Supplementary Material

Table *SM-1.* Municipality and productive chain code´s

Code	Municipality	Symbol
	Agave	
040	Cuautinchan	
121	San Diego la Mesa Tochimilzingo	
150	Huehuetlán el Grande	
153	Tecali de Herrera	
166	Tepeojuma	
193	Tzicatlacoyan	
201	Xochiltepec	
	Avocado	
010	Ajalpan	
017	Atempan	
019	Atlixco	
033	Cohuecan	
035	Coxcatlán	
036	Coyomeapan	
046	Chapulco	
050	Chichiquila	
058	Chilchotla	
069	Huaquechula	
116	Quimixtlán	
156	Tehuacán	
173	Teteles de Ávila Castillo	
174	Teziutlán	
175	Tianguismanalco	
186	Tlatlauquitepec	
188	Tochimilco	
195	Vicente Guerrero	
199	Xiutetelco	
207	Zacapoaxtla	
208	Zacatlán	
217	Zoquitlán	
	Banana & Citrus	
002	Acateno	
025	Ayotoxco de Guerrero	
076	Hueytamalco	
158	Tenampulco	
	Berries (B)	
026	Calpan	
048	Chiautzingo	
053	Chignahuapan	
060	Domingo Arenas	
071	Huauchinango	
074	Huejotzingo	
075	Hueyapan	
208	Zacatlán	
	Coffee	
002	Acateno	
006	Ahuacatlán	
010	Ajalpan	
014	Amixtlán	
017	Atempan	
025	Ayotoxco de Guerrero	
028	Camocuautla	
029	Caxhuacan	
030	Coatepec	
036	Coyomeapan	
039	Cuautempan	
043	Cuetzalan del Progreso	
049	Chiconcuautla	

Code	Municipality	Symbol
	(continue) Coffee	
050	Chichiquila	
061	Eloxochitlán	
068	Hermenegildo Galeana	
071	Huauchinango	
072	Huehuetla	
075	Hueyapan	
076	Hueytamalco	
077	Hueytlalpan	
078	Huitzilan de Serdán	
080	Atlequizayan	
084	Ixtepec	
086	Jalpan	
088	Jonotla	
089	Jopala	
100	Naupan	
107	Olintla	
109	Pahuatlán	
111	Pantepec	
116	Quimixtlán	
123	San Felipe Tepatlán	
145	San Sebastián Tlacotepec	
162	Tepango de Rodríguez	
167	Tepetzintla	
174	Teziutlán	
178	Tlacuilotepec	
183	Tlaola	
184	Tlapacoya	
186	Tlatlauquitepec	
187	Tlaxco	
192	Tuzamapan de Galeana	
197	Xicotepec	
202	Xochitlán de Vicente Suárez	
204	Yaonáhuac	
207	Zacapoaxtla	
208	Zacatlán	
210	Zapotitlán de Méndez	
213	Zihuateutla	
215	Zongozotla	
216	Zoquiapan	
217	Zoquitlán	
	Fig (F)	
200	Xochiapulco	
207	Zacapoaxtla	
	Native maize´s	
005	Acteopan	
006	Ahuacatlán	
012	Aljojuca	
013	Altepexi	
014	Amixtlán	
017	Atempan	
019	Atlixco	
022	Atzitzihuacán	
026	Calpan	
033	Cohuecan	
043	Cuetzalan del Progreso	
045	Chalchicomula de Sesma	
048	Chiautzingo	
053	Chignahuapan	
060	Domingo Arenas	
074	Huejotzingo	

Code	Municipality	Symbol
	(continue) Native maize´s	
075	Hueyapan	
083	Ixtacamaxtitlán	
094	Libres	
096	Mazapiltepec de Juárez	
104	Nopalucan	
105	Ocotepec	
108	Oriental	
122	San Felipe Teotlalcingo	
130	San Juan Atenco	
132	San Martín Texmelucan	
137	San Nicolás Buenos Aires	
142	San Salvador El Seco	
143	San Salvador El Verde	
148	Santa Isabel Cholula	
149	Santiago Miahuatlán	
152	Soltepec	
154	Tecamachalco	
156	Tehuacán	
161	Tepanco de López	
170	Tepeyahualco	
172	Tetela de Ocampo	
175	Tianguismanalco	
177	Tlacotepec de Benito Juárez	
179	Tlachichuca	
180	Tlahuapan	
186	Tlatlauquitepec	
188	Tochimilco	
189	Tochtepec	
200	Xochiapulco	
203	Xochitlán Todos Santos	
205	Yehualtepec	
207	Zacapoaxtla	
208	Zacatlán	
211	Zaragoza	
	Pitaya-pitahaya	
027	Caltepec	
035	Coxcatlán	
079	Huitziltepec	
082	Ixcaquixtla	
124	San Gabriel Chilac	
129	San José Miahuatlán	
147	Santa Inés Ahuatempan	
149	Santiago Miahuatlán	
156	Tehuacán	
169	Tepexi de Rodríguez	
171	Tepeyahualco de Cuauhtémoc	
203	Xochitlán Todos Santos	
205	Yehualtepec	
206	Zacapala	
214	Zinacatepec	
	Vanilla	
025	Ayotoxco de Guerrero	
064	Francisco Z. Mena	
086	Jalpan	
111	Pantepec	
197	Xicotepec	

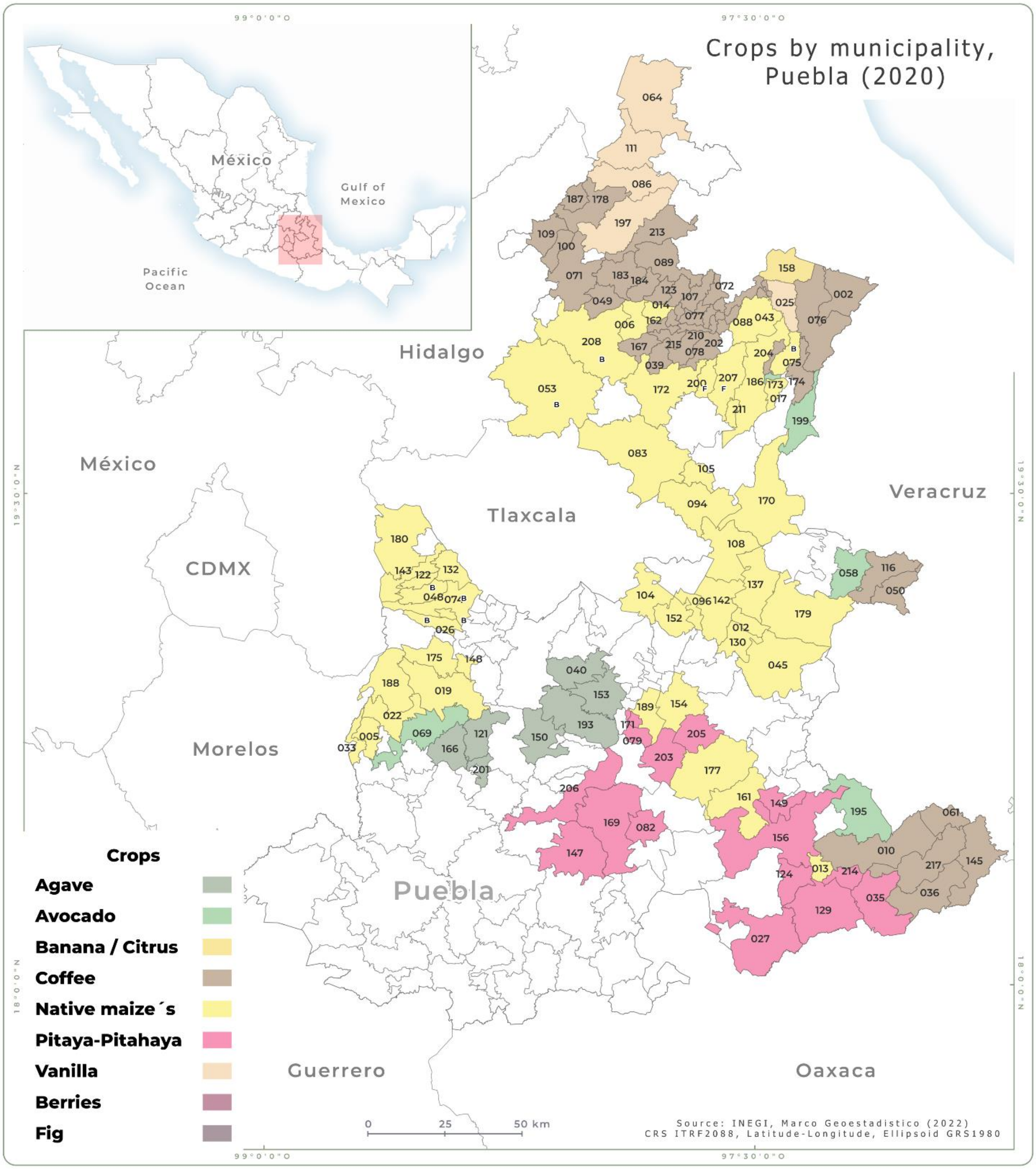


Fig. SM-1. Spatial distribution of strategic crops in the State of Puebla, 2020.

Source: Own elaboration with information from INEGI (2022).

I. Data and Calculations from Section II

Requirement of water by plants

Crop evapotranspiration.

Real Crop Evapotranspiration (ETc) —estimated value of water required by crops throughout the entire vegetative cycle— was calculated using an indirect method by applying empirical formulas based on climatic data. The Blaney-Criddle equation considers two important parameters: the average monthly temperature and the percentage of monthly light hours in relation to the annual total. Originally, the method was designed to calculate the ETc during the entire vegetative cycle of the crop, using the following equation (FAO, 2006):

$$ETc = Kg * F \qquad \text{Eq. (1)}$$

Where: ETc = Crop evapotranspiration, in cm; Kg = Total adjustment coefficient that depends on the crop and the location of the study area, dimensionless; and F = Climatic factor that is equivalent to the global ETP (Potential Evapotranspiration), which is calculated with the following formula:

$$F = \sum_{i=1}^{n} fi \qquad \text{Eq. (2)}$$

Where: fi = Monthly values of the climatic factor or ETP, in cm.

$$fi = [Ti + 17.8/ 21.8] * Pi \qquad \text{Eq (3)}$$

Where: Ti = average monthly temperature, in °C; Pi = percentage of light hours of the month with respect to the annual total, in percentage (%), obtained from Table SM-2.

Table SM-2. Percentage of light hours of the month with respect to the annual total (%).

Lat. N (º)	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
15	7.94	7.37	8.44	8.45	8.98	8.80	9.03	8.83	8.27	8.26	7.75	7.88
16	7.93	7.35	8.44	8.45	8.98	8.80	9.03	8.83	8.27	8.26	7.75	7.88
17	7.86	7.32	8.43	8.48	9.04	8.87	8.27	8.22	8.27	8.22	7.69	7.80
18	7.83	7.30	8.42	8.50	9.09	8.92	9.16	8.90	8.27	8.21	7.66	7.74
19	7.79	7.28	8.41	8.51	9.11	8.97	9.20	8.92	8.28	8.19	7.63	7.71
20	7.74	7.26	8.41	8.53	9.14	9.00	9.23	8.95	8.29	8.17	7.59	7.66
21	7.71	7.24	8.40	8.54	9.18	9.05	9.29	8.98	8.29	8.15	7.54	7.62
22	7.66	7.21	8.40	8.56	9.22	9.09	9.33	9.00	8.30	8.13	7.50	7.55
23	7.62	7.19	8.40	8.57	9.24	9.12	9.35	9.02	8.30	8.11	7.47	7.50
24	7.58	7.17	8.40	8.60	9.30	9.20	9.41	9.05	8.31	8.09	7.43	7.46
25	7.53	7.13	8.30	8.61	9.32	9.22	9.43	9.08	8.30	8.08	7.40	7.41
26	7.49	7.12	8.40	8.64	9.38	9.30	9.49	9.10	8.31	8.06	7.36	7.35
27	7.43	7.09	8.38	8.65	9.40	9.32	9.52	9.13	8.32	8.03	7.36	7.31
28	7.40	7.07	8.39	8.68	9.46	9.38	9.58	9.16	8.32	8.02	7.22	7.27
29	7.35	7.04	8.37	8.70	9.49	9.43	9.61	9.19	8.32	8.00	7.24	7.20
30	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.34	7.99	7.19	7.14
31	7.25	7.00	8.36	8.73	9.57	9.54	9.72	9.24	8.33	7.95	7.15	7.09
32	7.20	6.97	8.37	8.75	9.63	9.60	9.77	9.28	8.34	7.95	7.11	7.05

Source: FAO, 2006

This method was modified by J. T. Phelan, who proposed the following correction to each of the monthly (fi), which is a function of the mean monthly temperatures (Ti), as shown in Equation 4 (Fernández et al., n.d.):

$$Kti = 0.031144Ti + 0.2396 \qquad \text{Eq. (4)}$$

1.1.1 **Water available from different sources**

Subsequently, the water balance was conducted to determine whether the water available from various sources is sufficient to meet the water requirements of each crop, using the following formula:

$$Bh = (Ad - ETc) * Ss \qquad \text{Eq. (5)}$$

Where: Bh = water balance, in m^3/ha; Ad = available water; ETc = crop evapotranspiration; and Ss = planted area, in ha.

$$Ad = Alle + Asp + Asb \qquad \text{Eq. (6)}$$

Effective rainfall was estimated using the USDA-Soil Conservation Service method:

If P<=250 mm per period:

$$Pe = P/125\ (125 - 0.2P) \qquad \text{Eq. (7)}$$

If P>250 mm per period:

$$Pe = (125 + 0.1P) \qquad \text{Eq. (8)}$$

Where: Pe = effective precipitation, in mm; and P = gross precipitation, in mm

1.1.2 Calculation of the Relative Water Stress Index

The Relative Water Stress Index (RWSI), as defined by UNESCO’s World Water Resources Assessment Program, quantifies the pressure that the water requirement of crops place on the available water (García, 2017). It was calculated from the following expression:

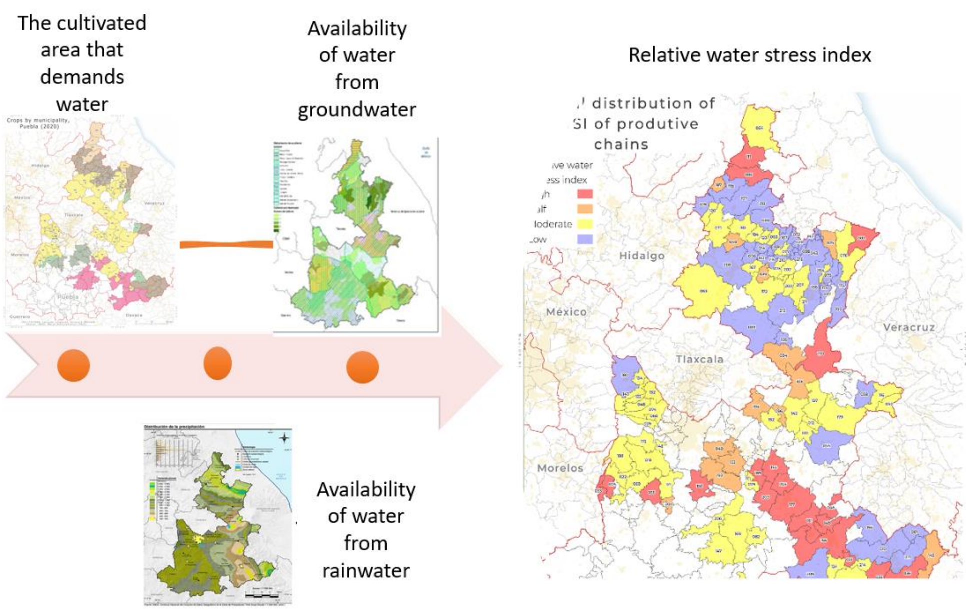
$$RWSI = A / Q \qquad \text{Eq. (9)}$$

Where: A = water demand in agriculture, measured in m^3/ha; and Q = available water supply, measured in m^3/ha

Source: Owns elaboration, 2023

Fig. SM-2. Supply-demand relationship according to Eq. 9.

The quantitative results were visually presented using the Geographic Information System, utilizing qualitative categories, as depicted in Fig. SM-2 and Table SM-1.



Source: Owns elaboration, 2023

Fig. SM-3 Creation of the RWSI using layers depicting crop demand and water availability.

Adapted from Morales-Mora et al. (2022).

Rates of intensity and metabolic density

The flow-fund relationships are intensive variables or rates of metabolic intensity, which represent qualitative characteristics of the metabolic elements (e.g., m^3 of water per day used per crop) and the metabolic density in space (background relationships). (e.g., kg of crops produced per hectare of land).

Four Metabolic Intensity Rates were considered: (i) Water application/water requirement ratio, expressed as a percentage (%). (ii) Water-soil interrelation, measured in m3/ha. (iii) Water metabolism within the production volume in the production chain, dimensionless. (iv) Water usage to generate $1.00 of production value, measured in m^3/$1.00. And three Metabolic Density factors were considered: (v) Monetary productivity of water, measured in $/$m^3$. (vi) Crop-water relationship, measured in kg/m^3. (vii) Relation of the local average yield to the national yield of the crop, expressed as a percentage (%).

Each factor is explained below:

a) Rates of metabolic intensity

(i) Ratio used water-required water (RAAr) in %

$RAAr = A/Ar$ Eq. (10)

Where: A = Water used, in m^3; Ar = required water, in m^3.

(ii) Water-land interrelation (IAT) in m^3/ha

$IAT = A/S$ Eq. (11)

Where: A = of the water used, in m^3; S = Planted area, in ha.

(iii) Water metabolism in volume of production within the productive chain (MAP), dimensionless:

$MAP = \%Vp/\%A$ Eq. (12)

Where: %Vp = Fraction of the production volume of the study area, expressed as a percentage (%); %A = Fraction of the water volume used from the Development Pole, expressed as a percentage (%). The ranges and qualitative rating were defined as follows:

Table SM-3. Metabolic efficiency

Range	Qualitative rating
<0 a 0.009	Very high
0.01 a 0.20	High
0.21 a 0.50	Medium
0.51 a 0.75	Low
0.76 a >1.00	Very low

Source: Owns elaboration, 2023

(iv) Water usage to generate $1.00 of production value (AVP) in m^3/$1.00

$$AVp = A/VP \quad \text{Eq. (13)}$$

Where: A = water volume used, measured in m^3; VP = Production value, expressed as $.

b) Rates of metabolic density

(v) Monetary productivity of water (P$A) in $/$m^3$

$$P\$A = VP/A \quad \text{Eq. (14)}$$

Where: VP = Production value, in $; A = Water used, measured in m^3

(vi) Crop-water interrelation (CWI) in kg/m^3

$$CWI = Vp/A \quad \text{Eq. (15)}$$

Where: Vp = Volume of production in kg; A = Water used, in m^3

(vii) Ratio of local average yield to the national average (RLN)

$$RLN=Rl/Rn \quad \text{Eq. (16)}$$

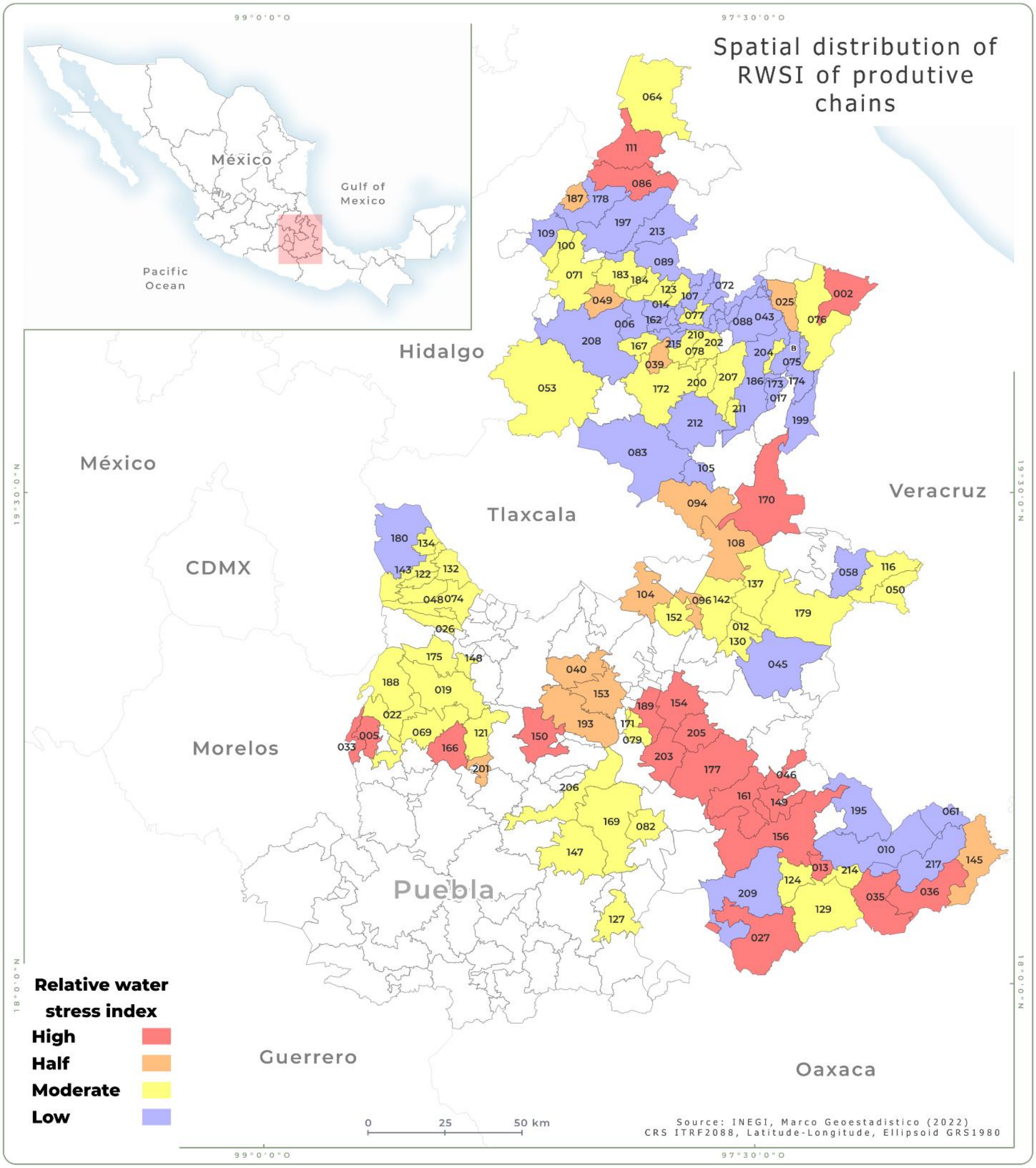
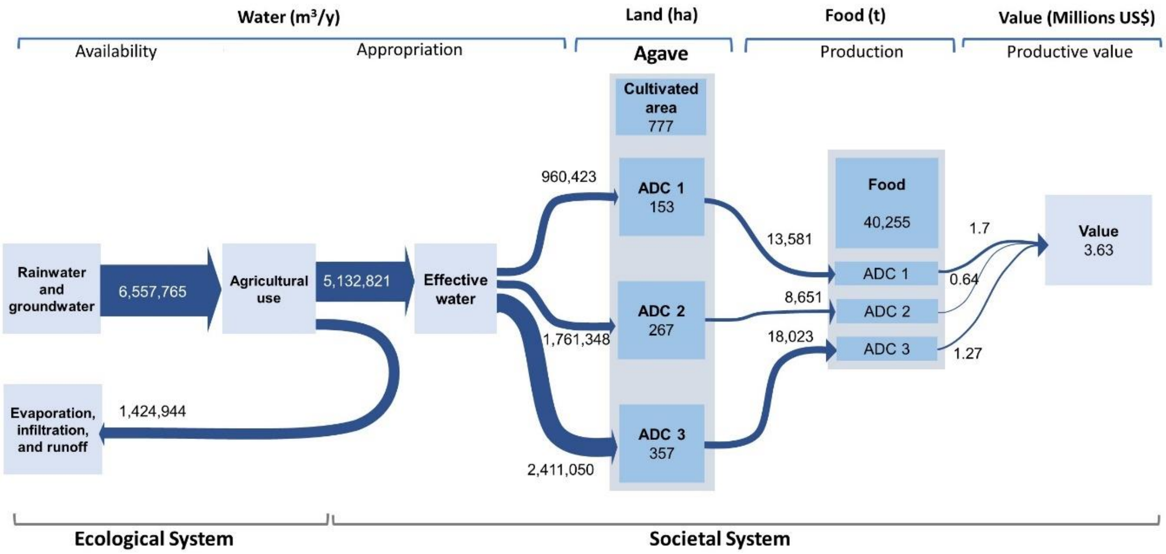


Fig. SM-4. Spatial distribution of RWSI (Relative Water Stress Index) of the Productive Chains.

Source: Own elaboration, 2023

Where: El=Local yield (t/ha); Rn=National yield (y/ha)

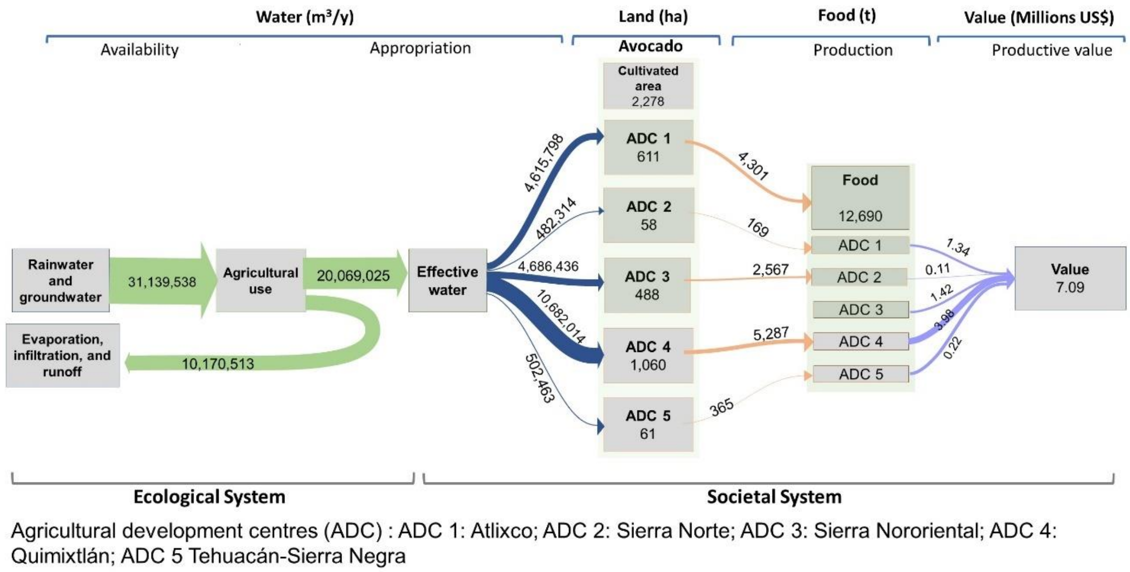
II. Grammar by crops in Agricultural Development Centres



Agricultural development centres (ADC); ADC 1: Tepeaca; ADC 2: Tepexi de Rodríguez; ADC 3: Chiautla de Tapia-Izúcar de Matamoros

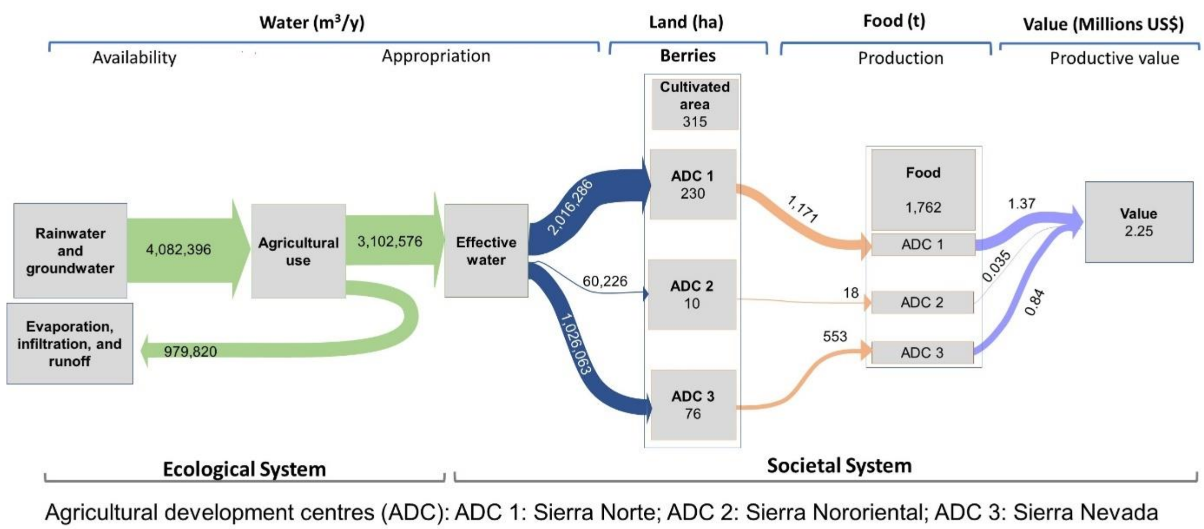
Source: Owns elaboration, 2023

Fig. SM-5. Grammar of Water-Food Nexus of the Agave in Agricultural Development Centres



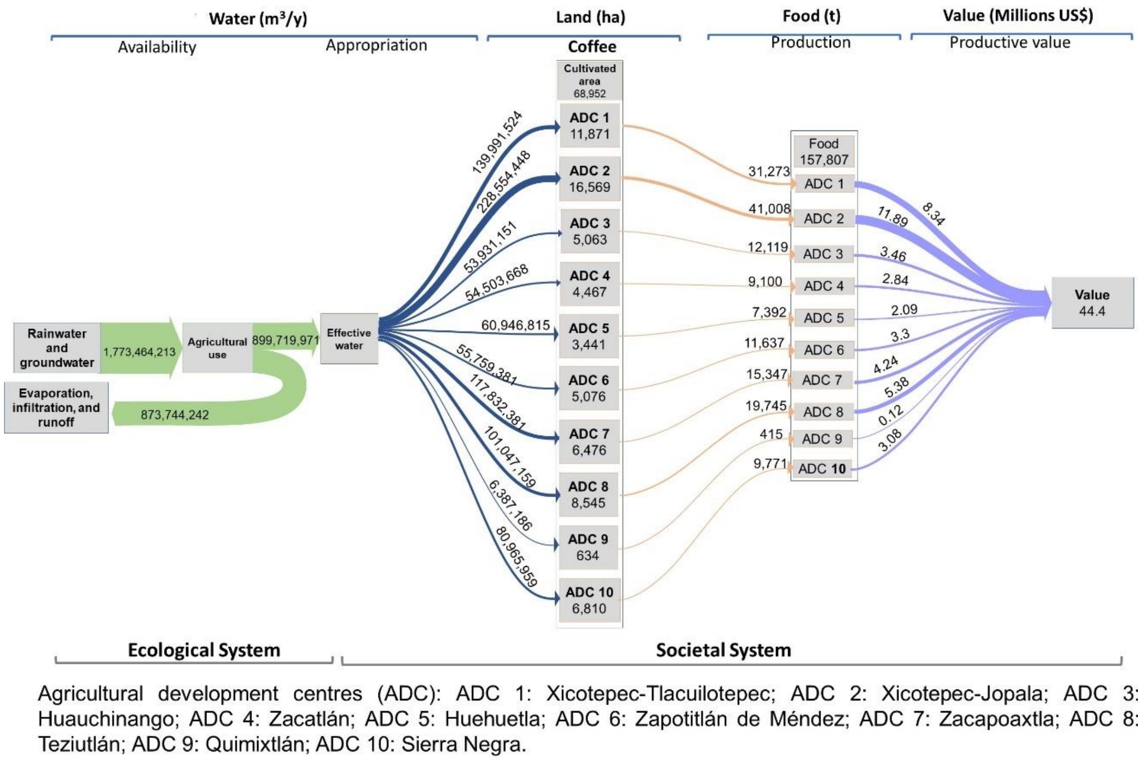
Source: Owns elaboration, 2023

Fig. SM-6. Grammar of Water-Food Nexus of the Avocado in Agricultural Development Centres



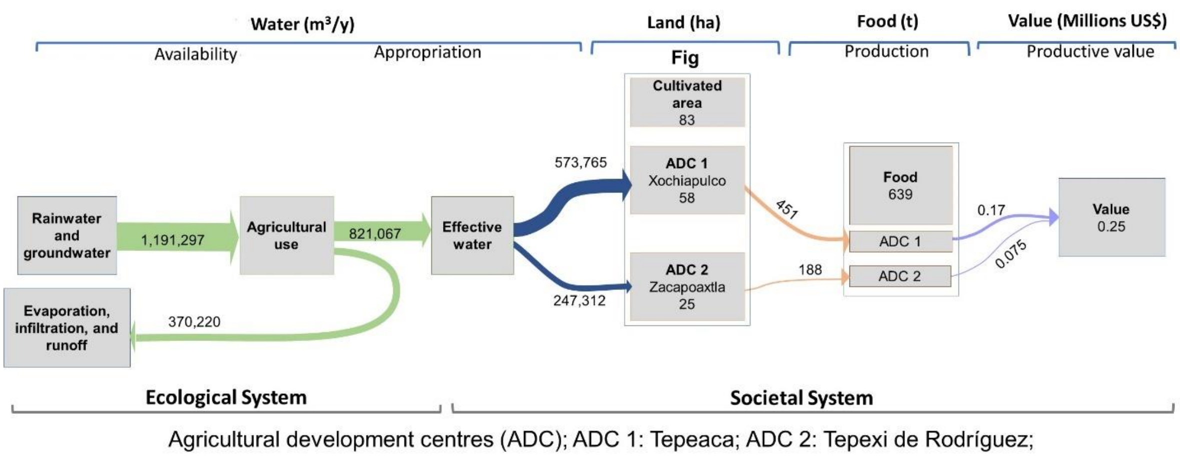
Source: Owns elaboration, 2023

Fig. SM-7. Grammar of Water-Food Nexus of the Berries in Agricultural Development Centres



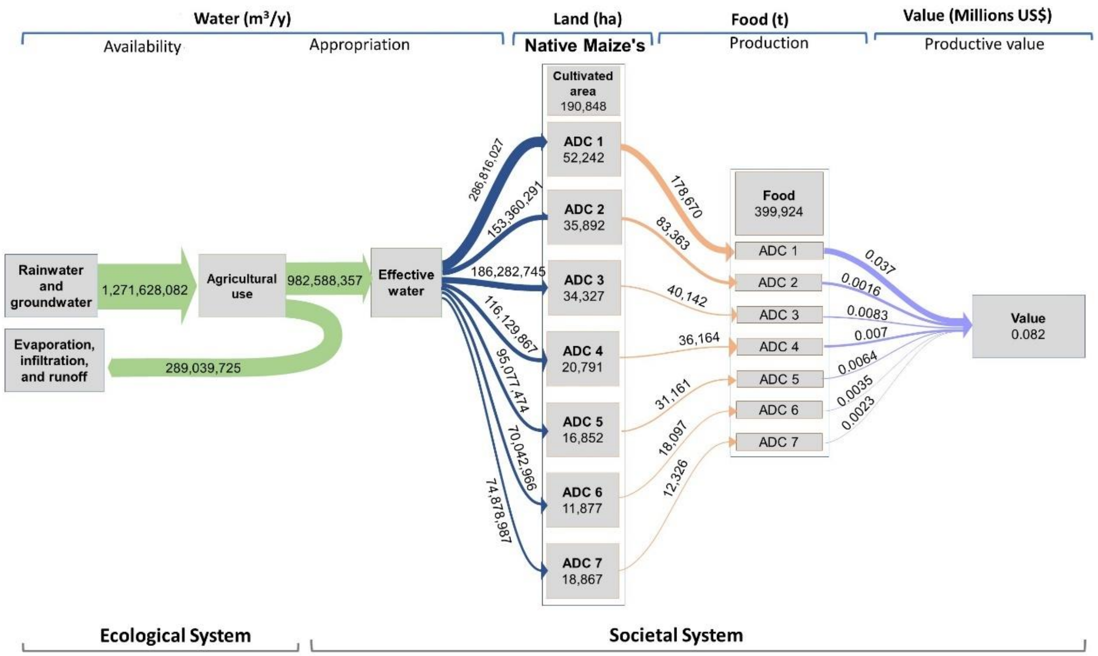
Source: Owns elaboration, 2023

Fig. SM-8. Grammar of Water-Food Nexus in Coffee Agricultural Development Centers



Source: Owns elaboration, 2023

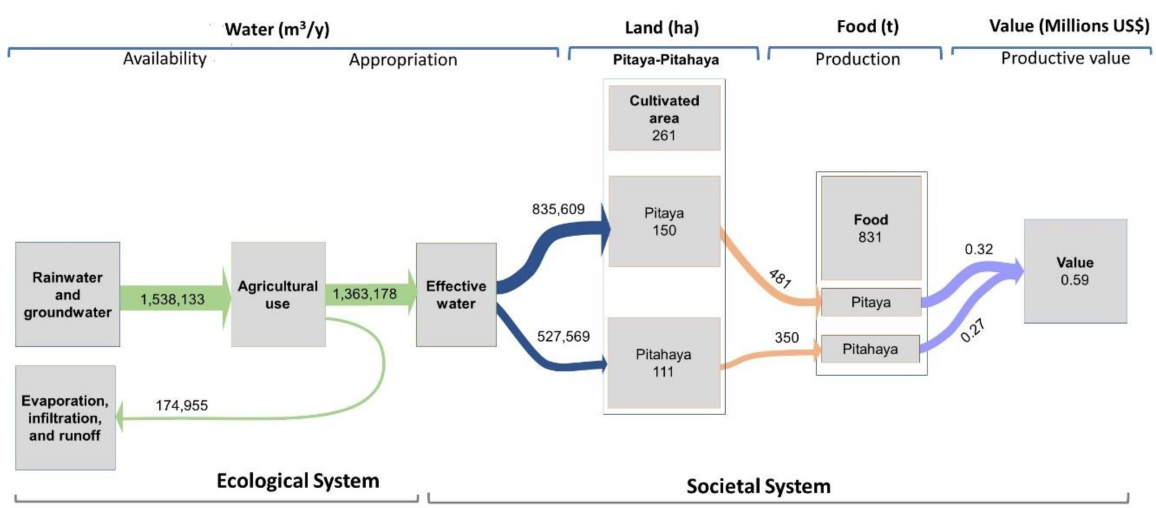
Fig. SM-9. Grammar of Water-Food Nexus of the Fig in Agricultural Development Centres



Agricultural development centres (ADC): ADC 1: Serdán; ADC 2: Libres; ADC 3: Sierra Norte; ADC 4: San Martín; ADC 5 Sierra Nororiental; ADC 6: Atlixco; ADC 7: Tehuacán-Tecamachalco

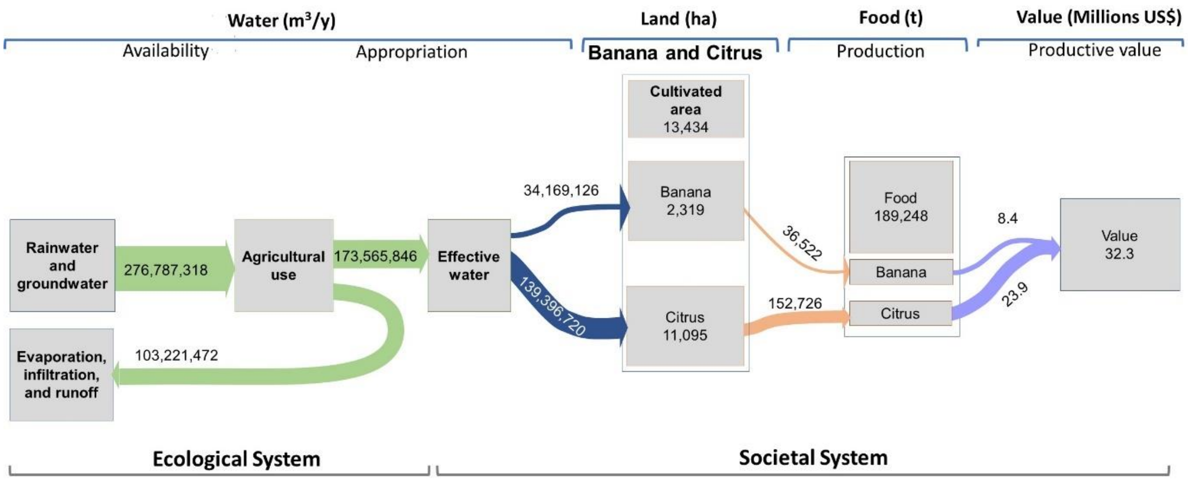
Source: Owns elaboration, 2023

Fig. SM-10. Grammar of Water-Food Nexus of Native Maize in Agricultural Development Centres



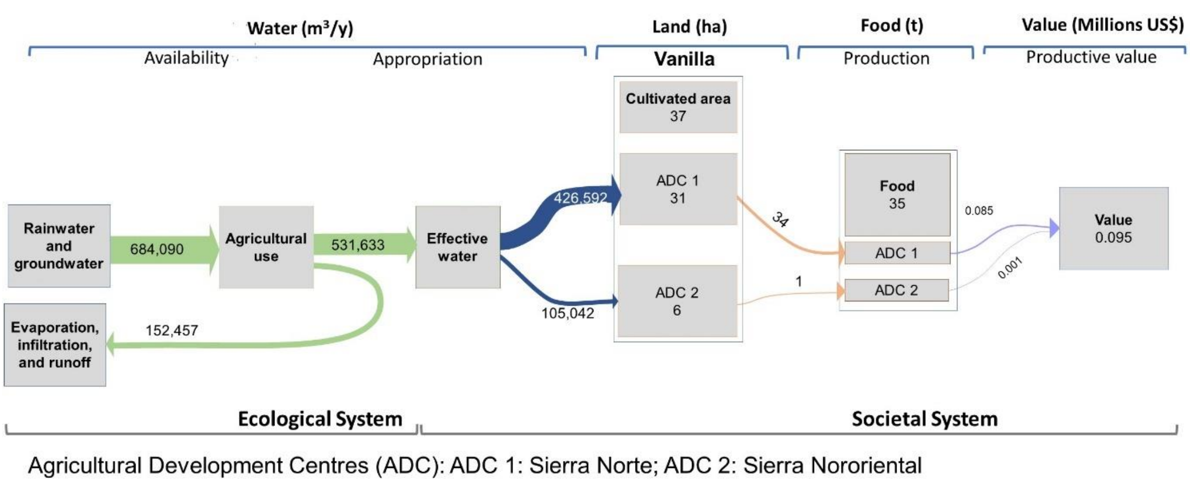
Source: Owns elaboration, 2023

Fig. SM-11. Grammar of Water-Food Nexus of the Pitaya-Pitahaya in Agricultural Development Centres



Source: Owns elaboration, 2023

Fig. SM-12. Grammar of Water-Food Nexus of the Banana and Citrus in Agricultural Development Centres



Source: Owns elaboration, 2023

Fig. SM-13. Grammar of Water-Food Nexus of the vanilla in Agricultural Development Centres

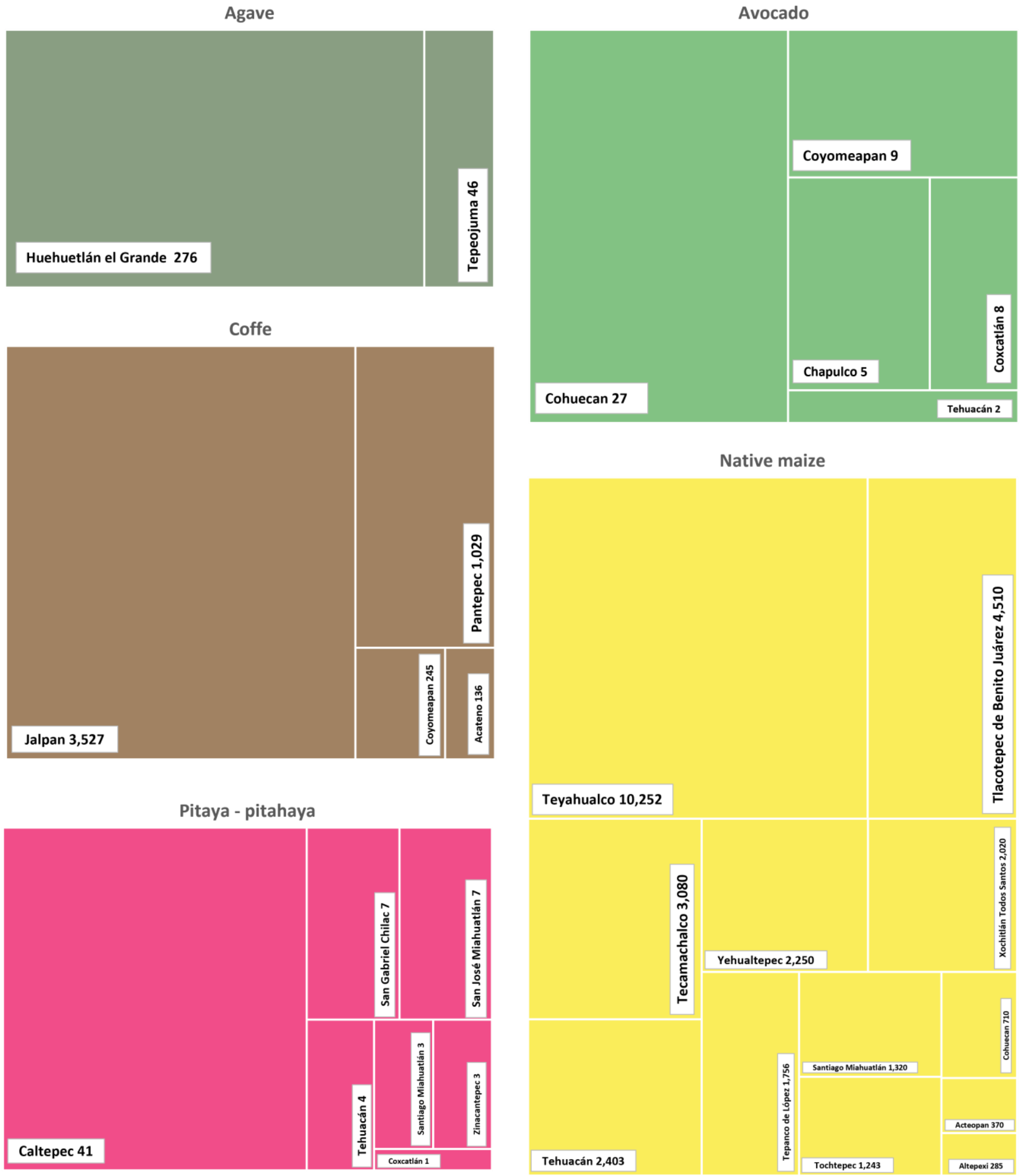


Fig. SM-14. Municipalities with a high RWSI (surface). The first number is the code of Municipality (see Table SM-5), and the second number is the tonnes by crops.
Source: Own elaboration, 2023

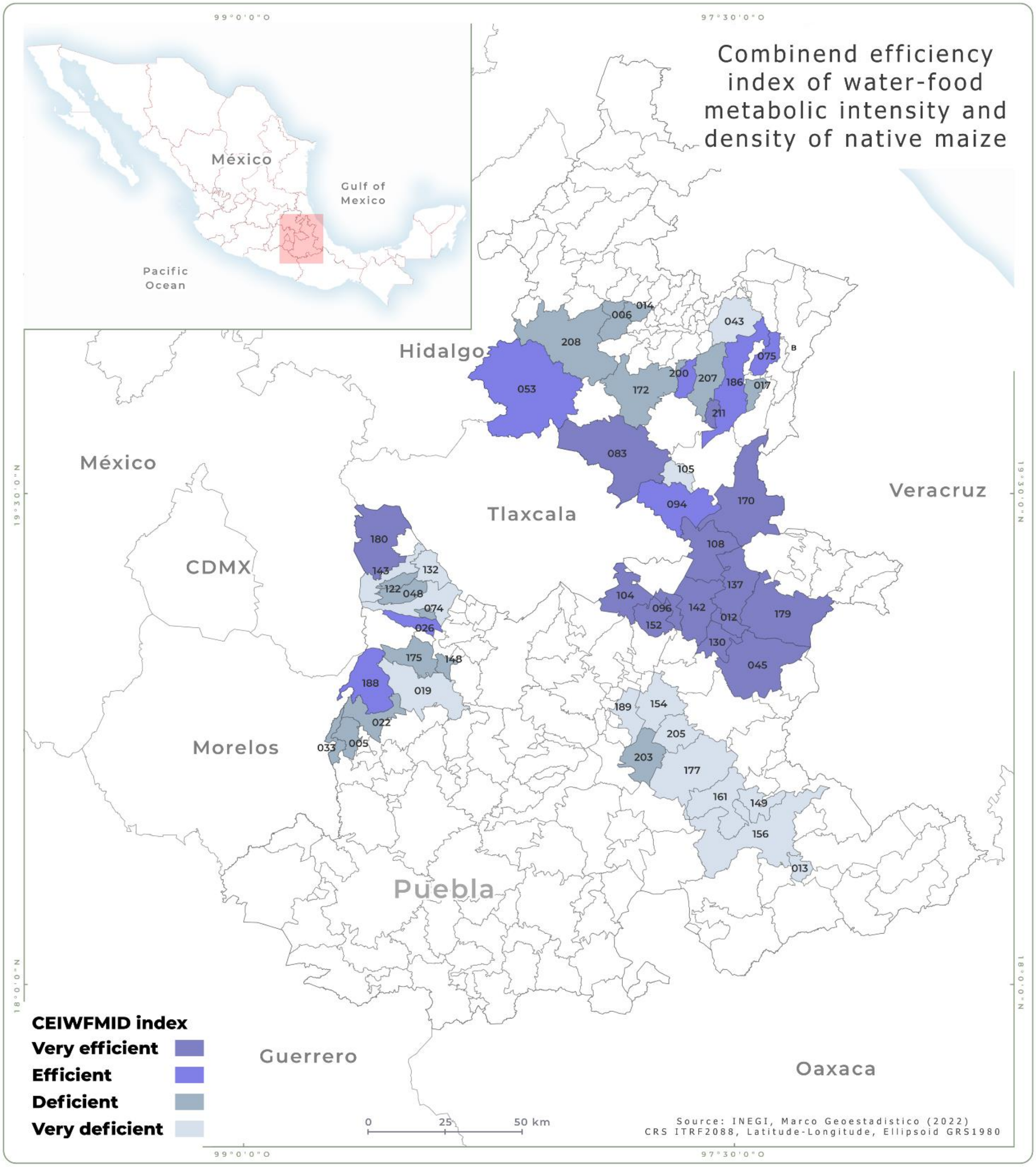


Fig. SM-15. Spatial distribution of municipalities by rank and classification of the Combined Efficiency Index of Water-Food Metabolic Intensity and Density (CEIWFMID).

Source: Own elaboration, 2023

Table *SM-4*. Combined Efficiency Index of Metabolic Intensity and Density (CEIMID). Native maize case. Classification Very Deficient.

Municipality	Population	Land	Requirement		Availability		IEHR	IEPA	IECIDM
		ha	Water hm³/y	Food t/y	Water hm³/y	Food t/y			
Santa Isabel Cholula	11,498	766	4.552	1,213	4.810	1,363	94.6%	89.0%	84.3%
Atempan	29,742	1,632	5.541	3,138	7.092	2,774	78.1%	113.1%	88.4%
Tetela de Ocampo	27,216	2,365	10.687	2,871	12.608	2,705	84.8%	106.2%	90.0%
Amixtlán	4,812	314	1.943	508	2.732	355	71.1%	142.9%	101.6%
Acteopan	3,070	370	2.937	324	2.039	459	144.0%	70.6%	101.7%
Chiautzingo	22,039	1,211	6.425	2,325	6.510	2,180	98.7%	106.7%	105.3%
Ahuacatlán	14,542	956	4.257	1,534	5.426	1,075	78.4%	142.8%	112.0%
Xochitlán Todos Santos	7,178	2,020	10.954	757	8.345	857	131.3%	88.3%	115.9%
Zacapoaxtla	57,887	2,282	11.273	6,107	13.576	4,323	83.0%	141.3%	117.3%
Cuetzalan del Progreso	49,864	2,323	16.065	5,261	23.482	2,899	68.4%	181.4%	124.1%
Huejotzingo	90,794	3,810	19.369	9,579	20.932	7,115	92.5%	134.6%	124.6%
Ocotepec	32,772	1,347	6.264	3,457	5.903	2,869	106.1%	120.5%	127.9%
San Salvador El Verde	34,880	1,321	7.008	3,680	7.101	2,498	98.7%	147.3%	145.4%
Atlixco	141,793	4,311	24.957	14,959	25.285	5,796	98.7%	258.1%	254.8%
Yehualtepec	26,392	2,250	12.201	2,784	9.296	1,113	131.3%	250.3%	328.5%
Tlacotepec de Benito Juárez	54,757	4,510	24.387	5,777	18.633	2,004	130.9%	288.3%	377.4%
Santiago Miahuatlán	30,309	1,320	7.799	3,198	4.751	1,294	164.2%	247.2%	405.8%
Tecamachalco	80,771	3,080	16.702	8,521	12.725	2,718	131.3%	313.5%	411.5%
Tepanco de López	22,218	1,756	10.374	2,344	6.320	893	164.2%	262.6%	431.1%
San Martín Texmelucan	155,738	2,319	12.303	16,430	12.466	3,382	98.7%	485.9%	479.5%
Tochtepec	22,454	1,243	6.741	2,369	5.135	557	131.3%	425.6%	558.7%
Altepexi	22,629	285	1.684	2,387	1.026	279	164.2%	855.7%	1404.6%
Tehuacán	327,312	2,403	14.197	34,531	8.649	2,613	164.2%	1321.5%	2169.3%
Total	1,270,667	44,193	238.618	134,055	224.840	52,119	106.1%	257.2%	273.0%

Source: Owns elaboration, 2023

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