Development of a SWAT-based methodology to evaluate, at municipal scale, the vulnerability of the agricultural sector to climate change

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SECRETARÍA DE AGRICULTURA, GANADERÍA, DESARROLLO RURAL, PESCA Y ALIMENTACIÓN

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Background and objective

General Background:

In México, it is expected that climate change will negatively affect the productivity of the agricultural sector, putting food production and security at risk.
(Source: Special Program for Climate Change 2014-2018. National Institute of Ecology and Climate Change)

Accordingly, it is necessary to adapt the agricultural sector to climate change. The vulnerability of the agricultural sector is a useful tool for designing plans for adaptation to climate change.

According to the IPCC, the vulnerability is a function of the adaptive capacity and the magnitude of the impact.

Objective:

The aim of this work was to develop a methodology to assess and map, at the municipal scale, the vulnerability of the agricultural sector to climate change.

Methodology

In order to achieve the stated objective, the following activities were carried out:

Development of the Theoretical framework for assessing, at municipal scale, the vulnerability of the agricultural sector to climate change . The framework included adaptive capacity and impact (Data availability was taken into account).

The theoretically developed framework was applied to 624 municipalities, grouped in eight basins located in the tropical southeastern Mexico. For each municipality and basin, they were carried out the following activities:

1) Characterization of each municipality according to:

a) The agricultural sector including crops and their statistics, use of technology and available infrastructure for production.
b) The socioeconomic aspects including Human and economic development and governance.
c) The natural resources including climate, soil and water.

2) **Development of a synthetic index to evaluate the adaptive capacity (ICA)**; which was made up of five sub-indices: availability and quality of natural resources (NR), level of human (HD), economic (ED), technology (TD) and infrastructure (ID) development and use.

3) **Development of an index to assess the magnitude of the impact on crop productivity (IIP)**; which was evaluated for 13 crops using the SWAT model, under the IPCC greenhouse gases emission scenario A1B, during the years 2012 (baseline), 2030, 2060 and 2090.

4) **Development of a municipal vulnerability index to climate change (IVM)**; which is calculated through a double entry matrix, considering three categories of ICA and IIP. The IVM for each municipality was classified as: extremely vulnerable, very vulnerable, vulnerable, low vulnerable and not vulnerable.

Methodology

Data sources:

The information needed to characterize the agricultural sector and the development of the ICA index, was available via the Internet, on the website of Mexican governmental institutions. This information is reasonably current. Below are listed the main ones:

- Instituto Nacional de Estadística y Geografía (INEGI).
- Servicio de Información Agroalimentaria y Pesquera (SIAP).
- Sistema Nacional de Información Municipal (SNIM).
- Consejo Nacional de Población (CONAPO).
- Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL).
- Comisión Nacional del Agua (CNA).
- Servicio Meteorológico Nacional (SMN).
- Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP).
- Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO).
- Comisión Nacional para el Conocimiento y uso de la Biodiversidad (CONABIO).
- Comisión Nacional Forestal (CONAFOR).
- Comisión Nacional de Áreas Naturales Protegidas (CONANP).
- Asociación Mexicana de Engordadores de Ganado Bovino (AMEG, A.C.).
- Scientific literature.
- Otheres.

The eight waterhseds and 624 municipalities

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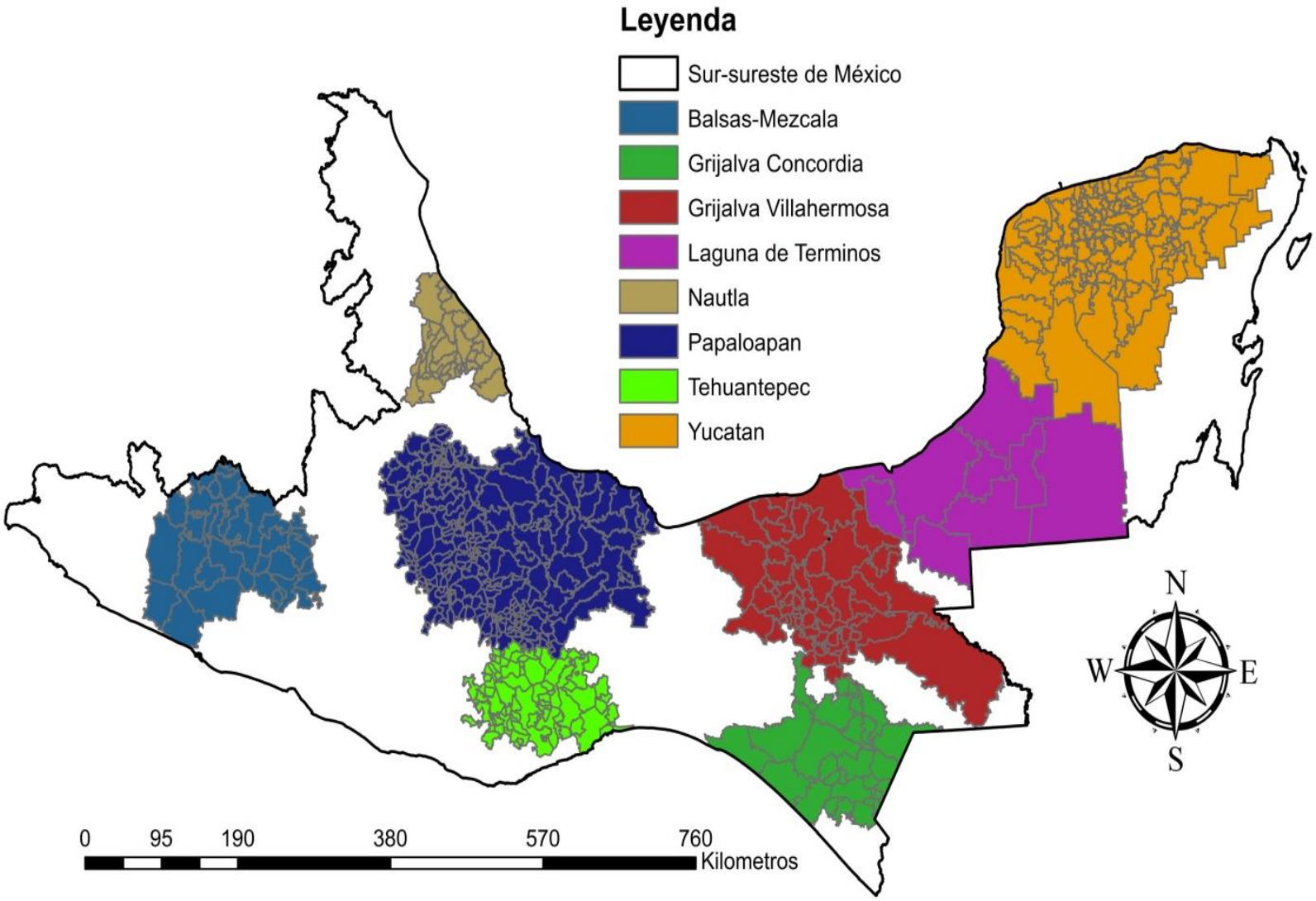
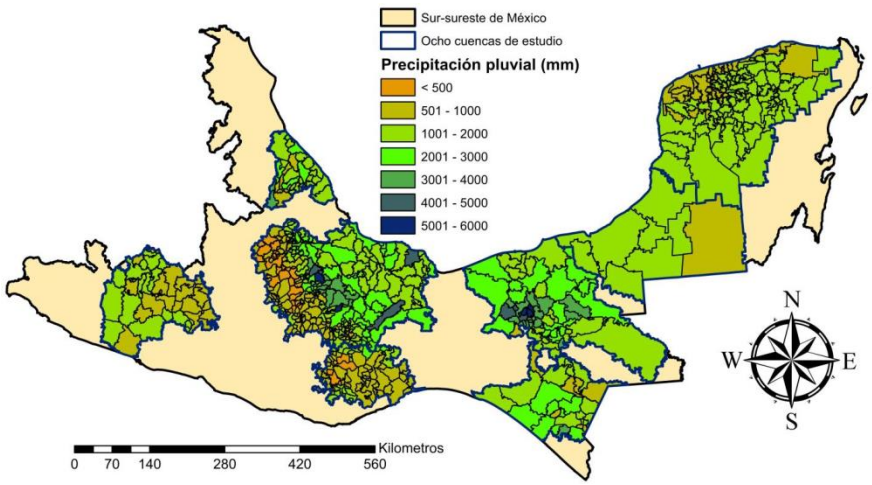
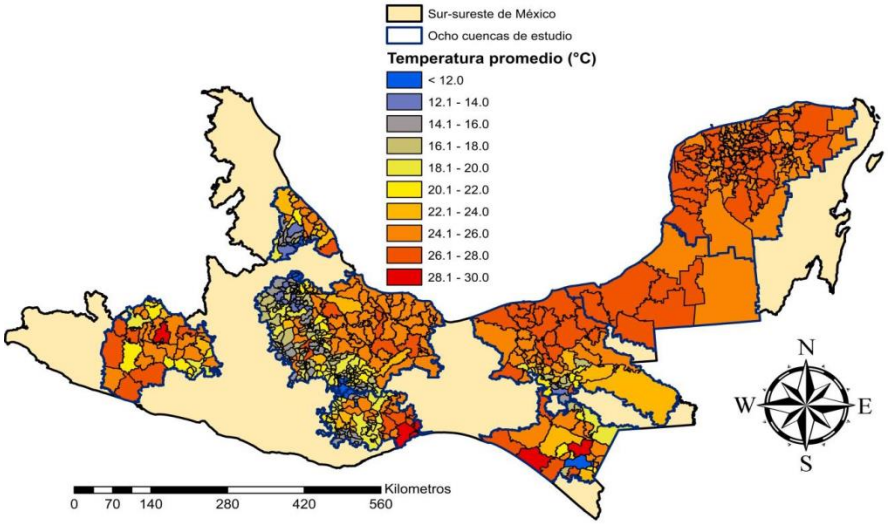


Climate

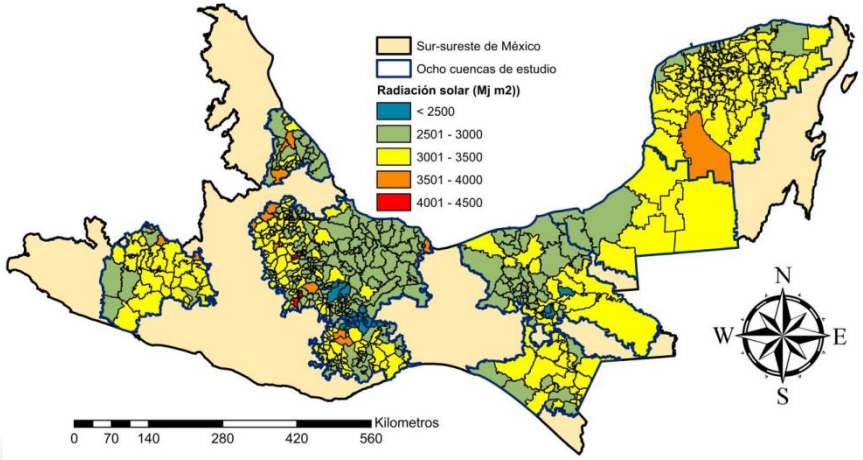
Anual total rainfall



Anual mean Temperature

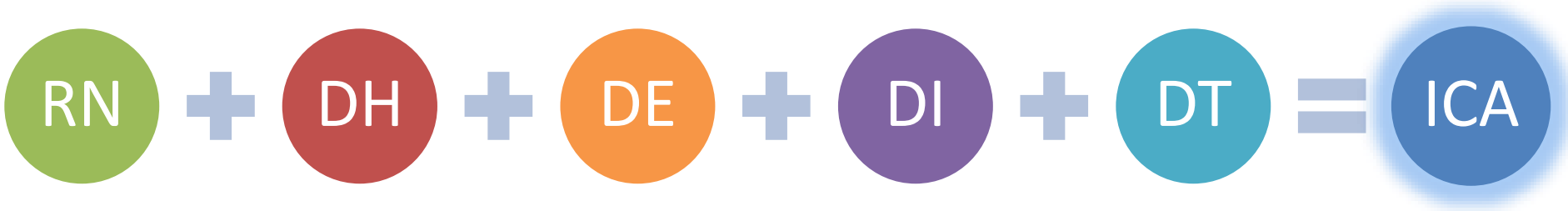


Anual total solar radiation



Methodology

Adaptive Capacity Synthetic Index (ICA)



Where:

RN = Natural Resources: Climate, soil, water.

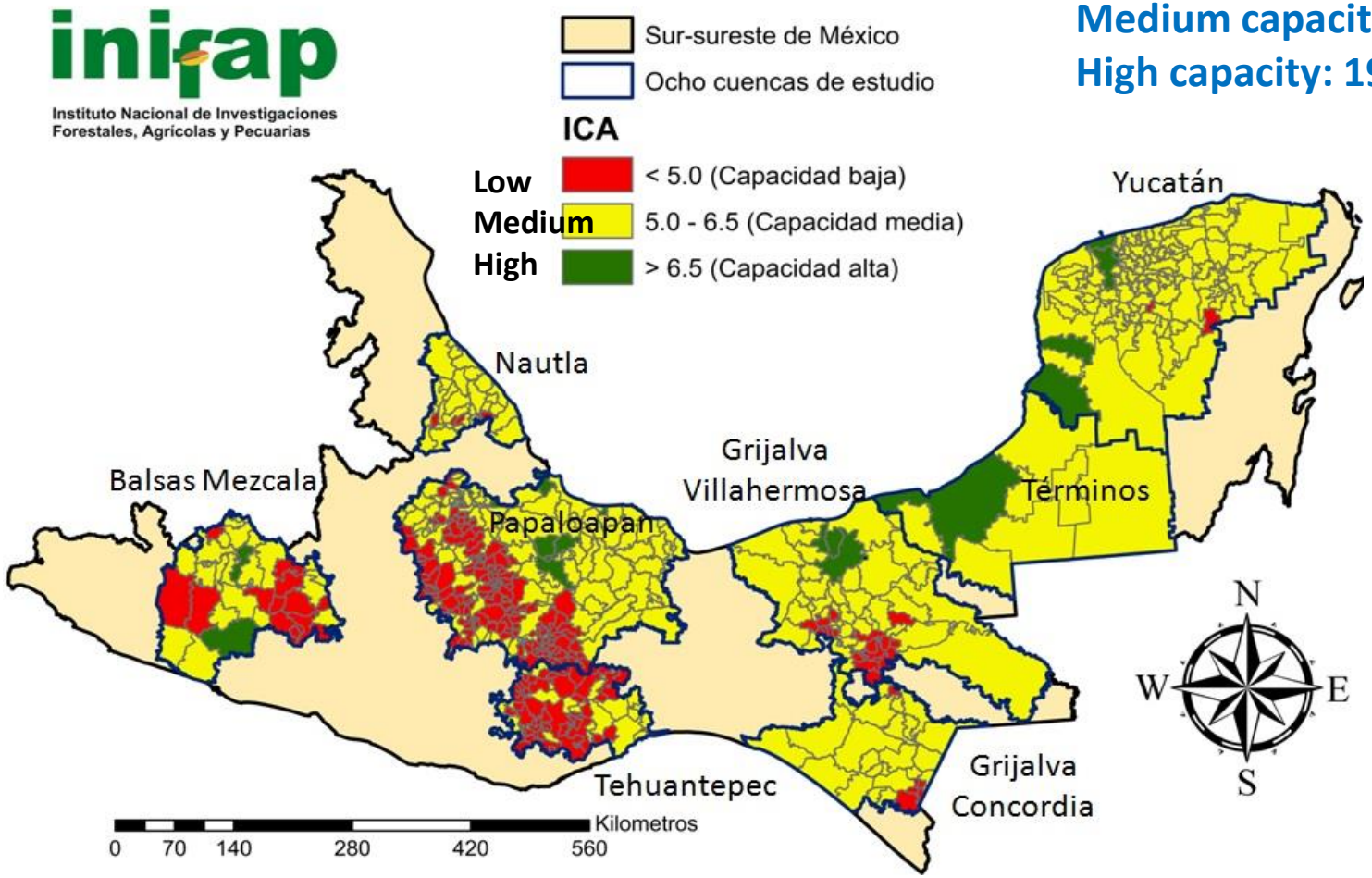
DH = Human Development: Gender equity, age, education.

DE = Economic Development: Gross domestic product, degree of marginalization and poverty rate.

DI = Development of infrastructure: Irrigation, machinery, transport, marketing-trade centers, postharvest equipment, animal husbandry equipment, pens cattle management, sawmills, others.

DT = Use of agricultural technology: irrigation, tillage, improved seeds, fertilization, weed, pest and disease control, Animal health, nutrition, reproduction, genetic improvement, reforested area, forest pest and disease control, fire control, controlled burns, forest thinning, technical assistance.

Results: Adaptive Capacity Index Map (ICA)



Low capacity: 255
Medium capacity: 350
High capacity: 19

Development of the index to assess the magnitude of the impact of climate change on crop productivity (IIP);

Experimental settings:

(8 basins) x (13 crops) x (4 periods) x (10 years as replicates) x (with and without adaptive measures) = 8,320 SWAT runs.

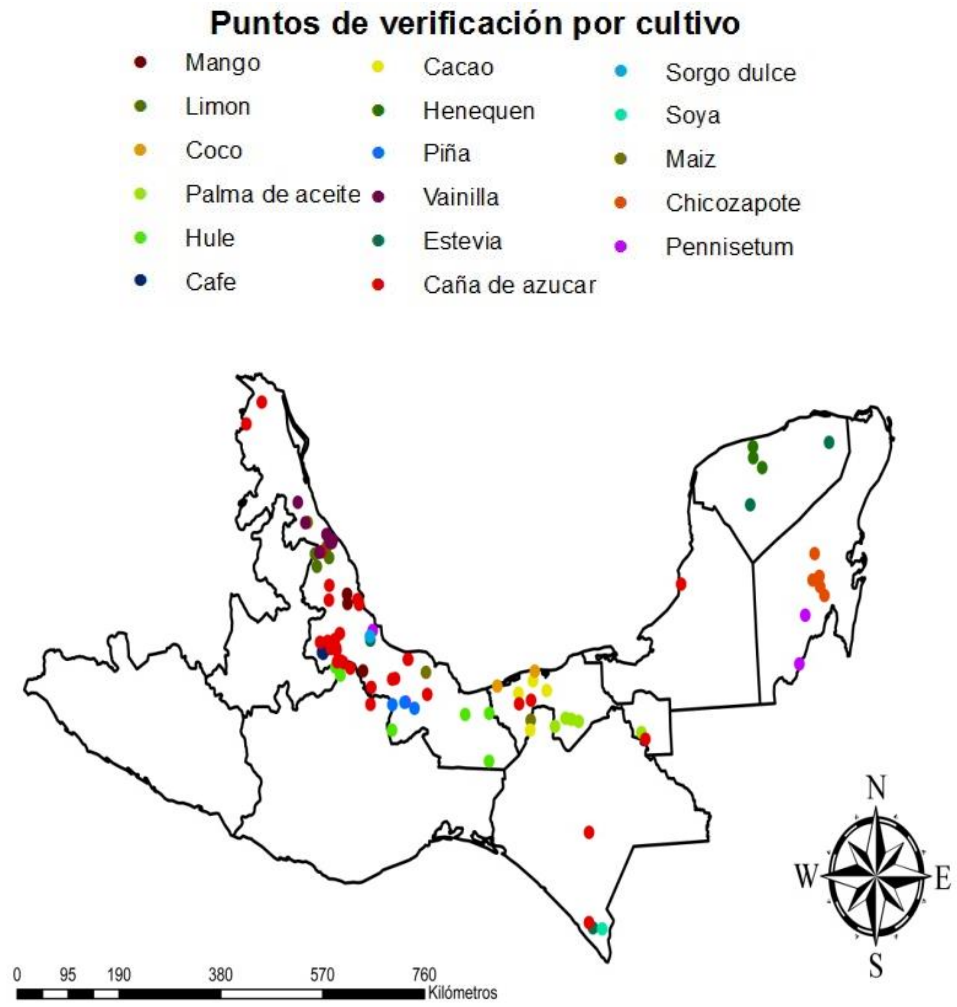
The SWAT model was used to evaluate the IIP for the 13 major crops in each of the 8 watershed: Corn, Dry beans, Rice, Grain sorghum, Sugar cane, Grasses, Lemon, Orange, Cocoa, Coconut, Pineapple, Banana and coffee.

The area occupied by these 13 crops corresponds to 85-95% of the total cultivated area in each of the 8 basins.

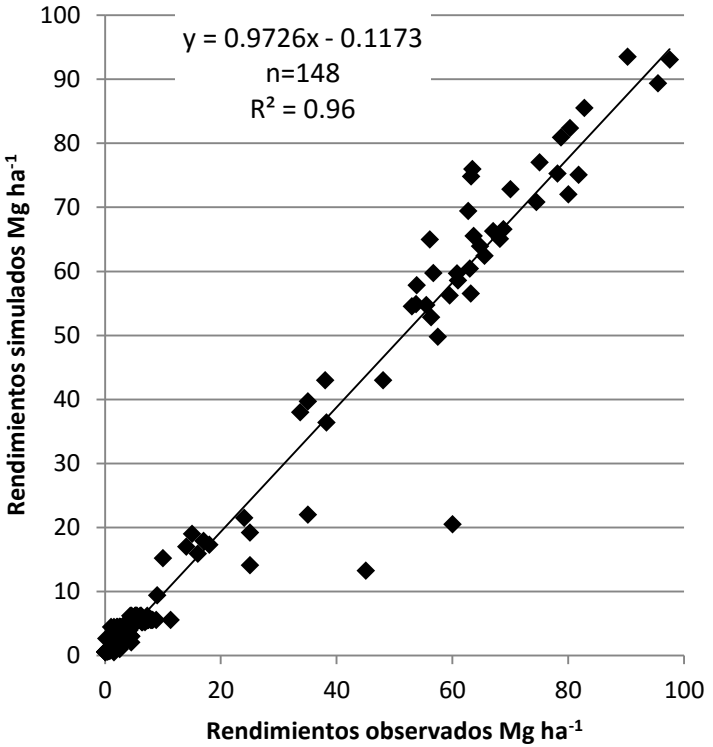
The IPCC A1B greenhouse gases emission scenario was chosen as the most representative for the area, with a 2.7 °C increase in temperatura and 15% reduction of anual rainfall, along four periods: 2012 as the baseline, 2030, 2060 and 2090. For each period 10 years were simulated as replicates.

Two conditions were simulated: with and without adaptive measures. For each crop the adaptive measure was represented by a heat tolerat variety.

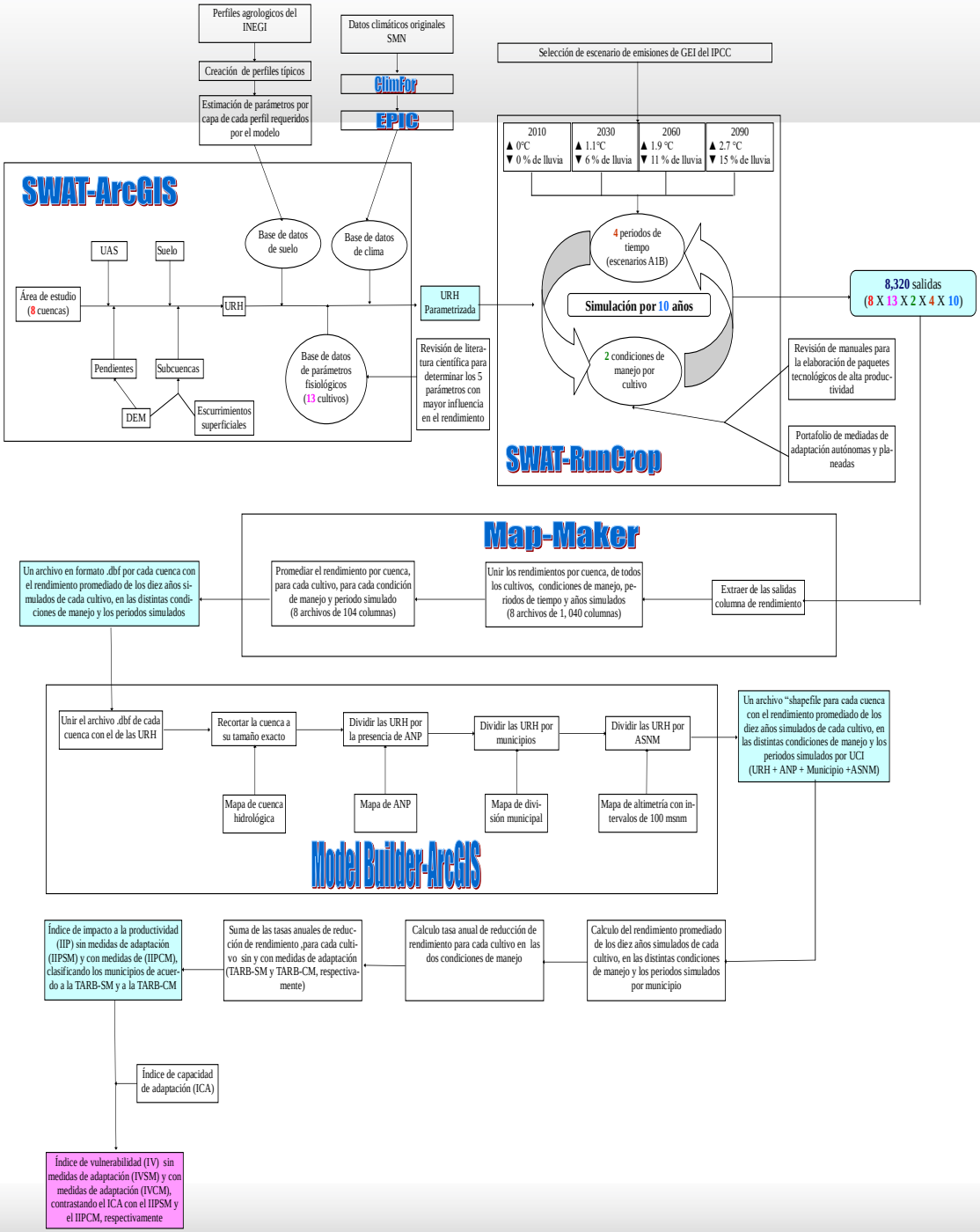
SWAT crop yields validation



Location of 148 points where crop yield as simulated by SWAT, was compared against the counterpart field yield



Statistical comparison of crop yield as simulated by SWAT, against field yield



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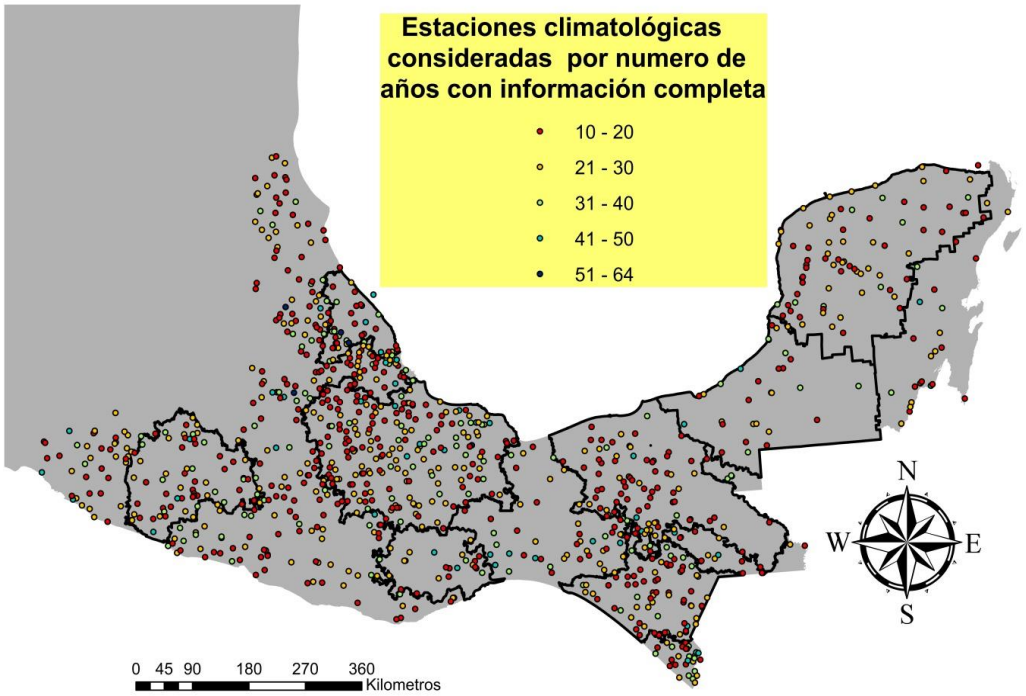
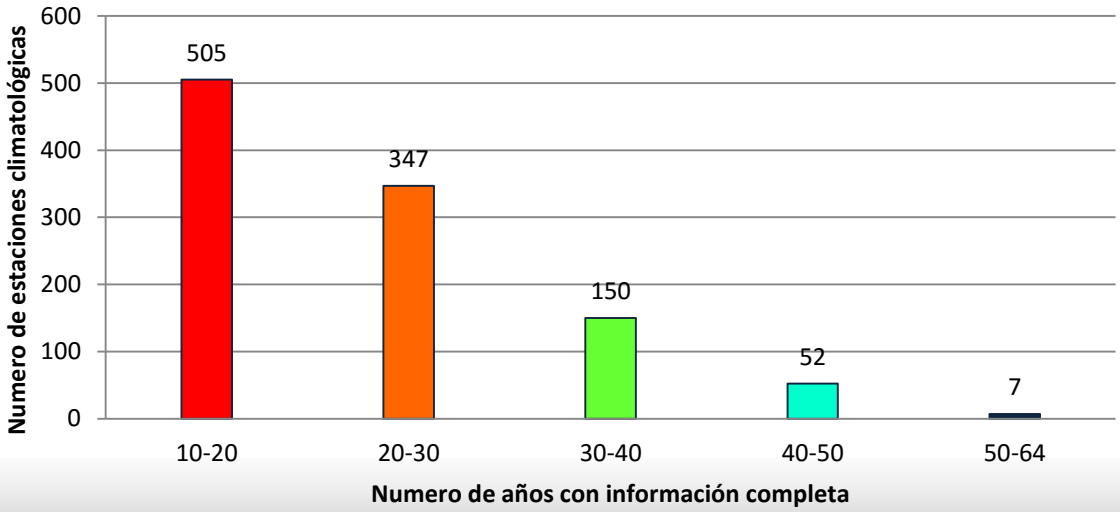
Flow chart of the proccess to simulate impact of climate change on crop yield

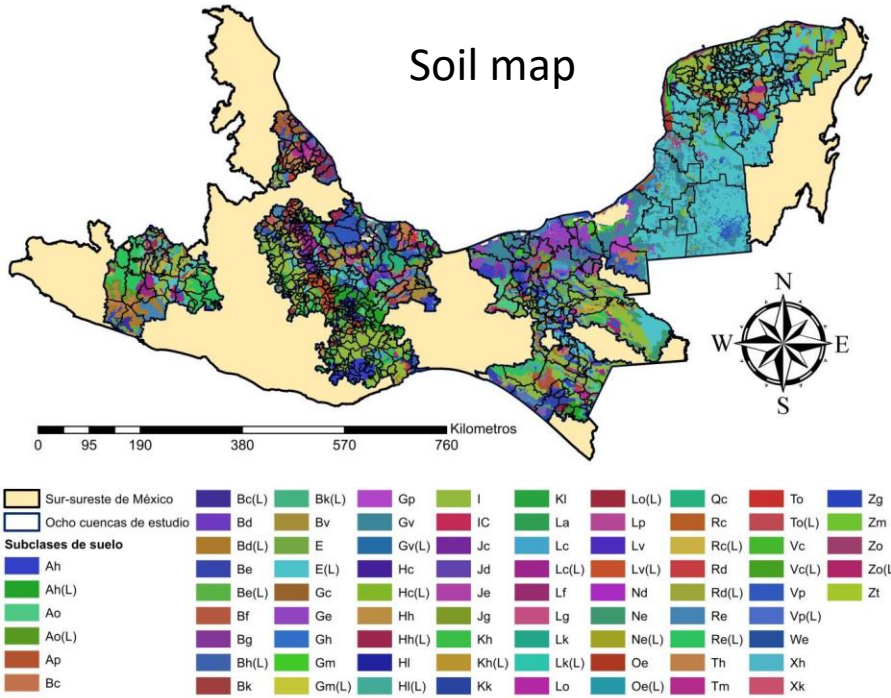
Weather stations



Stations with complete set of data



Soil map

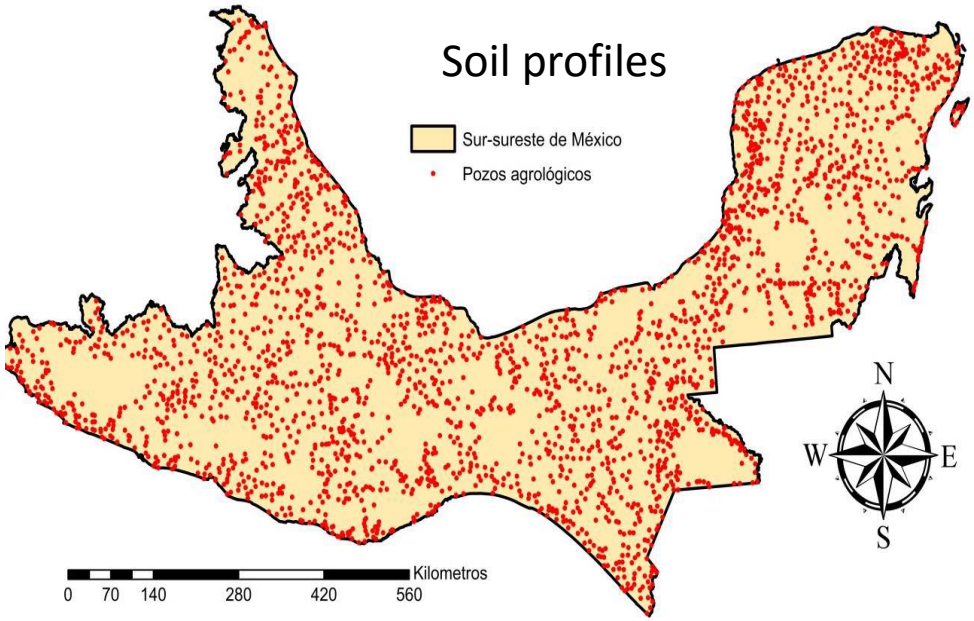


Sur-sureste de México
Ocho cuencas de estudio

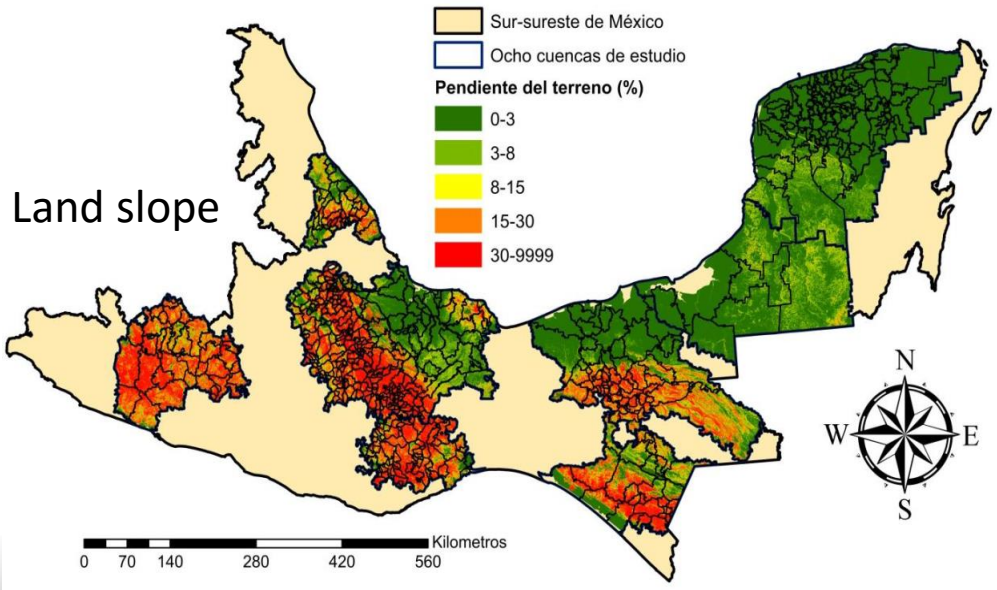
Subclases de suelo

Ah, Ah(L), Ao, Ao(L), Ap, Bc, Bc(L), Bd, Bd(L), Be, Be(L), Bf, Bg, Bh(L), Bk, Bk(L), Bv, E, E(L), Gc, Ge, Gh, Gm, Gm(L), Gp, Gv, Gv(L), Hc, Hc(L), Hh, Hh(L), Hl, Hl(L), I, IC, Jc, Jd, Je, Jg, Kh, Kh(L), Kk, Kl, La, Lc, Lc(L), Lf, Lg, Lk, Lk(L), Lo, Lo(L), Lp, Lv, Lv(L), Nd, Ne, Ne(L), Oe, Oe(L), Qc, Rc, Rc(L), Rd, Rd(L), Re, Re(L), Th, Tm, To, To(L), Vc, Vc(L), Vp, Vp(L), We, Xh, Xk, Zg, Zm, Zo, Zo(L), Zt

Soil profiles

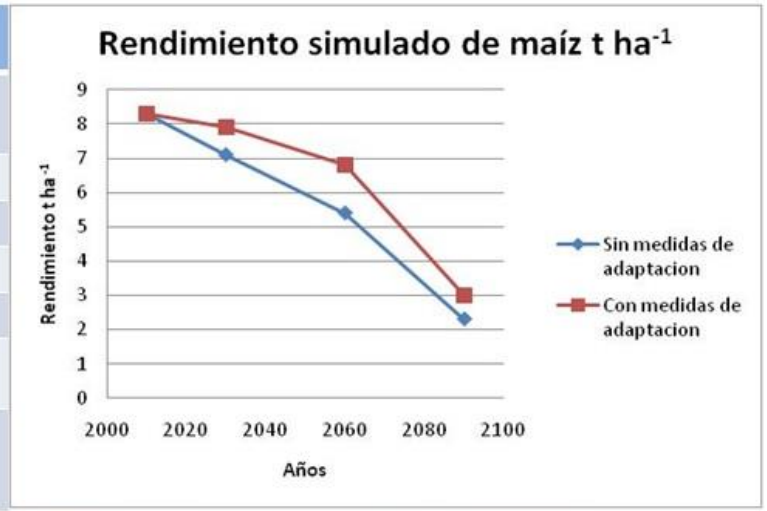


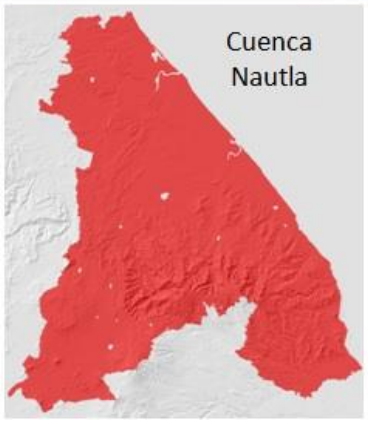
Land slope



Results

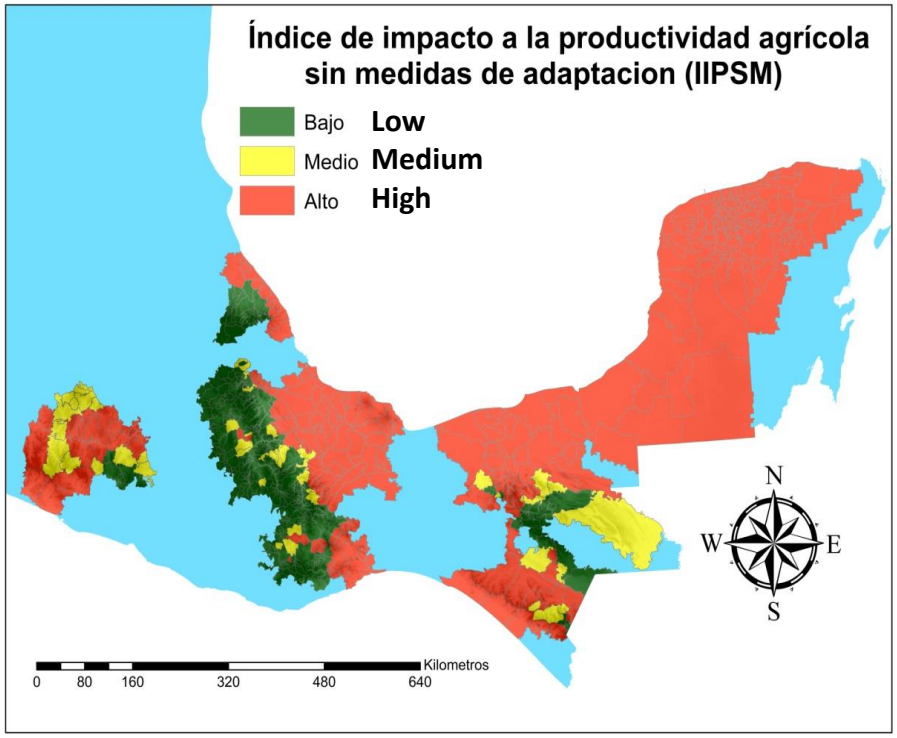
	Rendimiento t ha^{-1} simulado de maíz	
Condiciones climáticas	Sin medidas de adaptación	Con medidas de adaptación
2010	8.3	8.3
2030	7.1	7.9
2060	5.4	6.8
2090	2.3	3
Pendiente de regresión t ha^{-1}	-0.07	-0.06
Reducción de rendimiento kg ha $^{-1}$ año^{-1}	-73.54	-64.49

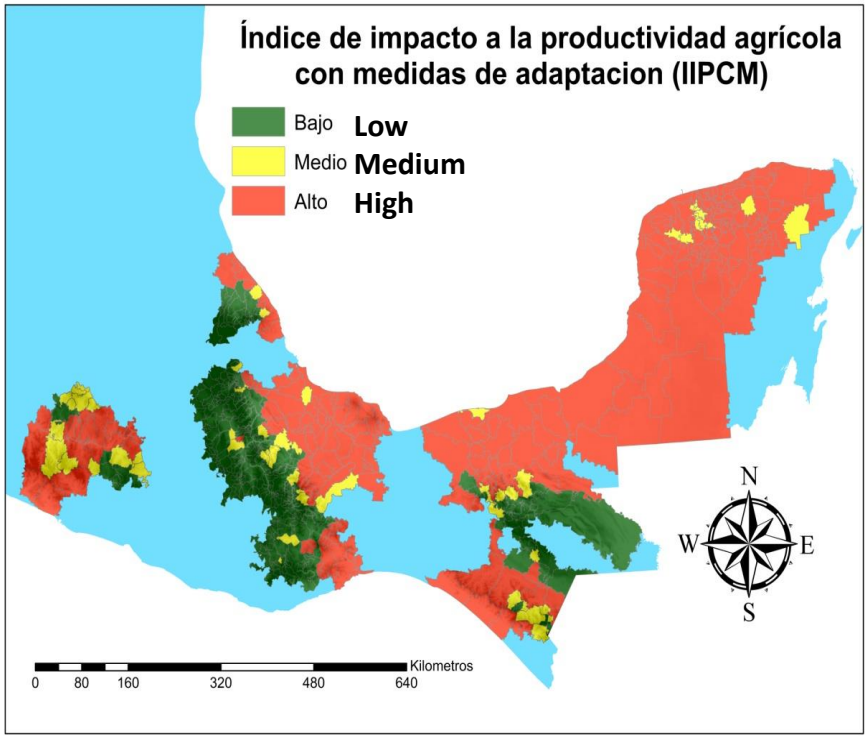




The index of the impact of climate change on crop yields per municipality (IIP), was obtained by weighing the impact in terms of the area occupied by each crop and then adding the impact of each of the 13 crops

Results





Index of impact on productivity (IIP) **without** adaptation measures

Low impact: 289
Medium impact: 51
High impact: 284

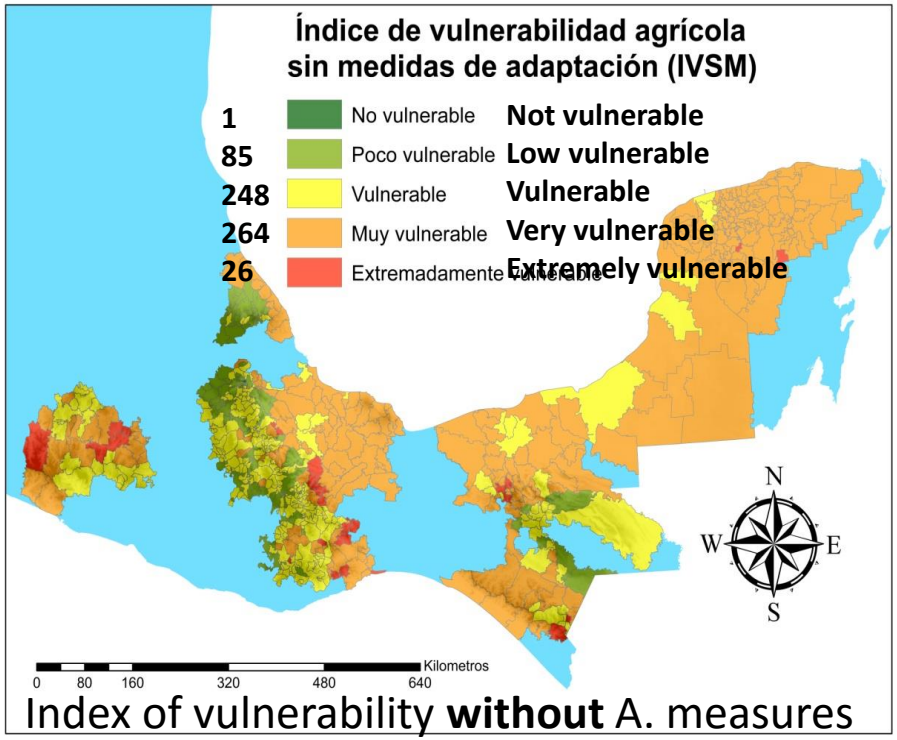
Index of impact on productivity (IIP) **with** adaptation measures

Low impact: 312
Medium impact: 60
High impact: 252

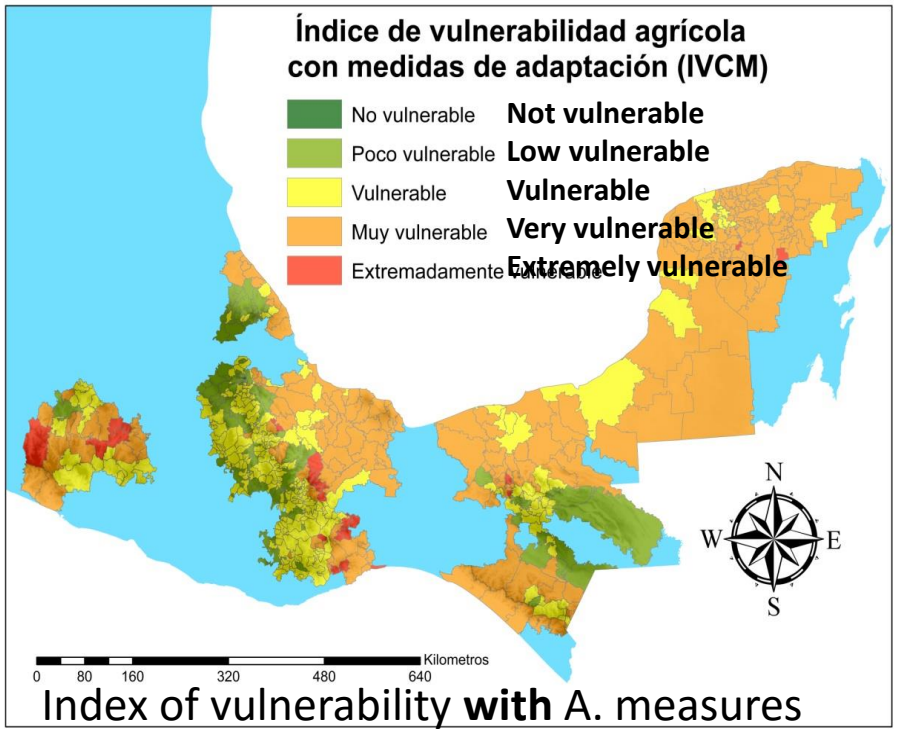
Reducción en la productividad de cultivos con mayor presencia en la zona, bajo condiciones de cambio climático (escenario A1B) a través del tiempo

	RN	DH	DE	DT	DI
	Capacidad de adaptación actual				
Magnitud del impacto esperado		Baja	Media	Alta	
	Bajo	Vulnerable	Poco vulnerable	No vulnerable	
	Medio	Muy vulnerable	Vulnerable	Poco vulnerable	
	Alto	Extremada-mente vulnerable	Muy vulnerable	Vulnerable	

Outline summarizing the methodology for determining, at the municipal scale, the vulnerability of agricultural sector to climate change.



Index of vulnerability **without** A. measures



Index of vulnerability **with** A. measures

Conclusions

It is concluded that the developed methodology and its associated databases, may be the basis to support decision-making and design, at the municipal scale and basin, plans for the adaptation of the agricultural sector to climate change.

However, the methodology is still site specific related, so it has to be tested and improved, in order to turn it into more universal one.

The authors thank to INIFAP for the financial support given to this work.