Policy Article

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

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ABSTRACT

Sustaining a resilient and reliable water cycle is a global challenge, which inevitably needs proper understanding and action at many levels. One quarter of the world's population depends on water from forested catchments, where behavior of atmospheric water nonetheless governs the forest-water interactions and thus the ultimate water availability. As per a coarse estimation the water vapors comprise one quarter of 1 % of atmospheric mass being equivalent to just 2.5 centimeters of liquid water over the entire Earth. Such water availability raises more tangible concerns for most people than do temperature and carbon. Ever escalating populations and living standards are badly impacting the earth's surface in variety of ways, as 1.5 million Km^2 of dense tree cover were reported to be lost between 2000-2012, leading to highly impeded access to fresh water. Majority of studies of how forest land use and its change influences climate and hydrology rely on models (mostly imperfect owing to pitiable/incomplete process understandings and poor parameterization). It is projected that land cover changes have caused a 5 to 6 % reduction in global atmospheric wetness. A plethora of alike estimations/inferences are included herein to offer relevant R&D insights on core theme of this paper, by encircling reviews of few global observations and findings towards forest influences on quality and quantity of water. With increasing demand for agricultural and urban land (owing to population/affluent life-styles) majority of forests are put under pressure. At this juncture tropical regions like India remains more crucial, as their water and land use policies are often influenced to big extent by many perceived effects from hydrological functioning of forested catchments. This paper offers certain food for thought by summarizing relevant scientific consensus of key aspects of forest-water relationships and 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 and forest management on various stream flow parameters, soil erosion, stream sedimentation, water quality, landslides and water uses. Owing to their inherent capabilities and capacities, the forests govern available moisture for tree growth, ET, soil infiltration, ground water recharge, and runoff; hence could be projected as futuristic 'water towers'. Hydraulic redistribution of water in soil remains other important activities by the forest, where tree root structures plays a vital role to facilitate both upward and downward water dynamics. Even under low to intermediate tree cover each tree remains capable to improve soil hydraulic properties even up to 25 m from its canopy edge, with higher hydrologic gains in comparison to associated additional losses (transpiration and interception). Among most profound and alarming insights offered by this write up are; critical knowledge gaps on understanding importance of forests to water, trends of findings from a few catchments based hydrological experiments on water yield, roles forest may play in regulating water fluxes and rainfall patterns. Other key messages offered for water and forest policy makers includes issues like water use by forests, flood flows, water quality, erosion, climate change, energy forest, and forest water productivities.

Keywords: Forests; Hydrology; Water-Quality; Forest-Water-Interactions; Water and Forest Policy Management; Catchments

1. INTRODUCTION

Theory and evidence indicate that forest trees and all other vegetation influence the water cycle in numerous ways. These influences are more imperative, more complex, and more poorly pigeonholed than is widely comprehended. While there is little doubt that changes in forest tree cover will impact the water-cycle, the wider significances remain difficult to predict as the underlying relationships and processes continues to be poorly categorized. Nonetheless, as forests are vulnerable to human activities, the linked aspects of the forest-water interactions are emerging as a burning issue, with source of risk and impending consequences towards water scarcity threats. Forests presently cover only about one third of Earth’s surfaces (FAO, 2016). Riitters et al., (2016) conducted a prime analysis of published maps of global tree cover derived from Landsat data, with varied patterns and dissimilar consequences and revealed that only in between 2000 to 2012, urban growth, agrarian land adaptations, logging, and forest fires resulted in the loss of some 1.5 -1.7 million km^2 of tree cover, which is about 3.2 % of global forest cover. The difference in loss rates was reported consistent in vast number (about 768) global ecological regions, while comparing the changes of forest interior area and linking them to the changes of total forest area; by detecting direct (pixel level) and indirect (landscape level) components of forest interior change. 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). As global deforestation and degradation increase, there is an even greater need for accurate data for assessing forest cover change and associated emissions (Baccini et al., 2012). Future steps for quantification of such forest degradation will certainly include an assessment of such causes, notably the addition of information on drivers of degradation. Sustaining a resilient and reliable water cycle is a global challenge, and requires understanding and action at many levels.

Forests always remain an integral constituent to any water cycle: they control stream flow, care ground water recharge, and through evapotranspiration (ET) bestow to cloud generation and precipitation. With variety of bio-physical control, they often act 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 embrace aspects like soil health, gravity, soil pedology, soil wetness and climate change. 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 causes of change operate on a very small scale, while other may influence 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 the end clients whose livelihood remains solely dependent on forest and agriculture-based earnings. If we talk on true source 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 varied essential purposes of water use (domestic, agricultural, industrial, and environmental) and water productivities. Energy, too plays a leading role at this interface and thus the forest-water-energy cycle connections brings a true foundation for mitigating water scarcity and global warming problems. 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 aids improved water and environmental quality, as they interact with water and soil in variety of ways, providing canopy surfaces which trap rain and thus allowing evaporation back into atmosphere. It also adjusts that how much water reaches forest floor as through fall and pulled water from soil for transpiration. Relationship between forests and water is nowhere unpretentious. 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); while majority of trees also release water into the atmosphere through ET, which often returns as precipitation locally (Ellison et al., 2017). Forest management can therefore have negative as well as positive impacts on water quantity and quality, species, temporal distributions, tree densities and other vital managerial features. It is also important to note that what is true for one context is not necessarily so for others. Present paper basically seeks to examine evidences about the probable contributions that forests and water with their stakeholders can make to achieve sustainable development by regulating forest-water interactions.

Accessibility of water determines where life (people/animals), can occur and is in turn prejudiced by such life. Increasing populations and improving living standards are impacting the earth’s surface in a variety of ways (Sayer et al., 2013). One and a half million square kilometers of dense tree cover were reported to be lost between 2000 and 2012 with a gross 2.3million loss and 0.8 million gain (Hansen et al., 2013).At the same time, other evaluations (Arnell et al., 2016) clearly established that impeded access to fresh water has generated various confronting issues, on which a concern is always desired to explain that whether we know enough to understand, predict, and address how forested land cover influences water availability (Teuling et al., 2010). Water vapors comprises one quarter of 1 % of the mass of the atmosphere equivalent to just two and half centimeters of liquid over the entire Earth (atmospheric water in the form of liquid droplets and ice adds less than one hundredth to this miniscule total). The behavior of this atmospheric water nonetheless governs forest water interactions and water availability on forested land. Thus, such water availability raises more tangible concerns for most people than do temperature and carbon. Another recent study (Sterling et al.,2013) has well projected that land cover changes have caused a 5 to 6% reduction in global atmospheric wetness. Most studies of how forest land use and its change influences climate and hydrology rely on models (Garcia et al., 2016; Mahowald et al., 2017), which at majority of time remains imperfect owing to poor or incomplete process understandings and poor parameterization (Maraun, 2015).

Among the most profound and alarming insights offered by this write up is the potential for non-linear behaviors: the indication that a continent or region that passes some threshold of forest loss might tip from a wet to a dry climate. While various details remain poorly characterized, and some are debated, the overall strong linkages among forest and water appear uncontroversial. We know that large scale forest loss or die-back will generally reduce atmospheric moisture, rainfall and cloud cover and increase the likelihood of drought and further loss or die-back. Present write up offers a categorized food for thought and its diagnostic interpretations/comparisons; by means of updated reviews arrived from huge investigations and relevant literature released by distinct researchers and subject experts in forest and water domain.

2. Methodological Portrayal

The forest-water nexus is rapidly growing in scholarly literature and policy settings as a novel way to address these 2 most complex natural resources and their R&D challenges. Efforts were made to identify tradeoffs and synergies of water and forest based hydrological nodes with internalize processes and their overall impacts to govern overall balancing of water and forest-based dealings. Variety of literature was sailed across by covering global knowledge source points via web services, published research journals, books, conference proceedings, on-line data sources and plethora of relevant and updated scientific literature. Some of the prevailing methods were reviewed and applied to derive a concise knowledge base of existing approaches and promoted development of analytical processes, whatever gets aligned within key theme of research paper. The systematic review of about 100 journal articles and book chapters was sensibly recited and analyzed for arriving on suitable transitory findings. A workable matrix was conceptualized where prioritized actors (processes and components) of hydrological set-ups were visualized and earmarked to evaluate their quantified magnitudes as well as patterns of changes for forested catchments of varied scales. Though the findings remained extremely voluminous, an effort was made to formulate a categorized and mini matrix of cause and effects and presenting the same in tabular formats for giving various kind of though provoking end impressions. Efforts were made to ensure minimum descriptive or textual information and best possible interrelationships across various elements and processes of water cycle and water transferring; and role of forest components therein. 3 to 4 major sets of indicators of forest processes that usually modify hydrology in forested catchments were assessed and their ultimate probable influences as 5 to 6 major watershed outputs were critically projected for varied but most common forest conditions (horizontal/vertical architecture, forest fire conditions, forest floor form etc.).What happens on various water-based indicators/processes when one components or sub-component of forest trail upward/downward, is attempted to be answered in crisped and condensed manner in such tabular results. Hydrological processes like interception, depression storage, evaporation, ET, infiltration, ground water recharges, soil moisture fluxes, surface runoff, floods, droughts and other entities were assessed by visiting published research-based knowledge banks and results from dozens of natural forest catchments, where suitable hydrological instrumentations and observation recordings were reported. It included end indicators like peak stages of flow depths, peak discharge rates, steady state soil infiltration, high flows, medium flows low flows, sediment based situations, forest density, canopy architectures, qualitative indicators of water in forest streams and other storages (surface, sub surface, underground), forest conditions (fire, roads, grazing, tree densities, vegetation types), and other exact snags like mass erosion, landslides, stream bank and riparian health.

While comparing and analyzing above interactions, a preliminary appraisal was achieved to comprehend specific and reproducible methods for such nexus valuations. Majority of such reported nexus methods looks to be fall short of fully capturing above interactions, as it involves enormous elements of uncertainties and invisible physical process components; which often remained highly uncertain, unpredictable, and thus confining them within only a conceptual framework. To overcome these limitations, background customary key papers were pain staked while deriving and arriving at key features of water-forest nexus analytical tackling. The prime operational elements considered remained updated, innovative, contextual, collaborative, and largely implemented works and reports. About 20 real ground based studies are depth fully sailed across to extract promising inferences and thus offering both the short comings as well as future line of works to bridge gaps at macro and micro scales, and thus offering line of sights for relevant researchers, field functionaries and policy planners.

2.1 Analytical Framework to Converse Forest-Water Relationships

In a far-reaching situation, the forest-energy-water nexus, or the interdependence of these 3 big players, continues to receive high attention; as their overall impacts exceedingly affects the balance among water supply and demand to meet the needs of growing populations, climate-related stresses and other infrastructure-based policy planning. Changes in forest lands, water and energy demand are absolutely linked to changes in regional temperature, precipitation extremes, and many components and processes of hydrologic cycle; which in turn affect the availability and as well as productivity of water. Additionally, the relevant vulnerabilities (both for water and forests) rely on the integration and prioritization of above cited processes across water cycle. A preliminary framework is set in this regard, and the same is discussed appropriately in below given segments of paper by covering salient processes, their inter reactions and the end impacts. Being natural resources, needs and analytical methods for water and forest, happens to be extremely wide, flexible and depth full. It is attempted here in by accommodating only prime components and their possible specimen interactions (based upon reporting from literature-based reviews) by being within a basic and fundamental knowledge discovery framework. Enormous number of analytical challenges were well-thought-out that have been projected by several relevant researchers which paved a way for better methodology developments for assessing forest-water interactions at varied scales of time and space. Here the major four challenges could be enlisted as (i) the timing of study and its objects, and how to address outcomes/impacts in a given time frame, (ii) need to systematically address system boundaries, (iii) estimation of the outcomes on behavior of economic actors and subsequent environmental impacts with a reliable reference framework covering policy- economy–environment chain, and (iv) interactions across varied/multiple policies of water, forest, and environment. Looking across these boundaries, findings (along with their contrasts) from several studies or researchers are considered in discussion across various segments and sub-segments of this write up.

3. FOREST FUNCTIONS AT CATCHMENT SCALE

One quarter of the world's population depends on water from forested catchments. Bosch and Hewlett (1982) offered a good review of catchment based hydrological experiments to regulate effect of vegetation changes on water yield and ET, by encompassing about 94 catchments and established the fact that accumulated evidence on the consequence of vegetation changes on water yield can be nicely used for practical purposes. Pine and eucalypt forest types were reported to cause on average 40-mm change in water yield per 10% change in cover and deciduous hardwood and scrub (Scott et al., 2008).Being highly organized natural system, any forest dominated catchment frequently 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 and 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 and ecological conditions favoring health and recreation of society and enhancing livelihoods and markets.

3.1 Hydrologic Functions and Relevant R&D

Hydrological processes in forest dominated catchments are usually found most complex and 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) transpiration taking water up from soil by roots and evaporating through pores in leaves; and (ii) interception with direct evaporation from surfaces of leaves/branches/trunks during rainfall. It altogether has superior 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 evidence for understanding/interpreting the relationships between forests and 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 and point 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 explanatory portrayal (Fig. 1) deliberates such overall hydrological elements at catchment scale with varied influences of forest elements. Forest are always reported to get intimately linked rainfall and water availability, as they play an important role in regulating fluxes of atmospheric moisture and rainfall patterns oven land. The impacts of forest derived ET as seen from satellite-based observations of rainfall over most of the tropics is reported by researchers and it is an established fact that if the air that passes over forests for ten days may typically produces at least twice as much rain as air that passes over sparse vegetation (Sparcklen et al., 2012). On the other hand, the forest loss and its degradation reduce ET with imperative implications for rains occurring thousands of kilometer downwind side (Debortoli et al, 2017).

Large-scale deforestation is reported to reduce rainfall in some regions to the extent of 30% (Lawrence and Vandecar, 2015). As such forest controls the rates and magnitudes of relative humidity too, which remains another governing factor for net pars of rain-runoff and their interrelationships to control loss of soils and nutrients. Researchers like Khain (2009) have well established the fact that a 10 % rise in relative humidity can lead to two to three times hikes in the amount of rainfall. Beside above the forests used to be a means of transportation of water (locally as well as globally), specifically during transport of moisture. Makarieva and Gorshkov (2007) offered a new concept namely the ‘biotic pump theory’ advocating atmospheric circulation that brings rainfall to continental interiors is driven and maintained by large continuous areas of forests often beginning from coasts. The theory explains that, through transpiration and condensation, forests actively create low pressure regions that draw in moist air from the oceans, thereby generating prevailing winds capable of carrying moisture and sustaining rainfall far within continents. Past researches have well quoted that we can no longer ignore tele-connections between areas that produce atmospheric moisture and those that receive this moisture as a main source of precipitation.

3.2 Environmental Functions

Under prevailing situations, use of forests has been shifted from single to multiple purposes; from exploitation into preservation and 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. 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 and 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 (Sodhi et al., 2010). 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.

Forest-driven water and energy cycles are poorly integrated into regional, national, continental and global decision-making on climate change adaptation, mitigation, land use and water management. This constrains humanity's ability to protect our planet's climate and life-sustaining functions. The substantial body of research was view reveals that forest, water and energy interactions provide the foundations for carbon storage, 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. If these functions are ignored, planners will be unable to assess, adapt to or mitigate the impacts of changing land cover and climate. Our call to action targets a reversal of paradigms, from a carbon-centric model to one that treats the hydrologic and climate-cooling effects of trees and forests as the first order of priority. For reasons of sustainability, carbon storage must remain a secondary, though valuable, by-product. The effects of tree cover on climate at local, regional and continental scales offer benefits that demand wide recognition. Therefore, stand tree centered researches (Syktus et al., 2016) insights were reviewed and analyzed to provide a knowledge-base for improving pertinent plans, policies and actions.

Forests are found to be a prime natural system to regulate water supplies and happens to be practically important resources to create so called 'water towers' for meeting the water demands across the regions, nations and globe as a whole. With their inherent capabilities and capacities, the forests govern available moisture for tree growth, ET, soil infiltration, ground water recharge, and runoff. Munoz-Villers et al., (2016) have well revealed the results where forests have amply exhibited higher rates of infiltration and dry season flows as compare to landscapes where lands are converted to agricultural use. Hydraulic redistribution of water in soil, was reported as another important activity by the forest, where tree root structures were found to play an important role to facilitate both upward and downward movement of water fluxes. Inside the soils. Ilstedt et al., (2016) reported higher ground water recharges under intermediate tree densities even on degraded lands, establishing that on degraded land cover (without tree) only a little water can infiltrate into the soil. Under low to intermediate tree cover each tree was reported to be capable o improve soil hydraulic properties up to 25 m from its canopy edge, with higher magnitudes of hydrologic gains in comparison to associated additional losses (transpiration/interception).

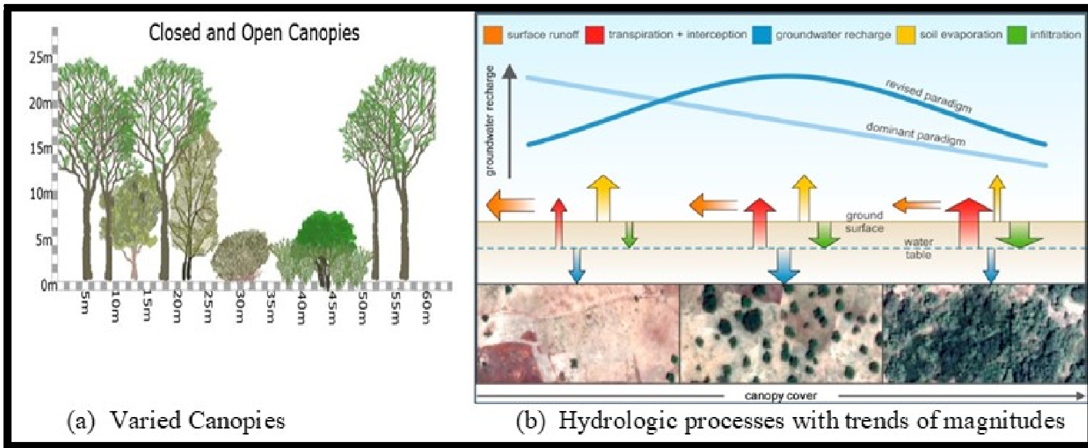

Fig. 1 Varied influences of forest canopies on hydrologic processes

3.3 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 and water, conserving soils and land through dense network of roots/other parts, offering buffering effects to regulate mass erosion/landslides, (iii) sizeable influences on local climate and greenhouse gas emissions, (iv) overall conservation of natural-habitat/biological-diversity, (v) recreational and other social functions in vicinity of cities, tourism and health resorts, (vi) protecting socio-economic and 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 and pollutants, (iii) mitigating downstream flooding, (iv) reductions in nutrient and 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 and 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 ET, (iii) adverse impacts on water quality (acidification, eutrophication, siltation, local flooding), (iv) antagonistic biological impacts (damaged spawning areas, clog gills), and (v) other effects (drinking water quality, killer conifers).

4. 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 10thin world, with 24.4% of land area under forest and 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 Km^2 i.e. about 21.54 % of total geographical area of country (ISFR, 2017). It includes variety of fractions/types of forests (Fig. 2), being 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, and 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 and 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)

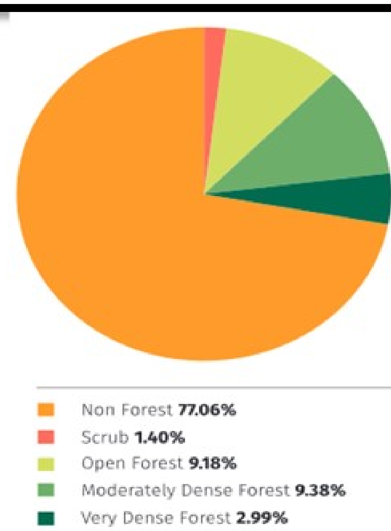

Fig. 2 Updated scenario in regards to Indian forest cover

5. CONTEMPORARY FOREST-WATER RELATIONS AND INTERACTIONS

Forest management practices are reported to have a noteworthy effect on potential use/yield of water at micro scale. On smaller catchments (<10 Km^2), cutting of forest-trees often increases the peak (flood) flows, specifically during small to medium-sized rainfall events. Here major determinants remained the rainfall amount and intensity, antecedent rainfall, catchment geomorphology, and vegetation type. Forests dominatingly influenced low flows to promote base flows, but its longevity of increase depended 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 were reported to found equally beneficial for water quantity and quality, which could be amended by adopting,

- Filtering and cleaning water as leaves and root systems can trap or convert harmful toxins, helping to prevent impurities from entering water systems.
- Controlling sediments by stabilizing sediments and preventing water pollution, habitats, and reservoir siltation.
- Protecting habitats by sheltering breeding grounds for aquatic species, providing nutrients and 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 and high velocities of overland flows.
- Increasing rainfall by enhanced evaporated water-vapors and 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 and 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 and 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 and Silviculture	Roads and 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	• Increased water temperature	• Increased water	• increased nitrate

temperature and chemistry	• riparian forest removal • fire retardants • chemistry change	temperature • Minor effect of fertilizer • short effects postharvest	• 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 and generally visualized effects, not predictions.			

6. 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, stream flow, eutrophication, acidification, water colour, dissolved organic, carbon and many other such issues. Water draining from native forests are mostly reported to have 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 groundwater in highly polluted areas. Many a time's forests may alter water colour 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 and its associates (sea level rise, coastal imbalances, land degradations, soil erosion/landslides) offering threats to forest water resources. Forested catchment is often found to experience 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 connectedness among soil and nutrient losses, forest felling, imports and exports of pollutants' to and from' water bodies. One of the most popular narrative offered by researchers 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 hill slope erosion and thus produces high-quality water that is free of sediment and other pollutants. Moreover, the condition of the soil surface and, particularly, the retention of understory vegetation, grasses and litter remain the primary causes to govern surface erosion on hill slopes and also along the stream banks. Riparian vegetation with a complex structure of grasses, shrubs and trees, too found playing 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 (Robert et al., 2016) 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) in any forested catchment.

a) Water Temperature which is affected by air temperature, storm water 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 prefers 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 (<1mg/L) showing forest stream health to suit drinking/aquatic use
g) Phosphates in safe levels (< 0.1 mg/L) to preserve forest streams as of unpolluted.

6.1 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 some of the 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/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 and alkalinity	✓ Forest canopies, offers increase in capture of acid pollutants in atmosphere, reducing stream pH
6. Apposite inputs of organic matter/nutrients	✓ Variety and seasonality of leaf litter inputs/microbial processes in the root zone; maintains energy and nutrient flows, effective ecological aquatic systems. ✓ 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 and management

6.2 Catchment Management Strategies

At catchment scale, the water resources management occurs within a highly integrated environment, where its quality and quantity and the aquatic ecosystem remains interlinked and interdependent. Salient indicators like turbidity/siltation, riverbank stability, eutrophication, pesticides/chemicals, acidification, water colour, 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 and litter), though fall, stem flow, vaporizations from tree surfaces, ET, heat fluxes from canopy and root parts, soil infiltration and other deeper movements, flow dynamics on overland planes and 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 and 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 and 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 and execution of ground based tailor-made 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	• Base flow increase • Soil moisture increase
4. Infiltration	• Reduced • Increased	• Overland flow and stream flow increases • Base flow increases
5. Stream flow	• Changed	• Increase in most eco-systems • Decrease in snow systems • Decrease in fog-drip systems
6. Base flow	• Changed	• Decrease with less infiltration • Increase with less infiltration • Summer low flows (+ve or -ve)
7. Storm flow	• Increased	• Volume greater • Peak flows larger • Time to peak flows shorter

6.3 Surface Water Acidification and Eutrophication

Forests and forest management practices are reported to always 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 found beneficial for protecting water quality, moreover natural forests can pose potential threats too, 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 at this juncture toward dynamic relationships among trees and 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 groundwater. 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 AND RESEARCH NEEDS

Based upon sailing across the periphery of past R&D on forest water interface, it becomes quite evident that we need to seriously and sensitively comprehend about prevailing scenery and characters of forest-water relations. It inevitably requires seeing across the array of given physiographic, climatic and 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, bringing following probable nodes at forefronts for bridging addressable knowledge gaps,

- Big data on forest-water interventions
- Advanced models and modelling 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 and 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 and quantifying of ultimate collective effects of forestation or deforestation, keeping focus towards local biodiversity, water protection, carbon management, water and 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) ET of forests, (iii) distributed hydrological modelling in forested catchments, (iv) end influences of land use changes inside the forests, (v) impacts of hydrology and oxygen limitation on forest growth, (vi) CO_2 efflux, and (vii) overall sustainability 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 and 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 and diffused pollution controlling drainage systems.
- Quantifying economic costs and 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.

There could be several key messages for policy makers dealing water and forest sector (Locatelli et al., 2015). A variety of interventions are involved in forest and water sector while dealing overall management and regulations of water and energy fluxes across any forest based physical system on the earth. Such issues always demand a proper realization and quantification at micro scales to facilitate better and accurate planning towards forest-water interactions at micro catchment scales. It includes below given major perspectives,

(a) Water Use by Forests: Features persuading water use by forests often include climate, forest and soil type, and others. In overall, forests use more water than petite types of vegetation just because of higher evaporation; they also have relatively lesser surface runoff, groundwater recharge and water yield. Region specific science-based forest management practices can have a noticeable influence on forest water use by swaying the mix of tree species and ages, the forest structure/architecture and even the size of the area harvested and left open.

(b) Dry-season Flows: Forests are always expected to reduce dry-season flows as much as or more than they decrease annual water yields. It is supposedly probable that in degraded agricultural catchments the extra infiltration related with afforested land might outweigh the extra evaporation loss from forests, resulting in increased rather than reduced dry-season flows; but this has rarely been reported/seen.

(c) Flood Flows: Forests may sizably mitigate small and local floods but do not appear to influence either extreme floods or those appears at outlets of larger catchment. One likely exception is reduction of downstream flooding by floodplain forest, where hydraulic roughness (the mixture of all elements that may cause flow resistance, such as forest litter, dead wood, twigs and tree trunks) may slow down and desynchronize overflows.

(d) Water Quality: Natural forests and well-managed plantations can effectually defend drinking-water supplies. Managed forests usually have lower input of nutrients, pesticides and other chemicals than more intensive land uses such as agriculture. Forests planted in agricultural/urban areas may reduce pollutants, especially when located on runoff pathways or in riparian zones. However, trees exposed to high levels of air pollution capture Sulphur/nitrogen and thus increase water acidification.

(e) Erosion: Forests are often known for protecting soils and reducing erosion rates and sediment delivery to streams. Forestry operations such as cultivation, drainage, road construction and timber harvesting may increase sediment losses, but best management practices can control such type of risks. Also, the planting forest on erosion-prone soils and runoff pathways can reduce and intercept sediment.

(f) Climate Change: Worldwide climate models predict marked changes in seasonal snowfall, rainfall and evaporation in many parts of the world. In the background of these changes the influence of forests on water quantity and quality may be happens as negative or positive. Where large-scale forest implanting is anticipated for climate change mitigation, it remains essential to ensure that it will not emphasize water shortages. Additionally, the shade provided by riparian forests may help to reduce thermal stress to aquatic life as climate warming intensifies.

(g) Energy Forests: Fast-growing forest harvests have vast potential for high water demand which ultimately can lead to reduced water yields. The local trade-off between energy generation prospects and water influences may be considered another key issue; specifically, in tropical regions like India where climate change certainly impends water resources.

(h) Water Productivity: ‘Water produces energy’ and ‘energy produces water’; both of these notions are the real think tanks for policy planners who so ever involved in forest and water sector. One is just not possible without other. Looking into this reversible relationship, the quantified water productivity remains one of the biggest aspects where forest-water issues needs to be dealt in such a way that more water can be created/conserved/consumed with least amount of energy and vice versa.

8. CONCLUSION

Author/s have made best possible effort to address 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 endeavoured to offer a deeper understanding of forest-water interactions. Potential forest and water management strategies based on such understanding deliberated 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 was found to be an effective option 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. Few key messages which holds enormous values for policy makers involved in water and forests sector are expounded which includes issues like (i) water use by forests, (ii) flood flows, (iii) water quality, (iv) erosion, (v) climate change, (vi) energy forest, and (vi) water productivities.

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 stream flow. Furthermore, if changing climatic patterns reduce precipitation, stream flow 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 and 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 and 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 and other benefits.
- Maintenance of good or high ecological status of water bodies 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 and sandy soils and their hydrological and environmental influences; and assessing reduction in water yield, base flows, and variability of small and larger floods are some of the other issues which needs proper attention.

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