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Original Research Article

Human pressure on water quality and water yield in the upper Grijalva river basin in the Mexico-Guatemala border

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ABSTRACT

Forest ecosystems are major providers of high quality water and contribute to maintain a better distribution of base flows during the year. However, these environmental services have been adversely affected by human pressure due to the decline and deterioration of forested areas and the inadequate management of water resources. To better understand the relations between human population, forest area and water quality and yield, at a regional level, we studied six catchments located in the upper Grijalva river basin in the border between Guatemala and Mexico. Measurements of twelve water quality parameters and water yield from nine sampling periods during 2011–2013 were analyzed through PLS (partial least squares) regression, ANOVA and linear mixed models to assess the season effect on water quality and the forest cover effect on water yield. An ordination by PCA (principal components analysis) and Pearson's pair-wise correlations were used to identify association between hydrological and social catchment features (forest cover, protection of riparian buffer strips, population density and urban areas). Our results suggest that overall water quality is higher during the dry season (higher values of dissolved oxygen and lower levels of total dissolved solids, total suspended solids, total phosphorus, chemical oxygen demand and temperature were observed). Water yield is positively related to forest cover and riparian buffer strips, becoming essential in maintaining water security for local populations. Major threats to water flux and their quality are related to human pressures and untreated wastewater discharges, which reduce water quality of the receiving rivers.

1. Introduction

Mountain forest ecosystems are major sources of fresh and clean water, highlighting the importance of their conservation and restoration to enable them to maintain a

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provision of water of high quality and quantity (Ponette-González et al., 2009). According to Körner and Ohsawa (2006), twenty percent (1.2 billion) of the world's human population lives in mountains or surroundings, and half of humankind depends closely on mountain ecosystems mostly for water provision. High rates of deforestation and forest fragmentation have affected extensive areas of the forest of Chiapas (Cayuela et al., 2006; Ochoa-Gaona and Gonzalez-Espinosa, 2000). The montane forests of southern Mexico and Guatemala are highly diverse formations (Breedlove, 1981) that include pine-oak forests, deciduous forest, montane cloud forest, among others. In addition to occasional natural perturbations (landslides, windstorms, fire), these forests have been subject for centuries to a wide range of human disturbances derived from slash-and-burn *milpa* agriculture (González-Espinosa et al., 2006). Frequent anthropogenic disturbance, increases the dominance of pine and drastically decreases floristic richness, mostly understory trees (Ramírez-Marcial et al., 2001). Changes in vegetation structure and species composition of the pine-oak forest toward a canopy dominated by pines alter microclimatic conditions inside the forest and are associated with impoverishment and soil compaction (Romero-Nájera, 2000).

Growing problems of water scarcity, environmental degradation, food insecurity and poor livelihood conditions and human health all require urgent policy and management measures, pointing attention to interrelationships between forests and water (Zingari and Achouri, 2007).

This relationship between forests and water has been studied since long time ago (Bosch and Hewlett, 1982; Hibbert, 1967; Van Lill et al., 1980). In the late 60s Hibbert (1967) reported results of thirty-nine studies on the effect of altering forest cover on water yield; taken collectively, these studies revealed that forest reduction increases water yield, and that reforestation decreases water yield. Later, in the same way, several authors argued that forests are major water users in the catchment, and that removing forest biomass increases the amount of water available in the lower areas of the catchment (Bruijnzeel, 2004; Calder et al., 2007; Dung et al., 2012; Nelson and Chomitz, 2006; Ponette-González et al., 2009; Stadtmüller, 1994; Stolton and Dudley, 2007). However, other authors claim that the presence of forests ensures rainfall in the region due to water evapotranspirated by forests, typically returned to the atmosphere with interest; thus, if forests are depleted, a decline in rainfall could be expected, leading to lower runoff over a wider region (Ellison et al., 2012; Salati et al., 1979; Sheil, 2014).

As analyzed in the above mentioned studies, continuous water flow is as relevant as total quantity, in terms of both maintenance of dry-season flow and absence of flooding during periods of heavy rain, in particular under extreme hydrometeorological events (Stolton and Dudley, 2007). Regarding the effects of forest conversion on water flow, "total water production" (total annual flow) must be clearly distinguished from "seasonal distribution of flow" (Bruijnzeel et al., 2011). According to Zingari and Achouri (2007), forested catchments (healthy forests) moderate variations of flow throughout the year, as compared to other land uses. Although natural forests and crops have different effects on flow, they do not show a consistent pattern, where location and types of dominant species in the forest become relevant (Stolton and Dudley, 2007).

In some cases, base flow in the dry season is diminished by the presence of trees because of increased evapotranspiration of the forest in the tropics (Kiersch, 2000). In other cases, forest clearance in semi-arid basins, caused strong decreases in flow in dry seasons due to the reduction of water infiltration and hence groundwater recharge (Mungai et al., 2004; Watkins and Imbumi, 2007). Differently, removing demanding water forest cover to prevent or mitigate droughts is highly recommended in some semi-arid areas (Calder et al., 2007). These examples highlight dissimilar outcomes, which might seem contradictory, but are only a response to local particularities. Expert opinions on forest-water yield remain heterogeneous and examples of diverse responses can be found (Stolton and Dudley, 2007). Despite variations found in certain contexts, literature shows that the presence of forests has in general a positive effect on the water cycle, not only in flow regulation but also improving the quality of water generated in the basin.

Regarding water quality, literature seems more unanimous. Several studies (Miller et al., 2011; Stadtmüller, 1994; Stolton and Dudley, 2007; Zingari and Achouri, 2007) suggest that forested basins generally produce water with lower concentrations of nutrients and sediments. Forested basins provide higher water quality than basins under other land uses, usually because the alternatives (agriculture, grassland, industry or settlements) generate greater amounts of pollutants (Stadtmüller, 1994; Stolton and Dudley, 2007) and (or) tend to destroy soil structure and facilitate erosion and sediment load in water (Schoonover et al., 2006; Zingari and Achouri, 2007). In recent years, the expansion of agriculture toward adjacent forested areas, promoting environmental land use conflicts, was seen as prime cause of enhanced soil erosion (Pacheco et al., 2014; Valle Junior et al., 2014a) with negative consequences on groundwater quality (Valle Junior et al., 2014b) and ecological status of riverine ecosystems (Valle Junior et al., 2015).

Nonetheless, when reviewing dry season *vs* wet season data, we found studies that report contrasting results (Alcocer et al., 1998; Santos et al., 2015a; Somura et al., 2012; Wong and Barrera, 2005); some studies report better water quality during the rainy season and others found the opposite.

Riparian ecosystems link water flux with their terrestrial catchment. Because of this physical proximity, they influence the structure of both aquatic and terrestrial communities and reduce sediment inputs, provide important sources of organic matter, and stabilize stream banks. In addition, riparian buffer strips can reduce inputs of solar radiation, hence the removal of riparian vegetation can increase water temperature and deteriorate water quality (Osborne and Kovacic, 1993; Stadtmüller, 1994). Deforestation and degradation of forest cover and riparian buffer strips have negative effects on water quality and water yield in the catchment; moreover, mismanagement of water resources further aggravates this situation.