Anonymous Referee #1

Thank you for the extensive comments. We are grateful to the referee for pointing us in the right directions to improve the manuscript. We have responded to all 40 of the detailed comments from this referee in the marked up manuscript. The responses to the detailed comments in the marked up manuscript are found attached at the end of this document.

Following are responses to comments in the referee reports.

1. Comment: *The paper aims an interesting topic that should be taken into account because of its relevance (soil erosion). The paper shows a great effort to study this problem and contrast this information with the people.*

   Response: *Thank you.*

   Changes in manuscript: *None required.*

2. Comment: *However, the introduction is very general.*

   Response: *We have shortened the text in the introduction to make it more to the point.*

   Changes in manuscript:

   > Soils contribute critical ecosystem services to humans, including, but not limited to food, clean water and air, and biodiversity (Pimentel and Burges, 2013; Brevik et al., 2015; Smith et al., 2015; Baveye et al., 2016). However, global estimates indicate that the fraction of land with highly-degraded soils increased from 15% of total land area in 1991 to 25% by 2011; most of the degradation is associated with water-induced soil erosion (UNCCD, 2013). The sustainability of soil-based ecosystem services depends on management choices by individuals, such as landowners, and institutions that set policies directly and indirectly impacting soil resources (Knowler and Bradshaw, 2007; Gomiero, 2016; Keesstra et al. 2016; Altieri, 2018). Soil erosion challenges tend to be greatest in the more heavily populated, under-developed, and ecologically fragile areas, where the adaptive capacity is weakest (Leh et al., 2013, Erkossa et al., 2015). In many instances, soil erosion and other land degradation processes result from social marginalization and limited economic and technological resources, resulting in landowners practices that favour economic gain over soil conservation (Pielke et al., 2007; Santibañez and Santibáñez, 2007; Tesfahunegn, 2013).

3. Comment: *Several sentences have not any references.*

   Response: *We have added citations at all locations requested in the reviewers' detailed comments, including 5 new references.*

   Changes in manuscript: *See re-written introductory paragraph in item 2. above. New references are as follows.*

Altieri, M.A., 2018. Agroecology: The science of sustainable agriculture. CRC Press.

Baveye, P.C., Baveye, J. and Gowdy, J., 2016. Soil "ecosystem" services and natural capital: Critical appraisal of research on uncertain ground. Frontiers in Environmental Science, 4: 41-53.

Gomiero, T., 2016. Soil degradation, land scarcity and food security: Reviewing a complex challenge. Sustainability, 8(3): 281-287.
Keesstra, S.D., Quinton, J.N., van der Putten, W.H., Bardgett, R.D. and Fresco, L.O., 2016. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil, 2(2): 111-116.
Knowler, D. and Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy, 32(1): 25-48.

4. Comment: *The study area regions are not-well explained. If you don0t live in Mexico, you cannot know where are the different regions and why soil erosion is higher or not.*

Response: *We have provided more information on the region in the study area description, including references indicating that vulnerability to soil erosion is high in the region. Also, please refer to the second paragraph in the revised Introduction section.*

Changes in manuscript:

a. *Revised and additional text in section 2.1 Study Area.*

The major economic activity in these communities is subsistence agriculture, consisting mainly of cultivating corn and beans, raising cattle, and gathering firewood. The region is typified by steep slopes (average of approximately 50% to higher than 100%) and, when combined with overexploitation of forests, has resulted in severe soil erosion (González-Espinosa et al., 2015). The majority of the soils in study region are regosols (51% of the study region area) and lithosols (40% of the area) (INEGI, 2015) which are indicative of rapidly eroding lands in very steep, mountainous areas (IUSS Working Group WRB, 2015).

b. *2nd paragragraph in revised secion 1 Introduction*.

Human activities that contribute to soil degradation include urbanization, road construction, deforestation, intensive livestock grazing, and agriculture (Brooks et al., 2003). In Mexico, 45% of the land area is severely or very severely degraded by water-induced erosion, aggravated by conversion from forested to agricultural land and accompanying cultivation practices (SEMARNAT, 2008). The underlying drivers of land conversion in Mexico are complex and vary among regions (Pfaff et al., 2014). Chiapas state has experienced some of the highest deforestation and soil erosion rates in Mexico (De Jong et al., 1999; Cayuela et al., 2006), such as in the Grijalva River basin (Laino-Guanes et al., 2016). Soil erosion in the basin threatens the sustainability of local subsistence agriculture, downstream communities subject to geologic hazards, such as landslides, and downstream hydropower generation capacity (Laino-Guanes et al., 2016). The basin is located primarily in southern Mexico, although the headwaters are in Guatemala (González-Espinosa and Brunel 2014). The basin has an annual average precipitation between 1200 and 4000 mm and is prone to flooding and erosion due to steep slopes and fragile soils (Gutierrez- Horacio and Triana-Ramirez, 2006). Soils in the Grijalva basin are degraded in more than half the basin area due to erosion (Colegio de Postgraduados, 2002), with negative impacts on rural social development (García-Barrios et al., 2009). Erosion is also problematic because collection of sediment in reservoirs threatens the production of hydropower in the basin, which provides 42% of the hydropower in México (Comisión Federal del Electricidad, CFE, 2013). Motozintla de

> Mendoza, a municipality located in the upper portion of the Grijalva basin and the subject of this study, has experienced severe erosion from catastrophic events such as during Hurricane Mitch (1998) and Hurricane Stan (2005) (Sánchez-Nuñez, 2012), when depths of at least three meters of sediment accumulated in areas adjacent to hillslopes and long-term erosion hazards (Suarez-Diaz, 2006; Sánchez-Nuñez, 2012).

5. Comment: *The conducted RUSLE did not show where you can find more soil erosion, no maps with soil erosion rates are showed.*

   Response: *Since the rates were estimated and field data was collected at 8 widely separated communities, we cannot interpolate soil erosion rates across the study region. This is an excellent idea for taking the research further, however. If we could develop regressions of estimated soil erosion rates to mapped LULC, soils, slopes, etc., we could interpolate across the region.*

   Changes in manuscript: *None required.*

6. Comment*: The survey is described with nor scientific spelling.*

   Response: *The text referred to by the reviewer is as follows.*

   > For example, one respondent said "For us the forests are very important because we need it for to obtain wood and then to use them for houses construction or for furniture materials, or also for wood selling, that's why the forest is almost ending, because we have good trees for wood and we can get money." Another respondent said that most people in the communities do not own large land areas and "If I reforest my land, where am I going to plant my maize, what am I going to eat, or what I will give to my kids for their food?" Several respondents mentioned that because they have big families, they cannot dedicate more land for reforestation. However, some respondents indicated that they should conserve the land because it is the source of their livelihood.

   We don't understand the reviewer's comment. These are direct quotes from community members. There is no expectation that the sentences will be scientifically correct. The quotes are meant to convey that correction of soil erosion problems is interconnected with livelihood issues.

   Changes in manuscript: *None required.*

7. Comment: *Statistical analysis was not explained.*

   Response: *We have added more explanation of the Chronback alpha, otherwise, we think the explanation is sufficient.*

   Changes in manuscript:

   > We estimated the Cronbach's alpha to assess the reliability of the overall measure of negative responses. The estimated $\alpha = 0.84$ is substantially higher than the rule of thumb of $\alpha = 0.7$ as a threshold for consistency, indicating that the overall measure of negative responses reliably captures the response to the five questions selected to indicate the overall response.

8. Comment: *There is not discussion!*

Response: *We have changed the section 3. Results to section 3. Results and Discussion and have included much more interpretation of the results of the RUSLE factors and the soil erosion rates.*

Changes in manuscript:

Revised section 3. Results and Discussion

Averages and standard deviations of the variables in the RUSLE soil erosion rate equation (1) are shown in Table 2, averaged over each community, except for the rainfall erosivity. The rainfall erosivity factor for the study area (R), based on a single climate station, was calculated as 17,000 MJ mm ha^{-1} h^{-1} yr^{-1}. This value of the R factor is high, relative to values from regions such as the US and Europe, but is near the range of R = 11,000 to 14,000 reported for Chiapas state by Baumann et al. (2002). The high rainfall erosivity factor is due to primarily to the squaring of high monthly precipitation in June to September (average rainfall = 225 mm/month) equation (2). However, values of R estimated with correlations based on monthly precipitation, such as equations (2) and (3), have been shown to generate higher values of R, compared to estimates based on higher frequency precipitation data (Yin et al., 2015).

The soil textural analysis results are as follows (mean ± standard deviation): organic matter fraction (%) = 5 ± 2, sand fraction (%) = 41 ± 11, clay fraction (%) = 20 ± 7, and silt fraction = 40 ± 8, across all plots and communities. Most (95%) of the plot soil sample textures classify as loams (48%), sandy loams (21%), clay loams (13%), and silt loams (13%). Overall, the soil erodibility factor, K, ranged from 0.09 to 0.325 ton ha h ha^{-1} MJ^{-1} mm^{-1} across all of the plots and communities. The average values of obtained for each community are shown in Table 2, indicating that most of the K values are between 0.018 and 0.031 ton ha h ha^{-1} MJ^{-1} mm^{-1}. Plot samples with extreme lower values of K (< 0.015 ton ha h ha^{-1} MJ^{-1} mm^{-1}, 5% of the plots) tend to have higher organic matter content and lower silt fractions; the reverse is found for the extreme higher values of K (> 0.035 ton ha h ha^{-1} MJ^{-1} mm^{-1}, 5% of the plots). In general, the values of K estimated for the study area are relatively low, compared to, for example, a range of values found in China and the US (Zhang et al. 2008; mean of 0.038 ton ha h ha^{-1} MJ^{-1} mm^{-1}). The values of K and all other RUSLE model factors for each community and sample plot are found in the supplemental information.

The LS factors, which range from 14 to 37 for the community averages, are high compared to typical values in Renard et al., (1997). These high values occur because many of the slopes on the plots were very high (mean ± standard deviation across all plots (%) = 67 ± 20). The projected horizontal slope lengths are also high, ranging from 23 to 286 m, indicating that long hillslopes with convex slopes are typical of the project study area.

The LULC fractions for the plots are community forest land (71% of plots), cultivated land (17% of plots), pasture land (6% of plots), and reforested land (6% of plots). The computed C factors range from 0.01 to 0.03. These values are relatively low compared to, for example, lands that are completely cultivated with grain crops (0.15 to 0.4; Panagos et al., 2015), and are typical of lands with mixtures of crops and forests (Panagos et al., 2015). All plots, except the cultivated land, had substantial areas of bare soil, ranging from 60% to 95%. The medium and highest C factor values (0.02-0.03) are found for community forest land, which is typically degraded (average bare soil coverage of 60%)

because of overexploitation for firewood collection by residents. The lowest *C* factor values (0.01) are associated with cultivated land areas that are completely occupied by corn. In this region, corn is grown continuously with slash and burn occurring after harvest. Higher values *C* factor values in are found in Barrio La Union, Ejido Carrizal, and Poblado Cambil, which are attributed to greater areas of bare soil in the forested areas.

Table 2 shows the average and standard deviation of values of the calculated soil erosion rates obtained for each community, along with averages and standard deviations across all plots and communities. By community, the highest erosion rates are found Poblado Cambil, due to relatively high soil erodibility and length slope factors and the presence of especially degraded forests (average fraction of bare soil = 81%) , as indicated by the values of the cover factor for this community. Carrizal Centro, Barrio La Union and Barrio Plan Grande had lower soil erosion rates, due primarily to lower slopes. The plots with the lowest estimated soil erosion rates also tended to have lower slopes, but also exhibited higher cover factors. The higher cover factors in these plots are usually associated with having more corn cultivation than community forest. In a study in a nearby region in Chiapas with similar land cover, high slopes, and no conservation practices, measured soil erosion rates were similar to those calculated here, although rates as high as 20,000 ton $ha^{-1}yr^{-1}$ were found where landslides recurred frequently (Santacruz-DeLeon, 2011). For perspective on the magnitude of these soil erosion rates, the Mexican federal government describes rates greater than 200 ton $ha^{-1}yr^{-1}$ as "very high" (SEMARNAT, 2008), while the Food and Agriculture Organization describes "very high" rates as exceeding 30 ton $ha^{-1}yr^{-1}$ (FAO, 2015). All but one of the estimated, community-wide soil erosion rates exceed the SEMARNAT "very high" levels. For individual plots, all but one plot erosion rate exceeded the FAO "very high" level and 60% of the plot erosion rates exceed the SEMARNAT "very high" level.

9. Comment: *Also, conclusions are really long and not specific.*

Response: *The conclusions have been rewritten and shortened.*

Changes in manuscript: *The revised conclusions section is as follows.*

The purpose of this study was to assess variability in vulnerability to soil erosion in six communities in the vicinity of Motozintla de Mendoza, Chiapas, México, where soil erosion threatens the long-term viability of the local subsistence agriculture and creates hazards for downstream communities. The estimated average erosion rates in the communities range from 156 to 413 ton ha-1 yr-1, greatly exceeding rates indicated as very high by FAO (> 30 ton ha-1 yr-1). Erosion rates are high due to steep and long slopes and high values of rainfall erosivity. Many of the highest soil erosion rates are found in communities that are dominated by forest land, but where most of the tree cover has been removed. Conversely, the lower erosion rates are often found where corn is cultivated most of the year, providing more cover than the forest land. Spatial variability in soil texture plays a smaller role in determining the spatial variability of soil erosion by community. According to the results of the soil erosion KAP survey, awareness of the concept of soil erosion was reasonably high in all of the communities, but awareness of the causes of erosion was considerably lower. More than half of respondents believed that reforestation is a viable option for reducing soil erosion, but only a third of respondents were currently implementing reforestation practices and another one-third indicated that they were not following any soil conservation practices. Survey respondents indicated that their adoption of government reforestation efforts have been hindered by their need to clear the land to sell forest products or for subsistence corn cultivation and difficulties in obtaining favourable tree stocks.

The negative responses to key KAP survey questions were compiled into a single index and aggregated by community, to provide an indicator of the community's capacity to sustain erosion control measures. The index of negative responses varied substantially by community. When combined with the average soil erosion rates, we see that the relationship between the magnitude of the soil erosion problem and the capacity to reduce soil erosion is inconsistent across the communities. One community, Barrio Vicente Guerrero, had the highest average negative response rate and the second highest soil erosion rate, indicating that this community is particularly vulnerable. At the very least, these results may be useful to natural resources managers in the communities and governmental agencies that are directing or participating in soil conservation and restoration efforts. However, we conclude that as long as the economic and productive needs of the communities are not provided for simultaneously with the advance of soil conservation and restoration efforts, the risk of soil erosion will increase in the future, which threatens their prosperity and that of communities downstream.

10. Comment: *For me, the paper cannot be accepted in this form. So sorry.*

    Response: *Thank you for the excellent comments. We are confident that you will find the revised version acceptable.*

    Changes in manuscript: *See items 1-9 above.*

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Assessment of Soil Erosion Vulnerability in the Heavily Populated and Ecologically Fragile Communities in Motozintla De Mendoza, Chiapas, Mexico

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Abstract. The physical aspects and knowledge of soil erosion in six communities in rural Chiapas, Mexico were assessed. Average erosion rates estimated with the RUSLE model ranged from 200 to 1,200 ha^{-1} yr^{-1}. [illegible] erosion rates are relatively high due to steep slopes, sandy soils and bare land cover. The lowest rates occur where corn is cultivated for much of the year and slopes are relatively low. The results of a knowledge, attitudes and practices (KAP) survey showed that two-thirds of respondents believed that the major cause of soil erosion was hurricanes or rainfall and only 14% of respondents identified human activities as causes of erosion. Forty-two percent of respondents indicated that the responsibility for solving soil erosion problems lies with government, as opposed to 26% indicating that the community is responsible. More than half of respondents believed that reforestation is a viable option for reducing soil erosion, but only a third of respondents were currently applying reforestation practices and another one-third indicated that they were not following any conservation practices. The KAP results were used to assess the overall level of knowledge and interest in soil erosion problems and their solutions by compiling negative responses. The community of Barrio Vicente Guerrero may be most vulnerable to soil erosion, since it had the highest average negative response and the second highest soil erosion rate. However, Poblado Camb[illegible]d the highest estimated soil erosion rate and a relatively low average negative response rate, suggesting that soil conservation efforts should be prioritized for this community. We conclude that as long as the economic and productive needs of the communities are not solved simultaneously, the risk of soil erosion will increase in the future, which threatens the survival of these communities.

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1 Introduction

Soils contribute critical ecosystem services to humans, including, but not limited to food, clean water and air, and biodiversity (Brevik et al., 2015; Pimentel and Burges, 2013, Smith et al., 2015). The sustainability of soil-based ecosystem services depends on management choices by individuals, such as farmers, foresters and land planners, that are motivated not only by individual perceptions but also by political decisions and broader public perceptions. Sustaining soil-based ecosystem services requires an understanding of complex socio-environmental phenomena resulting from the interactions between biophysical and socio-economic factors operating at a range of spatial and temporal scales (Wilson et al., 2016). Soil erosion and other land degradation processes result from a long chain of processes with varying drivers, the most common of which are social marginalization and limited economic and technological resources. These drivers tend to lead landowners to maximize yield through soil cultivation practices that often lead to increased soil erosion (Pielke et al., 2007; Santibañez and Santibáñez, 2007). Problems caused by soil erosion include but are not limited to loss of productivity, mass wasting, and compromising water supply systems. The major factors that cause soil erosion are human activities such as urbanization, road construction, deforestation, intensive livestock grazing, and agriculture (Brooks et al., 2003). While land degradation is often assumed to be a deliberate result of human intervention, in certain socio-environmental contexts, degradation is not perceived as deliberate by local actors; instead their actions come as a result of learning and adapting to new terms. However, at some point, the scale of degradation reaches a threshold where the risks are too high for the greater population. While soil conservation and restoration policies are meant to solve these problems, they may conflict with agricultural and other livelihood activities. Successful long-term soil conservation and restoration programs need to simultaneously identify areas that most vulnerable to erosion and consider the needs and interests of people who are could be indirectly or directly impacted (Toledo-Aceves et al., 2011, Assefa and Hans, 2015).

Global estimates indicate that the fraction of highly-degraded land increased from 15% of total land area in 1991 to 25% by 2011; most of which is associated with water-induced soil erosion, and is continuing to increase (UNCCD 2013, Sunday et al., 2012, Prosdocimi, 2016). Soil erosion challenges tend to be greatest in the more heavily populated, under-developed, and ecologically fragile areas, where the adaptive capacity is weakest (Leh et al., 2013, Erkossa et al., 2015). Agriculture is the main cause of soil losses (Laudicina et al., 2015, Keesstra et al., 2016a). Tesfahunegn (2013) suggests that soil degradation associated with poor farmers attempting to increase production to feed growing population exacerbates soil erosion, especially in regions where the economy mainly depends on agriculture. In Mexico, 44.9% of the land area is severely or very severely degraded by water-induced erosion, aggravated by conversion from forested to agricultural land and accompanying cultivation practices (SEMARNAT, 2008). The underlying drivers of land conversion in Mexico are complex and vary between regions (Pfaff et al., 2014). Chiapas state has experienced some of the highest deforestation and soil erosion rates in Mexico (De Jong et al., 1999; Cayuela et al., 2006), such as in the Grijalva River basin. Soil erosion in the basin threatens the sustainability of local subsistence agriculture, downstream communities subject to geologic hazards, such as landslides, and downstream hydropower generation capacity. The basin is located primarily in southern Mexico, although the headwaters are in Guatemala (González-Espinosa and Brunel 2014). The basin has an annual average precipitation between 1200 and

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4000 mm and is prone to flooding and erosion due to steep slopes and fragile soils (Gutierrez- Horacio and Triana-Ramirez, 2006). Soils in the Grijalva basin are degraded in more than half the basin area due to erosion (Colegio de Postgraduados, 2002), with negative impacts on rural social development (García-Barrios et al., 2009). Erosion is also problematic because collection of sediment in reservoirs threatens the production of hydropower in the basin, which provides 42% of the hydropower in México (Comisión Federal del Electricidad, CFE, 2013). Motozintla de Mendoza, a municipality located in the upper portion of the Grijalva basin and the subject of this study, has experienced severe erosion from catastrophic events such as during Hurricane Mitch (1998) and Hurricane Stan (2005) (Sánchez-Nuñez, 2012), when depths of at least three meters of sediment accumulated in areas adjacent to hillslopes and long-term erosion hazards (Suarez-Diaz, 2006; Sánchez-Nuñez, 2012).

Observations of soil erosion rates are made from experimental plots and river sediment yields (Pimentel et al., 1995; Stallard, 1998; Hooke, 2000; Lal, 2003; Wilkinson & McElroy, 2007). However, these collecting these observations can be expensive and thus observations of soil erosion rates are usually sparse, especially in marginalized regions. An alternative approach to estimating soil erosion rates is to use of soil erosion models (Naipal et al., 2015). One of the most frequently applied models to estimate soil erosion is the semi-empirical, process-based Revised Universal Soil Loss Equation (RUSLE) model (Renard et al., 1997, Wischmeier & Smith, 1978). RUSLE uses rainfall data, soil type, topography, vegetation cover, and conservation practices to estimate soil erosion (Fernandez et al., 2003). Studies have shown that the application of RUSLE model is a useful and efficient tool for assessing and mapping the vulnerability of soil erosion across a wide range of ecosystem types, including mountainous tropical watersheds (e.g. Millward & Mersey, 1999; Jain et al., 2001; Lu et al., 2004; Jasrotia & Singh, 2006; Dabral et al., 2008; Yue-Qing et al., 2008; Kouli et al., 2009; Pandey et al., 2009; Prasannakumar et al., 2012)

The assessment and solution of soil erosion problems requires not only physical analyses and technical interventions but an understanding of the underlying social factors as well (Pereira et al., 2016, González-Espinosa et al., 2015; Blaikie and Brookfield, 2015; Keesstra et al., 2016b). Since landowner perceptions are generally dependent on the cultural and socio-political context of a given area, it is necessary to carry out studies that integrate local perceptions, preferences and attitudes regarding soil management (Subirós et al., 2016). However, most studies underlying soil conservation and restoration programs do not ask those affected by soil erosion for their input on the causes and potential solutions for soil erosion (Kelly et al., 2009, Marques et al., 2015). This lack of interaction with the group of people most familiar with issues surrounding soil erosion may explain why the problem persists, despite a long history of research and programs aimed to encourage farmers to adopt soil conservation practices (Zegeye et al., 2010; Jara-Rojas et al., 2013, Teshome et al., 2014). The decision of landowners to use and manage the land in a way that minimizes erosion depends on their perception of the landscape (Marques et al., 2015). If the farmers perceive the problems of erosion and their responsibility for managing their own land, they may be willing to adopt new, soil-conserving practices (Assefa and Hans, 2015). The knowledge and attitudes provided by landowners is supposed to result in more efficient implementation of soil conservation policy measures, underscoring the need to use information about social perceptions and cultural values in management and planning (Marques et al., 2015).

Previous research in the region comprising Motozintla de Mendoza, Chiapas, has revealed that environmental problems are often linked to fragmented governance of natural resources, leading to declines in local inhabitant's environmental concern and connections with the local landscape (Ochoa-Gaona, 2001, Ochoa-Gaona and González-Espinosa, 2000; Cayuela et al., 2006, Laino-Guanes et al. 2016). This finding suggests that engaging local communities in soil conservation efforts is not a straightforward issue in the region and that assessment of the relationship between people and environmental issues, including their perceptions of the importance of environmental issues and their willingness to participate in practices that minimize environmental impacts, is needed. Knowledge, attitudes and practices (KAP) surveys are often used to collect information on a specific population on what is known, what they believe, and what they do or have been doing, primarily in relation to public health issues (WHO, 2008; Launiala, 2009). KAP surveys are straightforward to design and interpret, and have been used in a broad range of environmental and natural resources management applications (e.g. Gumucio, 2011; Sibiya & Gumbo, 2013; Tuyet-Hanh et al., 2013, Babbar et al., 2014; Aparicio-Eff[illegible] al., 2016). With application to soil erosion and management, knowledge includes causes and locations of erosion in the community, attitudes include the perceptions of the magnitude of the problem and who is responsible for the problem, and practices include the level of adoption of soil conservation methods (e.g. Ajayi, 2007).

Natural resource managers need to understand the spatial variations in vulnerability to soil erosion, so that they can identify "hot spots" where soil degradation is especially intensive and prioritize implementation of soil conservation and restoration efforts (Biswas et al., 2015). However, most studies of spatial variations in soil erosion vulnerability focus only on the physical aspects and not the socioeconomic dimensions that relate to the potential for soil conservation efforts to be sustainable. We propose, then, that spatial variation in vulnerability to soil erosion should incorporate both a biophysical metric of the risk of soil erosion and a measure of community members' views of the problem of soil erosion. The goal of this paper is to assess soil erosion rates and understand the relationship between knowledge, attitudes and practices to mitigate soil erosion in six communities in the municipality of Motozintla de Mendoza, Chiapas, an area with severe soil erosion problems. We determine the physical and social vulnerability to soil erosion in this area using the RUSLE model to estimate spatially variable soil erosion rates and a KAP survey to understand differences in understanding among the communities regarding soil erosion. We integrate this information to suggest ways to prioritize the communities in which soil conservation and restoration efforts may be most likely to be sustainable.

2 Methods

2.1 Study Area

This work occurred in six communities: Benito Juarez Centro, Carrizal Centro, Barrio Vicente Guerrero, Barrio La Union, Barrio Plan Grande in the municipality of Motozintla de Mendoza, and Poblado Cambil in the municipality of Mazapa de Madero, all located in the southeast of the Sierra Madre of Chiapas (see Figure 1). The communities were

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chosen because of previous connections made with local community leaders through local academic institutions. The major economic activity in these communities is subsistence agriculture, consisting mainly of cultivating corn and beans and raising cattle. The region is typified by steep slopes and erodible soils and, when combined with overexploitation of forests, has resulted in severe soil erosion (González-Espinosa et al., 2015). The regional annual average temperature is from 14 to 24°C. Annual precipitation follows an increasing trend from north to south with values from 800 to > 5000 mm/year (Gordillo, 2009). Erosion rates were estimated and associated field measurements were taken at eight plots per community with land uses or land covers (LULC) that are typical of the individual communities, as determined in an intensive LULC survey in each community. The LULC categories included community forest land (71% of plots), cultivated land (17% of plots), pasture land (6% of plots), and reforested land (6% of plots). All LULC plots, except the cultivated land, had substantial areas of bare soil, ranging from 60% to 95%. The community forest land is typically degraded (average bare soil coverage of 60%) because of overexploitation for firewood collection by residents. The cultivated land is used for growing corn; these plots were always completely occupied by corn.

2.2 Soil Erosion Rate Calculations with the RUSLE Model

Soil erosion rates in the RUSLE model were calculated according to Renard et al. (1997)

$$A = RKLSCP \tag{1}$$

where A is the average soil loss (ton ha^{-1} yr^{-1}), R is the rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1}), K is the susceptibility of soils to erosion (ton ha h ha^{-1} MJ^{-1} mm^{-1}), L is the slope length (dimensionless), S is the slope magnitude (dimensionless), C is the cover and crop management factor (dimensionless), and P is the conservation practice factor (dimensionless). A modified form of the conventional equation for rainfall erosivity factor was used because of the lack of high-resolution rainfall data (Arnoldus, 1980, Renard & Freimund, 1994):

$$R = 95.77 - 6.081F + 0.4770F^2 \tag{2}$$

where F is the modified Fournier index, as in

$$F = \sum_{i=1}^{12} \left(\frac{r_i^2}{R} \right) \tag{3}$$

where r_i is the monthly precipitation and R is average annual precipitation. Daily data from the period 1980 to 2009 were obtained for the closest meteorological station (Buenos Aires, Chiapas, 7.6 km on average from the study communities) from the Comisión Nacional del Agua. The soil erodibility factor (Wischmeier et al., 1971) is a function of the physico-chemical soil properties:

$$K = \left(\frac{1}{7.59}\right)\left[2.1\times10^{-4}\left(12-OM\right)M^{1.14}+3.25\left(s-2\right)+2.5\left(p-3\right)\right]/100 \tag{4}$$

where *OM* is organic matter, *M* is the product of the modified silt size (0.002-1.0 mm) fractions, silt size, and sand size fractions, *s* is the structure code, *p* is the permeability code, and 7.59 is a factor accounting for conversion from English to metric units. For more details on these variables, see RUSLE documentation (Foster, 2005). Soil textures and organic were measured from soil samples (see following section).

McCool et al., (1989) evaluated the slope steepness factor as

$$\begin{aligned} S &= 10.8\sin\theta + 0.03 \text{ for } \theta < 9\% \\ S &= 16.8\sin\theta - 0.50 \text{ for } \theta \geq 9\% \end{aligned} \tag{5}$$

where θ is the slope. The slope length factor was estimated with the following equation (McCool et al., 1997):

$$L = \left(\frac{\lambda}{72.6}\right)^{m} \tag{6}$$

where λ is the horizontal projection, 72.6 is the RUSLE unit plot length in feet, and *m* is a slope exponent variable, which is related to β as $m = \beta/(1+\beta)$ Foster et al. (1977). For conditions where the soil is suceptible to rill and interrill erosion, McCool et al., (1989) relates β to the local slope:

$$\beta = (\sin\theta / 0.0896)/\left[3.0(\sin\theta)0.8 + 0.56\right] \tag{7}$$

The cover management factor is (Yoder et al., 1997)

$$C = (PLU)(CC)(SC)(SR)(SM) \tag{8}$$

where *PLU* is the prior land use sub-factor (dimensionless), *CC* is the canopy cover sub-factor (dimensionless), *SC* is the surface cover sub-factor (dimensionless), *SR* is the surface roughness sub-factor (dimensionless), and *SM* is the soil moisture sub-factor (dimensionless). *PLU* is computed by

$$PLU = C_f C_b \exp\left[\left(-c_{ur}B_{ur}\right)+\left(c_{us}\frac{B_{us}}{C_f c_{uf}}\right)\right] \tag{9}$$

where C_f (dimensionless), C_b (dimensionless), c_{ur} (ha mm kg^{-1}), and c_{uf}, (ha mm kg^{-1}), are coefficients related to subsurface consolidation and soil residual organic matter; B_{ur} is the mass density of live and dead roots in the upper inch of soil (kg ha^{-1} mm^{-1}), and B_{us} is the mass density of incorporated surface residue in the upper inch of soil (kg ha^{-1} mm^{-1}). *CC* is the canopy cover sub-factor (dimensionless), given by

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$$CC = 1 - f_c \exp\left(-0.1H\right) \tag{10}$$

where f_c is the fraction of land surface covered by canopy and H is the vertical distance from the land surface to the canopy (m) (Renard et al., 1997).

The surface cover sub-factor SC is given by

$$SC = \exp\left[-bS_p\left(\frac{0.24}{R_u}\right)^{0.08}\right] \tag{11}$$

where b is an empirical coefficient, S_p is the fraction of land covered by surface cover, and R_u is the surface roughness as defined by Renard et al., (1997). The surface roughness sub-factor is given by:

$$SR = \exp\left[-0.66\left(R_u - 0.24\right)\right] \tag{12}$$

The soil moisture sub-factor SM is the yearly average of daily values assigned as 0 and 1 during wet and dry periods, where wet and dry periods are determined from meteorological records. Finally, the value of the P sub-factor was set equal to one, since no practices are applied for soil erosion control (Kouli et al., 2009) in the studied communities.

2.3 Field Measurements

Soil sample collection took place in the six communities during summer 2011. In each community, eight 1,000 m^2 circular plots (Ramírez-Marcial et al., 2014) were established. Slope steepness was measured in each plot using a clinometer (McCool et al., 1997). In each plot, six soil samples were taken at three randomly-located points along a straight line at depths of 0-20 cm and 21-40 cm respectively. The soil sampling yielded a total of 288 soil samples (6 communities, 8 plots per community and 6 samples each plot). The soil samples were dried, sieved and analyzed for texture by the Bouyoucos procedure, method from AS-09, NOM-021-RECNAT-2000, and organic matter by the method of Walkley and Black, AS-07, NOM-021-RECNAT-2000 (SEMARNAT, 2002). The calculation of slope angles and lengths was carried out with Google Earth, using a polygon covering the study area. Horizontal lines were drawn from the sample location to the end of the slope (according to McCool, et al., 1989) using the add paths tool. Each line corresponded to a slope length for the respective plot. The slope length factor was measured from uphill to downhill using the Show Elevation Profile tool.

2.4 KAP Survey

Prior to conducting the survey, interviews with six community members, municipal authorities, government agencies, and academics were conducted to understand the knowledge of the community with respect to soil erosion. The resulting survey was piloted with 12 community members and the survey questions were adjusted based on these results. The KAP survey of residents in the communities was carried out during the spring of 2012. Households were

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selected randomly, with the goal interviewing 60% of the 296 households in the six communities, since 60% is the typical household occupancy rate in the communities. The surveys were designed for any members of a household above the age of 18 The survey questionnaire included four sections: (1) interviewee demographic data (9 questions); (2) questions assessing knowledge of soil erosion (10 questions); (3) questions assessing attitudes towards soil erosion (4 questions); (4) an open-ended question corresponding to the interviewee's soil erosion prevention practices. The knowledge section of the survey was aimed at determining the interviewee's understanding of what soil erosion is, their perspective on the causes of erosion, and how the land under study can be conserved either through preventive measures or control measures. The complete questionnaire can be found in the supporting information. The surveys were carried out in Spanish by a team of five interviewers, including the first author and four interviewers trained by the first author. The data collection technique was face to face interviews using the structured KAP survey methodology (Gumucio, 2011). Interviewers first explained the objective of the survey, asked for the consent of the interviewee, and then asked the survey questions as written. If further explanations were needed, they were provided in a non-technical way. The complete survey is found in the Supplemental Information.

3. Results

3.1 Soil Erosion Rates

The rainfall erosivity factor for the study area was calculated as 17,000 MJ mm ha^{-1} h^{-1} yr^{-1} using equation (2). The average and standard deviation of values of the soil erodibility obtained for each community are shown in Table 2. Overall, K ranged from 0.011 to 0.042 ton ha h ha^{-1} MJ^{-1} mm^{-1}, with the lower values corresponding to soils with relatively high clay contents (Renard et al., (1991). The values of K and all other sub-factors for each community and sample plot are found in the Supporting information. The LS factors are high compared to typical values in Renard et al., (1997). These high values occur because many of the slopes plots were very high (greater than 60°). The C sub-factor values range from 0.03 to 0.06; according to Renard et al., (1991), C values vary from 0 to 1.5, indicating a well -protected soil and a disturbed soil, respectively. Most of the cover vegetation in the study area was forested, but with substantial areas of bare soil. Values of C were relatively similar, except for the higher values in Barrio La Union, which are attributed to greater areas of bare soil.

In Table 2, the average and standard deviation of values of the calculated soil erosion rates obtained for each community are given. For perspective on the magnitude of these soil erosion rates, SEMARNAT describes rates greater than 200 ton $ha^{-1}yr^{-1}$ as "very high" (SEMARNAT, 2008), while the Food and Agriculture Organization describes "very high" rates as exceeding 30 ton $ha^{-1}yr^{-1}$ (FAO, 2015). Poblado Cambil has the highest soil erosion rates, because of a combination of relatively high soil erodibility, length slope, and cover factors. Barrio Vicente Guerrero and Barrio Benito Juárez Centro had the next highest calculated soil erosion rates, due to high length slope factors in most plots in these communities. The remaining communities, Carrizal Centro, Barrio La Union and Barrio Plan Grande had lower soil erosion rates since plots in these communities had lower K, C or LS sub-factors. The lowest and highest soil erosion rates in the individual plots varied over an order of magnitude (100 and 2,050 ton $ha^{-1}yr^{-1}$,

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respectively). As expected. the highest values of soil erosion rates are associated with high slope length and steepness. The lowest values occur where corn is cultivated for much of the year, providing cover during the highest precipitation times of year, and slopes are relatively low. In a study in a nearby region in Chiapas with similar land cover, high slopes, and no conservation practices, measured soil erosion rates were similar to those calculated here, although rates as high as 20,000 ton $ha^{-1}yr^{-1}$ were found where landslides recurred frequently (Santacruz-DeLeon, 2011).

3.2 KAP Surveys

The interviews were conducted over a 15 day period and involved a total of 236 households. In total, 60% of all households in the communities were interviewed, with a range of 58% to 71% of households interviewed across the six communities. There were five non-responses, giving a non-response rate of 2%. Only 14% of interviewees have education beyond elementary school. A small fraction (5%) have occupations other than farming their own land or as housewives. Almost all interviewees (99%) incomes were less than or equal to $1,000 Mexican pesos per month (US$ 56/month using the exchange rate as of April 10, 2016); of those who have incomes, 60% receive government support. The complete results of the KAP survey are provided in the Supplementary Information.

The response to the question on the survey "Do you know what soil erosion is?" indicated that 69% of resopndents did not know the term soil erosion, with 81% and 57% of females and males not knowing the term, respectively. However, the following question on the survey, "Do you know what the most eroded area of the community is?" was accompanied by a brief explanation of soil erosion. In response, 91% of females and 95% of males were able to identify the area with most erosion.
The majority of respondents (70%) indicated that the major cause of soil erosion in their communities was either hurricanes or rainfall. Only 14% of respondents identified human activities— deforestation, road construction or agriculture— as causes of erosion. On the other hand, most respondents (69%) thought land use in eroded areas were associated with human activities (common forest land, crop land, grazing land, human settlements, or logging lands).

The most frequent response to the question regarding consequences of soil erosion was landslides, with deaths (11%) and soil infertility (10%) as the next most frequent responses other than "Don't know," which included 28% of responses. Most (62%) respondents obtained information about soil erosion from personal experience, followed by experiences related by family members (16%), suggesting that community members usually react to soil erosion after it has occurred, rather than a cautionary approach of conservation practices that are related to information obtained from government or school. However, 42% of respondents indicated that the responsibility for solving soil erosion problems lies with government, while 26% indicated that responding to soil erosion as the responsibility of the community. An additional 17% of respondents said that the responsibilities should be shared by the community and government. More than 50% of respondents believed that reforestation is a viable option for reducing soil erosion with an additional 16% responding that reforestation with terracing is a useful solution. Several respondents added that, while reforestation is a useful soil conservation practice, they would only engage in reforestation if the government were to pay for the reforestation. Thirty-seven percent of respondents were currently employing

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reforestation practices on their land. Roughly one-third of respondents indicated they were not following any conservation practices.

Several respondents said that reforestation activities have been limited by several issues. First, community members are required to complete a document requesting trees for reforestation; however, many community members are completely or partially illiterate and cannot complete the forms. Second, the reforestation programs supply pines and cypress, but, community members usually prefer oak trees because they think that they are unlikely to see the benefits of timber species, whereas they are more accustomed to using oaks, for example, for firewood. Third, the numbers of trees that are supplied to the communities each year is usually insufficient to cover the demand. While most respondents indicated that reforestation was important, many indicated that soil erosion problems were not as important as livelihood issues. For example, one respondent said "For us the forests are very important because we need it for to obtain wood and then to use them for houses construction or for furniture materials, or also for wood selling, that's why the forest is almost ending, because we have good trees for wood and we can get money." Another respondent said that most people in the communities do not own large land areas and "If I reforest my land, where am I going to plant my maize, what am I going to eat, or what I will give to my kids for their food?" Several respondents mentioned that because they have big families, they cannot dedicate more land for reforestation. However, some respondents indicated that they should conserve the land because it is the source of their livelihood.

In general, the KAP survey results imply that a substantial fraction of respondents has low degrees of awareness and perception of erosion issues and most respondents do not see that reforestation efforts to combat soil erosion will be successful. However, differences in the KAP survey results between communities may offer information about their potential to engage in and sustain appropriate soil conservation practices. As a measure of this potential, the negative responses to the KAP survey questions were compiled by community, with the notion that lower negative response rates indicate greater capacity to adopt soil conservation practices. The negative responses include: "No" for the knowledge of the term "soil erosion" and locations of most eroded areas; "Don't know" for the questions on causes of soil erosion, land use in eroded areas, consequences of soil erosion, and sources of information; "Don't know" or "No one" for the question on responsibility for solving soil erosion problems; "Don't know" or "Nothing" for the questions on practices for reducing of soil erosion; and "No" to the question on whether there are solutions to the problem of soil erosion.

Table 3 gives the percentages of negative responses normalized to the overall average percentage of negative responses, by community ($Y_{i,j}$ where i is the question index and j is the community index) and the overall normalized percentage of negative responses averaged over all questions for each community ($\overline{Y}_j$). We estimated the Cronbach's alpha to assess the reliability of the overall measure of negative responses. The estimated α = 0.84 is substantially higher than the rule of thumb of α = 0.7 as a threshold for consistency. By inspection, the results in Table 3 also show that normalized negative responses are relatively consistent across the questions for each community. However, the averages across all questions show substantial differences by community. A multiple group F-test analysis on $\overline{Y}_j$ gives

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a *p*-value of 0.014, implying that the values of $\overline{Y}_j$ are significantly different between each community. Comparing the results in Tables 2 and Table 3, Poblado Cambil has the highest estimated soil erosion rates and a relatively low average negative response rate. Barrio La Union has relatively low soil erosion rates and high negative response rates. On the one hand, these results suggest that soil conservation efforts may have the greatest and lowest potential payoffs in communities with the characteristics of Poblado Cambil and Barrio La Union, respectively. On the other hand, the results suggest that Barrio Vicente Guerrero may be most vulnerable to soil erosion, since this community had the highest average negative response rate and the second highest soil erosion rate.

4 Conclusions

The purpose of this study was to assess soil erosion vulnerability in six communities in the vicinity of Motozintla de Mendoza, Chiapas, México, where soil erosion threatens the long-term viability of the local subsistence agriculture and downstream communities, which are subject to landslides and related geologic hazards. We collected and measured soil samples for characteristics related to erodibility, collected field observations on land use-land cover, and applied a quantitative model of soil erosion rates. Average erosion rates estimated with the RUSLE model ranged from 200 to 1,200 $ha^{-1}yr^{-1}$; this range is at as much as an order of magnitude higher than rates indicated as very high by national and international agencies. Erosion rates are relatively high in all communities due to steep slopes and deforestation and the highest soil erosion rates are found in areas with especially high slope length and steepness. The lowest erosion rates occur where corn is cultivated for much of the year and slopes are relatively low. We developed and implemented a KAP survey aimed at understanding community perceptions of soil erosion. The results of the survey showed that most respondents were able to identify areas in their communities with the greatest erosion. The majority of respondents indicated that the major cause of soil erosion was heavy precipitation. While only a small number of respondents identified human activities as causes of erosion, most respondents knew that eroded areas were in areas undergoing cultivation or other human activities. Almost half of respondents indicated that the responsibility for solving soil erosion problems lies with government, as opposed to a quarter indicating that the community is responsible. More than half of respondents believed that reforestation is a viable option for reducing soil erosion, but only a third of respondents were currently implementing reforestation practices and another one-third indicated that they were not following any conservation practices. Comments by survey respondents indicated that reforestation efforts have been limited by lack of land area for reforestation, the need to sell forest products for income, and inaccessibility of the application process for obtaining trees.

We integrated the erosion rate and social survey results to rank the communities in terms of vulnerability to soil erosion. The survey results were synthesized into an indicator of the community's ability to sustain erosion control measures, by calculating an overall rate of negative responses to questions on knowledge, attitudes, and management practices related soil erosion. This analysis revealed that the relationship between soil erosion rates and negative responses was inconsistent across the communities. It may be easy to blame the communities for the high soil erosion rates calculated in this region of Mexico on a lack of awareness of the causes of and solutions to soil erosion problems.

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However, while land degradation is often assumed to be a deliberate result of human intervention, in certain socio-environmental contexts, degradation is not perceived as deliberate by local actors; instead their actions come as a result of learning and adapting to new terms that affect their livelihoods, which also may vary across communities. We conclude that as long as the economic and productive needs of the communities are not solved simultaneously, the risk of soil erosion will increase in the future, which threatens the prosperity of these communities.

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Table 1. Demographic information for all respondents.

Gender	Count	Percentage
Female	123	52%
Male	113	48%
Ages (18-89)	**Count**	**Percentage**
18-30	57	24%
31-40	58	25%
41-55	66	28%
over 56	55	23%
Education level	**Count**	**Percentage**
No school	9	4%
Some elementary school	115	49%
Finished elementary school	80	34%
Some middle and high school	30	13%
Finished middle and high school	2	1%
Employment	**Count**	**Percentage**
City (various)	6	3%
Clerical	1	<1 %
Housewives	115	49%
Community (various)	5	2%
Farming	108	46%
Student	1	<1 %
Incomes (monthly average, Mexican pesos)	**Count**	**Percentages**
Equal or less than 2500	2	1%
Equal to 1500	2	1%
Equal or less than 1000	143	61%
No incomes	89	38%
Type of incomes	**Count**	**Percentage**
Government support	142	60%
No salary	89	38%
Other	5	2%

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Table 2. RUSLE factors and model results

Community	Soil erodibility factor (ton h ha^{-1} MJ^{-1} mm^{-1})		Length slope factor (-)		Cover management factor (-)		Soil erosion rate (ton ha^{-1} yr^{-1})	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Benito Juárez Centro	0.020	0.003	100	37	0.023	0.004	820	260
Barrio Vicente Guerrero	0.021	0.005	99	42	0.028	0.004	930	480
Carrizal Centro	0.018	0.005	82	47	0.028	0.004	660	400
Poblado Cambil	0.031	0.008	82	20	0.030	0.000	1200	360
Barrio Plan Grande	0.027	0.005	42	20	0.025	0.007	460	210
Barrio La Union	0.021	0.005	88	39	0.041	0.041	670	560

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Table 3. Normalized percentages of negative responses to survey questions, averaged over communities. Percentages of negative responses are normalized to overall percentages for given survey question.

Community	Knowledge						Attitudes	Practices			Average
	Knowledge of the term “soil erosion:” No	Knowledge of location of most eroded areas: No	Causes of soil erosion: Don’t know	Land use in eroded areas: Don’t know	Consequences of soil erosion: Don’t know	Source of information: Don’t know	Responsibility for solving soil erosion problems: Don’t know/ No one	Reduction of soil erosion: Don’t know/ Nothing	Soil conservation practice utilized Don’t know/ Nothing	Solutions to soil erosion problems: None	
Benito Juárez Centro	1.02	1.16	1.10	1.06	1.27	0.88	0.83	1.27	1.08	1.06	1.07
Barrio Vicente Guerrero	1.22	1.44	1.01	1.08	1.29	1.27	1.30	1.25	1.42	1.37	1.25
Carrizal Centro	1.16	1.10	1.37	1.18	0.87	0.95	0.96	1.31	1.08	11.3	1.11
Poblado Cambil	0.84	0.79	1.03	0.96	0.69	0.72	0.71	0.78	0.65	0.58	0.80
Barrio Plan Grande	0.57	0.50	0.45	0.65	0.66	0.44	0.56	0.57	0.68	0.42	0.56
Barrio La Union	1.20	1.36	1.18	1.01	0.98	1.47	1.12	1.38	1.00	1.23	1.19

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Figure 1. Study area: Motozintla de Mendoza municipality (inside white line) and location of six study communities.

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