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Comparative study determining the impacts of broadleaved and Needle leaved forest harvesting on hydrology and water yield: State of knowledge and research outlook

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Abstract

Water availability both at present and in the future is of primary importance for sustaining life on earth. The forest role in carbon sequestration and their impacts on water yield and the hydrological cycle is currently a burning issue within the scientific community. As a general concern, different forest types and cover may vary in their effects on water interception and discharge due to various structural and growth attributes, with implications to the water supply to downstream ecosystems. Changes in forest cover impose either positive or negative impacts on catchment hydrology depending on the direction and degree of changes. To reconcile the forest carbon sequestration and water conservation, there is a dire need to understand the mechanistic linkage between the two services. By conducting literature, we examine the impacts of forest cover change in the shape of deforestation on catchment water yield for contrasting forest types: coniferous forests and broadleaved forests. The results found that deforestation of 68% of broadleaved and 71% of needle leaved forests lead an increase in streamflow of up to 16% and 27% for broadleaved and needle-leaved forests, respectively. This research provides a scientific insight about when where and why to cut/plant the trees with a particular focus on sustainable forest management practices to mitigate the global warming issue for gaining maximum and long term socio-economic benefits.

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Introduction

Forests covered around 30% of the land surface (Bonan, 2008) and considered as the promising role in many ways by providing a vast quantity of ecosystem services (Costanza *et al.,* 1997; Li *et al.,* 2019), like NTFP's (medicinal plant, honey, oil, pickle etc), Carbon sequestration, clean drinking water, nutrient recycling as well as biodiversity conservation (Nasi *et al.,* 2002; Wang *et al.,* 2017; Masiero *et al.,* 2019). It is evident in understanding that among all of these ecosystem services, carbon sequestration and water are the primary services linked with the provision of many other functions of the forest ecosystem. Forest on one side by sequestrating carbon increase the productivity as well as considered as proposed strategy to mitigate the global warming issues (Krankina *et al.,* 1997; Ruddell *et al.,* 2007; Sun *et al.,* 2016; Ullah *et al.,* 2019), on other side, forests are also deliberated as facilitating of rainfall (van der Ent *et al.,* 2010) and clean drinking water. However, because of the escalating surge in the world's population, causing a higher demand for water and land resources for food and fiber products at the expense of forests. The primary cause of the drastic increase of CO_2 concentration in the atmosphere is due to anthropogenic disturbance along with Land use and cover changes and over-exploitation of forest resources in the shape of deforestation (Law *et al.,* 2003; Houghton, 2007; Houghton, 2012). The demand for wood and fiber products for household and industry, enhance the afforestation schemes that have been launched for the last few decades in several parts of the world (FAO, 2010: Payn *et al.,* 2015). For example: The considerable increase from 4.06% to 6.95% of total afforested area for the last few decades. This upsurge was most speedy in the temperate zone on the regional level of East Asia than by Europe, North America, and Southern and Southeast Asia (Payn *et al.,* 2015). These expansions accompanied by a parallel increase in concerns regarding water losses (Andréassian, 2004; Jackson *et al.,* 2005) in shape of annual streamflow reduction (Trabucco *et al.,* 2008) consequently, the decline in water availability to downstream users (van Dijk and Keenan, 2007). These, afforestation schemes triggered a reduction of up to 52%, among which 13% of the complete drying of streams on a global level (Jackson *et al.,* 2005). Especially the drylands areas, those might be more vulnerable to climate extremes due to their high ecohydrological sensitivity (Matyas and Sun, 2014) accompanied by an increase in streamflow following forest cutting (Bosch and Hewlett, 1982; Jones and Post, 2004).

The world's forest-growing stock is composed of two-thirds of broadleaf trees and one-third of needle leaf trees (FAO, 2010). There are many studies have been reported the interrelationship between deforestation and their influences on water yield vary globally depending on different forest types (Hornbeck *et al.*, 1993; Vildan and Michael, 1996; Vazken Andreassian, 2003; Komatsu *et al.,* 2011; Troendle *et al.,* 2001; Pike and Rob, 2003; Adams and Flower, 2006).

It was reported that from 1990 to 2015 the global forest cover falling from 31.85% to 30.85% (Payn *et al.,* 2015). Deforestation on one side enhances stream water level, but on the other hand has many adverse impacts on whole ecosystem, e.g., land degradation, biodiversity disturbances, flood, disturb the chemistry of carbon water and nitrogen cycle, as well as other environmental problems which may collectively intensify the global warming.

Therefore, a piece of explicit knowledge on how forest types would shape the tradeoff between forest productivity and ecosystem water loss is a pre-requisite for assisting regional forestry planning and forest management in the context of carbon sequestration and water conservation (Li *et al.,*2019).

In this fight between forest carbon and water, the negative influences of forest on streamflow might be to control the proportion of forest cover at the catchment scale, which has the potential to modify the streamflow regime (Zhang *et al.,* 2012). For this purpose, it is dire need to understand better the affiliation between runoff concerning forest cover proportion (Brown *et al.,* 2013).

This research highlighted the research gaps of deforestation schemes, and their prone and corns for society and how to tackle these issues to gain and maintain maximum availability of forest ecosystem services on sustainable basis (Fig.1) as carbon-water interrelation entirely depends upon many factors, the most dominant factors and forgiven climate, forest types, and structure, age as well as soil. The objective of the study is to simulate the hydrological effects of different deforestations scenarios of broadleaved and needle-leaved forests on a global scale.

Materials and methods

Data collection and processing

We have compiled this large data set of deforestation studies and their impacts on water yield from research articles published peer review journals; research from the World's forest, consisting total of 71 watershed sites of Needle leaved forest stand and 103 sites belongs to broadleaved forest stand with totaling of 319 observations from all over the world. We compiled this data sets from 22 peer-reviewed journals as well as reports from governmental and nongovernmental research institutes, representing many parts of the world. The forest types were classified into needle leaved and broadleaved for this study. All the information gathering about different deforestation activities on water yield was compiled, with mean annual streamflow before and after treatment.

Testing of Significance

First we have performed the Normality test i.e Shaprio-wilk test, this test showed that the conditions of normality and homogeneity of variance were or not met. Later nonparametric Kruskal–Wallis tests were applied if normality and homogeneity of variance were not met. In each case, the dependent variable was either the proportional change in water yield following change in factors of evaluation i.e deforestation percentage.

The significance test suggests that the water yield rate isn't the same in each of the two or more region ($p < 0.001$). Statistical package Origin Pro-2016(9.3) have been used in this experiment.

Results and discussion

The results of Shaprio-wilk test rejected normality at $P<0.0001$ as shown in Fig. 2. Similarly, the Kruskal-Wallis test showed significant increase in streamflow after deforestation in broadleaved forests of the world with $P<0.0001$. The summery of test statistic is mentioned in Table.1.

Table 1. Representing the summery of test statistics for Pre and Post treatment water yield in broadleaved and needle leaved forest.

Treatments	n	Chi-square	DF	P-value
Pre-NL vs Post NL	188	102.33	01	<0.0001
Pre-BL vs Post BL	139	165.14	01	<0.0001

The results also indicated that before treatment annual streamflow of broadleaved forests was 775mm per annum whereas, after treatment of 68% of forest harvesting, leads to an additional of 150mm of water added into streamflow with total of 925mm, leading to annual increase of 16% in the streamflow of broadleaved forests in the world as shown in Fig. 3(a). Regression analysis also demonstrate that correlation between deforestation and change in water yield is consistent, with increasing trend along with the increase of deforestation percentage with $R^2=0.21$, $p<0.001$ as shown in Fig. 4(a). Broadleaved are mainly known as nutrient-rich area species, warm weather, and continuous availability of sunshine in the spring season that actually boosts photosynthesis process with their extensive set of leaves. Especially in the winter season, deciduous species which are in the majority of broadleaves leaves e.g., Oak, maple, and elm, etc. which lose chloroplast cells that are the main drivers for capturing sunlight and ultimately leaves changes their color and finally fall to the ground. Movement of energy into roots, tree enters into dormancy condition. However, there are few exceptions like live Oak, eucalyptus, and the majority of the tropical forest belongs to a broadleaved group, which is evergreen species.

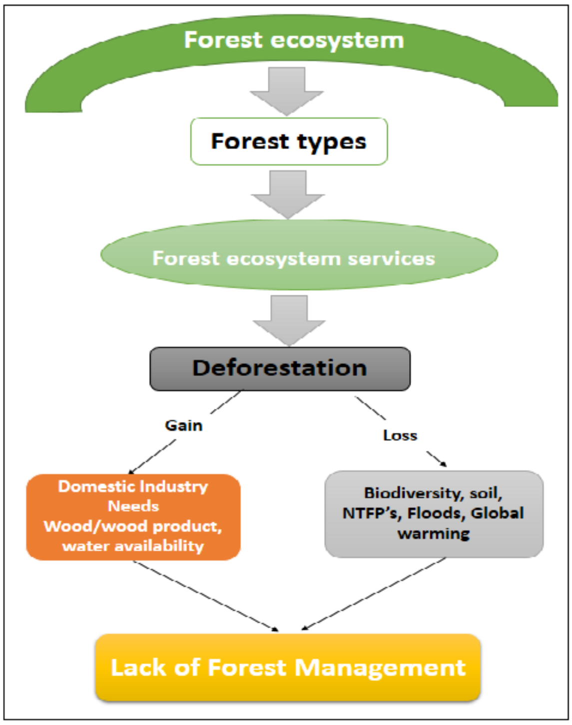

Fig. 1. Conceptual framework showing the core issue during deforestation scheme and their prone and corns.

They do not lose their leave in the dormancy period. Our results are primarily following the findings of many regional watershed studies. The results reveals that on global level the impact of deforestation on streamflow also depend on the forest subtype e.g., in broadleaved evergreen Eucalyptus species on streamflow was positive with higher increase in streamflow reported by many previous research investigations (Cornish, 1993; Stoneman, 1993; David *et al.*, 1994; Lane and Mackay, 2001; Watson *et al.*, 2001).

Similarly, another study deciduous broadleaf forest catchments in North America showed a significant increase in the water quantity after fifteen years of clear-felling (Lynch and Corbett, 1990; Hornbeck *et al.*, 1993). In another regional collection of research investigations of streamflow showed highly significant results with a consistent increase in water yield after harvesting of broadleaved deciduous forest stands (Bosch and Hewlett, 1982: Stednick, 1996: Fahey and Jackson, 1997). Similar results have reported by (Watson *et al.*, 2001; Cornish, 1993; Stoneman, 1993; Lane and Mackay, 2001) the same in broadleaved evergreen which is mainly in line with our research findings as a whole.

The results of Shaprio-wilk test rejected normality at $P<0.0001$ as shown in Fig. 2. Similarly, the Kruskal-Wallis test showed significant increase in streamflow after deforestation in needle leaved forests of the world with $P<0.0001$. The summery of test statistic is mentioned in Table.1. The results clearly reveal that before treatment annual streamflow of needle leaved forests was 410mm per annum whereas, after treatment of 71% forest harvesting, leads to an additional of 111 mm of water added into streamflow with total of 521 mm with annual increase of 27% in the streamflow of needle leaved forests in the world as shown in Fig. 3(b). Regression analysis also demonstrate that correlation between deforestation of needle leaved forest and change in water yield is also consistent, showing increasing trend along with the increase of percentage cut area of forest with $R^2=0.23$, $p<0.001$ as shown in Fig. 4(b).

Needle leaved or conifers are consisting of long thin leaves.

The majority of needle-leaved are evergreen species, so they remain on tree whole year, and the replacement process is slow and continuous, there are few exceptions of Tamarack and larch are needle-leaved deciduous tree species.

Their leaves are usually smaller, rough structure, tighter needles having spatiality of wind and pest resistant as well as waterproofing than broadleaved and deciduous species. They can withstand harsh weather of spring season with poor nutrient soils. In many of previous big data sets, it indicated that needle-leaved forests, consumption, and utilization of water are relatively higher and deforestation treatment caused a significant increase in water yield (Anderson *et al.*, 1976; Bosch and Hewlett, 1982;

John, 1996; Scott *et al.,* 2000; Adams and Flower, 2006; Komatsu *et al.,* 2011). Similarly, the clear-felling in large watersheds(>2000ha) showed a significant upsurge in water yield with around 25% cut resulted in a 52% increase in water yield of that particular area (Burton, 1997).

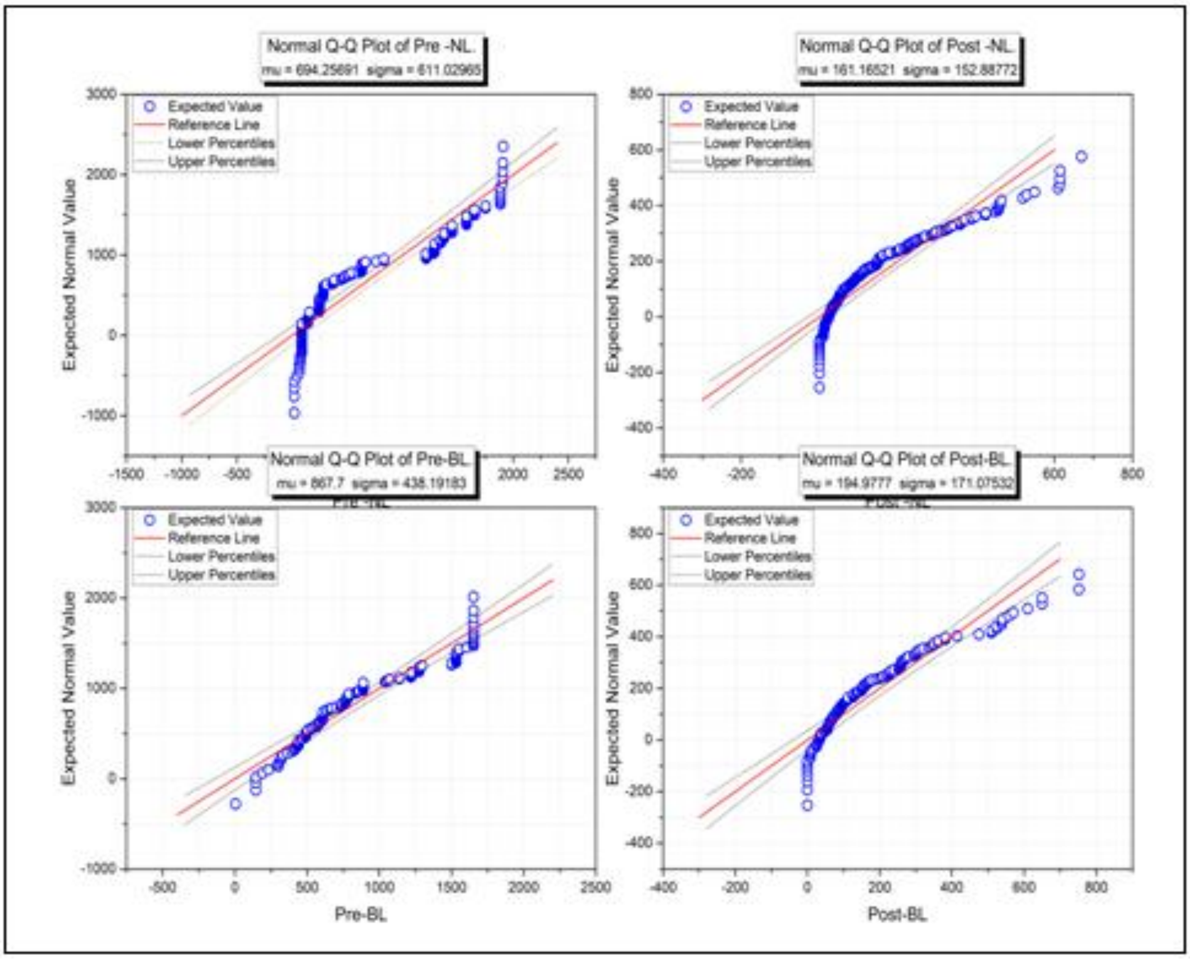

Fig. 2. Shaprio-wilk test rejected normality at P<0.0001 in pre and post deforestation of (a)Broadleaved and (b) Needle leaved forests in the global dataset.

*Pre-BL: Pretreatment streamflow of Broadleaved forest, Post-BL: Post treatment Increased in streamflow of Broadleaved forest, Pre-NL: Pretreatment streamflow of needle leaved forest, Post-NL: Post treatment Increased in streamflow of needle leaved forest.

These results are unique of its type because, in previous studies, it was only compared deforestation causes an increase or decrease in streamflow between both forest types after treatment without knowing, that before and after treatment, what actual increase in streamflow in these forest types?

In this study, we have also come to know that in broadleaved forests, the majority of the area seems sufficient water area, whereas needle-leaved forests lie in water-deficient zones, as shown in Fig.3(a & b). The reason for higher water consumption of majority of the needle-leaved forest is due to their evergreen in nature.

They consume water whole year, whereas in broadleaved because of the presence of a majority of deciduous species might be the prominent reason for their efficient utilization of water during the dormant season of the year.

There is a common belief that broadleaved having more runoff because of less annual evapotranspiration than needle-leaved forests.

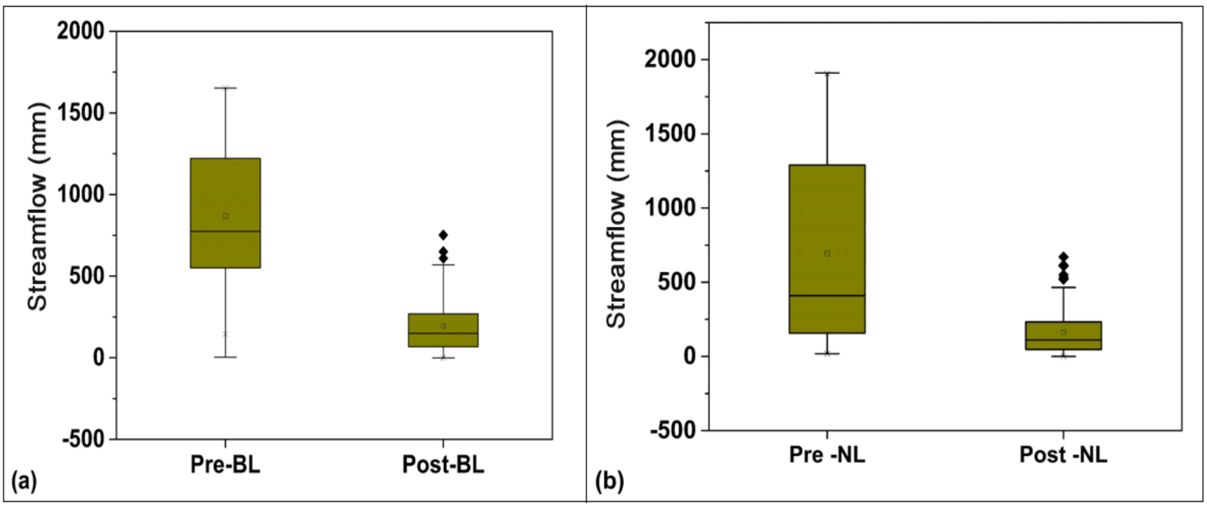

Fig. 3. Illustrating the Post treatment increase in water yield (mm) in (a) Broadleaved and (b) Needle leaved forests on global scale catchment studies.

*Pre-BL: Pretreatment streamflow of Broadleaved forest, Post-BL: Post treatment Increased in streamflow of Broadleaved forest, Pre-NL: Pretreatment streamflow of needle leaved forest, Post-NL: Post treatment Increased in streamflow of needle leaved forest.

This is mostly known belief that, in broadleaved deciduous forest with higher winter precipitation (e.g., the United States) (Bosch and Hewlett, 1982; Landsberg and Gower, 1997; Komatsu *et al.,* 2011), broadleaf forests are usually evergreen like in New Zealand (Landsberg and Gower, 1997) and their winter precipitation is typically low as well as in Japan (Komatsu *et al.,* 2010).

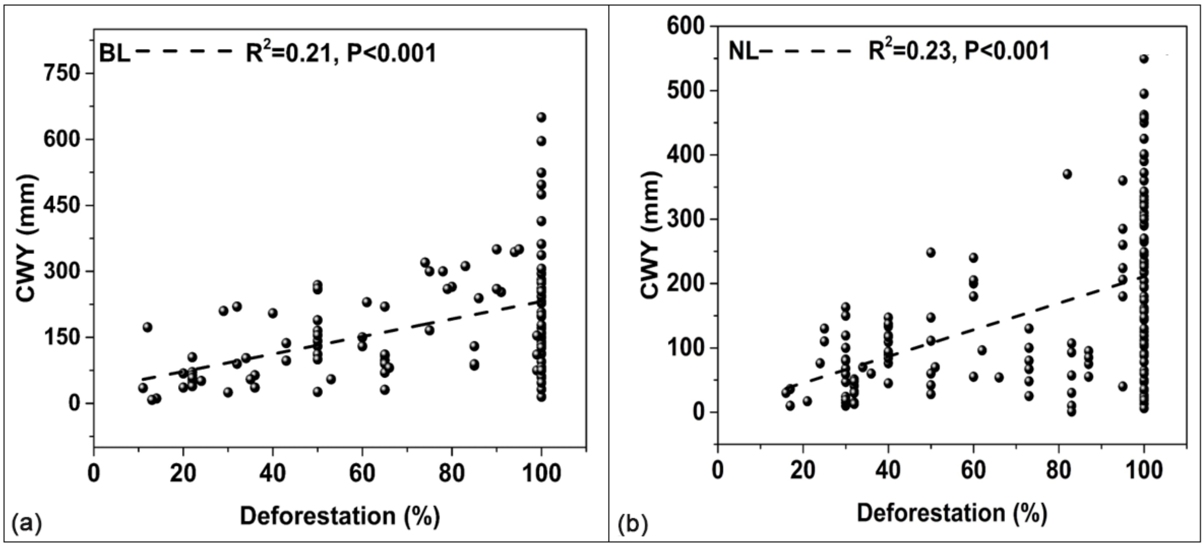

Fig. 4. Showing the consistent increase in water yield (mm) after deforestation in (a) Broadleaved and (b) Needle leaved forests of dataset.

*Pre-BL: Pretreatment streamflow of Broadleaved forest, Post-BL: Post treatment Increased in streamflow of Broadleaved forest, Pre-NL: Pretreatment streamflow of needle leaved forest, Post-NL: Post treatment Increased in streamflow of needle leaved forest.

In our dataset consisting of both broadleaved deciduous in the majority than broadleave evergreen species of the forest. Therefore, we can say that this might be one of the reasons for having a more significant increase in annual water yield than needle-leaved after harvesting. Experiments in small and large forest areas in broadleaved and needle-leaved forests respectively.

In this range, the relationship between pre-harvest water yield and water yield increase after harvesting varied greatly in both of the forest types of the world. However, we have also suggested that there might be many other factors involved in the variation of streamflow response to deforestation of different forest types e.g., elevation, slope, area, soil, climate, are the prime factors influencing the water yield of a particular forest stand.

Conclusion

This study showed that water yield response to cover changes is unpredictable among needle leaved and broadleaved. However, some general conclusions can be justified. Deforestation of conifers showed a more considerable annual increase in water yield than deciduous forest. However, this decrease might be their associated factors, especially climate, topography, growth stages, and soil.

In most cases, the reduction of cover less than 20% did not project a clear picture of the increase of annual water yield in most of the cases.

The catchment studies results are complicated to express very precisely due to the variation in experimental conditions as well as different ways of conducting research trails. However, the available data representing valuable information about the role of forest structure on hydrology especially in high and low rainfall area that will be helpful for decision-makers to take a practical step for modifying the current Carbon sequestration policy.

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Abbreviation

FAO- Food and Agricultural Organization, NTFP's- Non-timber forest products, USA-United State of America.

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