Analysis of Ecosystem Services in the Oaxacan Mixtec Region, (Tiltepec Watershed)

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Abstract**—***The present work analyzes the sources of supply and regulation of ecosystem services (ES) in the Tiltepec watershed, Oaxaca, Mexico, specifically the production of fuelwood, water for human consumption, forage for domestic livestock, as well as regulation for runoff and sediments estimated with the MUSLE model (Modified Universal Soil Loss Equation), Random sampling points were defined according to the soil used and coverage, to determine production of fuelwood and forage. Firewood was evaluated in quadrants of 10 x 10 m for tree strata and 5 x 5 m for shrub strata. Forage production was determined with lines of 20 m and quadrants of 0.25 x 0.25 m to determine biomass and vegetation cover. Water supply was estimated with inflows from springs and the storage capacity of infrastructure works and water demand estimated with the current population and the maximum daily and hourly consumption. The estimated average fuelwood consumption was 1.4 kg person^{-1} day^{-1}for a total volume of 3,189.5 m^3. The estimated average forage yield was 856.6 kg ha^{-1} and a grazing coefficient of 13.9 ha animal unit (AU$^{-1)}$, with a census of 171.7 AU. The springs produce a daily volume of 150.4 m^3 and the storage water capacity is 184.7 m^3 for human consumption and 718.5 m^3 for irrigation and recreational uses. With the MUSLE model, a reduction in runoff of 33.93% and 62.93% in specific degradation was estimated comparing the current scenario with that of 1984. The presence of ES in the Tiltepec watershed is essential to provide well-being to local people and regulation of erosion process through works, soil and water conservation practices. These will enable better provision of goods and services.*

Keywords— provision and regulation services, water, forage, firewood and sediments.

I. INTRODUCTION

The term ecosystem services (ES) aroused as a result of an environmental movement in the 1970s, was promoted by conservation biologists when defining nature as a service provider, with the purpose of increasing public interest in conservation of biodiversity (Sullivan, 2009). With the creation of the organization "Millennium Ecosystem Assessment" in the 90's, interest in having tools to evaluate consequences of change in the ecosystems, establish bases and actions necessary to improve conservation and sustainable use of ecosystems and their contribution to human well-being (MEA, 2005). Despite advances and growing publications, however, there is still a lack of consensus on elements that should be included in the ES concept and its integration in decision-making of public policy on management of natural resources (De Groot *et al*., 2010).

ES consider all the benefits that society obtains from ecosystems (MEA, 2005), both directly and indirectly (De Groot *et al*., 2002), including conditions and processes through which natural ecosystems and species that make them up, sustain and nourish human life (Daily, 1997). In short, it is the relationship between ecosystems and human beings (supply-delivery and value), the latter in economic terms or non-tangible dimensions (Balvanera *et al*., 2012).

ES are classified as providing, regulating, cultural and support services (Balvanera and Cotler, 2011). Provision or tangible goods, are all those benefits provided by ecosystems that meet specific human needs, examples of these goods are those provided by plants (food, medicine, fiber), animals (meat, skin, workforce) and environment (water, air, soil). (WWF, 2015; De Groot *et al*., 2010). Regulating services refer to the natural or semi-natural capacity of ecosystems to regulate ecological processes and maintain life supports (De Groot *et al*., 2002). These services control and/or modify environmental parameters (Balvanera and Cotler 2011), so that the less disturbed ecosystem, regulation is performed optimally, but at a higher intensity of use these services decrease their effectiveness (De Groot *et al*., 2010). Cultural services are those benefits that man perceives from ecosystems (tangible or intangible) with a symbolic, cultural or intellectual value (Balvanera and Cotler, 2011). (De Groot *et al*., 2002) divides them into recreational and informational; the former is valued according to the accessibility of ecosystems and their value decreases with the intensity of use or degradation of them, while the latter are a function of information contained in the ecosystems and decrease with the degree of conversion. Support services are the processes and functions that characterize ecosystem, and are necessary for production of other services, and their benefits are indirect and long-term (Balvanera and Cotler, 2011).

The analysis of the ES should take into account scales of time and space, include direct and indirect factors that influence their provision (Galán *et al*., 2012). Some proposed approaches to the study of ES are: diagnosis, identification, perception, assessment, and appropriation (Almeida *et al*., 2007; Quétier *et al*., 2007), socio-ecosystem analysis (biophysical, economic-productive and socio-political-cultural) (Balvanera *et al*., 2010) and use of cartographic tools to identify, characterize and value them (Bagstad *et al*., 2013a) integrating ecological, economic and geographical aspects (Bagstad *et al*., 2013b).

The Oaxacan Mixtec culture Ñu'u Savi or "People of the rain" has faced problems for food production (agricultural and livestock) due to its abrupt relief and lack of water. The inhabitants have transformed natural ecosystems through slash-and-burn systems to open cultivation and pasture areas. Their poor management has caused problems of erosion and loss of soil fertility (Spores, 1967; Lind, 2008). A harmonious relationship between man and nature is reflected in the welfare of society through ecosystem services (CONABIO, 2006). However, when an ecosystem service is affected at expense or to detriment of other services, and even at expense of the ecosystem service itself, the quality of life on present and future population is affected (Galán *et al*., 2012).

In the Oaxacan Mixtec area, the relationship between population and ecosystem has been one of overexploitation of natural resources, causing their deterioration or scarcity. Accelerated deforestation and overgrazing have caused soil erosion, reduction of water retention capacity, loss of fertility, shortage of firewood, scarcity of forage, reduction of water supply, among others. WWF (2015) mentions that loss of biodiversity and deterioration of vegetation cover is mainly due to hillside agriculture and overgrazing, activities that impact regulation of other services such as soil fertility, water quality, climate regulation, erosion; impacts that negatively affect agricultural production, livestock, and quantity and quality of water.

WWF (2015) identified, evaluated and socially valued ES in the Mixtecan region, identifying some key provision services such as: production of food derived from agriculture and livestock, fodder, water for human consumption, use of firewood and wood. It also considered regulation of erosion as a very important service since it has a direct impact on provision of other services.

Firewood is an ES of provision and mainly source of fuel for rural communities. Some studies on their availability start from a forest inventory to know available volume, according to species susceptible for exploitation (Contreras *et al*., 2003a), and complementing them with interviews to know socioeconomic and cultural characteristics for use, extraction and preference (Quiroz and Orellana, 2010; Santos *et al*., 2012). According to (Ghilardi *et al*., 2007) the ecosystems that contributed the most fuelwood are mangroves, tropical forests, broadleaf and coniferous forests with 5.1, 3.1, 2.6 and 2.4 t ha^{-1} year^{-1} above ground in dry weight. The consumption of firewood per ecological zone for Mexico is 3 kg DM hab^{-1} day^{-1} for humid tropical regions, 2 kg DM hab^{-1} day^{-1} in temperate zones and 1.5 kg DM hab^{-1} day^{-1} in semi-arid zones (Masera *et al*., 2010). (GIRA, 2014) reported a supply of firewood of 273 thousand tMS for the Mixtecan region of Oaxaca and a consumption of 311 thousand tMS year^{-1} for the municipality of Yanhuitlán and availability of firewood of 2,793 m^3 and 203 m^3 was estimated for coverage of 60-100% and 20-60% with an average consumption of 1.8 kg person^{-1} day^{-1} (Contreras *et al*., 2003a). Tiltepec reports a consumption of 1.21 loads of firewood (30 kg family^{-1} week^{-1}) (Cruz and Aguirre, 1992).

Livestock and agricultural transformation are the main factors associated to land use change in Mexico, losing between 189 thousand to 501 thousand hectares of tropical forests and 127 thousand to 167 thousand hectares on temperate forests (Balvanera *et al*., 2009). Grazing lands are defined as lands of natural or introduced vegetation where grasses, herbaceous and shrubs predominate (Pellant *et al*., 2005), for livestock grazing (INIFAP, 2011) and wildlife and soil and water conservation (CONAZA, 1994). These grazing areas are characterized as areas with physical limitations for agricultural production, generally have low rainfall, rugged topography, poor drainage, dry or sandy soils (Cruz and Aguirre, 1992). The four principles for the management of the grazing land are: time, distribution, type/class of livestock and animal load. Being the carrying capacity, the maximum animal load that allows maintaining and improving vegetation and even other resources involved (Walker, 1995).

The Technical Advisory Committee for Grazing Loads (COTECOCA) established for the state of Oaxaca a minimum of 0.80 ha AU^{-1} year^{-1} and a maximum of 33.40 ha AU^{-1} year^{-1} and an average of 4.12 ha AU^{-1} year^{-1} (SAGARPA, 2009). (Contreras *et al*., 2003b) noted that 3.1 ha per grazing animal is required considering only sheep and goats, that is, 24.8 ha AU^{-1} for the municipality of Yanhuitlán. (Cruz and Aguirre, 1992) reported for Tiltepec a real animal load of 0.36 AU ha^{-1} (2.81 ha AU^{-1}) from March to October and 0.26 AU ha^{-1} (3.84 ha AU^{-1}) from November to February, including cultivated areas after harvesting.

Water is an ES supply regulated by infiltration, retention and storage processes (De Groot *et al*., 2002), as well as vegetation cover, precipitation, topography, soil properties and subsoil characteristics (Balvanera *et al*., 2009; Galán *et al*., 2012).

The land resource is an ES of sustenance, provision and regulation that functions as a reserve of goods that generate a flow of other services. Forming processes are carried out (nutrient cycle, hydrological cycle and biological activity) and degradation (physical, chemical and biological) (Dominati *et al*., 2010). Water erosion as a degradation process is a function of soil properties, topography, soil cover and human activities. Erosion and sediment production is estimated with models such as: Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE), Water Erosion Prediction Project (WEPP), Limburg Soil Erosion Model (LISEM), MIKE-11 software developed by Danish Hydrologic Institute (DHI), Simulator for Water Resources in Rural Basins (SWRRB), Chemical Runoff and Erosion from Agricultural Management Systems model (CREAMS), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), among others (Merritt *et al*., 2003).

This research identified and quantified some ecosystem services of provision (production of water, firewood and fodder) and regulation (sediment retention and runoff production) with the MUSLE model for the Tiltepec basin, Oaxaca.

II. MATERIALS AND METHODS

The study area covers 968.21 ha and it is located between the coordinates 17° 26'40.2"and 17°29'9.96" North Latitude, and 97°21'12.96"and 97°23'31.2" West Longitude. The basin is 2,520 meters above sea level and a terrain slope from 2% to 40%, with an average slope of 25%. The dominant land use and vegetation are temperate pine-oak forests that occupy approximately 70%, xerophilous scrub (11%), pasture (6%), agricultural area (8%) and without apparent vegetation (6%). According to INEGI, sedimentary and igneous extrusive rocks are the predominate ones. Within the sedimentary rocks are: siltstone, sandstone and conglomerates; for igneous origin, the andesite. The soils that appear are: luvisols, pheozem and vertisols.

In order to know the current situation and importance of firewood supply, 42 surveys were applied to the inhabitants that represent 65% of total homes, to know their use, places of collection, species that they prefer, cost per load, main uses, frequency of extraction, among other aspects. To quantify the supply of firewood, a stratified random sampling method was carried out, which consisted by dividing the study area into subgroups of vegetation type, according to the information generated by World Wildlife Fund (WWF, 2010). For each type of vegetation, a simple random sampling method was carried out to know the production of firewood (supply) in dry weight (branches, trunks or dead trees). Quadrants of 10 x 10 m were used for arboreal species and 5 x 5 m for shrubs. Samples were taken per species to determine the density of the woody material according to the method proposed by (Olesen, 1971) cited by (Fernández *et al*., 2014).

Grazing and herbaceous dominance sites were identified, in each site a line 20 m length was drawn with east-west orientation, 6 quadrants of 0.25 x 0.25 m were located and the vegetation cover was determined by supervised classification of digital images; the plant material from three quadrants was cut (beginning, middle and end), separated by species to estimate the available dry matter (supply). To know the demand for forage, a livestock inventory was carried out in the community to estimate the animal units feeding on the grazing lands.

The current demand for water was estimated for the year 2030 considering domestic consumption per capita (CONAGUA, 2007), the current population reported by the Population and Housing Census (INEGI, 2010) and the total growth rate for the state of Oaxaca by 2030 published by the National Population Council (CONAPO, 2010-2015).

The average amount of water required to meet population needs, on daily basis, was calculated considering the average daily per capita expenditure (l s^{-1}) and the total number of inhabitants. To meet population daily water needs the maximum hourly consumption, for a standard year, was calculated considering the maximum daily and hourly consumption coefficients, 1.40 and 1.55 respectively. The supply of water was quantified with an inventory of fresh water supply sources, springs water production was gauged volumetrically and the storage water capacity of the existing reservoirs was evaluated to know the production and storage capacity for fresh water.

Sediment production was estimated applying the MUSLE model, (Zhang *et al*., 2009) for 1984 and 2015; the year of 1984 was selected as the beginning of the soil conservation and rehabilitation works by the Ministry of Agriculture, and since then several strategies have been implemented for soil conservation, reforestations, and rules for grazing and management of natural resources. The climatic information reported by INIFAP, for the station of Santo Domingo Yanhuitlán, for 2015 was entered in MUSLE. Soil samples were taken at 30 cm depth to determined texture (percentage of sands, silts and clays), and content of organic matter to obtain soil erodibility factor (K), (Wischmeier and Smith, 1978). To calculate the LS factor, a 15 m spatial resolution Digital Elevation Model (DEM) was used.

The values of MUSLE factor C were defined according to the classification of land use made by World Wildlife Fund (WWF, 2010), from satellite images, and values proposed by (Kirkby and Morgan, 1980) and (Figueroa *et al*., 1991). The weighted value for Numerical Curve was assigned according to the land use, treatment, hydrological condition and soil hydrological groups. The values were defined for previous and current conditions.

For the MUSLE management practices factor "P", an inventory was made in the field to know, quantify and georeferenced the type of works within the basin. The values were assigned based on (Kirkby and Morgan, 1980, 1997) and (Figueroa *et al*., 1991) and weighted according to the surface by type of practices.

III. RESULTS AND DISCUSSION

The supply of water from the springs of Santa María Tiltepec is 1.74 l s^{-1} with a daily volume of 150.3 m^3 and a storage capacity of 184.7 m^3 for human consumption and 718.5 m^3 for irrigation water and recreational uses. The main source of supply is the "Yuyunkono" spring with an average rate of 1.37 l s^{-1} (117.9 m^3 day^{-1})[2] that is complemented by the Nodaza springs, with a flow of 0.185 l s^{-1} (15.9 m^3 day^{-1}) and Tiltepec with 0.191 l s^{-1} (16.5 m^3 day^{-1}) (Table 1).

[2] The flow of the springs is reduced by up to 50% in the period of drought.

TABLE 1
WATER SUPPLY SANTA MARÍA TILTEPEC, OAXACA, MEXICO.

Source	Flow (l s^{-1})	Volume (m^3 day^{-1})	Capacity(m^3)
Spring "Yuyunkono"	1.365	117.9	
Pond for irrigation 1	0.564	48.7	159.2
Pond for irrigation 2	-	-	124.1
Storage tank 1	-	-	68.3
Storage tank 2	-	-	67.0
Spring “Nodaza”	0.185	15.9	-
Nodaza storage tank	-	-	49.6
Spring "Tiltepec"	0.191	16.5	-
Reserve "Alberca"	0.505	43.6	435.3
Excess	0.568	49.1	-
Total springs	**1.741**	**150.31**	
Human use storage			**184.7**
Storage for other uses			**718.5**

For the year 2010 the average daily demand of fresh water by the 220 inhabitants was 0.25 l s^{-1}, for an annual volume of 8,030 m^3, maximum daily flow of 0.36 l s^{-1} and an hourly maximum rate of 0.55 l s^{-1}. The water supply, including storage capacity, exceeds the demand of the population, even at peak demand. During the dry season, the water in the springs decreases and is barely enough to satisfy the demand; hence the importance of the infrastructure works for storage and distribution of water. According to the population growth trend, by 2030 it is estimated that the water demand will be 0.27 l s^{-1} with an annual volume of 8,541 m^3, a maximum daily flow of 0.38 l s^{-1} and an hourly demand 0.59 l s^{-1}; it means that population growth would increase the demand for water by 6.4%.

The supply of water in the locality is sufficient to supply drinking water to the current and future population even in the most critical conditions. However, the availability of water to support productive activities is critical during drought years for irrigation from springs.

The yield production between 2005 and 2015, associated with annual precipitation, mid-summer drought and minimum application of inputs, varies from 0.8 to 0.45 t ha^{-1}for beans, 1.0 to 0.45 t ha^{-1}for corn, and 1.8 to 0.9 t ha^{-1}for wheat. In the region precipitation plays an important role in production since it can reduce crops average yield up to50% (Figure 1).

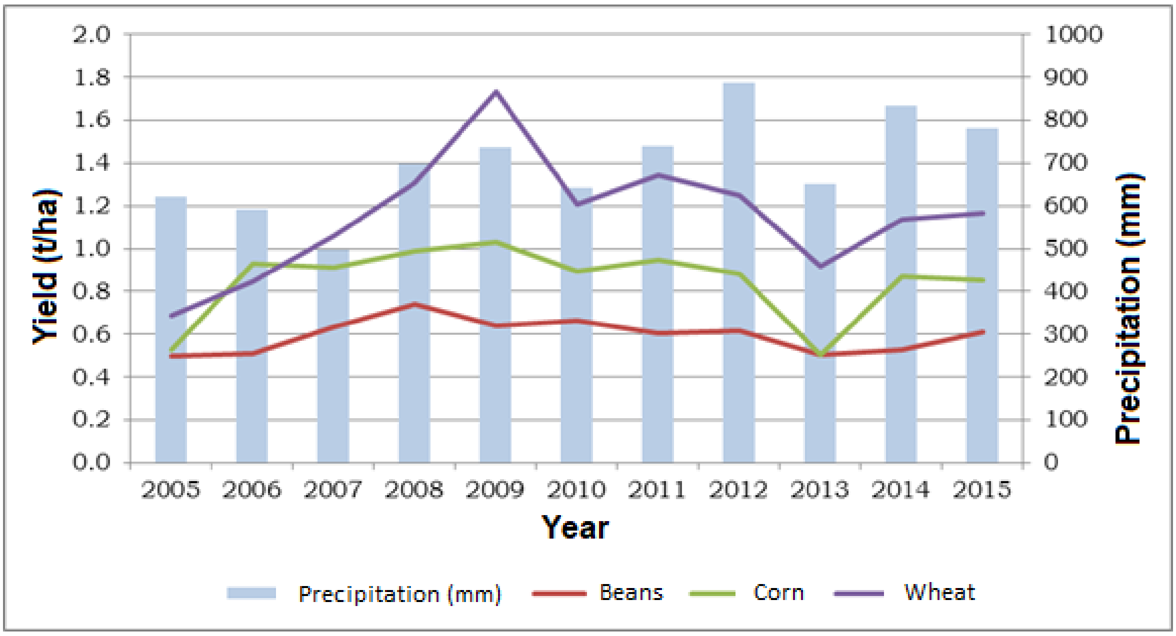

FIGURE 1. Temporal variability of the production of basic crops.

During the 11-year period analyzed corn surface loss was the most affected, varying endangering plots from 100 to 750 ha, corresponding to 7 to 55% of area affected, respectively; for bean and wheat the reported surface losses on plowed area, were 24% and 52%, respectively (Figure 2).

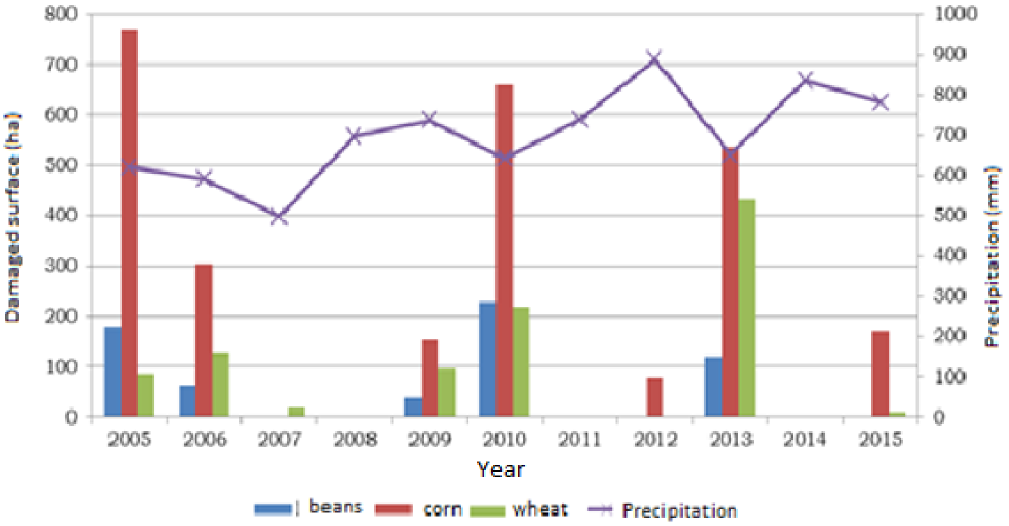

FIGURE 2. Losses in production in the period from 2005 to 2015.

With regard to the use of firewood, 62% of households combine LP gas and firewood as a fuel source, 24% use only firewood and the rest only gas; the wood is used for domestic purposes and in a lesser proportion for industrial activities. It is used mainly to boil food (40.5%), especially those that require a lot of cooking time such as beans and meat, make tortillas (23.8%), heat water (23.8%), and occasionally to process bread (4.8%). The average consumption per capita is 1.4 kg day^{-1}, equivalent to annual consumption of 124 m^3; similar values to those reported by Contreras *et al*., (2003a) between 1.5 to 2.0 kg person^{-1} day^{-1} for the neighboring community of Yanhuitlán, Oaxaca.

Generally, firewood is collected (94.4%) from natural extraction areas of the community and the rest is purchased from firewood vendors of this community; 54.3% of demand is supplied by men, 22.9% by children, and the rest by housewives. Men usually travel 5 to 7 km away and carry loads between 30 to 60 kg, while housewives usually get it around the town, collecting only what is necessary for the day's consumption. The household wood supply is as follows: 9.1% is supplied twice a week, 36.4% each week, 27.3% every fifteen days, 12% every twenty days, and 15.2% monthly or every 2 months.

From the interview, 36.6% of respondents estimate firewood cost above $2.50 pesos kg^{-1}, 26.6% from $2.00 to $2.50, 23.3% that varies between $1.50 to $2.00 and 13.3% estimate less than $1.50. The annual price of wood consumption goes from $394.80 to $6,843.20 pesos, with an average cost of $2,384.61 and coefficient of variation of 78.6%. This variation represents the subjective value that each inhabitant gives to the use and type of firewood to satisfy their needs.

One of the most used tree for firewood is oak (Figure 3), due to its slow combustion, capacity to produce coal, and longer heat capacity; among oak species used are: yellow oak (*Quercus magnoliifolia* Née), white oak (*Q. castanea* Née), red oak (*Q. conspersa* Benth), spoon oak (*Q. crassifolia* Humb. & Bonpl.), oak tree (*Q. laurina* Bonpl). Other species used by housewives, for easy access, are: Guaca (*Leucaena leucocephala*), Tepozán (*Buddleja parviflora* H. B. K.), jarilla (*Dodonaea viscosa* (L.) Jacq.), black chamizo (*Baccharis heterophylla*) and yunuyaca (*Eysenhardtia polystachya* (Ortega) Sarg.). Species such as: strawberry tree (*Arbutus xalapensis* H.B.K), black strawberry or tini (*Comarostaphylis polifolia* (Kunth) Zucc. Ex Klotzsch.) and manzanita (*Arctostaphylos pungens* H. B. K.) are the preferred species in rainy season because their trunks do not absorb water**.**

Other species that are used for firewood are: ocote (*Pinus oaxacana* Mirov.), Sumac (*Rhus standleyi* Barkley), juniper (*Juniperus flacida* Schl.), Ramón (*Cercocarpus fothergilloides* Kunth), ramonal (*Ceanothus caeruleus* Lag.), Tlalixtle (*Amelanchier denticulata*), aile or elite (*Alnus sp*.) and willow (*Salix sp*.), among others.

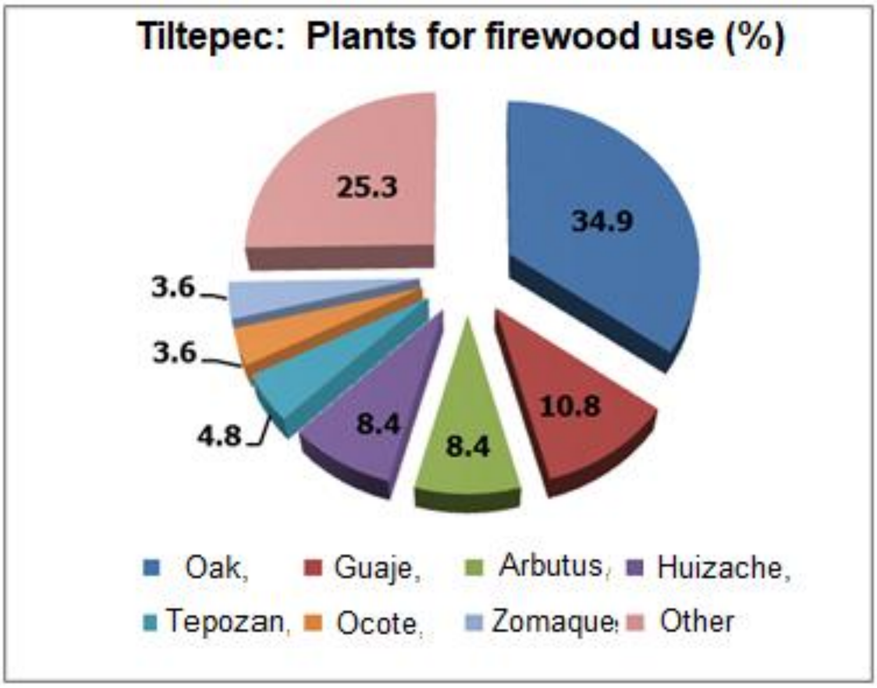

FIGURE 3. Main species for firewood use

The types of vegetation that predominate, as sources of firewood supply, are: 25% oak-pine forest, 20% pine-oak forest and 8% xerophilous forest (Figure 4 and Table 2). The pine-oak forest ecosystem produces 4.08 m^3 ha^{-1} of firewood, followed by the oak-pine forest with 2.22 m^3 ha^{-1} and finally the xerophilous scrub with 1.60 m^3 ha^{-1}. A total volume of 3,189.5 m^3 was determined. The forest ecosystems of pine, oak and shrubs are those ES that supply firewood for well-being of rural population, as reported by (Díaz and Balvanera, 2014). The results of the firewood sampling show that the humidity contents vary between 10% and 40% depending on the climatic conditions of each site, the specific gravity of firewood ranges between 750 and 940 kg m^{-3} and wood available volume goes between 1 and 5.5 m^3 ha^{-1}.

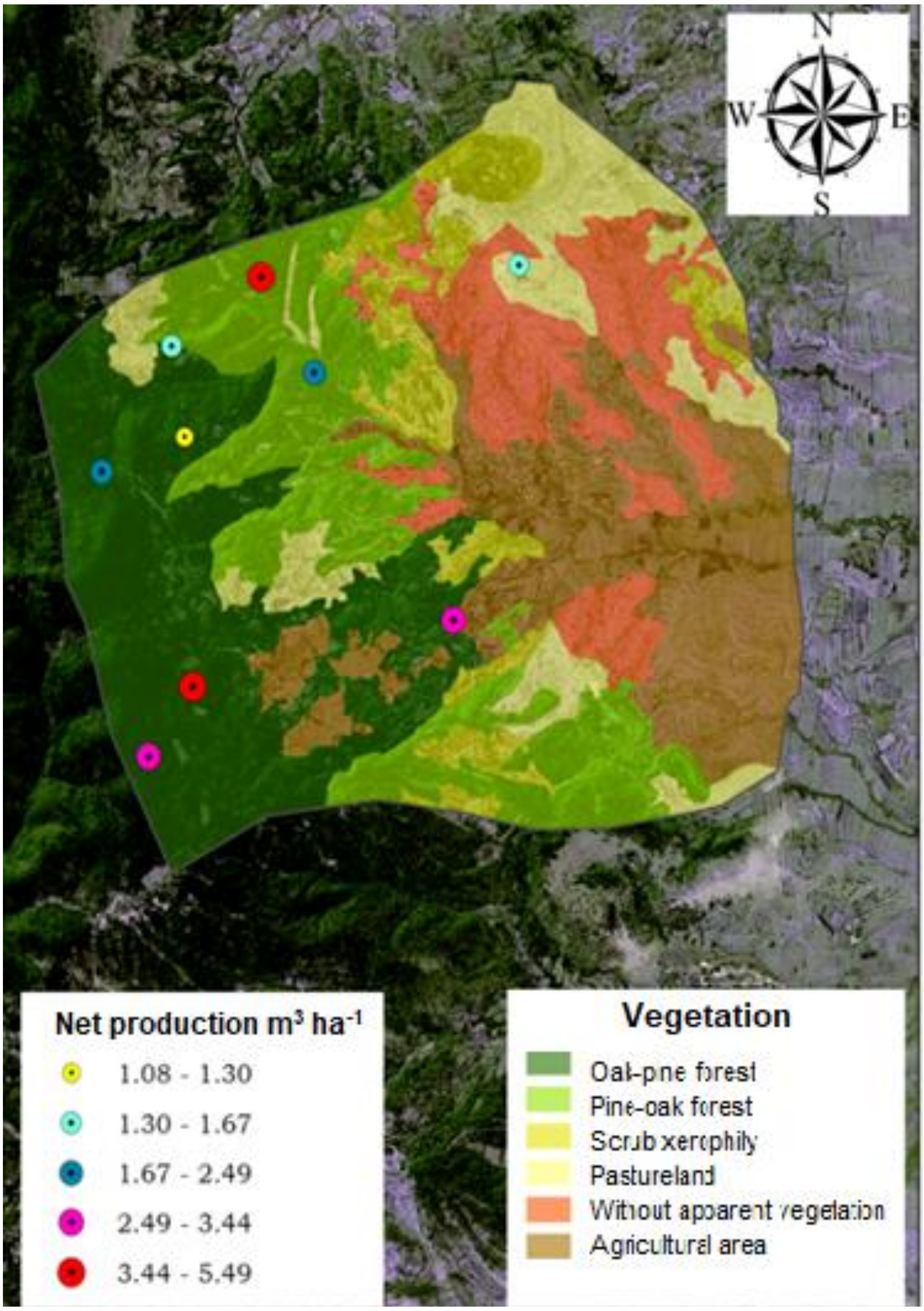

FIGURE 4. Land use and vegetation at Santa María Tiltepec, Oaxaca.

TABLE 2
FIREWOOD PRODUCTION AT SANTA MARÍA, TILTEPEC, OAXACA.

Type of vegetation	Area (ha)	Net production ($m^3 ha^{-1}$)	Total volume (m^3)
Oak-pine forest	534.8	2.22	1,188.90
Pine-oak forest	420.8	4.08	1,715.30
Scrub xerophilous	178.5	1.6	285.3
Pastureland	245.2	-	-
Without apparent vegetation	274.7	-	-
Agricultural area	458.4	-	-
Total	**2,112.30**		**3,189.50**

Source: self-made.

Nine sites were sampled in rangeland, which were selected according their dominant gramineous and legume species. For plant cover, the grassing sites were classified by (INE, 1994) as a regular condition. Sites with the best green coverage varies between 45 and 48%, in contrast, sites with bare soil are between 28 and 41%, which are the most susceptible areas for soil erosion (Table 3).

TABLE 3
CHARACTERISTICS OF RANGELAND SITES

Site	Green Coverture (%)	Dry Coverture (%)	Organic Matter (%)	Stone (%)	Bared soil (%)
1	31.9	37.1	7.9	14.0	9.1
2	27.7	26.6	6.9	23.7	15.0
3	48.2	12.4	16.1	1.5	21.8
4	38.7	11.5	15.9	4.9	28.9
5	25.7	14.9	16.9	1.2	41.2
6	33.9	32.0	27.7	1.1	5.3
7	30.6	16.6	43.5	0.0	9.3
8	46.8	14.4	4.3	3.9	30.5
9	45.7	14.9	12.2	13.6	13.7
Average	**36.6**	**20.1**	**16.8**	**7.1**	**19.4**

The biomass production of grazing sites is very variable, and the average dry matter production is around 800 kg ha^{-1} year^{-1}, with sites producing higher than 2t ha^{-1} year^{-1} (Table 4). The range coefficients vary between 4 and 28.4 ha AU^{-1} with an average of 13.9 ha AU^{-1}. These results were reported by (Contreras *et al*., 2003b) for the neighboring area of Cerro del Jazmín (24.8 ha AU^{-1}) and (Cruz and Aguirre, 1992) that went from 2.81 to 3.84 ha AU^{-1}.

TABLE 4
BIOMASS PRODUCTION AND PASTURE COEFFICIENTS FOR THE TILTEPEC BASIN.

Site	Biomass (Kg ha^{-1})	$\sum(\mathbf{MUAE} * \mathbf{UF}) *$	AUR $**$	$\mathbf{ACC(AUha^{-1})}$	$\mathbf{AC(haAU^{-1})}$
1	1,028.2	616.9	4,927.5	0.13	8.0
2	821.7	493.0		0.10	10.0
3	340.0	204.0		0.04	24.2
4	910.2	546.1		0.11	9.0
5	288.8	173.3		0.04	28.4
6	1,217.6	730.6		0.15	6.7
7	714.4	428.7		0.09	11.5
8	2,033.2	1,219.9		0.25	4.0
9	355.5	213.3		0.04	23.1
Average	**856.6**	**514.0**	**4,927.5**	**0.104**	**13.9**

*** Sum of the biomass production by the use factor (UF = 60%)**

**** Consumption of forage per animal unit per year, taking into account that it consumes 3% of its weight.**

ACC animal carrying capacity, AUR animal unit requirement, AC Animal Capacity, MUAE mass per unit Area for each species, UF used factor

$$ACC = \frac{\sum(MUAE * UF)}{AUR}$$

The composition of grass is variable according to the landscape physiographic position within the basin. In the group of grasses species were found: *Hilaria cenchroides* Kunth, *Bouteloua triaena* (Trin. Ex Spreng.) Scribn., *Bouteloua curtipendula* (Michx.) Torr., and *Bouteloua hirsuta* Lag; Cruz, (1992) classifies them as moderately to heavily consumed by livestock. In the group of legumes was found: *Crotalaria pumila* Ortega (cascabelito or sonajita), *Desmodium subsessile* Schltdl. (tick), and *Medicago polymorpha* L. (wheelbarrow). *Dalea spp*. was found in some sampling sites with average production of 165 kg ha^{-1} of dry matter, but it was not included to estimate animal load by hectare, because this specie is preferably consumed by goats, which is not a desirable animal for the management grassing strategy at Tiltepec.

The composition of the herd is 40 AU for cattle, 20 AU for donkeys, and 111.7 AU for sheep, with a total of 171.7 AU, of which only sheep use rangelands for grazing; on average there are 5.2 and 4.5 AU per owner of cattle and sheep, respectively.

In the study area there were 86 hectares of land with severe degradation problems that represent 9% of the total area of the basin (968 ha), but the soil recovery strategy works and regulations for use of forest areas and pastures, established by the community, have contributed to improving coverage in the upper part of the basin.

Sediment production, estimated by the MUSLE model, using daily precipitation for Yanhuitlán climate station and weighted parameters (K, LS, C, P and CN) for 1984 and 2016 are shown in (Table 5).

TABLE 5
PARAMETERS USED TO RUN THE MUSLE MODEL IN TILTEPEC BASIN.

Micro basin:	**TILTEPEC**	
Input parameters:	**Current scenario (2016)**	**Before (1984)**
Area of the basin (ha):	968.21	968.21
Weighted K factor:	0.029	0.025
Weighted LS factor:	6.932	6.932
Weighted C factor:	0.113	**0.198**
P factor:	0.987	**1.000**
CN initial weighted:	74.2	**79.6**
L (Length of main cause, meters):	4,103.61	4,103.61
H (Unevenness of the main channel, meters):	337.00	337.00
Optional input parameters:		
Average slope (s) (%)	8.168	8.168
Slope length (m):	150.0	150.0
m (coefficient per slope range, administration):	0.5	0.5

For both evaluation periods it was found that runoff and sediment production occur between May to September.The change indicators (Table 6) show that the drained water was reduced by 33% (from 67.8 to 44.8 mm) and the instantaneous maximum runoff by 17% (149.2 to 123 m^3 s^{-1}) which indicates apparent benefits on the water regulation processes with possible increasing of aquifer recharge, decreasing in surface flow, and reduction of soil erosion; that could favor water supply for springs on which population depends (Figures 5a and 5b).

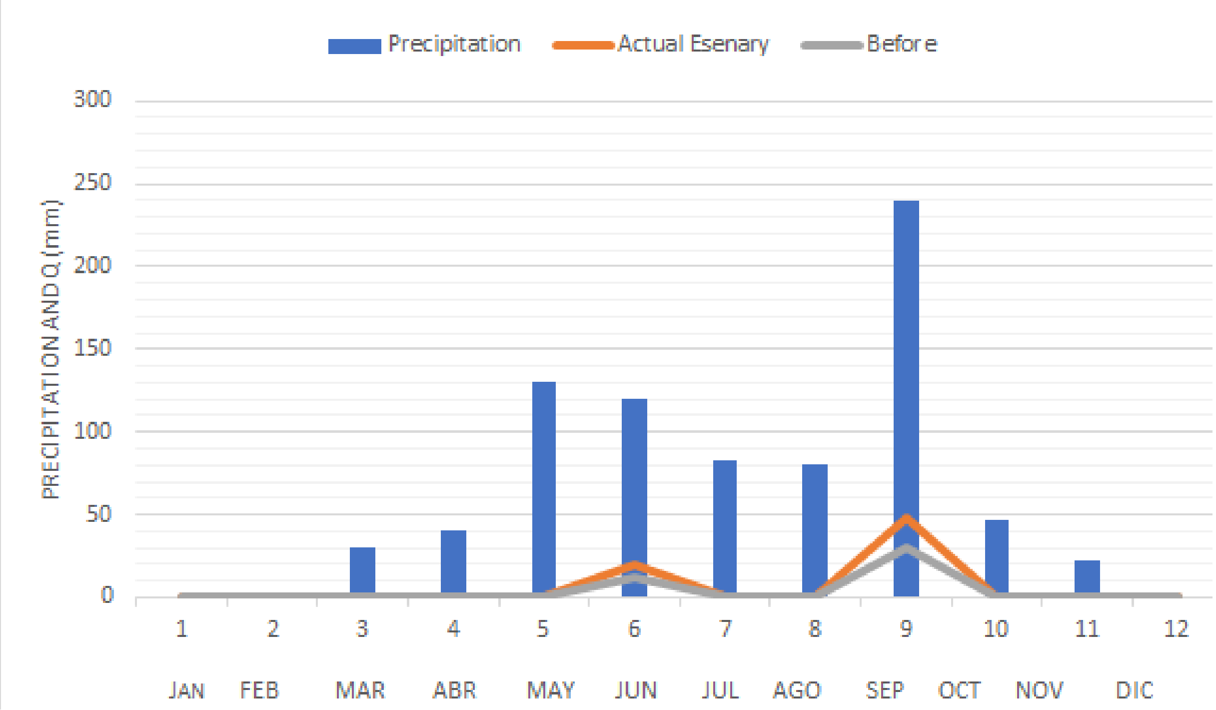

FIGURE 5A. Precipitation and runoff in the Tiltepec basin.

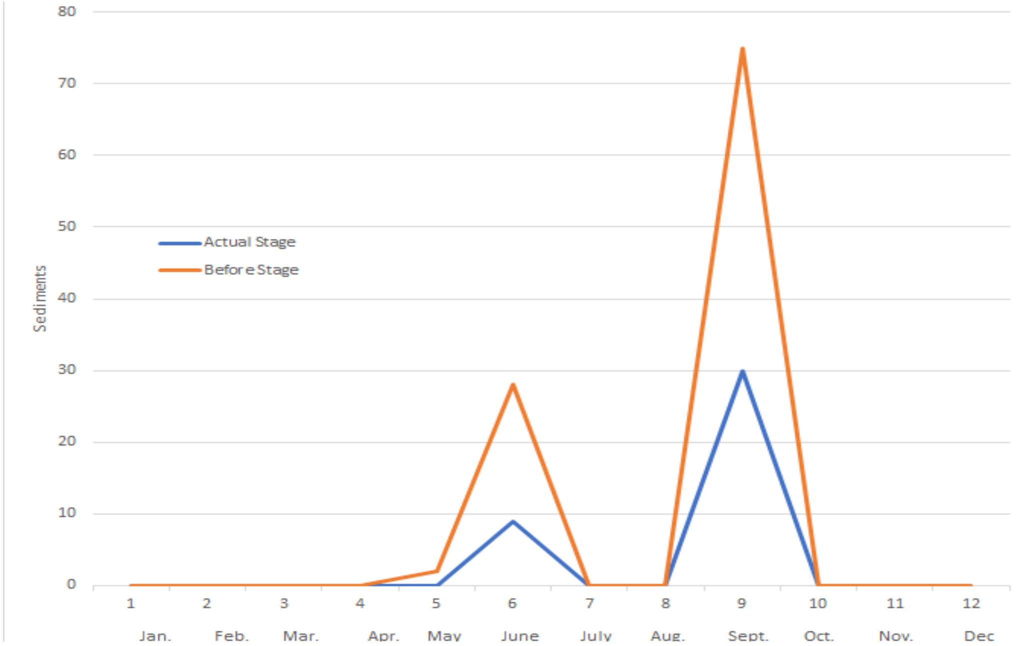

FIGURE 5B. Sediments in the Tiltepec basin.

TABLE 6
INDICATORS OF CHANGE ON REGULATING ECOSYSTEM SERVICES FOR WATER AND EROSION YIELD.

Condition	Precipitation (mm)	Q (mm)	q_p (m^3/s^{-1})	DRC	Specific degradation
Before	782.3	67.8	149.2	0.09	104.4
Current scenario	782.3	44.8	123.0	0.06	38.7
% change		**33.88**	**17.60**	**33.88**	**62.95**
DRC dimensionless runoff coefficient					
Q Runoff (mm); q_p (m^{-3} s^{-1}) Maximum runoff					

The specific degradation of Tiltepec watershed estimated by MUSLE model indicates a reduction of almost 63% as a result of the actions of reforestation, recovery of forest biomass and constructed structures for soil conservation. The estimated soil degradation rate was similar to the specific degradation obtained by (Lira, 2018) that reports sediment retention between 8.3 and 13 t ha^{-1}, and similar to the information reported by (WWF, 2015).

IV. CONCLUSION

The Tiltepec basin, despite the pressure on the use of natural resources to which it is subject, over time has modified part of its natural conditions but still retains some provision functions of its ecosystems that support economic activities of the settlers.

The supply of water is enough to satisfy the current demand of the population, even in the dry season, and for the population estimated for 2030.

Changes in fuel use habits have reduced the pressure on forests; however, firewood remains an important source of fuel. Besides, actions of forest management (reforestations and use only of dry materials) have allowed having a sufficient supply of this resource.

Grazing lands have the potential to recover their degraded areas and provide suitable areas for livestock production, especially with the establishment of highly palatable species for livestock.

The actions for soil and water conservation, reforestation and regulations for rangelands use, have allowed to improve the basin's regulation services and change the environmental conditions; these actions have allowed to reduce the surface runoff sediment yields.

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