17

Sensitivity of Mexico's Farmers: A Sub National Assessment of Vulnerability to Climate Change

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1. Introduction

In ecology and systems theory, sensitivity refers to the ability of an environmental system which deals with stress or disturbance´s. Sensitivity is the degree to which a system is affected, or its ability to respond to a stimulus, in this case, climate stimulus (Smit et al., 2009). Some concepts that have been applied to natural systems are stability, resilience and flexibility, which may well be applied to human systems. Stability refers to the ability of a system to remain fixed or unchanged when exposed to a disturbance. Resilience refers to the ability of the system to rebound from a disturbance that could be experienced. Flexibility is the degree of manoeuvrability that exists within the system. Despite their application in ecology, the boundaries in human systems between these concepts are not clear and kept on being discussed (Smithers and Smit, 2009). But what we can be certain of is that the terms described above have gained attention in recent years because they influence the internal definition of systems and their vulnerability to changes in climate systems (Klein and Nicholls, 1999).

The IPCC recognizes the vulnerability to climate change as "the degree to which systems are able or unable to address the negative impacts of climate change" (Parry et al., 2007), referring to geophysical, biological and socioeconomic systems. They point out that vulnerability may relate to the vulnerable system (a city, an agricultural activity), the impact on the system (flood) or the mechanism that drives it (melting). Cutter (1996) and the Third Assessment Report of the IPCC (McCarthy et al., 2001) identified three components that determine the vulnerability of a system or group of people: their exposure, sensitivity and adaptive capacity. In fact, since the second IPCC report (1996) it was recognized that "the most vulnerable systems are those more sensitive to climate change and with less adaptability." More information on the vulnerability analysis can be found in Berry et al., 2006; Bohle et al., 1994, Downing and Patwardham, 2006, Kelly and Adger, 2000; whereas in the present work the definition of IPCC on vulnerability is used and especially in this chapter on climate sensitivity, a component of vulnerability.

The sensitivity, according to the IPCC (2007), is "the degree to which a system is affected by a disturbance, either adversely or beneficially, by variability or climate change," and points out that the effects can be direct or indirect. Sensitivity refers to the extent such a system will

respond to a change in climate. This measure determines the level at which the system will be affected by a particular stress, or how the system will be affected by climate change. O'Brien´s report (2004) indicates that human and environmental conditions are what would worsen or lessen the impacts of a given phenomenon.
The sensitivity analysis attempts to directly link future climate change scenarios with its potential effects or impacts (Downing and Patwardham, 2006). That is, the purpose is to understand the process by which future scenarios result in hazards or impacts on a particular group or system. An important aspect pointed out by the authors is that it is possible to identify points of intervention and response options.
The literature reveals few evaluations of climate sensitivity from the perspective of vulnerability and climate change. For example, O'Brien (2004) to measure the sensitivity under exposure to climate change built a climate sensitivity index, which measured the soil aridity and the dependence on monsoon in India. Besides, a sensitivity evaluation to climate stimuli at national and municipal level is not known in Mexico. Thus, the objective of this study was to contribute to the analysis of climate sensitivity in Mexico, by evaluating the sensitivity of the municipalities in the country to the stimulus of climate change. Another objective was to apply indicators to assess the current state of the agricultural sector (in infrastructure and land production capacity), and by using scenarios of future climate change the possible impacts on agriculture, livestock and forestry in the country, as sensitive components to climate change.

2. Methods

The method used in this paper was organized into three components: (I) selection of indicators to assess the sensitivity to climate change, (II) obtaining an index of sensitivity to climate change and (III) mapping of the sensitivity to climate change in the municipalities of Mexico. The aim of the first component was to obtain indicators to assess both the existing capacity to address climate change and the potential impact on agricultural activity (agriculture, livestock and forests) that is expected to occur in the municipalities. It was in this way how the current sensitivity to future climate change was represented. Indicators were selected into three groups; the first one was about existing infrastructure, the second one about land capacity and the last one about the impacts of climate change on natural and productive resources (agriculture, livestock and forests). The main source of data was the Agriculture, Livestock and Forestry Census by the National Institute of Statistics and Geography (INEGI, 2009), as well as the results for agriculture (Monterroso et al., 2011a), livestock (Monterroso et al., 2011b) and forests (Gómez et al., 2011) obtained for Mexico at national level. The information was processed geographically in ArcGIS (version 9.3) and statistically in SPSS (version 18). The sensitivity index was built and then we proceeded to develop it´s mapping, as detailed in the following paragraphs.

2.1 Selection of indicators

The selected indicators to evaluate the sensitivity of the municipalities were grouped into: a) indicators of existing infrastructure b) indicators of land capacity and c) indicators of climate change impacts on natural and productive resources. The first two groups establish the current conditions and therefore the ability (or inability) to cope with climate change. The third group is the translation of possible future scenarios of climate change and its impacts on farming, livestock and forestry in Mexico. Table 1 presents information about the indicators applied.

Existing infrastructure indicators include the total number of greenhouses and/or nurseries in the municipality, the total existing irrigation systems, percentage of production units that reported insufficient infrastructure in the municipality and all machinery in the municipality. The information for the infrastructure indicators was obtained from the Agriculture, Livestock and Forestry Census (INEGI, 2009) and corresponds to that reported for each production unit within the municipalities. The indicator referring to the total number of greenhouses and/or nurseries in the municipality represents the total amount reported by the production units within the same municipality. The selection of this indicator was based on that the larger the number of greenhouses or nurseries within the same municipality, the greater the production capacity, presenting even better quality than the production dependent only on rain irrigated. Thus, the larger existing capacity in greenhouses and/or nurseries, the lower the sensitivity of the municipality. This allowed us to identify the most sensitive municipalities, given its low amount of actual existing infrastructure. In regards to the total irrigation systems, they represent the sum of all existing systems within the municipal production units, regardless of the present type of irrigation. The central hypothesis for the selection of this indicator is that the smaller the number of irrigation systems existing in a municipality the lower its capacity to cope with climatic variations, therefore, the greater its sensitivity to change. The third indicator was the total reported machinery, and is the sum of those reported by each production unit within a municipality. The selection as an indicator was considered because the total amount of machinery in a municipality makes reference to the capacity to do work in agriculture in less time, which means higher production efficiency. If machinery for work is available at the municipalities, it is hoped that they will be more able to adapt to climate change conditions, for example, and will be therefore less sensitive. The last indicator, insufficient infrastructure, includes the percentage of total production units within the same municipality which reported failure in infrastructure for agricultural, forestry or livestock production. The selection of the indicator was based on the fact that the greater the percentage of insufficient reported infrastructure within a municipality the greater the sensitivity to changes is considered, thus presenting greater vulnerability. The four indicators above were considered enough to evaluate the degree of sensitivity of the municipalities, in regards to existing infrastructure, since a system with infrastructure will be less sensitive to changes to any climatic variable.

To evaluate the land capacity we include the assessment of its current state in terms of production capacity, because if there is any land degradation, agricultural production will be more difficult to be carried out, making it possible to identify the municipalities with these characteristics as more sensitive, compared with those that do not have this problem. The selected indicators in this group were five: total hectares reported with loss of soil fertility, total hectares with presence of salts, total hectares with presence of some degree of erosion, total surface area without vegetation and finally total hectares with presence of some degree of contamination. The information was also obtained from the Agriculture, Livestock and Forestry Census (INEGI, 2009) and corresponds to that reported for each production unit within the municipalities. The loss of soil fertility includes the total reported hectares per production unit within a municipality that reported this feature. The indicator presence of salts comes from the total number of hectares reported by the production units with problems of salinization of soils in each municipality. Similarly, the erosion indicator refers to the total hectares per production unit that have reported the presence of some degree of erosion of their soil within a municipality. The total surface area indicator without apparent vegetation refers to the total sum of hectares reported by the production units within a municipality. Finally, the pollution indicator includes the total hectares reported with pollution problems per production unit within a municipality.

Indicators of climate change impacts on natural resources were considered as sensitive elements of the production system, since a negative change in them will means a reduction in the land productive capacity. They include the changes suggested by climate change on agricultural suitability, as exemplified by the production of rainfed maize in Mexico. As the authors point out (Monterroso et al., 2011a), the suitability for cultivation was classified into four classes: very suitable, suitable, marginally suitable and unsuitable, thus forming the baseline scenario. The climate change scenarios used were Echam and Hadgem, according to the A2 group by 2050. The new outputs for agricultural potential for the cultivation of maize were also classified in the same number of classes. Modelled changes are also included both in the livestock capacity and forest suitability; the first by analysing the change in the stocking rate and the second by the shift in suitability for some forest species. The livestock suitability (Monterroso et al., 2011b) refers to the stocking rate needed to sustain one animal unit, expressed as the number of hectares needed per animal unit per year (ha/AU/year). Six classes were defined for livestock suitability: 0-1, 1-5, 6-10, 11-50, 51-100 and +100, all in ha/AU/year. Climate change scenarios were the same as those used in the agricultural suitability and their application were also ordered in the same number of classes. In regard to forests, forest species were selected representing the groups of tropical vegetation, temperate and semi-arid, as is mentioned in Gómez (2011). The defined classes were also four, both for the base scenario and climate change scenarios: suitable, moderately suitable, marginally suitable and unsuitable.

2.2 Sensitivity Index to climate change

Sensitivity to climate change is the degree to which a system is affected, or its response to climate change. To represent the ability to cope with changes in the municipalities of Mexico four infrastructure indicators were proposed and five for land capacity. To include the future impact on the evaluation of the sensitivity on the agricultural sector, the outputs of climate change scenarios were included and their corresponding result in the agricultural, livestock and forest suitability by 2050.

This research considered that the sensitivity in the municipalities of Mexico is based on existing infrastructure, the productive land capacity and the change in agriculture, livestock and forest potential to climate change, as shown in the following formula:

$$\text{Sensitivity} = f\ (\text{existing infrastructure, productive land capacity, natural resources}) \quad (1)$$

According to the four selected indicators who represent the existing infrastructure with information at municipal level, the variable can be represented as:

$$\text{Infrastructure} = f\ (\text{total greenhouses, total irrigation systems, total machinery, percentage of insufficient infrastructure}) \quad (2)$$

To estimate the sensitivity of the current production capacity of the land, five indicators were considered about the current state, represented as:

$$\text{Land Capacity} = f\ (\text{percentage of fertility loss, total hectares with salinity, total hectares without vegetation, total contaminated hectares}) \quad (3)$$

Natural resources, as the sensitive elements of the system, were included as the future potential aptitude change in agricultural, livestock and forest suitability caused by climate change, and can be represented in the following formula:

$$\text{Natural resources} = f\,(\text{percentage of area used by primary sector, current agricultural suitability, } \Delta \text{ future agricultural suitability, current livestock suitability, } \Delta \text{ future livestock suitability, current forest suitability, } \Delta \text{ future forest suitability}) \quad (4)$$

Table 1 presents information on units of measurement of the original indicators, the minimum and maximum values and the standard deviation of each indicator.

Indicator	**Code**	**Min**	**Max**	**Average**	**Standard Deviation**	**Variance**
Greenhouses	S1	0	1857	6.8	43.8	1921.6
Irrigation systems	S2	0	11403	288.0	661.1	437116.8
Sufficient infrastructure	S3	0	89	9.1	12.0	144.0
Reported machinery	S4	0	3484	33.4	120.1	14427.1
Fertility losses	S5	0	100	22.8	20.1	407.0
Salt-affected soils	S6	0	22222	56.7	723.8	523957.6
Soil erosion	S7	0	11648	47.0	494.7	244809.6
Hectares without vegetation (ha)	S8	0	197878	865.3	6692.6	44791159.9
Contaminated hectares	S9	0	2263	4.3	63.9	4087.1
Primary activities	S10	0	100	65.7	21.4	458.2
Base agriculture	S11	0	4	2.0	1.3	1.9
Base livestock	S12	1	10	3.6	1.2	1.5
Base forests	S13	1	4	3.6	0.6	0.4
Echam Agriculture	S14	0	4	2.1	1.4	1.9
Hadgem Agriculture	S15	0	4	2.1	1.3	1.9
Echam livestock	S16	1	10	3.5	1.2	1.5
Hadgem livestock	S17	1	10	3.3	1.3	1.8
Echam Forests	S18	1	4	2.8	1.1	1.2
Hadgem Forests	S19	1	4	3.0	1.0	1.0

Table 1. Statistical values of sensitivity indicators.

All values (s1 ... s19) were standardized (z) to eliminate the measurement units and consider all the variables implicitly equivalent in terms of the collected information. In future scenarios of agriculture, livestock and forest suitability, probabilities and future risks were not considered for being out of the context in the index.

Once the indicators had been standardized the sub-indexes were constructed to represent the partial value of the evaluated subcomponent (sensitivity). Thus, the formula (2) of existing infrastructure was expressed as:

$$\text{Infrastructure} = (S1 + S2 + S3 + S4) / 4 \quad (5)$$

Following this idea, the formulas (3) and (4) are represented as:

$$\text{Land capacity} = (S5 + S6 + S7 + S8 + S9) / 5 \quad (6)$$

$$\text{Natural Resources} = (S10 + S11 + S12 + S13) / 4 \quad (7)$$

With the information of the sub-indexes (5), (6) and (7) the baseline sensitivity scenario was constructed defined here as the current scenario of sensitivity. The formula (8) then represents the current sensitivity of the municipalities in Mexico. This is defined as the sum of the production capacity of the land plus the capacity of natural resources (which together denote the productivity potential) minus the existing infrastructure, (denoting a greater potential to address a harmful climatic stimulus), represented as:

$$\text{Current Sensitivity} = (\text{Land capacity} + \text{Natural Resources}) - \text{existing Infrastructure} \quad (8)$$

Or specifically, the current sensitivity index is given by:

$$Current\ Sensitivity = \left(\frac{S5 + S6 + S7 + S8 + S9}{5} + \frac{S10 + S11 + S12 + S13}{4} + (1 - \frac{S1 + S2 + S3 + S4}{4})\right)/3 \quad (9)$$

Since the subcomponent of natural resources is the one that assesses the climate change scenarios and their potential impacts, a sub-index for each of the two applied scenarios was built. As shown in formula (9), to build the base scenario, variables were used without climate change scenarios (S1 ... S13). To estimate the change in current sensitivity when considering climate change scenarios the same formula was used (9) but including the expected changes on natural resources, as shown below:

$$Future\ Sensitivity_{\ Echam} = \left(\frac{S5 + S6 + S7 + S8 + S9}{5} + \frac{S10 + S14 + S16 + S18}{4} + (1 - \frac{S1 + S2 + S3 + S4}{4})\right)/3 \quad (10)$$

$$Future\ Sensitivity_{\ Hadgem} = \left(\frac{S5 + S6 + S7 + S8 + S9}{5} + \frac{S10 + S15 + S17 + S19}{4} + (1 - \frac{S1 + S2 + S3 + S4}{4})\right)/3 \quad (11)$$

From the above it was possible to compare the current sensitivity (9) with the one estimated by climate change scenarios (10) and (11). The results are presented below.

2.3 Mapping sensitivity to climate change in Mexico

Once the sub-index of sensitivity was built, the value obtained was assigned to each municipality, allowing the hierarchization of the municipal level of sensitivity in the country. The values were divided into quintiles and assigned a qualitative indicator of sensitivity (Table 2):

Sensitivity index	0-20	21-40	41-60	61-80	81-100
Severity of sensitivity	Very low	Low	Moderate	High	Very high

Table 2. Criteria applied for sensitivity in the municipalities of Mexico

Finally, with the information obtained the sub-index and the severity of the sensitivity could be drawn on maps at municipal level.

3. Results and discussion

In this study, the sensitivity was defined as a function of the existing infrastructure, land capacity and natural resources. Sensitivity to climate change is the degree to which the municipalities of Mexico will be affected, or their ability to cope with climate change. The results are presented in that order, the current sensitivity and future sensitivity which included climate change scenarios.

3.1 Current sensitivity

The infrastructure sub-index reflects the total amount of production equipment, in terms of the total number of greenhouses, irrigation systems, machinery and producers viewpoint as to whether the infrastructure is enough, for each municipality. The five municipalities with less infrastructure reported are: Xocchel and Opichén (Yucatán), San Gabriel Mixtepec and Santa Catarina Tayata (Oaxaca) and Sochiapa (Veracruz). All of them did not report having greenhouses and have only one machine or none for the entire municipality. The existing irrigation systems are less than twenty or even none in Sochiapa. It is reported that in more than 80% of the production units there is insufficient infrastructure. This shows the lack of infrastructure facilities and therefore a greater sensitivity to climate phenomena. On the other hand, the five municipalities that reported better infrastructure´s are Villa Guerrero, Ixtlahuaca (Mexico), Nuevo Ideal (Durango), Cuauhtémoc (Chihuahua) and Mexicali (Baja California). The first two are those who reported more greenhouses and irrigation systems. The amount of machinery for agricultural work is more than a thousand units per municipality, only in Ixtlahuaca was reported less than 100. Table 3 summarizes the main results for each component of the index.

Land capacity assesses the current condition of the land, as to whether or not this presents some degree of degradation, such as salinity, erosion, pollution, loss of fertility or if vegetation is absent on its surface. The five municipalities with further degradation in their land are: Ensenada (Baja California), Ocampo (Coahuila), Camargo (Chihuahua) and Ahome and Navolato (Sinaloa). Although these municipalities did not report having significant losses due to lack of fertility, they reported problems of salinity and erosion. In the case of Ensenada, for example, is the one that reports the largest surface without vegetation and with pollution problems on their land. On the other hand, the five municipalities that did not report problems on their land are Chicxulub (Yucatan) and San Juan Atepec, Santa Catarina Zapoquila, Santa Maria Ixcatlán and Santos Reyes Pápalo in Oaxaca.

The natural resources group represents the degree of suitability of land production (agriculture, livestock and forestry) and the percentage of municipal area devoted to these primary economic activities. The municipalities that have greater sensitivity are Pocitlán (Jalisco), San Agustin de las Juntas and San Francisco del Mar in Oaxaca as well as Ixmatlahuacán (Veracruz), since almost its entire surface are devoted to primary activities (municipalities of Oaxaca with a 97%) mainly agriculture. On the contrary, the municipalities with less sensitivity because of their natural resources productivity potential are: Cuajimalpa (DF), Empalme (Sonora), Telchac Puerto (Yucatan), Ciudad Madero (Tamaulipas) and Zoquitlan (Puebla). This happens because these municipalities do not rely solely on farming and do not have some degree of suitability for farming, livestock or forestry.

The current sensitivity index was obtained by integrating the results of the three previous subindexes in formula (9). Figure 1 shows the behaviour of the three components and their participation in this index. It is possible to observe how two subindixes reflect the behaviour of the current sensitivity in the municipalities. In the infrastructure variable, the greater the amount of existing infrastructure the lower the sensitivity; on the contrary, the fewer infrastructure the greater the result of its sensitivity. With regard to the natural resources variable, the lower (or absence) the agricultural suitability, the lower sensitivity, and the greater the suitability the greater the sensitivity obtained.

STATE	MUNICIPALITY	S1	S2	S3	S4		Infraestructure Index	
Yucatán	Xocchel	0	8	11	0		2.88	Less existing infrastructure, more sensitive
Oaxaca	San Gabriel Mixtepec	0	11	11	1		2.87	
Veracruz	Sochiapa	0	0	13	0		2.84	
Oaxaca	Santa Catarina Tayata	0	16	17	1		2.75	
Yucatán	Opichén	0	18	20	1		2.68	
Baja California	Mexicali	12	4847	97	929		-2.75	More existing infrastructure, less sensitive
México	Ixtlahuaca	103	11403	94	65		-3.88	
Chihuahua	Cuauhtémoc	27	1182	82	2356		-4.10	
Durango	Nuevo Ideal	5	788	89	3484		-6.32	
México	Villa Guerrero	1857	3288	82	1022		-12.56	
		S5	S6	S7	S8	S9	Land capacity Index	
Baja California	Ensenada	9	3280	2093	197879	2263	14.54	Less land capacity, more sensitive
Coahuila	Ocampo	5	6314	11649	40216	0	7.40	
Chihuahua	Camargo	7	34	11194	69037	0	6.37	
Sinaloa	Ahome	11	22223	310	84	2	6.08	
Sinaloa	Navolato	23	20922	468	15627	1	6.37	
Oaxaca	San Juan Atepec	0	0	0	0	0	-0.30	Greater land capacity, less sensitive
Oaxaca	Santa Catarina Zapoquila	0	0	0	0	0	-0.30	
Oaxaca	Santa María Ixcatlán	0	0	0	0	0	-0.30	
Oaxaca	Santos Reyes Pápalo	0	0	0	0	0	-0.30	
Yucatán	Chicxulub Pueblo	0	0	0	0	0	-0.30	
		S10	S11	S12	S13		Natural Resources Index	
Veracruz	Ixmatlahuacan	62	4	10	4		1.72	Greater dependence and greater agricultural suitability, more sensitive
Jalisco	Poncitlán	74	4	9	4		1.66	
Oaxaca	San Francisco del Mar	97	4	10	2		1.37	
Oaxaca	San Agustín de las Juntas	97	4	6	4		1.33	
Distrito Federal	Cuajimalpa de Morelos	44	1	2	2		-1.39	Less dependence and less agricultural suitability, less sensitive
Sonora	Empalme	41	1	4	1		-1.40	
Yucatán	Telchac Puerto	20	0	4	2		-1.45	
Tamaulipas	Ciudad Madero	0	4	3	1		-1.54	
Puebla	Zoquitlán	26	1	4	1		-1.58	

Table 3. Municipalities of Mexico with greater sensitivity according to sub-index of infrastructure, land capacity and natural resources

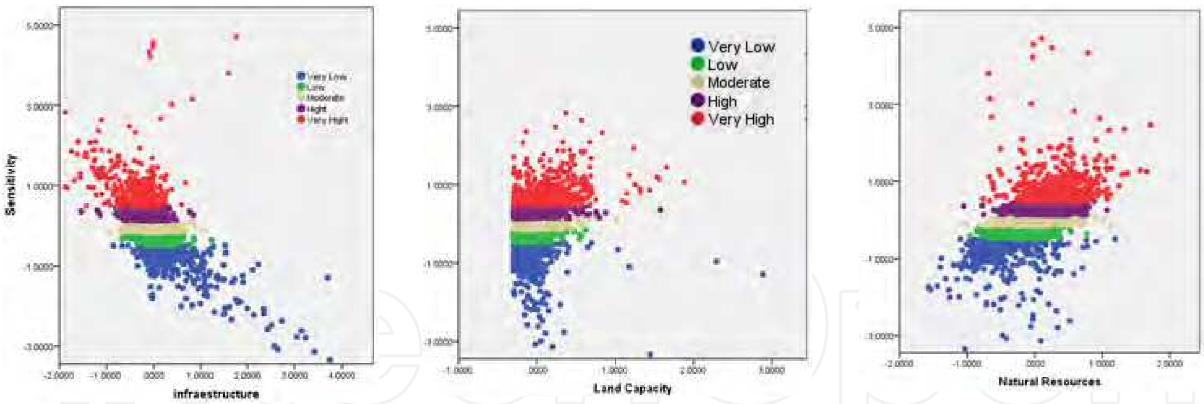


Fig. 1. Distribution of the participation of infrastructure, land capacity and natural resources in the current sensitivity index.

The index then represents the sensitivity observed in the municipalities and was classified into five groups according to their severity: very high, high, moderate, low and very low sensitivity. The obtained results for the sensitivity index present a minimum value of -4.19 (very low sensitivity) and a maximum of 4.6 (very high sensitivity) with a separation range of 8.78. The index distribution is shown in Figure 2 and their spatial distribution for the country in Figure 3.

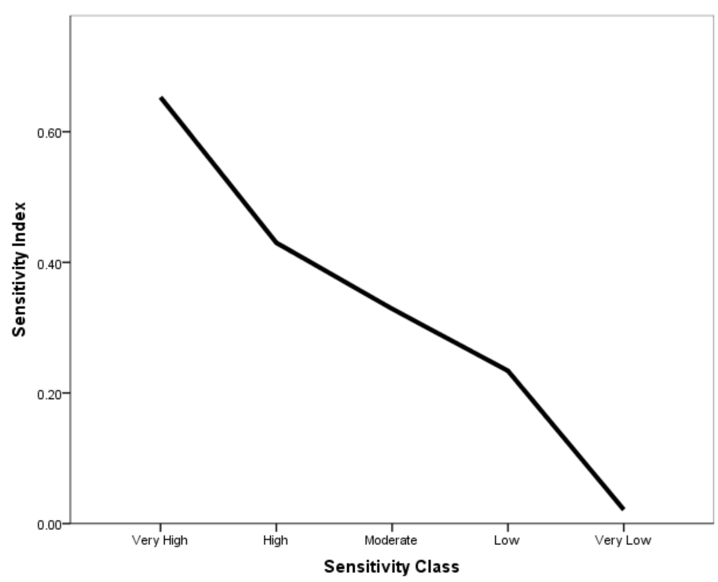


Fig. 2. Current sensitivity index and class grouping.

The municipalities with the highest sensitivity index, or those more sensitive, are concentrated in the northern part of the country and are Ensenada (Baja California), Ocampo (Coahuila), San Nicolas Tolentino (San Luis Potosi), Camargo (Chihuahua), Navolato (Sinaloa), Manuel Benavides (Chihuahua), Sahuaripa and Divisadero (Sonora). The municipality identified as the most sensitive of the country is Ensenada (with an index value of 4.6), in Baja California. Although the agricultural production units in the municipality report that there are greenhouses (80), irrigation systems (1137) and machinery (191), problems of soil degradation were also reported, with over 3000 hectares with salinity problems, 2000 hectares with erosion and the same number of hectares contaminated, besides reporting more than 190 000 hectares without apparent vegetation. The problem of soil degradation is what best explains the sensitivity of the municipality, since existing infrastructure and some degree of suitability was found for agricultural productivity. In addition, the municipality uses over 30% of its surface to primary economic activities, being a municipality that is not solely dependent on the agricultural sector.

On the other hand, municipalities with the lowest sensitivity index, or those less sensitive are Tenancingo (Mexico), Guerrero (Chihuahua), Durango (Durango), Fresnillo (Zacatecas), Mexicali (Baja California), Ixtlahuaca (Mexico), Cuauhtemoc (Chihuahua), Nuevo Ideal (Durango) and Villa Guerrero (Mexico). The municipality found as the least sensitive of the country is Villa Guerrero (with an index value of -4.19) in the state of Mexico. This municipality is characterized for having insufficient existing infrastructure and very little degradation of soils, which explains the behaviour of being the least sensitive. Natural resources are productive and well suitable for agriculture but only 44% of its area is devoted to primary economic activities.

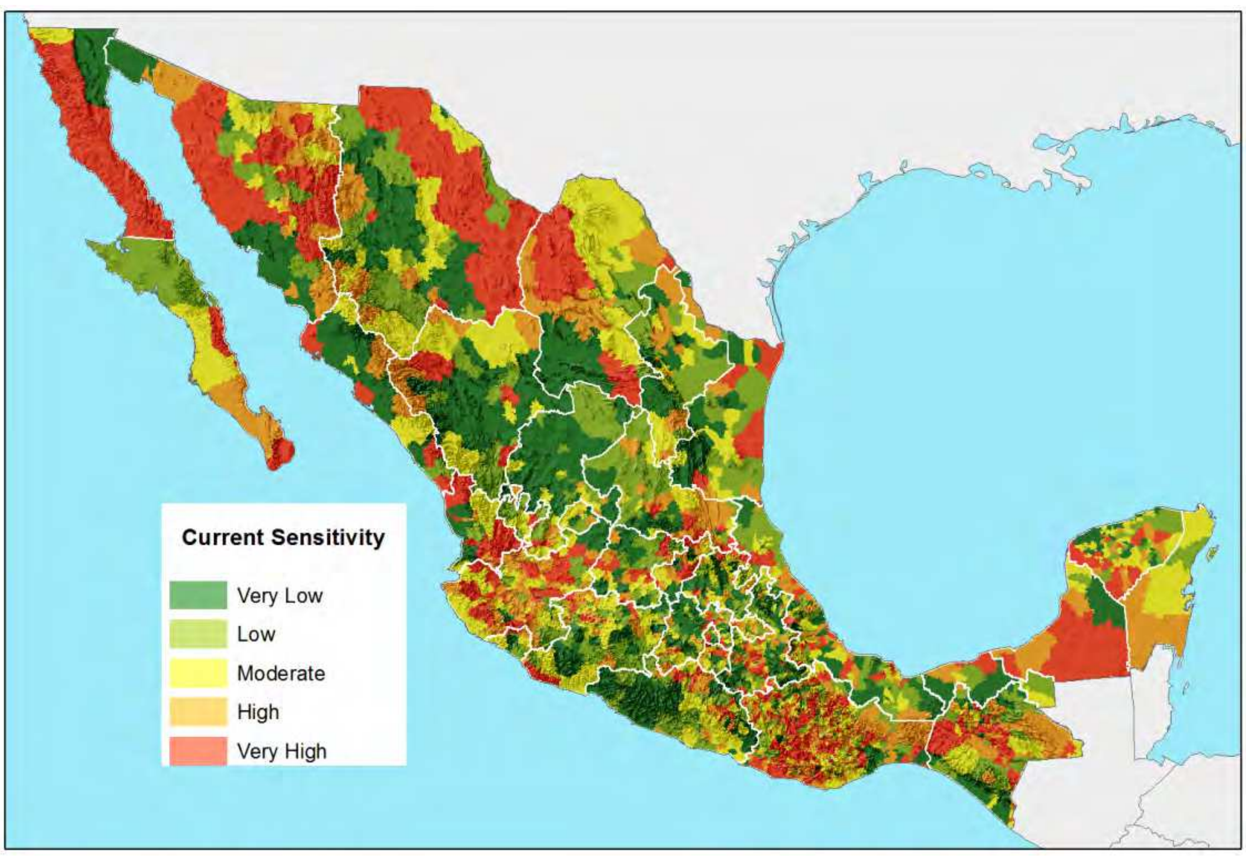


Fig. 3. Current spatial distribution of the sensitivity index in Mexico.

3.2 Sensitivity to climate change

To assess the future sensitivity under climate change scenarios only the possible impacts on the agricultural, livestock and forestry suitability in the country were used, within the natural resources group. Existing infrastructure and land capacity were not modelled with climate change scenarios. So that formulas (10) and (11) described above were applied to obtain the same number of sensitivity indexes to climate change.

Table 4 and Table 5 show the obtained results for the sensitivity index as reported by the scenarios Hadgem and Echam. It was found that according to both models the five most sensitive municipalities continue to be Ensenada, Ocampo, San Nicolas Tolentino, Camargo and Sahuaripa. However, the severity of the sensitivity will be higher when presenting higher values in future indexes. This can be explained by analyzing the potential of change in land suitability. Land suitability was assessed by the authors for agricultural activities (Monterroso et al., 2011a), livestock (Monterroso et al., 2011b) and forests (Gómez et al., 2011). Land suitability refers to the climate and soils potential to develop a productive activity, in this case, agriculture, livestock and /or forestry. When the outputs of these climate change scenarios are incorporated they indicate that, in general for the country, temperature will increase, and precipitation will increase in some areas and will decrease in others. This behavior of the climatic variables will modify the future capacity of the land, so in those places where temperature is expected to raise and rainfall to lower they will be more limited to produce food, therefore, are more sensitive.

State	Municipality	Infraes-tructure (current)	Land Capacity (current)	Natural Resources (current)	Natural Resources (Echam)	Current Sensitivity Index	Future Sensitivity Index (Echam)
More sensitivity:							
Baja California	Ensenada	-0.05	14.54	-0.73	-0.30	4.59	4.73
Coahuila	Ocampo	1.22	7.40	-0.19	-0.14	2.81	2.83
San Luis Potosí	San Nicolás Tolentino	0.99	5.39	0.40	0.51	2.26	2.30
Chihuahua	Camargo	0.31	6.37	-0.04	0.03	2.21	2.23
Sonora	Sahuaripa	1.02	4.20	0.26	0.52	1.82	1.91
Less sensitivity:							
Nayarit	Santiago Ixcuintla	-2.14	0.01	0.52	-0.22	-0.54	-0.78
Mexico	Ixtlahuaca	-3.88	0.01	0.24	0.93	-1.21	-0.98
Chihuahua	Cuauhtemoc	-4.10	0.23	-0.65	-0.02	-1.51	-1.30
Durango	Nuevo Ideal	-6.32	-0.06	0.23	0.34	-2.05	-2.01
Mexico	Villa Guerrero	-12.56	0.04	-0.05	0.26	-4.19	-4.09

Table 4. Municipalities of Mexico with future major and minor sensitivity to climate change according to the Echam model.

However, although the most sensitive municipalities in the current scenario will remain the same in the future, the vast majority of municipalities will see a change in their sensitivity. To show the above, Table 6 is presented in which the current sensitivity scenario is compared with the two future sensitivity indexes applied. In the columns is the current sensitivity index, while in the rows are the kinds of sensitivity for each model. In the main diagonal and in italics is the total number of municipalities that will not change their sensitivity when incorporating climate change scenarios is shown. Below the main diagonal are all the municipalities that increase their sensitivity when including climate change scenarios. Above the diagonal are all the municipalities that reduce their sensitivity.
In the current scenario, moderate class municipalities to very low add up 1473 from a total of 2454 municipalities reported for Mexico, which means 60%. 981 municipalities are

sensitive under current conditions, in other words, 40% of the municipalities in Mexico are in the high and very high classes. According to the model Echam, a total of 1100 municipalities (44%) will remain with the current sensitivity level, 686 will observe an increase (29%) and 668 (27%) will decrease its sensitivity. What the model Hadgem indicates is a very similar behavior, since 1054 municipalities (43%) will remain under current conditions, 707 (29%) will increase and 693 (28%) will decrease its sensitivity. The spatial distribution of the indexes under future conditions of climate change is presented in Figure 4.

State	**Municipality**	**Infraes-tructure (current)**	**Land Capacity (current)**	**Natural Resources (current)**	**Natural Resources (Hadgem)**	**Current Sensitivity Index**	**Future Sensi-tivity Index (Hadgem)**
More sensitivity:							
Baja California	Ensenada	-0.05	14.54	-0.73	-0.37	4.59	4.70
Coahuila	Ocampo	1.22	7.40	-0.19	0.17	2.81	2.93
San Luis Potosi	San Nicolas Tolentino	0.99	5.39	0.40	0.52	2.26	2.30
Chihuahua	Camargo	0.31	6.37	-0.04	0.19	2.21	2.29
Sonora	Sahuaripa	1.02	4.20	0.26	0.75	1.82	1.99
Less sensitivity:							
Mexico	Tenancingo	-2.23	0.11	0.34	-0.12	-0.60	-0.75
Mexico	Ixtlahuaca	-3.88	0.01	0.24	0.16	-1.21	-1.24
Chihuahua	Cuauhtemoc	-4.10	0.23	-0.65	-0.64	-1.51	-1.50
Durango	Nuevo Ideal	-6.32	-0.06	0.23	0.34	-2.05	-2.01
Mexico	Villa Guerrero	-12.56	0.04	-0.05	-0.30	-4.19	-4.27

Table 5. Municipalities of Mexico with future major and minor sensitivity to climate change according to the Hadgem model.

Future Sensitivity		Current Sensitivity*				
		Very Low	Low	Moderate	High	Very High
Echam	Very Low	277 (56)	120 (24)	63 (13)	23 (5)	8 (2)
	Low	131 (27)	175 (36)	109 (22)	54 (11)	22 (5)
	Moderate	53 (11)	130 (26)	154 (32)	111 (23)	43 (9)
	High	18 (4)	53 (11)	113 (23)	192 (39)	115 (24)
	Very High	11 (2)	14 (3)	52 (11)	111 (23)	302 (61)
Hadgem	Very Low	279 (57)	115 (23)	67 (14)	24 (5)	6 (1)
	Low	129 (26)	165 (33)	123 (25)	53 (10)	21 (4)
	Moderate	60 (12)	126 (25)	126 (25)	130 (26)	48 (10)
	High	13 (3)	67 (14)	131 (26)	175 (35)	106 (21)
	Very High	9 (2)	19 (4)	44 (9)	109 (22)	309 (63)

* In parentheses the percentage that represents the total of the municipalities within each class is shown.

Table 6. Total municipalities by sensitivity class compared with future scenarios.

The existing infrastructure is an indicator that lowers the final weight of the sensitivity. The greater the amount of existing infrastructure for the agricultural activity, the lower its sensitivity. In an early analysis, this would suggest increasing the infrastructure with the aim of reducing future sensitivity to climate change. However, this would be wrong since other variables should be also considered. According to the results found, the infrastructure variable is not the biggest problem of sensitivity in Mexico, but it helps to reduce climatic stress. Figure 4 presents a simulation where the three variables are maximized hipothetically: infrastructure, land capacity and natural resources. If all the municipalities in the country would have the highest infrastructure reported, the sensitivity index would drop to the low sensitivity class (red line). This shows how important the infrastructure is in our sensitivity index.

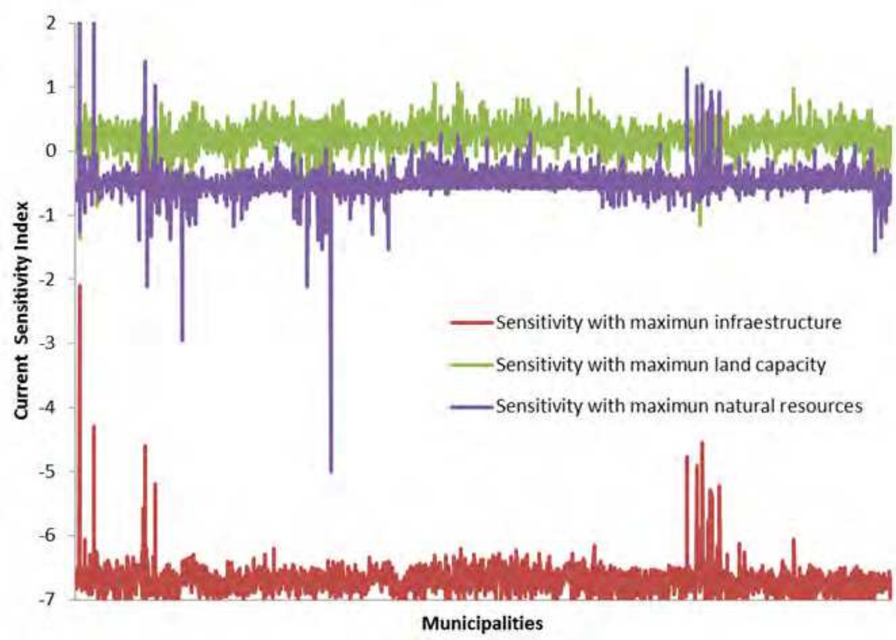


Fig. 4. Sensitivity index with hypothetical maximum data.

However, under these hypothetical conditions, some municipalities in the country continue to show sensitivity, shown as peaks in Figure 4. So it is worth analysing the other two variables. Land capacity variable represents higher values in the index (green line) and therefore determines to a large extent the current and future sensitivity, this is the variable that integrates the degree of degradation of soils, or the amount of problems in the agricultural production units. Even under hypothetical conditions this variable always remains positive. The third variable, natural resources (blue line) were the elements assessed under climate change scenarios and are those that show some degree of future impact of climate change. Municipalities that increase their sensitivity can be observed, while others lower it, under the assumption of presenting the best values of agricultural potential and natural resources.

Sensitivity in this work evaluates the degree of stress in the system. A system close to its sensitive limits will suffer more damage for climate change. In this case, the municipalities of Mexico are sensitive to climate change impacts on natural resources. The possible changes on temperature and precipitation suppose that the future suitability for agriculture will be affected. The production capacity of the land in Mexico has been diminished already, mainly by soil degradation. This is seen in our index, which for the current scenario presented values that increased sensitivity. In summary, currently the country's municipalities are already sensitive and this sensitivity increases by incorporating climate change scenarios.

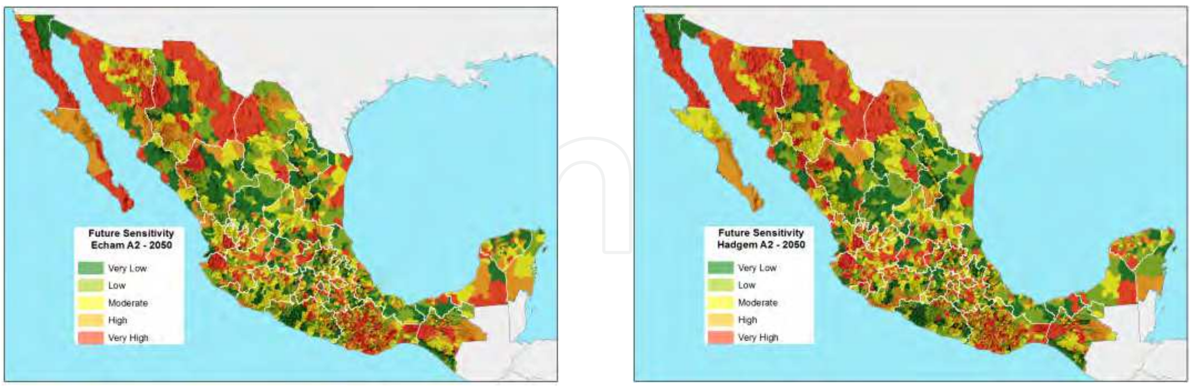


Fig. 5. Spatial distribution of sensitivity under future climate change scenarios.

The magnitude of the sensitivity, as the extent to which a system is affected in its current form, by climate change or variability is manifested in the municipalities of Mexico differently. Some regions are more sensitive than others. This can be attributed to several factors, among which the dependence of municipalities to primary activities stand out (agricultural production, livestock and forestry). Of all the municipalities, 1528 (62%) dedicate over 60% of their surface to such activities, and 16% (411 municipalities) dedicates over 90% of their surface to the primary sector. If the amount of existing irrigation systems is added to the 60% of the municipalities of Mexico the result will be 100 irrigation systems or less. This reflects that the primary activity keeps being very important in Mexico and that it is also dependent on the natural climatic conditions to take place. Hence, this is a sensitive group to any future changes in climate.

The sensitivity is a component of vulnerability, it is the internal element that allows its characterization. The sensitivity, together with the exposure, determines the potential impact of climate change, without considering adaptation. Therefore it is important to continue studies in Mexico on vulnerability, but which includes exposure and adaptive capacity. Moreover, it is also important to work with the uncertainty of working with models of future climate change. Currently, only 817 municipalities (33%) have some degree of suitability for agricultural production, the rest (67%) carries out agricultural activities but under marginal conditions, requiring higher production inputs. From the climate change scenarios, Echam model suggests there will be 811 (33%) and the Hadgem model 766 (31%) municipalities that will show some degree of future suitability to continue doing agriculture. This uncertainty in the models should also be considered when making decisions.

This study shows the kind of sensitivity and where this sensitivity takes place. However, further more detailed studies at local level must be carried out to promote adaptation measures. Decision makers in the country must decide where to apply economic resources and implement actions, so that a practical use of this work is to assist in making decisions using criteria that consider climate change.

4. Conclusion

This study contributes to the sensitivity analysis, an element of vulnerability, in Mexico. Much of the literature reports this type of studies within a broader context of vulnerability analysis,

but rarely is this studied independently. In Mexico, studies on vulnerability have come into existence only recently, but none has been addressed at a national and municipal level.
The sensitivity of the municipalities of Mexico was evaluated under current conditions and considering climate change scenarios. For this purpose, a current sensitivity index was built and two more that show future scenarios of climate change. To calculate the indexes a simple linear formula was used, so it was possible to combine the variables studied. By applying the indexes, it was possible to characterize the current and future sensitivity of the municipalities of Mexico, based on indicators that assessed the potential impact of climate change, including the potential change in the agricultural, livestock and forestry suitability in the country.
The results showed that the municipalities in Mexico are sensitive even without considering climate change. When climate change scenarios are included the future sensitivity increases. Contrary to what was expected, the existing infrastructure is not the variable that better explains the current and future sensitivity. According to the results, it would be inappropriate to suggest the extension of agricultural buildings in order to decrease the sensitivity of the municipalities. The production capacity of the land is the variable that best helps explain the current and future sensitivity. However, the level of current land degradation presents high values and determines to a greater extent the agricultural potential of the municipalities of Mexico. Therefore, it is essential to promote soil improvement and conservation activities, to reduce to some degree the future sensitivity to climate change. Currently the most sensitive regions are the northern states, and under conditions of climate change are expected to remain so. This let us propose that the region must be addressed immediately to be in a better position to face the challenges that climate change poses.
One disadvantage observed is the weight that the infrastructure represents in the model, for which in the future it is recommended to consider more variables in the study of sensitivity in the country.
Considering the previous thing, we believe that it is possible to apply the methodology in other places of the world. It will have to pay attention to the chosen variables and consider the local information as a principal source of information. As we have written it, more indicators of land capacity will allow obtaining better results in a sensitivity analysis. Also, climate change scenarios will have to be according to the targets of the study and preferable downscaled.
It is difficult to assure if the mexican farmers are more or less sensitive that other farmers in the world. First, because in accordance with the results the north zone of the country is more sensitive to climate change that the south region. In this context, the most sensitive region is comparable with the results presented by O'Brien (2004), where the authors evaluated soil aridity and dependence of the monsoon, both related to land capacity. From the agronomic point view, the north region of the country will be more sensitive to climate change. But at the other side, from the economic point view, maybe the south region of the country will be a land of opportunity.

5. References

Berry, P.M., Rounsevell, M.D., Harrison, P.A., Audsley, E. (2006) Assessing the vulnerability of agricultural land use and species to climate change and the role of policy in facilitating adaptation. *Environmental science and policy* 9, 189-204.

Bohle, H.G., Downing, T.E., Watts, M.J. (1994) Climate change and vulnerability: Toward a sociology and geography of food insecurity. *Global Environmental Change* 4, 37-48.

Cuttler, S.L. (1996) Vulnerability to environmental hazards. *Progress in Human Geography*. 20, 529-539.

Downing, T., Patwardham, A., (2006) Technical paper 3: Vulnerability assessment for climate change adaptation., in: Lim, B., Spanger, E. (Eds.), *Adaptation Policy Framework*. United Nations Development Program., New York, USA, p. 251.

Gómez, J.D., Monterroso, A.I., Tinoco, J.A., Toledo, M.L., Conde, C., Gay, C. (2011) Assessing current and potential patterns of 16 forest species driven by climate change scenarios in México. *Atmósfera* 24, 31-52.

INEGI, (2009) *Censo Agrícola, Ganadero y Forestal* 2007, Instituto Nacional de Estadística y Geografía. INEGI, Aguascalientes, México.

IPCC, (1996) Summary for policymakers: Scientific-technical analyses of impacts, adaptations and mitigation of climate change., in: Watson, R., Zinyowera, T., Moss, R. (Eds.), *Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change.* Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

IPCC, (2007) Summary for Policymakers, in: Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J., Hanson, C.E. (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Kelly, P.M., Adger, W.N. (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic change* 47, 325-352.

Klein, R., Nicholls, R. (1999) Assessment of coastal vulnerability to climate change. *Ambio* 28, 182-187.

McCarthy, J., Canziani, O., Leary, N., Dokken, D., White, K. (2001) *Climate Change 2001: Impacts, adaptation and vulnerability.*, Cambridge, UK.

Monterroso, A.I., Conde, C., Rosales, G., Gómez, J.D., Gay, C. (2011a) Assessing current and potential rainfed maize suitability under climate change scenarios in México. *Atmósfera* 24, 53-67.

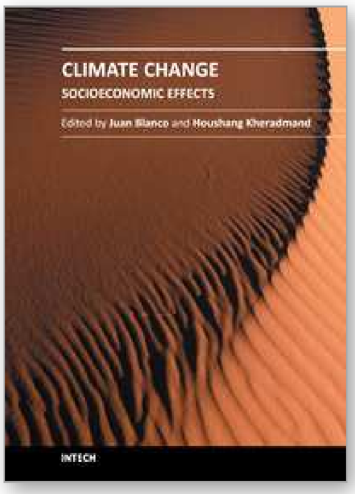
Monterroso, A.I., Gómez, J.D., Toledo, M.L., Tinoco, J.A., Conde, C., Gay, C. (2011b) Simulated dynamics of net primary productivity (NPP) for outdoor livestock feeding coefficients driven by climate change scenarios in México. *Atmósfera* 24, 69-88.

O'Brien, K.L., Leichenko, R.M., Kelkar, U., Venema, H.M., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., West, J. (2004) Mapping vulnerability to multiple stressors: climate change and globalization un India. *Global Environmental Change* 14, 303-313.

Parry, M., Canziani, O., Palutikof, J.P., Coautores (2007) *Resumen técnico. Cambio Climático 2007: Impactos, Adaptación y Vulnerabilidad*. Aportes del Grupo de Trabajo II al Cuarto Informe del Panel Intergubernamental sobre Cambio Climático., Cambridge, U.K.

Smit, B., Burton, I., Klein, R., Wandel, J., (2009) An anatomy of adaptation to climate change and variability, in: Schipper, L., Burton, I. (Eds.), *The Earthscan reader on adaptation to climate change.* The Earthscan Reader, Sterling VA, USA, p. 459.

Smithers, J., Smit, B., (2009) Human adaptation to climatic variability and change., in: Schipper, L., Burton, I. (Eds.), *The Earthscan Reader on Adaptation to climate change.* The EarthscanReader, Sterling VA, USA, p. 459.



Climate Change - Socioeconomic Effects
Edited by Dr Houshan Kheradmand

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This book shows some of the socio-economic impacts of climate change according to different estimates of the current or estimated global warming. A series of scientific and experimental research projects explore the impacts of climate change and browse the techniques to evaluate the related impacts. These 23 chapters provide a good overview of the different changes impacts that already have been detected in several regions of the world. They are part of an introduction to the researches being done around the globe in connection with this topic. However, climate change is not just an academic issue important only to scientists and environmentalists; it also has direct implications on various ecosystems and technologies.

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