere to the earth by precipitation and eventually back to the atmosphere by evaporation, with the process driven by energy from the sun. Table 1, offers some food for thought on a few such indicators where one needs to get enriched, before planning or acting upon any kind of forest-water interaction task at catchment scale. It depicts probable influences across factors like water yield, peak flows, low flows, erosion, landslides, sedimentation, and water temperature & its chemistry, along with relevant research gaps. Such hydrological responses to changes in forests are governed by below given varied principles in accordance to site conditions.

Table 1 Magnitude & duration of direct hydrologic effects on catchment outputs by forests

Indicators	*3 sets of forest processes that usually modify hydrology in forested catchments*		
Watershed Output	Fire	Forest harvest & Silviculture	Roads & Trails
Water yield	• High-severity fire • increased annual water yields • little effect of low-severity fire	• increased water yield • magnitude and duration of response varies	• Little or no effect
Peak flows	• High-severity fire • increased peak flows • effect is short lived	• Increase peak flows • magnitude and duration of response varies	• Increased peak flows • long-lived effects • affect extreme events
Low flows	• High-severity fire	• increased low flows • little effect of low severity fire	• Increased low flows • deficit as forester grow • Overall little/ no effect

Erosion, landslides, sedimentation	• High-severity fire • increased erosion and sedimentation in streams • less effect from low fire	• Increased surface erosion, landslides, and sedimentation; • effects may be long lived	• Increased surface erosion (road surfaces, gullies) and landslides • Enlarged sedimentation
Water temperature and chemistry	• Increased water temperature • riparian forest removal • fire retardants • chemistry change	• Increased water temperature • Minor effect of fertilizer • short effects post-harvest	• increased nitrate • delivered chemicals (salt, oil) to streams
Research gaps	• Uncertainty about effects beyond few years • magnitude and persistence of downstream effects • effects of salvage logging	• Uncertainty about effects beyond one/two decades • magnitude and resistance of downstream effects • effects on habitat and aquatic ecosystems	• Uncertainty about road effects on extreme floods and in watersheds >1 Km^2
Note :Above are merely & generally visualized effects, not predictions.			

5. FOREST WATER QUALITY AND CLIMATE CHANGE

Benefits of forests for water quality are always at the forefront. Well-managed or even unmanaged forests/forest-lands are normally beneficial for protecting water quality. They contribute sizably in stabilization of steep slopes and reducing slide damage, preserving the quality of drinking-water supplies and many other ecosystem services. The major positive features remain to govern issues like; Turbidity, siltation, riverbank stability, pesticides/chemicals, streamflow, eutrophication, acidification, water color, dissolved organic, carbon and many other such issues. Water draining from native forests mostly has a lower nutrient content than that draining from more intensive land uses, which reflects a sound conservation aspect. Contrarily on other side (only localized issue) some of the tree canopies capture atmospheric pollutants, which may sometime promote high levels of nitrate in surface and groundwaters in highly polluted areas. Many a time's forests may alter water color in streams draining peaty soils due to cultivation, drainage and mineralization of organic matter. Greater coloration can affect drinking water treatment and truly represents a loss of soil carbon. Implications of climate change & its associates (sea level rise, coastal imbalances, land degradations, soil erosion/landslides) offering threats to forest water resources. Forested catchment often experienced reduced soil erosion and sediment entering streams by: refining soil structure and stability; increasing soil infiltration rates; reducing rapid surface run-off; and providing shelter from wind. There remain enormous popular narratives in regards to connectiveness among soil & nutrient losses, forest felling, imports & exports of pollutants' to & from' water bodies. One of the most popular narrative is that "Forests reduce erosion and conversely, the removal of forests increases erosion". It is well established fact that a well-managed catchment (good stands of forests, free of grazing and other disturbances) minimizes hillslope erosion and thus produces high-quality water that is free of sediment & other pollutants. Moreover, the condition of the soil surface and, particularly, the retention of understory vegetation, grasses and litter are the primary determinants to govern surface erosion on hillslopes and also along the streambanks. Riparian vegetation with a complex structure of grasses, shrubs and trees, plays a significant role here to oversee water quality parameters. Many positive impacts of the cohesive strength of the roots of forest tress are established by researchers showing closer relevance to forest-water relationships.

Though water quality is a big subject to pronounce, but restricting it towards catchment runoff standpoint, there remains few basic indicators (given below) to quantitatively designate the water (overland runoff, stream water, stored water) across many parts of a forested catchment.

a) Water Temperature which is affected by air temperature, stormwater runoff, groundwater inflows, turbidity, and exposure to sunlight.
b) pH which use to be a measure of a solution's acidity via number of hydrogen ions. Largest variety of freshwater aquatic organisms prefer a pH range between 6.5 to 8.0.
c) Turbidity being a measure of how particles suspended in water affect water clarity indicating suspended sediment and erosion levels.
d) Conductivity as an effective measure to indicate presence of polluting discharges (μmhos/cm) and thus ensuring a safe range to care aquatic life (150 to 500 μS/cm).
e) Dissolved Oxygen to reflect level of support to aquatic life (best values : 5-10 mg/L)
f) Nitrate normal levels (<1 mg/L) reflecting health of forest streams to suit drinking or aquatic utilities.
g) Phosphates in safe levels (< 0.1 mg/L) to preserve forest streams as of unpolluted.

5.1 Ecologic Effects of Forest Conversions

Forests stabilize soils; therefore, soil is more readily eroded following removal of vegetation, and is transported as sediment into floodplains and other areas of lower topography directly into stream channels. The effects of historical land use conversion towards agricultural use (in particular row-crop agriculture), on soil erosion and subsequent sediment deposition were always found profound by past researchers. In the same fashion the effects of forest conversion on water quality or water chemistry too are of great significance, as in majority of cases the undisturbed forested watersheds are generally associated with low stream-water concentrations of most ions. Consequently, net export of macronutrients, or nutrients required in large quantities (N, P, K) from uninterrupted forested catchments is often negative, showing a sum of forest biomass. Table 2 provides probable contributions of forests in ecological regards.

Table 2 Forest contributions to preserve/maintain water based environmental needs

Water-based Ecological Requisites	Likely Contributions of Forests
1. Well-oxygenated water free of pollutants	✓ Well-designed and managed forests protect the soil and can act as a trap or sink for contaminants ✓ Riparian buffer areas have an important role in intercepting sediments, nutrients and pesticides
2. Adequate light reaching the water to support aquatic life	✓ A variable density of tree cover is a key component to provide the right balance of light and shade
3. Range of natural features/habitats (pools, riffles, bars, wetlands, ponds, backwater channels, connected floodplains)	✓ The binding action of tree roots helps to maintain these for strengthening and stabilizing river banks, reducing erosion and bank collapse
4. Region/site-specific appropriate vegetation	✓ Native riparian offers an ideal cover for protecting river morphology

5. Normal range in acidity & alkalinity	✓ Forest canopies, offers increase in capture of acid pollutants in atmosphere, reducing stream pH
6. Apposite inputs of organic matter/nutrients	✓ Variety & seasonality of leaf litter inputs/microbial processes in the root zone; maintains energy & nutrient flows and effective ecological functioning of aquatic ecosystems. ✓ Twigs/leaves/terrestrial invertebrates that fall from forest canopies into the water, serves as food for aquatic organisms
7. Natural range in water flows, velocities, and depths	✓ Reduced water flows can impede fish access decreasing available habitat for freshwater life ✓ Forests can reduce water flows, but this effect can be ameliorated by good forest design & management

6. CATCHMENT MANAGEMENT STRATEGIES

At catchment scale, the water resources management occurs within a highly integrated environment, where its quality & quantity and the aquatic ecosystem remains interlinked and interdependent. Salient indicators like turbidity/siltation, riverbank stability, eutrophication, pesticides/chemicals, acidification, water color, dissolved oxygen, organic carbon; all plays a decisive role in deciding the level of sensitivity of particular zone or extent of water or forest segments. From strategic managerial considerations one need to properly identify and understand various regulatory mechanisms inside the catchment; which governs the water from qualitative perspectives. It involves various nodes like, interceptions (canopy & litter), though fall, stem flow, vaporizations from tree surfaces, evapotranspiration, heat fluxes from canopy & root parts, soil infiltration & other deeper movements, flow dynamics on overland planes & streams, and other active links. If we look into basic practices that can lead to leading pollutions, the most vital ones are (i) clear felling of forests, (ii) forest roads, and (iii) forest fires & land use alterations. Catchment management strategies always need to be re-aligned in a way that there remains ample scope for land and water modifications to offer better and higher magnitudes of water conservation/harvesting and recycling across different parts of catchment. These practices include, increasing opportunities for soil infiltration, prolonging time of runoff concentrations, diminishing flow velocities, creating bigger & a greater number of water storage elements, and reducing evaporation losses from water bodies. A generalized spectrum of such probable effects is provided in Table 3.
This altogether makes the assessing/monitoring/measuring/managing of water quality at catchment scale, a highly tedious task. Below given managerial targets could be set to attain planning & execution of ground based tailormade region specific actions,

a) Reducing overland runoff through canopy interception and transpiration
b) Increasing soil porosity through the organic horizon and root systems
c) Slowing down overland flow velocity through litter coverage
d) Reducing the terminal velocity of raindrops through canopy interception
e) Enhancing soil aggregates and binding through root reinforcement

Table 3 Specific effects of individual hydrologic processes in forested catchments

Hydrological Processes	Type of Changes	Specific Effects
1. Interception	• Reduction	• Moisture level smaller • Greater runoff in small storms • Increased water yield

2. Litter storage of water	• Litter reduced • Litter not affected • Litter increased	• Less water stores • No change • Storage increases
3. Transpiration	• Temporary elimination	• Baseflow increase • Soil moisture increase
4. Infiltration	• Reduced • Increased	• Overland flow & stream flow increases • Baseflow increases
5. Streamflow	• Changed	• Increase in most eco-systems • Decrease in snow systems • Decrease in fog-drip systems
6. Baseflow	• Changed	• Decrease with less infiltration • Increase with less infiltration • Summer low flows (+ve or -ve)
7. Stormflow	• Increased	• Volume greater • Peak flows larger • Time to peak flows shorter

6.1 Surface Water Acidification and Eutrophication

Forests and forest management practices can affect surface water acidification in a number of ways, where primary means remains ability of tree canopies to capture more Sulphur/Nitrogen pollutants from atmosphere than other vegetation types. Activities pertaining to cultivation, drainage, roads, fertilizer use, felling/harvesting, and restocking have their own effects. A second way that tree planting can exacerbate acidification is through uptake of base cations (calcium, magnesium, sodium and potassium) from soil. Tree canopies could be effectual at enhancing deposition of sea-salt aerosols from atmosphere, which remains greatest along coastal areas/storms. Well-managed forest land is often beneficial for protecting water quality, moreover natural forests too can pose potential threats, via linked interactions between the water, canopy, and atmosphere. Forests can benefit or even impend water quality by ample exchange of atmospheric ammonia with vegetation surfaces. Eutrophication, often plays a vital role in context to dynamic relationships among trees & water. It is generally believed that the water draining from natural forests has a lower nutrient content than that draining from more intensive land uses, indirectly reflecting the status of nutrient inputs and soil disturbances. Very often low nitrate concentrations are visible in runoff from forest catchments, as compare to agricultural or other land parcels having intensive land use patterns. Moreover, in highly polluted areas, the tree canopies arrest atmospheric pollutants, which usually promote high levels of nitrate in surface and groundwaters. Broadleaved forests are known to provide an effective nutrient buffer for water draining adjacent land, especially in riparian zones. Nutrient uptake is reported to be strongest during younger stages of growth and declines rapidly with age. Riparian forest buffers are extremely effective solutions to intercept such pollutants.

7. KNOWLEDGE GAPS & RESEARCH NEEDS

We need to seriously and sensitively comprehend about such scenery & characters of forest-water relations, seeing across the array of given physiographic, climatic & social structures. If we keep hydrologic cycle in background, such complexity further increases with the interactive effects of multiple drivers like, land use change, climate change, population growth, and the nature's variability. This altogether advocates to espouse more R&D efforts on forest water hydrology, offering following probable nodes for bridging addressable knowledge gaps,

- Big data on forest-water interventions
- Advanced models and modeling attempts on forested catchments (pure/mixed)
- Linking decisions of water supply reservoir storage, inter-basin water transfers, land use alterations, river flows, and trade-offs between water resources & carbon sequestration
- Bringing proven results on better understanding/linkages of forest flows with physics

Key environmental services provided by the forests are being well recognised in current days where aspects like carbon sequestration, water protection, biodiversity, soil quality, and other favourable environments for aquatic and human life; are given significant importance at varied scales. All these environmental services are in fact amply exaggerated by various types of forest management, knowledge, and comportments in which forests are managed at catchment scales (Gaur and Gaur, 2017). There is a need to better understanding & quantifying of ultimate collective effects of forestation or deforestation, keeping focus towards local biodiversity, water protection, carbon management, water & soil quality, and many other environmental forest ecosystem services. Effects of deforestation on litter transport, decomposition rate and invertebrate communities in spring fed stream ecosystems are another sensitive forest extent for coming time. Other vital aspects could be, (i) to get acquainted with net effects of whole-tree harvesting v/s stem-only harvesting, (ii) evapotranspiration of forests, (iii) distributed hydrological modelling in forested catchments, (iv) end influences of land use changes inside the forests, (v) impacts of hydrology & oxygen limitation on forest growth, (vi) CO2 efflux, and (vii) overall ssustainability perspectives in routine forest operations/management. A better understanding, data, information and knowledge is still required via combination of targeted field and modelling studies, to appropriately outline few imperative issues like,

- Quantifying impact of upland forests on water quantity & quality at catchment scale
- Field testing of models and further quantification of impacts that floodplain of forested catchment can have on mitigating large flood events.
- Quantifying effects of targeted planting of forests on diffused pollution within catchments, in relation to infiltration basins, riparian buffers, pollutant pathways.
- Developing best practices for managing floodplains of forested catchments.
- Counting real water use of wider range of forest species with evaporation guestimates
- Quantifying effects of flood flows & diffused pollution controlling drainage systems.
- Quantifying economic costs & benefits of forest impacts on water and water services, developing improved climate change water use impacts models, and region-specific monitoring on long-term effects of forests.

8. CONCLUSION

Concludingly, present writeup addressed certain basic as well as wider issues which often revolves around forests and water segments. Elementary hydrological functioning and significance of various processes and elements were attempted to offer a deeper understanding of forest-water interactions. Potential forest and water management strategies based on such understanding deliberates forest and water management strategies when water is prioritised over other forest-related goals (such as biomass accumulation or the sequestration of carbon in standing forests). Explicitly prioritising water in forest management attempts to reset our priorities toward more sustainable strategies for long-term forest health and human welfare. There exits vast opportunities and equally vast challenges to govern qualitative as well as quantitative aspects of water in forested catchments. Need of the hour is to properly understood and assign priorities for tackling relevant indicators, variables or methods, to ensure improved harnessing with a balanced approach where productive as well as protective factors both are equally cared. There exist vast knowledge gaps in land-use/water nexus panorama at regional scales; which demands equal attention to tackle ’forest-water-energy’ trio in a smart and effectual manner. It all together lead to offer a strong foundation for achieving truer forest-based adaptation and mitigation goals. Forests have ample scope and capabilities to mitigate problems related to water scarcity and global warming, however as on day the majority of forest-driven water and energy cycles are poorly integrated into regional, national, continental and global decision-makings, which have severe influences towards climate change adaptation, mitigation, land use and water management in forest dominated catchments. This constrains humanity’s ability to protect our planet’s climate and life-sustaining functions. The substantial body of reviewed research have well revealed that forest, water and energy interactions provide the foundations for carbon storage, carbon sequestration (Gaur and Gaur, 2017), for cooling terrestrial surfaces and for distributing water resources. Forests and trees must be recognized as prime regulators within the water, energy and carbon cycles.

Water is very seldom considered first in forest management perhaps because the co-occurrence of forest and water are so common. Clean, abundant water is an extraordinary ecosystem service that is always provided by forests. Depending on the place, meteorological settings, size of the forest and time of year, forest water may be flowing, stagnant, a dripping leak, a clear running or silt laden rivulet or even a cascading river. However, some form of flowing water from these ecosystems seems as natural as the trees that edge them for good reason. However, as global climate air temperatures and climate variability continue to upsurge, the relationship between forests and water flow remains highly changing. Various studies have shown that incoming precipitation is first used by vegetation with the excess used to then saturate the soil column. Only after these two situations are met, the water then begins to drain from forest ecosystem as streamflow. Furthermore, if changing climatic patterns reduce precipitation, streamflow may be even further reduced compared to historic conditions. However, some reductions maybe moderated if forest mortality reduces plant water demand, but the evidence for this impact usually remains uncertain. Present paper has examined & discussed a range of forest and water related issues, topics, and strategies that respond to some of the contests, out of which a few overarching conclusions,

- An overall approach to water-sensitive landscape management needs to recognize the importance of critical water zones-water source areas and riparian/wetland areas as well as surrounding buffer zones that have the greatest impact on socio-hydrologic system.
- Knowledge and data for a complete understanding of these coupled socio-hydrologic systems remain inadequate, hence there is need for better monitoring, as well as an improved used of new techniques, which include modelling, the use of new data sources and techniques, as well as a greater sensitivity to local observation and alternative (including indigenous) knowledge systems.
- Sequestration of carbon in standing forests and lack of understanding of landscape-scale effects amongst hydrological & forest science communities/policymakers are swelling concerns to govern risk of policy failure in handling forest water resources.
- There is an imperative need to expand the way forest and water managers are trained, to bring them together in a more integrated way so that in the future, forests can be managed explicitly for water & other benefits.

- Maintenance of good or high ecological status of waterbodies of forest catchments by preserving high-quality drainage waters with lowered nutrient/pesticide/sediments is another crucial need.
- Assessing reductions in water use and increased water yield as younger forest matures, maintenance of water yield, and probably base flows, across large parts of catchment ; overlying clay soils & sandy soils and their hydrological & environmental influences; and assessing reduction in water yield, base flows, and variability of small & larger floods are some of the other issues which needs proper attention.

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