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Water societal metabolism in Yucatan Peninsula. The impact of climate change on the recharge of groundwater by 2030

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Abstract:

The demographic and economic growth in Yucatan peninsula (YP) in recent years has caused changes on the hydrological response and flow of the water cycle. The growth effects and its impact on the society are poorly understood. Here we present an estimation of water consumption and its evolution based on the analysis of Yucatan Peninsula's societal metabolism, using the interdisciplinary tool MuSIASEM. Societal metabolism together with metabolic patterns generate a new narrative on how the YP development is linked to the uses of water, considering social functions, as well as the biophysical limits established by the annual recharge of groundwater, being it the main source of water supply. Given the current trends in YP socio-economic growth and climate change scenarios, our results show superlinear scaling relations between water metabolic rate and water consumption which leads increase in water consumption and 23% decrease in groundwater recharge by year 2030. The consequences of this scenario are particularly worrying for the near future, given the current socio-economic structure in YP, highly dependent both on the services (i.e., tourism) and agriculture sectors.

Keywords: MuSIASEM; Groundwater recharge; Yucatan Peninsula; water consumption; societal metabolism

1. Introduction

1.1. Interdisciplinary approach in water resources

Water is a determining factor for the functioning of any society. It participates in productive activities such as irrigation, livestock, fisheries, hydropower generation and in households. At the same time, it fulfills the basic function of maintaining the integrity of the natural environment. However, the growth and development of societies have changed the hydrological response and flow of the water cycle through different means (Grobick, 2010; Savenije et al., 2014). These include fundamentally the direct diversion of water flows to water supply, network transformation of the stream and changes in the characteristics of natural drainage, through deforestation and urbanization (Savenije et al., 2014).

Huang, Vause, Ma, and Yu, (2013) describe the different socio-economic and natural factors which influence water consumption. Lifestyle changes increase the consumption of goods and services, with a consequent increment in water consumption rates. In the medium and long term, water supply tends to be fixed, rigid and constant by the biophysical limits of each region (Camdessus et al., 2006). In addition, changes in water quality reduces the volume available for consumption, converting a renewable resource to a limited one (Aguilar Ibarra and Durán Rivera, 2010). According to Leff (2008), water consumption doubles every 20 years, duplicating the population growth rate (i.e., while the world population grew nearly three times in the last 50 years, water demand grew about six times). Water stocks are diminishing in many areas of the world because the rate of water pumping of aquifers (especially for crop irrigation) is higher than the natural recharge rate of rain and snow (Tyler Miller Jr. and Spoolman, 2008).

Water is a complex system, not only from the environmental, scientific or technical points of view, but also by its political, social and economic implications for management. It is necessary to carry out a series of technical, administrative, financial and communication measures among all stakeholders simultaneously to devise common objectives in water use and management (Camdessus et al., 2006). Water systems link to the ecosystem, as well as to the social system. Likewise, water systems show complex dynamics, feedback loops in their flows within the same cycle, and possess a considerable degree of uncertainty (Liu et al., 2007).

Approaches such as eco-hydrology (McClain et al., 2012; Rodríguez-Iturbe, 2000; Zalewski et al., 1997) and socio-hydrology (Savenije et al., 2014; Sivapalan et al., 2014, 2012) allows studying this complex system at different scales. These eco-social approaches are relatively new and with rapid growth in hydrological studies. Both examine the interactions of the hydrological system within ecosystems and/or human factors, to understand the dynamics and characteristics of water systems as a whole. Similarly, Integrated Water Resources Management (IWRM) is an approach that promotes the coordinated development and management of water, soils, and other associated resources in order to maximize economic and social well-being in an equitable manner without compromising the sustainability of ecosystems (Morales N. and Rodríguez T., 2007; UNDP and GW-MATE, 2010). These multiple conceptual frameworks coincide with an integral vision of water resources management, including social and environmental factors to the analysis. Here we use societal metabolism as a multi-dimensional tool which can be applied to the study of water as a flow within societies. It aims to meet most of the characteristics of current conceptual frameworks and facilitates the understanding of a problem that is complex by its very definition.

1.2. Societal water metabolism

The concept of societal metabolism describes the manner in which human societies organize their growing exchanges of energy and materials with the (Ayres, 1997; Fischer-Kowalski, 1998; Giampietro and Mayumi, 2000a; Haberl et al., 2011; Martinez-Alier, 1987). Societal metabolism begins when societies appropriate the and energy (input), and it ends when are deposited as waste, fumes, or residues in natural areas (output). Between these two steps, occur other processes, where materials are circulated, transformed and consumed (Toledo, 2013).

Societal metabolism puts its emphasis on the relationship between flows and the agents that transform input flows into output flows, while maintaining and preserving their own identity. Hence, it connects funds (i.e., the agents and transformers of a process) and flows (i.e., the elements that are utilized and dissipated) to generate indicators characterizing specific features of the system. It contributes to explain the interrelationships among natural, social and economic processes, which are relevant for sustainable development (Fischer-Kowalski and Haberl, 2000; Sorman, 2014). Analyzing a complex system using the methodology of societal metabolism can be an alternative to providing an overview of the multiple streams involved in the system, and understanding the interactions and their effects on society.

If we analyze water consumption across the activities of a society, such as agriculture, industry, energy generation, services, and everyday life, we can understand the societal metabolism of water as the study that describes how society uses this resource to maintain its development through time (Madrid-López, 2014). Water metabolism is defined as the entire process of water flows, where changes in quantity and quality occur under the effects of nature and human society in the hydrological cycle (Lemos et al., 2013; Wu et al., 2016). Figure 1 shows the various interactions between water uses and economic sectors. This structure will vary according to each territory of analysis. It is determined by the supply and demand of flows, the size of the productive sectors, and reuse systems (i.e., loops). These interactions can be altered by population growth, increased demand, as well as the ever-increasing needs of an economic system with a philosophy of perpetual growth (Leff, 2008). Through the societal metabolism analysis, it is possible to analyze in detail the intermediate processes with which water interacts with productive activities within society.

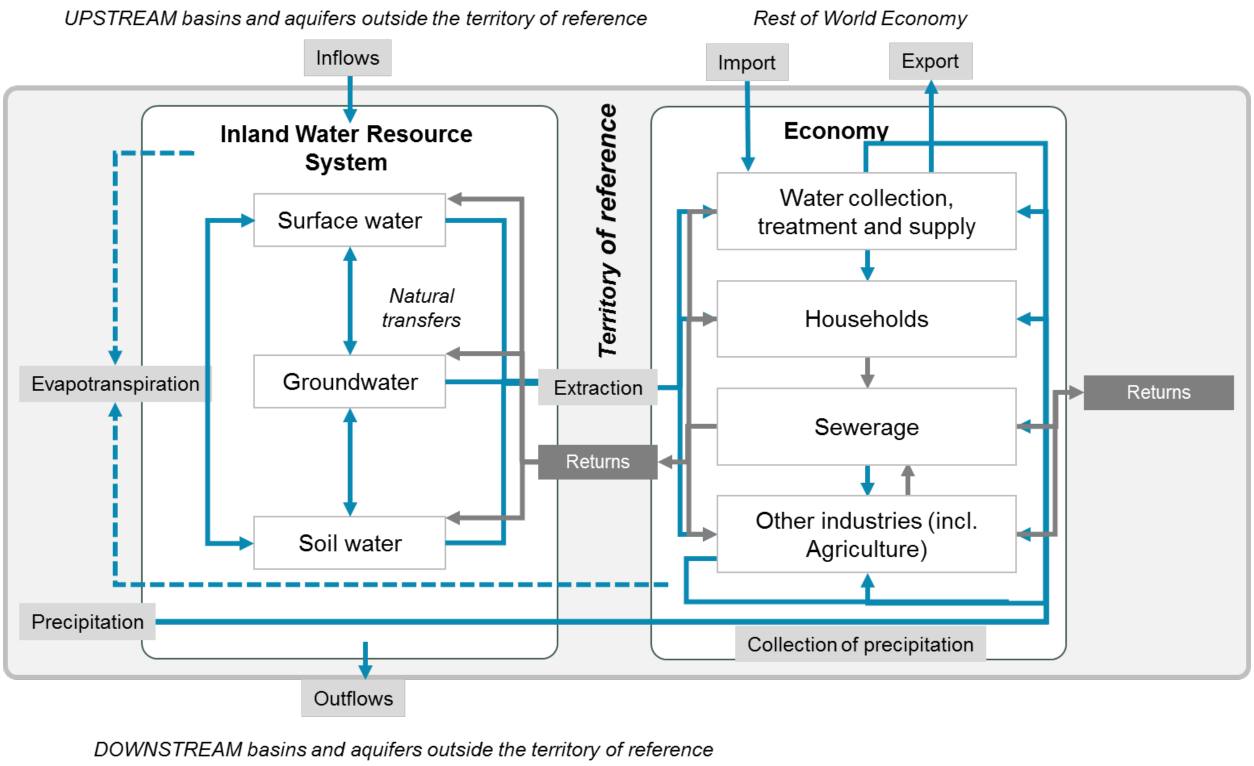

Figure 1. Main flows of between inland water resources system and economy. Source: Adapted from (ONU, 2011; UNEP, 2012). Flows into the ocean are not considered.

Water can be analyzed as a flow within the metabolism of a city or region, so that the entry and exit of the system can be linked to the amounts of water entering and leaving the society from the study of the water balance (Murat Özler, 2015). This 'basic metabolism' is based on the natural reproduction of resources: water, air, and plant or animal biomass (Fischer-Kowalski and Haberl, 2000). In order to perpetuate the exchanges between environmental resources and social processes, processes must be within the limits established by the ecosystem's metabolism (Martinez-Alier, 1987). The problem of societies with unsustainable growth, observed under the societal metabolism perspective, is that the magnitude of the resources flows and energy exceeds the production capacity of the natural systems in which they are found: either in the provision of resources, or in their capacity to absorb waste or emissions (Fischer-Kowalski and Haberl, 2000).

1.3. Interaction between water and society in Yucatan Peninsula

Yucatan Peninsula (YP) is located in southeastern Mexico. It includes the States of Campeche, Quintana Roo and Yucatan. In terms of water administration, the National Water Commission (CONAGUA in Spanish) divided the territory in Hydrological-Administrative Regions. YP belongs to the Hydrological-Administrative Region XII (CONAGUA, 2016a), which is divided in four hydrographic basins: Grijalva-Usumacinta (RH30), West Yucatan (RH31), North Yucatan (RH32), and East Yucatan (RH33) (Figure 2).

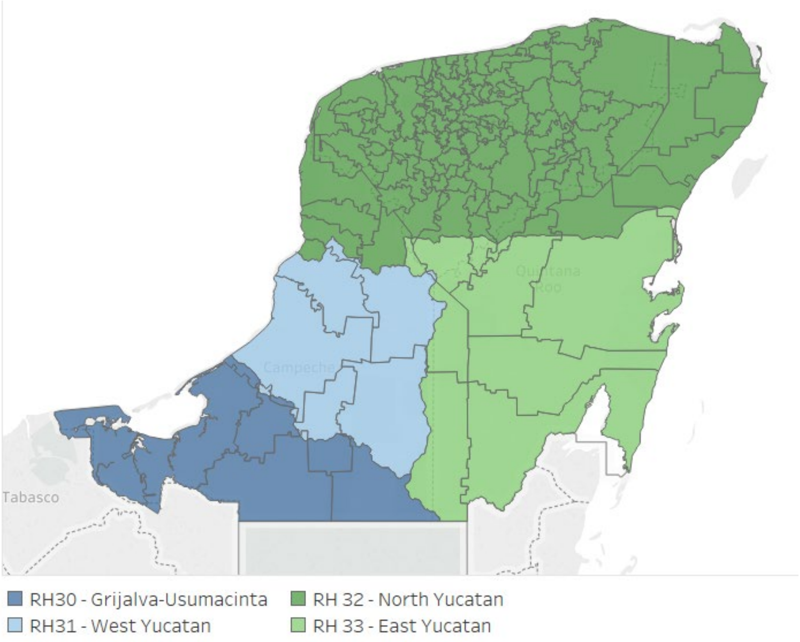

Figure 2. Hydrological-Administrative Region XII in the Yucatan Peninsula with hydrographic basins.

With an average annual precipitation of 1100 mm (CONAGUA, 2016a; INEGI, 2015), a karstic relief and flat topography, the entire peninsula functions as a recharge zone, and has a great infiltration capacity (Bauer-Gottwein et al., 2011; Holliday et al., 2007).

Nevertheless, changes in water balance are expected for the coming years due to precipitation reduction and temperatures increase (Alan et al., 2015; Rodríguez-Huerta et al., 2019; Sánchez Aguilar and Rebollar Domínguez, 1999). Besides, risk of contamination and saline intrusion near the coast limits the intensive use of groundwater (Aranda-Cirerol et al., 2010; Pérez Ceballos and Pacheco Ávila, 2004). The main sources of groundwater contamination in the YP aquifer are lack of wastewater treatment in rural communities, poor technical quality of sanitary sewer systems and low efficiencies of existing treatment plants (DOF 2015). In addition, agro- and breeding industries (specially pig and poultry, with a fast development in the area), consume pesticides and fertilizers in large quantities (Batllori Sampedro, 2015; OCDE, 2008). Infectious diseases associated to water quality are one of the main public health problem, due to high levels of bacterial contamination (SEMARNAT, 2015). Different studies set Yucatan in an unenviable place, being one of the states with the highest rates of illness and mortality due to Acute Diarrheal Disease (EDA), especially in children under 5 years old (Instituto Nacional de Salud Pública, 2013; SINAVE and Secretaría de Salud, 2012).

The demographic and economic growth of YP has caused pressure on the different ecosystem services, and their impacts are still unknown and ignored in the development plans of the region. Together with metabolic pattern, societal metabolism, generates a new narrative on how the YP development is linked to water uses, considering not only economic indicators but also its social functions, as well as the biophysical limits established by the main source of supply, the aquifer. This paper aims at diagnosing water consumption and characterizing societal water metabolism in the existing socio-economic system of the YP. To do so, we identify regional (i.e., states) similarities and differences in water uses and groundwater recharge (the main source of water supply), to finally determine whether consumption is within the limits established by the biophysical recharge conditions of groundwater. Besides, this diagnosis aims to fulfill one of the main hydrological research challenges in the region defined by Bauer-Gottwein et al. (2011) which includes the process of exchanging water for human use and water for ecosystems, and the consequences of incessant economic development and population growth.

2. Methodology

2.1. MuSIASEM

The analysis of societal metabolism presented here is based on the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (hereafter referred to as MuSIASEM) tool introduced by Giampietro and Mayumi (2000a, 2000b, 1997). It is an open framework that takes into account economic, environmental and social aspects, and distinguishes flows, such as water, energy, food, or monetary (IASTE, 2014). It is a decision support tool for different scenario analysis, including current trends and preferred scenarios to stay within the boundaries of the ecosystem. The MuSIASEM system of accounting is useful for the water metabolism study, as it allows us to deal with the multi-dimensionality of water and to connect non-equivalent definitions of performance across societal and ecological narratives (Giampietro et al., 2014).

Based on water metabolic rates (WMR), the methodology focuses on the interlinkage and relationship between human activities (HA) and consumed water (water use per hour). MuSIASEM describes the time distribution (fund) and water consumption (flow) for different hierarchical levels, which are defined by productive sectors in society as (equation 1):

$$WMR_i = WU_i/HA_i \tag{1}$$

where WMR_i is the water metabolic rate for productive sector i. The allocation of human activity (HA), measured in hours, assesses the productive sectors size of the socioeconomic system. The distribution profile of HA connects demographic and social parameters (Giampietro and Mayumi, 2000b). MuSIASEM facilitates the interdisciplinary analysis at different operational and dimensional levels, which gives the study a global visibility to problems with a systemic complexity, such as sustainable management of the water.

In Figure 3, the hydrological region represents the first hierarchical level of the analysis (n), which determines the biophysical limits of groundwater. This level can be drilled-down from the political division of the peninsula (State - municipality), to finally classify the uses from the different productive sectors. The first sublevel (n - 1) defines the groups of off stream uses of water that integrate remunerative activities and domestic uses. The last level of analysis (n-2) is further segregated following the division established by the classification of water uses provided by CONAGUA and adjusted to the classification of the volumes counted by the Public Registry for Water Duties and Rights (REPDA)[1]. Multiple uses represent concession titles registered with two or more water uses. For YP this classification is mainly composed of agricultural and livestock uses.

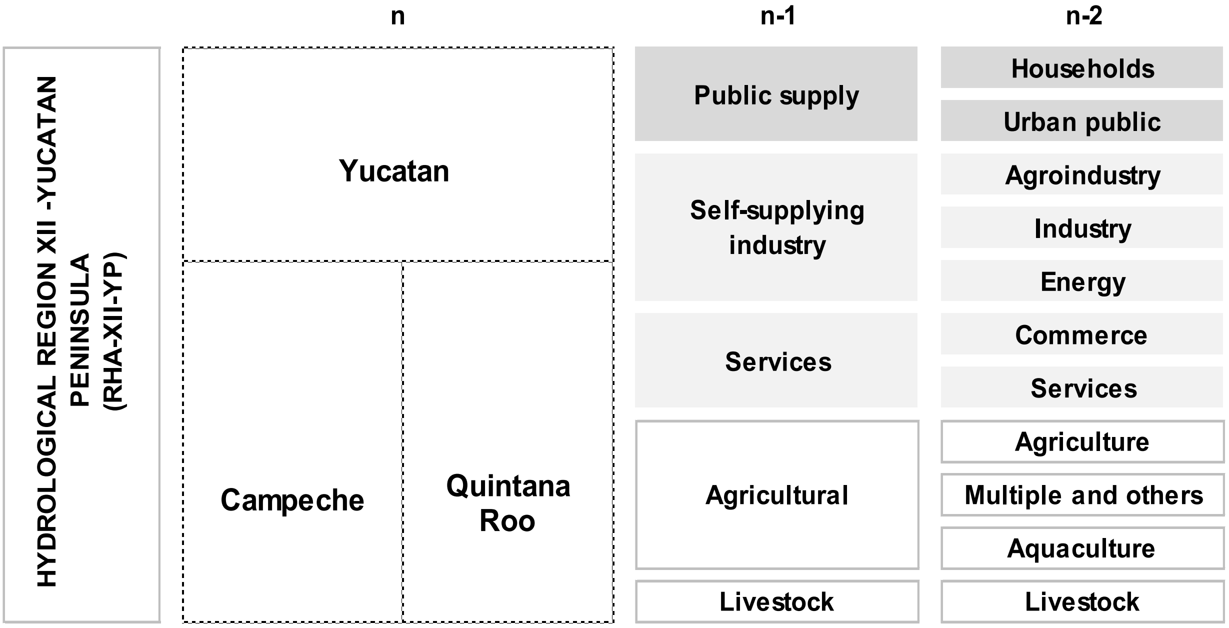

Figure 3. Structure of MuSIASEM in the hydrological region XII.

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[1] The Public Registry for Water Duties and Rights (REPDA for its Spanish translation, sp., *Registro Público de Derechos de Agua*) is an instrument of CONAGUA to regulate the exploitation or use of the national waters, their distribution and control, as well as the preservation of their quantity and quality, in order to achieve their integral sustainable development.

2.2. Demographic Data

MuSIASEM considers demographic variables (i.e., populations size) and ratios (i.e., dependency ratio), and social variables (i.e., employment, level of education and workload) looking at the profile of distribution of human activity over a given set of categories (Giampietro et al., 2013). According to data from the Population National Council of Mexico (sp., *Consejo Nacional de Población, CONAPO*), in 2010, YP reached a population of 4 million, and it is expected to reach 5.8 million by 2030. Yucatan represents 48% of the YP population, and it will remain the State with the largest population by 2030. With an average age of 25.7 years, its dependency ratio[2] was 54% in 2010, and is projected to remain around of 51% by 2030 (Figure 4).

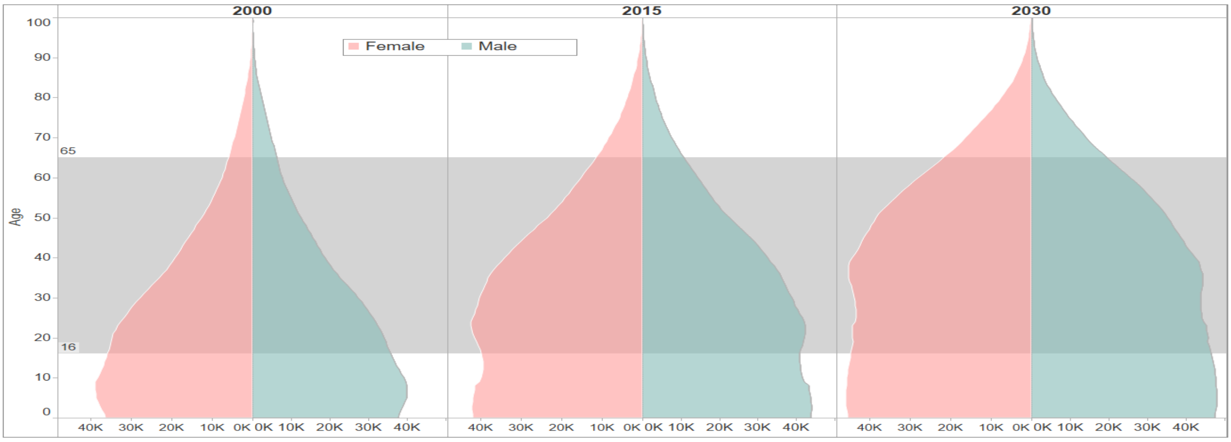

Figure 4. Population forecasts for Yucatan Peninsula. Data from **(CONAPO, 2015)**

Data about employment and hours worked (Figure 5) has been fine-grained into gender, age range and productive activity with the information of the National Survey of Occupation and Employment from the National Institute of Statistics and Geography (sp., *Instituto Nacional de Estadística y Geografía. INEGI*) (INEGI, 2010). Socio-economic data at the municipal level were obtained from reports by INEGI and the National Institute for Federalism and Municipal

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[2] The dependency ratio is the proportion of dependents (people under 15 or over 64) over the working age population (between 15 and 64 years).

Development (sp., *Instituto Nacional para el Federalismo y el Desarrollo Municipal*) (INEGI and INAFED, 2014) , and by the participation rates for economic sectors presented by the Secretary for Economic Development *(*sp.*, Secretaría de Fomento Económico, SEFOE)* SEFOE (2016).

Figure 5. Description of the labor structure in the Yucatan Peninsula. a) Working population pyramid. b) Weekly average hours worked by sector and genre. c) Distribution of employment by sector and State (YP)

The total hours for human activities by each productive sector i, is estimated by equation 2:

$$HA_i = total\ working\ weeks \cdot avg.hours\ worked\ per\ week \cdot number\ of\ employees \qquad (2)$$

2.3. Water balance in Yucatan Peninsula

Table 1 shows the water balance of the hydrological region XII of YP (Campeche, Quintana Roo and Yucatan). According to this balance, the maximum volume of groundwater that can be extracted is 7926 hm^3/year, corresponding to the annual average recharge received by the aquifer (25107 hm^3/year) less the natural discharge compromised (17181 hm^3/year) (CONAGUA, 2018). From this balance, the allocated volume in 2018 (4469 hm^3/year) meant 56% of the maximum available groundwater

Table 1. Water balance for RHA-XIII Peninsula de Yucatan 2018. Cozumel aquifer was excluded (2035). Source: (SEMARNAT and CONAGUA, 2018)

Input (hm^3 / year)		**Output (hm^3 / year)**		**(%) part.**
Groundwater recharge	25,107	Natural discharge	17,181	68%
		Water availability	3,457	14%
		Allocated volume (REPDA)	4,469	18%
Total	25,107	Total	25,107	

Although soil's characteristics contribute to groundwater recharge, there are local differences in the types and characteristics of the system (Steinich and Marín, 1997). Estimations coming from the application of monthly water balance models (Rodríguez-Huerta et al., 2019)[3] show (Table 2) a recharge between 118 mm ± 33 mm per year, with maximum recharge of 23,956 hm^3, within the range of other studies carried out with different methodologies which show a recharge of around 10% - 15% of the total annual precipitation (Bauer-Gottwein et al., 2011; CONAGUA, 2015; Gondwe et al., 2010; INEGI, 2002; Lesser, 1976; SEMARNAT,

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[3] Data visualization: https://public.tableau.com/profile/edgar.rodriguez.huerta#!/vizhome/GroundwaterrechargeYucatanPeninsula/VIZ

2015). However, it also shows that the recharge is not uniform throughout the YP. There are specific areas with a higher recharge: southwest of Campeche, center of Yucatan (where the hydrogeological reserve is located), and northeast of Yucatan, between the municipalities of Cenotillo and Tizimín. The northern region of the YP, with less precipitation, does not receive vertical recharge (Figure 6), but it benefits from the underground flows that go from the center of the peninsula to the north, and discharge in the coastal regions (Null et al., 2014).

Table 2. Estimation of water balance in the Yucatan Peninsula. Precipitation (P), Actual evapotranspiration (ETa) and recharge (R).

State	P (mm)	ETa (mm)	R (mm)	P (hm^3)	ETa (hm^3)	R (hm^3)
Campeche	1235	947	254	68045	52178	13880
Quintana Roo	1205	1,007	158	51302	42858	6643
Yucatan	1054	926	88	41513	36436	3433
RHA-XII-YP	1173	959	176	160860	131472	23956

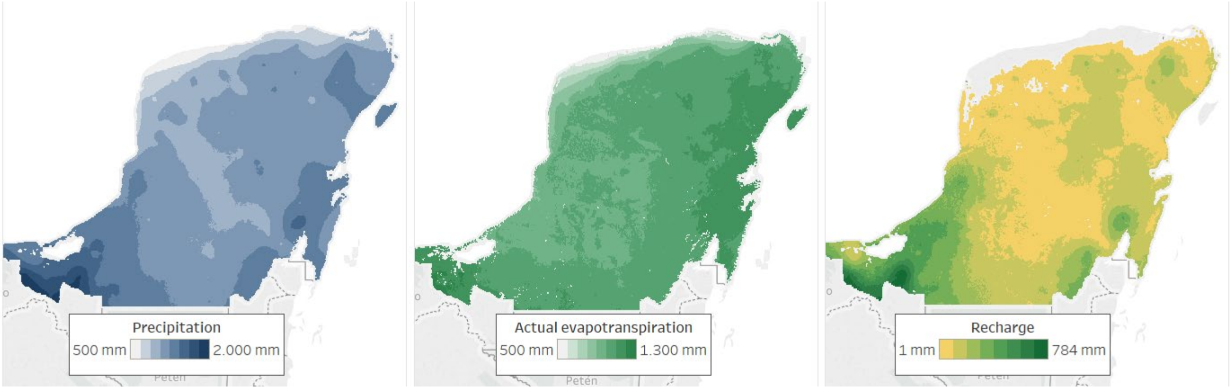

Figure 6. Estimation of water balance in YP.

2.4. Water consumption

As said before, the use of water for each productive sector in Mexico is allocated through the REPDA (CONAGUA, 2017; CONAGUA and SEMARNAT, 2017). According to it, in less than 15 years, water exploitation has increased more than three times, with the Yucatan State having the highest consumption, with 46.5% of the total (Figure 7). In 2017, the allocated volume in YP was 4792 hm³, with public supply representing 640 hm³ (13 %), agricultural uses 3449 hm³ (72 %) and industrial uses 691 hm³ (14 %). The public supply category takes into account water delivered through the drinking water pipeline distribution system that supply the households and services connected to the network distribution (CONAGUA, 2017, 2016a, 2009). Although industry and services (IN + SE) sectors represent only 3% of the volume allocated in YP, the consumption of small and medium-sized enterprises (SMEs) is included in the classification of public supply, being connected to the drinking water network and not having specific water use permits. The increase in consumption in Quintana Roo occurs in the service sector, and it is caused by the growth of the tourism economic subsector along the Cancun-Riviera Maya corridor.

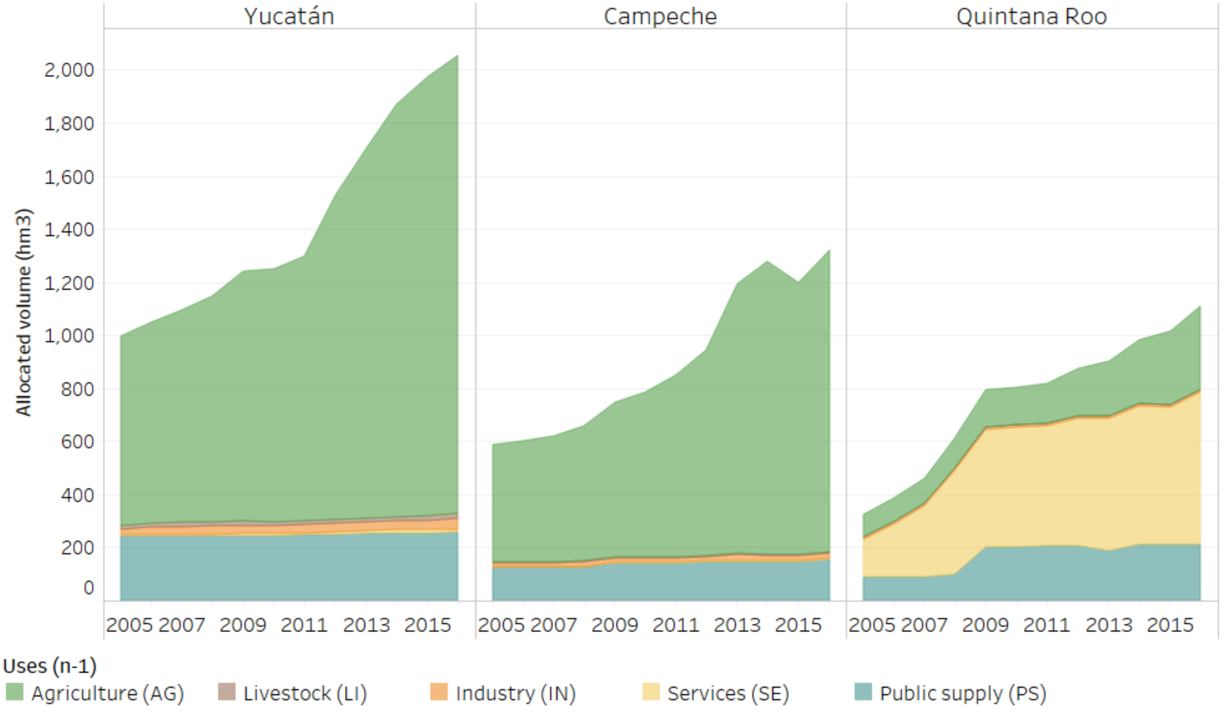

Figure 7. Trend of allocated volume in YP (2005 – 2016). Data from **(CONAGUA, 2017)**

Even though these are the official data, the allocated volume does not represent the real consumption, though it does allow for inferences and comparisons among sectors and uses in the country (Estrada Medina and Cobos Gasca, 2012; Pérez-Espejo and Constantino-Toto, 2016). To explain the behavior of consumption and its relation with the social structure, we calculate water uses for the domestic and the different productive sectors. This approach on water uses will serve as a new reference for water consumption, acknowledging the amounts allocated by REPDA that represents the planning of water exploitation.

2.4.1. Primary sector

Agricultural use was estimated from the following sources.

- **Crop Water Requirements** (**CWR**). We applied equation 3, where ET_o is the potential evapotranspiration, and K_c is the crop coefficient by each grow stage (Allen et al., 1998). CWR provides a view of water consumption, dividing water use into precipitation (green water) and irrigation requirements (blue water). We also consider losses in irrigation processes, which are between 40% and 50% in the region (Cob and Romero, 2011; Tun Dzul et al., 2011).

$$ET_c = ET_o K_c \qquad (3)$$

- **Climatological data**. We used monthly average precipitation and potential evapotranspiration for each municipality data from Fernández Eguiarte et al. (2015).
- **Crop production**. Data obtained from the Agri-food and Fisheries Information Service (sp., *Servicio de Información Agroalimentaria y Pesquera*, *SIACON*) database (SAGARPA, 2017), disaggregated by:
    - Crop
    - Cycle (Fall-Winter, Spring-Summer, Perennials)
    - Municipality

For crop information, like growth stages and coefficients (K_c), we used pre-loaded data from CROPWAT software (FAO, 2014), as well as FAO studies (Allen et al., 1998; Chapagain and Hoekstra, 2004). Additionally, several coefficients were adjusted from regional and crop-specific studies (Dávila Lara and Guevara Granda, 2014; Kelso-Bucio, Henry A.; Bâ, Khalidou M.; Sánchez-Morales, Saúl; Reyes-López, 2012; López Avendaño, 2009; Ruiz Corral et al., 2013; SAGARPA et al., 2015). Crop data coefficients are included in the supplementary information (Supplementary information 1) as well as CWR results by crop group and municipality (see also section 4). To calculate the effective rain, we chose the method of the Soil Conservation Services of United States Department of Agriculture (USDA SCS) (Chapagain and Hoekstra, 2004).

Water use in livestock sector was calculated by mean values of consumption (drinking and services) for each species given by Mekonnen and Hoekstra (2010), using water footprint methodology. For specific cases, like turkey and bees, the values considered were 1.07 liters per day (V&S Asociados, 2014) and 3 liters per day (SAGARPA, 2000) respectively. These consumption factors are multiplied by the number of heads (inventoried and slaughtered) of each species[4] according to the SIACON database (SAGARPA, 2017).

Considering these data, the water use in the primary sector reaches 1,770 hm^3, which compared to the 3,183 hm^3 reported by REPDA, represents 56% of the total volume allocated (Figure 8). This estimation for the agricultural sector allows us to disaggregate the consumption beyond the official data of REPDA, and use the consumption at a level of crop group, to apply them in performance indicators (section 4).

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[4] For the case of bees, number of hives is considered.

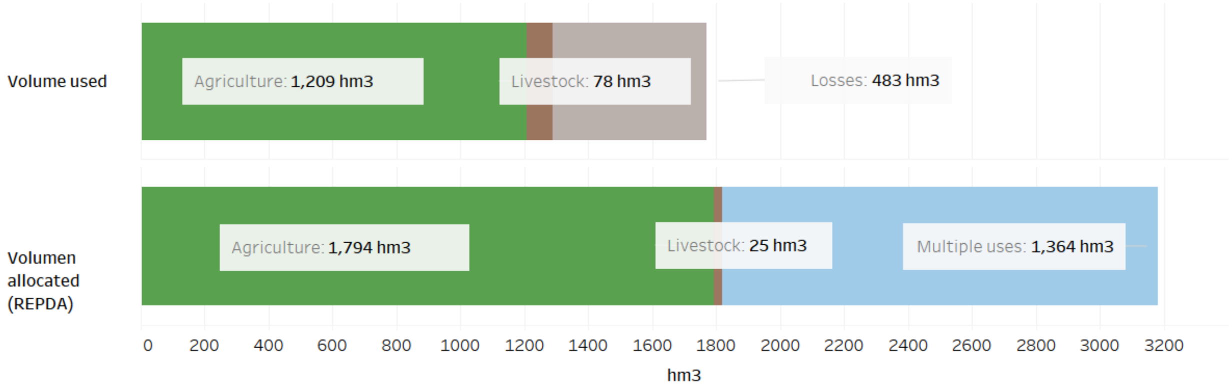

Figure 8.Comparison between allocated and used volume for YP in 2016. Losses consider 60% efficiency.

2.4.2. Industry and services

There are eight industrial subsectors that concentrate approximately 83.5% of water consumption in Mexico (CONAGUA, 1991): sugar, paper and cellulose, beverages, food, textiles, chemicals, petroleum, and iron and steel industries. Although differences in water use between industrial and service sectors are significant, essentially due to differences in area and volume of productive activity, due to the lack of information on the uses for each of the different economic activities, we have assumed the following criteria:

- **Intensity by industry.** Here we consider consumption factors established in the study *'Compendium of indicators on the use of water in industry'* (CONAGUA and IMTA, 2001) in units m^3/Mg. Data are estimated from the information of the 2009 and 2014 economic censuses (INEGI, 2014a), dividing the value of production by the average price of each type of activity (INEGI, 2017). For the generation of electrical energy, consumption is estimated based on the gross generation of electrical energy (SENER, 2018), and the specific rates of water use for generation plants expressed in liters per kilowatt-hour for each type and cooling system (CONAGUA and IMTA, 2001). In the case of the tourism sector, consumption was obtained from the base usage per night according to room’s category, given by CONAGUA (2016a), multiplied by the number of nights sold by State and category, according to the tourist economic census (INEGI, 2014b). For other industries and commercial activities, we have assumed an average consumption of 250.2 m^3/month and 27.42 m^3/month respectively, as indicated in the drinking water and sewerage manual (CONAGUA, 2016b).

- **REPDA.** The allocated volume of REPDA permits, as already mentioned, is not the consumption data, but the theoretical limits for industrial end services sectors. Therefore, it is important to consider them. In the case of YP, the uses for the generation of electric power are included in the industrial group.

Our results for year 2016 (Figure 9) indicate an average use of 22.7 hm^3 and 52.7 hm^3 for secondary and tertiary sectors in Campeche and Yucatan, respectively. However, if we compare both estimations for Quintana Roo, the consumption increases to 514.6 hm^3, which indicates the atypical consumption for tourism sector in this state. This value is approximately 10 times more than the average consumption in the sector for YP. This is mainly due to the style of accommodation offered and to the annual number of visitors, which approaches 17 million tourists, with an average stay of 2 nights (SEDETUR (Secretaría de Turismo), 2018).

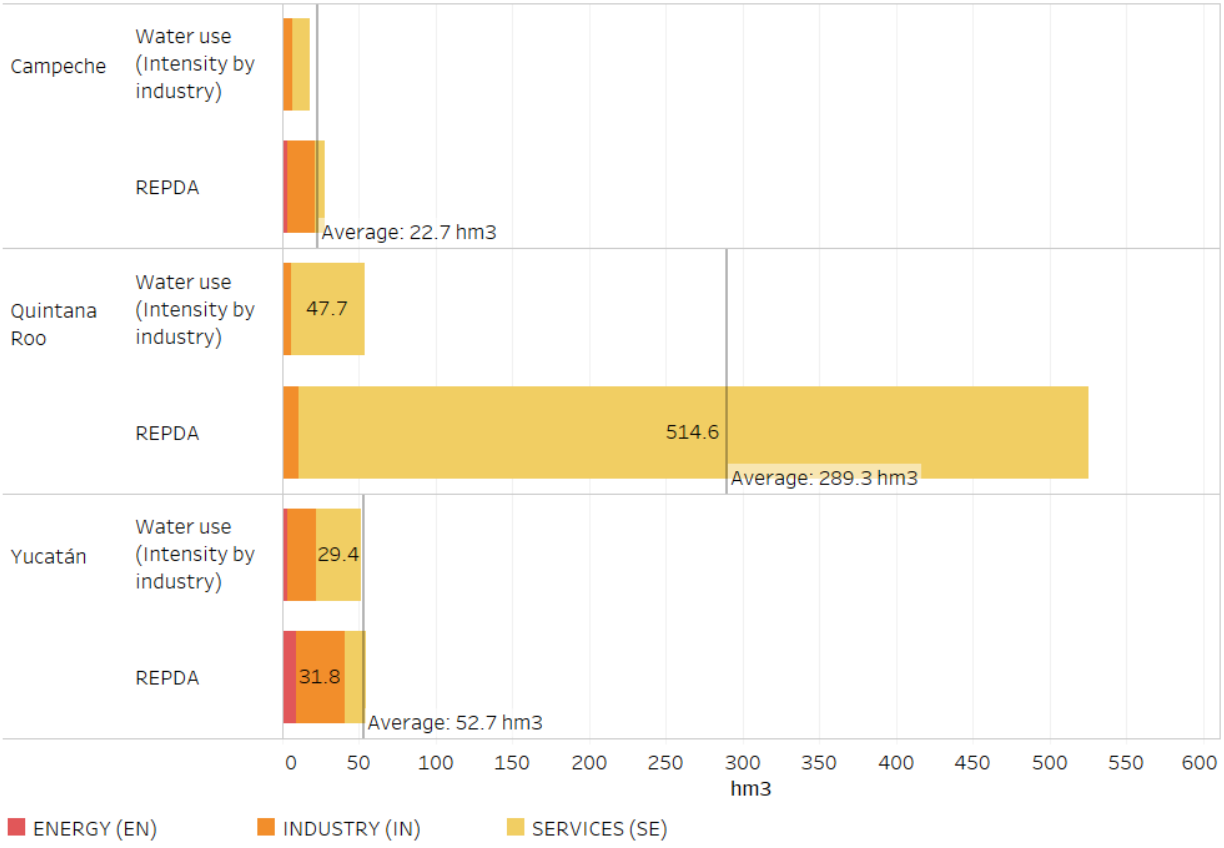

Figure 9. Water use for industry and services sectors by State in YP (2016).

2.4.3. Households

Due to the lack of information at the municipal level, calculation is based on the number of habitants in each locality (CONAPO, 2015), multiplied by the daily consumption according to regional socioeconomic levels and climatological characteristics (Table 3). Data on daily consumptions by socioeconomic level were obtained from the Manual of Drinking Water, Sewage and Sanitation (CONAGUA, 2016b), which categorizes urban and rural localities as well as climatic conditions for daily consumption in urban regions. The socioeconomic distribution for each municipality is estimated according to López Romo (2011).

Table 3.Estimation of water consumption for domestic use in YP (2016)

Type of locality	**Socio-economic level**	**Population**	**Consumption per capita (litters per day)**	**Net water uses in household sector (m^3)**
Rural	High	957	100	34,949
	Medium	45,078	100	1,645,361
	Low	104,176	100	3,802,432
Urban	High	126,085	243	11,183,087
	Medium	2,878,439	206	216,429,835
	Low	1,532,421	198	110,748,079
Total		4,687,157		343,843,742

Water losses in municipal networks present during the distribution process are also considered. The experience in Mexico indicates that in the medium and long term it is possible to reach efficiency values between 25 and 30% (CONAGUA, 2016b). In the case of Mérida, Yucatan's capital, the losses are around 50% (JAPAY (Unidad de Transparencia), 2016). For our case study, a network efficiency of 60% was defined as an intermediate value between the current efficiency and the established 70% objectives (CONAGUA, 2016b). The domestic consumption in YP during 2016 between 481 hm^3 and 624 hm^3 (Figure 10).

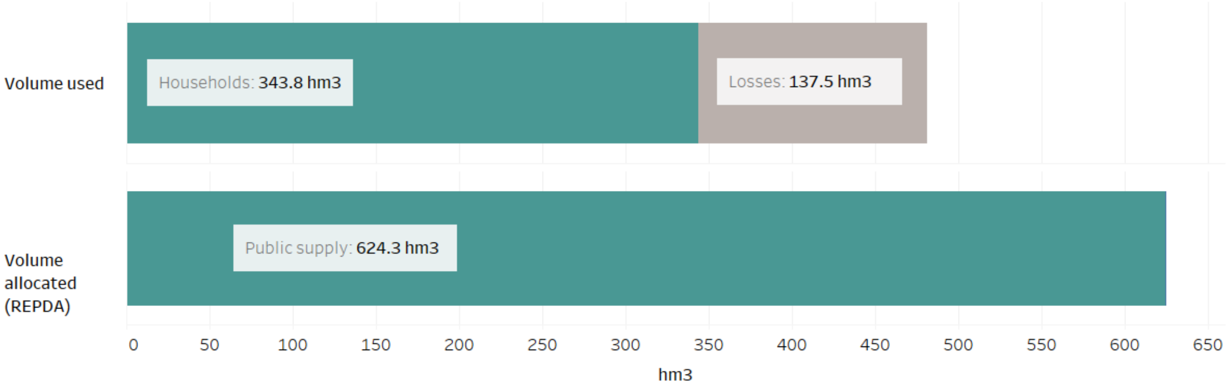

Figure 10. Allocated volume and estimated use (hm^3) in YP (2016). Water distribution network efficiency of 60%

2.5. Geographical levels

Our analysis granulates regions or municipalities, in order to distinguish socio-economic differences among specific areas. For this case study, we chose two areas both located in Yucatan with totally different characteristics: an urban area with mainly domestic and industrial uses, and an agricultural one with important irrigation districts (Figure 11):

- The city of Merida concentrates 50% of the population in 2% of the area of the state. Most industries are also located on the outskirts of the city. Its populations are expected to increase 24% by 2030. Its main problem is urban growth without clear water management policies, as well as the lack of efficient drainage and sewage infrastructures.
- JIOBIOPUUJ reserve is a biocultural conservation reserve covering part of five municipalities (Muna, Oxkutzcab, Santa Elena, Tekax and Ticul)[5] with 130,000 habitants, 20% as rural population, and an expected growth of 29% by 2030. It concentrates archaeological sites and important Mayan settlements, as well as areas of jungle. Within the region there is an irrigation district (Ticul) with an area of 9,000 ha., the largest in Yucatan. Irrigation districts are a compact cultivation area with one or more common sources of water supply. CONAGUA directly supervises, and grants concessions to civil associations to manage their use, and conserve the irrigation infrastructure (Pedroza González and Hinojosa Cuéllar, 2014).

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[5] Due to the availability of data, the 5 complete municipalities are considered as the reserve area JIOBIOPUUJ

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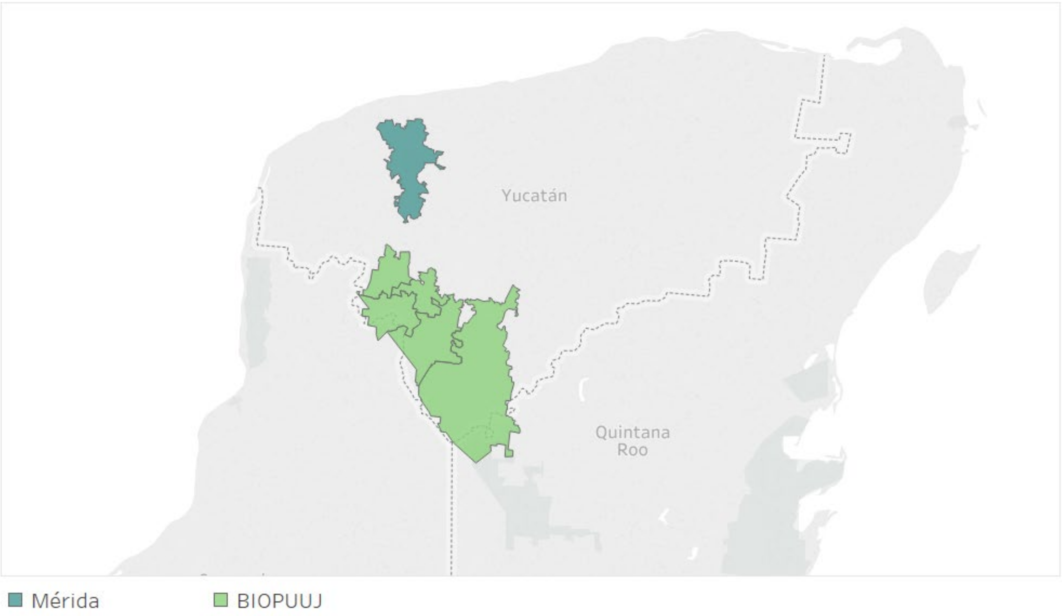

Figure 11. YP map, with Mérida and JIOBIOPUUJ sub-regions included in this MuSIASEM analysis.

3. Results

3.1. Water balance and renewable water

In YP the renewable water per capita exceeds 5,000 m^3 / per capita per year (CONAGUA, 2016a; UNEP-DHI et al., 2016). This value is more than three times the defined water stress limit of 1,700 m^3 / per capita per year (WWAP (World Water Assessment Programme), 2012). However, recharge is not always concentrated in the most populated regions or with the highest consumption. If we drill down and split, water availability varies at different geographical scales (i.e., hydrographic basins) and we can identify that the average data does not apply equally to each region (Table 4).

Table 4. Renewable water by state and hydrological basin. Data from: (Rodríguez-Huerta et al., 2019)

Renewable water (m^3/y/hab)	**Campeche**	**Quintana Roo**	**Yucatan**	**RHA-XII-YP**
Grijalva-Usumacinta (RH30)	22,345			22,345

West Yucatan (RH31)	10,925		3,909	10,916
North Yucatan (RH32)	4,354	1,355	1,518	1,571
East Yucatan (RH33)	39,248	12,253	5,888	13,024
RHA-XII-YP	15,062	4,101	1,600	5,111

The hydrological basin analysis let us compare consumptions and an estimated amount of vertical recharge corresponding to the area of each basin, assuming no runoff in the region and disregarding underground flows that occur within the groundwater, and relevant for coastal areas mainly – (Albornoz-Euán and González-Herrera, 2017; Carballo Parra, 2016; Cervantes Martínez, 2007; Gondwe et al., 2010).

3.2. Water metabolic rates in YP, States and municipalities

Water metabolic rate (WMR) describes how societies consume water according to their socio-economic structure, with the objective of observing the behavior and evolution of the consumption for each productive sector. WMR characterizes the typology of consumption to compare it with other regions. For water consumption data, we use consumption results (section 2.4) as well as REPDA data. As shown in Table 5, rates vary depending on how the consumption is considered: through allocated volume (max), or estimated use (min). For example, metabolic rate in YP varies between 58 l/h to 110 l/h, a pattern describing how productive sectors consume water at the State level in the peninsula. Considering only those volumes mentioned by REPDA, WMR has increased in YP from 58 l/h in 2005, to 110 l/h in 2016, an increase of 8.96% liters per available hour per year.

Table 5. Water metabolic rate (WMR) in l/h in Yucatan Peninsula (YP) for 2016 (HH: Households, PW: Paid work, AG: Agriculture; IN: Industry; SE: services).

Level		Yucatan	Campeche	Quintana Roo	YP
N	**WMR**	**78 - 110**	**58 - 164**	**32 - 78**	**58 - 110**
N-1	WMR (HH)	13 - 15	13 - 22	14 - 17	13 - 17
N-1	WMR (PW)	580 - 844	425 - 1339	159 - 511	397 - 812

N-2	*WMR (AG)*	*5447 - 7979*	*2355 - 7606*	*2746 - 3839*	*3926 - 7099*
N-2	*WMR (IN)*	*37 - 84*	*34 - 113*	*22 - 46*	*33 - 80*
N-2	*WMR (SE)*	*22 - 10*	*21 - 13*	*34 - 402*	*27 - 179*

Figure 12 shows WMR time evolution from year 2005 to year 2016. Each productive sector presents a characteristic growth pattern in its metabolic pattern (WMR, in l/h) as a function of its water consumption (REPDA, in hm^3).

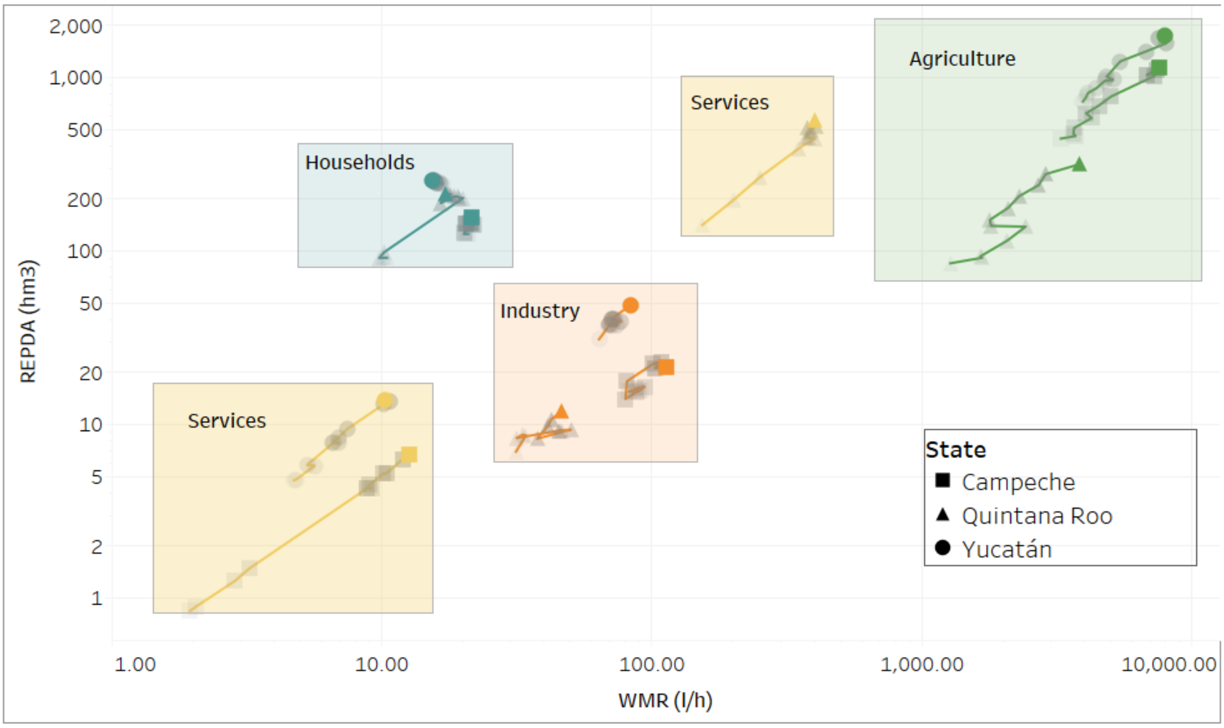

Figure 12. Evolution of water metabolic rate (WMR) and allocated volume (REPDA) in YP (2005 – 2016). Data shown in double logarithmic scale.

Campeche and Yucatan have patterns with similar behavior, however we clearly appreciate that Quintana Roo has a relevant weight in the service sector – merely focused on tourism—, with consumption patterns 10 times higher than the rest of the peninsula.

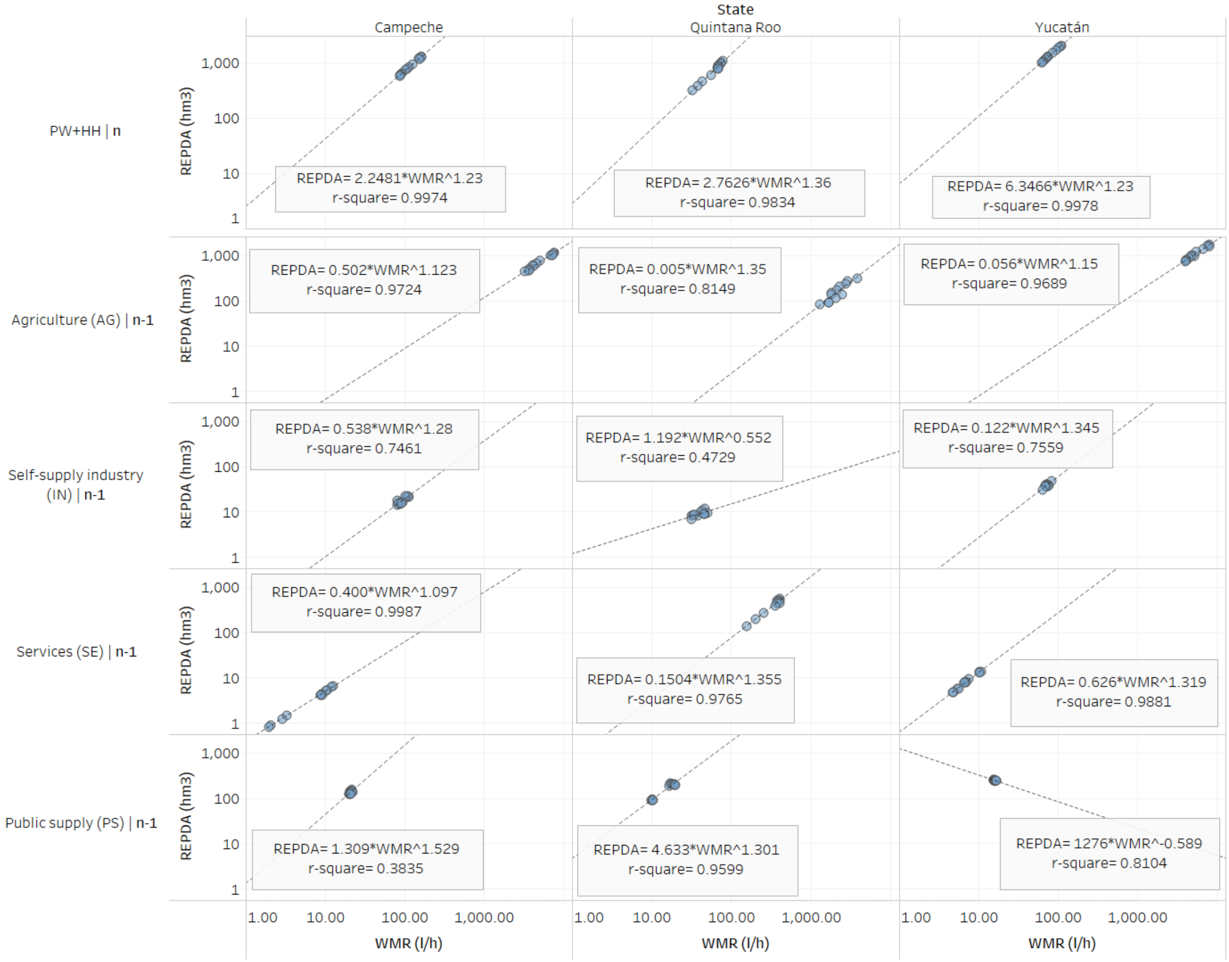

Figure 13. Scaling behavior (see Table 6 for corresponding power law fittings) between WMR (l/h) and REPDA (hm^3), and for the aggregate YP region and economic sectors. Data shown in double logarithmic scale.

Table 6. Scaling exponents for power law fittings (see Figure 13) with adjusted R^2 and 95 percent confidence interval, for the aggregate YP region and economic sectors. Values in bold indicate significant results (i.e., considering both tails of the confidence interval).

	Campeche			**Quintana Roo**			**Yucatan**		
Sector	b	R^2	$95\%CI$	b	R^2	$95\%CI$	b	R^2	$95\%CI$
Yucatan Peninsula (n)	**1.23**	0.99	[1.18, 1.27]	**1.36**	0.98	[1.23, 1.49]	**1.23**	0.99	[1.19, 1.27]
Agriculture (AG) | (n-1)	**1.12**	0.97	[0.99, 1.26]	1.35	0.81	[0.89, 1.81]	**1.15**	0.97	[1.00, 1.30]
Self-supply industry (IN) | (n-1)	1.28	0.74	[0.75, 1.81]	0.55	0.47	[0.14, 0.97]	1.34	0.76	[0.80, 1.89]
Services (SE) | (n-1)	**1.10**	0.99	[1.07, 1.12]	**1.36**	0.97	[1.07, 1.12]	**1.32**	0.98	[1.22, 1.42]
Public supply (PS) | (n-1)	1.53	0.38	[0.14, 2.92]	**1.30**	0.96	[1.11, 1.49]	-0.59*	0.81	[-0.79, -0.39]

Metabolic patterns values (WMR) and their relation to water allocated (REPDA) can be used as a reference or benchmark to define expected values of water consumption per available hour of the different productive sectors. Table 6 shows the scaling exponent b for each sector, obtained from a best fit to a power law scaling relation, shown in Figure 13, of the form $REPDA \sim WMR^b$, including adjusted R^2 and 95% confidence interval. With the exception of public supply in Yucatan, and self-supply industry in Quintana Roo, all values indicate super linear scaling relations with $b > 1.00$, implying a remarkable level of unsustainability in the water use evolution for the different States and productive sectors.

A geographical drill-down describes the relationship between flows and funds according to each socio-economic structure. It facilitates the understanding of the relationships within the system and helps for the implementation of appropriate local policies for sustainable development. For example, mainly urban areas (like the previously mentioned Merida city) have higher rates than State consumption pattern for the domestic (HH) and services (SE) sectors, while agricultural areas as BIOPUUC show an emphasis on the consumption pattern of the primary sector (AG) (Table 7).

Table 7. WMR (l/h) related to water allocated (REPDA) broken down by case study, MuSIASEM level (n) and economic sector. Data from 2016.

Level	WMR	Merida	JIOBIOPUUC
N	*Total*	*27.3*	*223.9*
N-1	Households	21.6	11.6
N-1	Paid work	73.5	2,593.3
N-2	Agriculture	3,453.3	11,388.5
N-2	Industry	133.5	8.2
N-2	Services	17.0	3.5

3.3. Estimation of water uses by 2030

We estimate here future consumption rates based on population growth for 2030, economic growth scenarios and historical patterns on WMR described in the previous section. For the estimation of water uses in the YP, the following scenarios were defined:

(1) **Uses as 2016 (U2016):** WMR calculated with the uses in section 2.4 for each productive sector. The estimation of water uses defines the lower limit of consumption. This scenario keeps constant the consumption pattern in each sector, but with the demographic change expected for 2030.

(2) **Uses with continuous growth (UCG):** WMR is estimated from 2% annual growth until 2030, which is equivalent to an accumulated increase of 30% in the metabolic pattern.

(3) **Moderate-growth (MG):** a smoothed growth of the metabolic rate is expected, reaching the limit of a sigmoid function. It is calculated from the historical data adjusted with a logarithmic regression of each metabolic pattern and productive sector. In this scenario we assume measures and policies to maintain stable patterns have been considered.

(4) **Business as usual (BAU):** This scenario assumes current growth rates. We use REPDA values and consider the metabolic patterns according to a lineal regression of the last 12 years (2005 – 2017).

For each scenario, we assume:

- The same percentage of the active population as at present-day.
- The employment in each sector according to the current proportion, taking into account gender and age range (STPS, 2016).

According to the WMR and population growth trend in YP, water consumption will be between 2811 hm^3 and 3635 hm^3 (scenarios 1 - 2). Using REPDA values (scenario 3 - 4) the consumption will vary from 5227 to 7955 hm^3 for 2030, which represent an increase 34% and 106% respectively compared to allocation in 2017.

Any policy on consumption should consider the biophysical limits of the environment, in this case, the conditions of the water cycle and how this can be modified in the coming years from the effects of climate change. We define these biophysical limits based on the possible effects that climate change will have on the recharge of groundwater in the near future. Here the effects of climate change on the RHA-XII-YP are based on the results of Rodríguez-Huerta et al. (2019), which considers 5 different models of general circulation (GCM). In general, GCMs estimate a reduction of 20 mm in annual precipitation together with a temperature increase of 1.15 °C. This decrease in rainfall could lead by one hand, to an increase in intense periods of drought, a decrease in the productivity of agricultural activities with a consequent reduction in food production (Galindo and Caballero, 2010); on the other hand, the increase in temperature will cause an increase in domestic consumption ratios, so the recharge will be lower, and the consumption rates will be higher with a population that continues to grow.

Figure 14 compares water uses estimated by each scenario presented in section 3.3 with the current recharge (CONAGUA data and calculated data), and with the range given by the new limits for the recharge of groundwater established by the effects of climate change (i.e., a reduction of 23% of groundwater recharge). Considering that the proportion of the natural discharge is kept at 60% (Table 1) of the total recharge[6] (SEMARNAT and CONAGUA, 2018), we observe that the consumption reaches or exceeds the recharge of groundwater in scenarios 3 and 4, exceeding by 2,850 hm^3 the limit of the average annual recharge in the last scenario, which compromises the natural discharge and makes the consumption of water untenable.

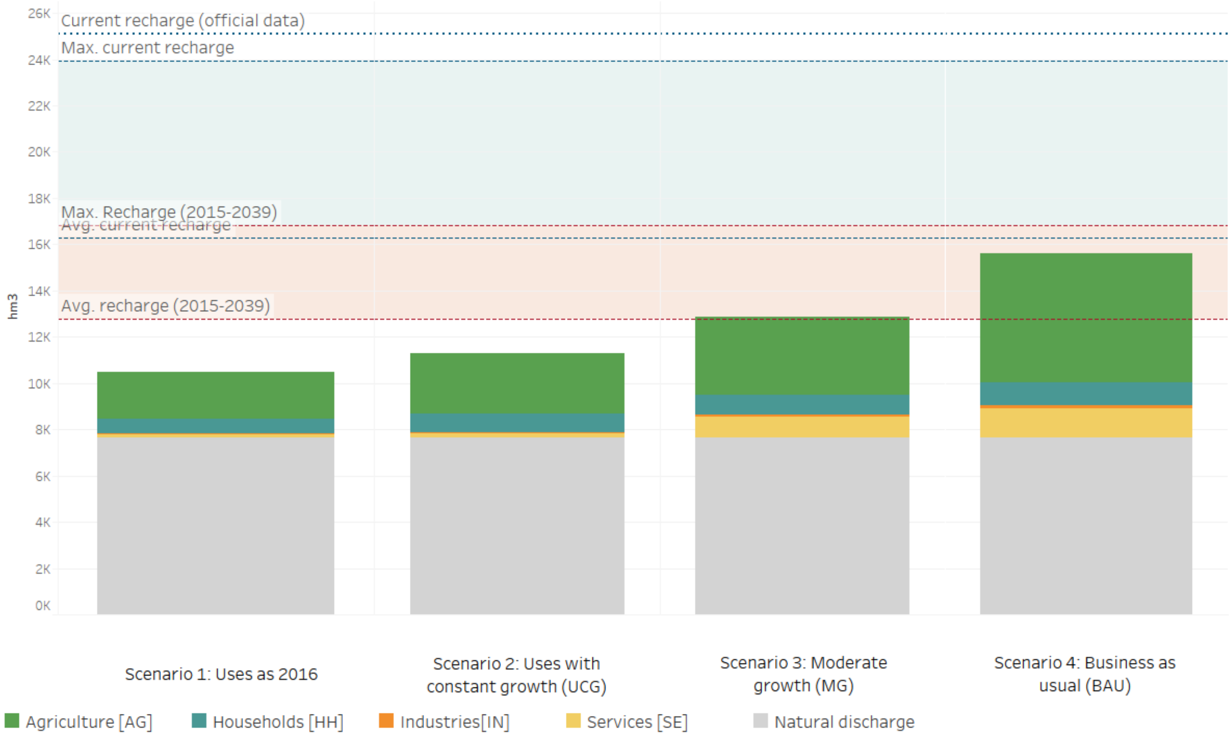

Figure 14. Comparison of estimated recharge for 2030 with water consumption for each scenario.

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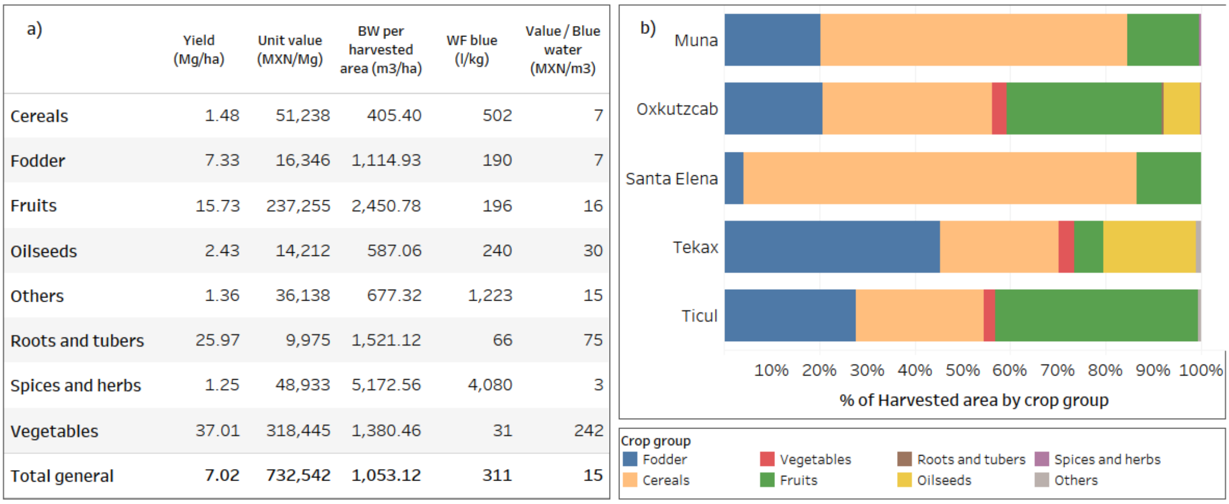
[6] Although data from CONAGUA establish a natural discharge of 60%, more studies are needed on a smaller scale to determine natural discharge through YP, which include the natural inhomogeneity in geological and topological variables in the peninsula.

4. Discussion and Conclusions

Our purpose with this analysis has been to identify patterns of consumption beyond general averages, 'per capita' indicators and for one particular geographical scale in the case of the YP. The increase in water consumption is not only linked to population growth but to the structure of the different productive sectors. This structure is not organized under a top-down hierarchical relationship but related to the particular demographic and economic dynamics found in the different regions. Our results identify the main metabolic links that affect water consumption, considering the social and economic factors that simultaneously drive the evolution of the metabolic pattern.

Metabolic and consumption values associated to each productive sector depend on the relative characteristics of the sector and its weight within the society. In general, similar societies will have similar patterns across sectors, either productive or domestic, with sublinear, linear or superlinear scaling exponents which suggest different levels of efficiency in the use of resources and growth (Bettencourt et al., 2007; Horta-Bernús and Rosas-Casals, 2015; West, 2017; West and Brown, 2005). In the same way that a modern society requires more exosomatic energy, it also occurs with water uses. The growth of WMR explains how each productive sector has evolved in the last ten years in YP, and how this development is related to an increasing water demand. For example, in 2016, the agricultural sector required 118% more water per working hour than it was needed in 2005, while industry and services sectors required more than 30% and 180% respectively. Although differences in the scaling exponent b suggest different evolutionary trends linked to different hierarchical and organizational levels (as shown in Figure 3) operating in different ways and according to multiple scales, aggregated results for the YP (Table 6, first row) suggest an increasingly demanding evolutionary trend in terms of water consumption. In the case Public supply of Yucatan, we cannot be sure that the negative trend represents less consumption in the future, because it is related to the fact that the assigned permit (REPDA) for public and domestic use has increased by 5% in the last 10 years, while the population has increased by 18% in the same period. For this case, it would be appropriate to investigate why this concession has increased at this rate.

At different geographical scales, our study describes different consumption patterns across YP, and compares the social and economic characteristics of each state, allowing the personalization of development plans, protection policies, or concrete actions that contribute to groundwater conservation. In this case, it is fundamental to review other relationships among flows and funds according to each one of the specific case studies. MuSIASEM methodology allows this process as a result of its multilevel accounting capacity, analyzing the information in a nested and hierarchical way while there is available information. For example, we can analyze the flows together with intensive indicators in the JIOBIOPUUC region mentioned in section 2.5 (Figure 15). If we can recognize patterns by type of crop, and compare them with the percentage of share of the harvest area, we can establish new mix of crops in each region that better adapt to climatic conditions and contribute a greater benefit to the region.



a)

	Yield (Mg/ha)	Unit value (MXN/Mg)	BW per harvested area (m3/ha)	WF blue (l/kg)	Value / Blue water (MXN/m3)
Cereals	1.48	51,238	405.40	502	7
Fodder	7.33	16,346	1,114.93	190	7
Fruits	15.73	237,255	2,450.78	196	16
Oilseeds	2.43	14,212	587.06	240	30
Others	1.36	36,138	677.32	1,223	15
Roots and tubers	25.97	9,975	1,521.12	66	75
Spices and herbs	1.25	48,933	5,172.56	4,080	3
Vegetables	37.01	318,445	1,380.46	31	242
Total general	7.02	732,542	1,053.12	311	15

Figure 15. a) Intensive indicators for crop group in BIOPUUC region (2017). b) Share (%) of harvested area by crop group.

Another, and complementary, approach would be to drill-down at a crop level. In this case, we break down the information for a specific crop (i.e., maize-grain) to differentiate water requirements, yield, or profitability according different cultivation conditions (cycle-irrigation mode) (Table 8). We observe that the yield in the rain-fed areas is lower than irrigation areas, which causes water footprint in rain-fed areas to be higher than the national average, between 1,700 and 1,900 l (Hoekstra and Chapagain, 2006; Mekonnen and Hoekstra, 2011). Another relevant aspect is the relationship between economic value and blue water, since there is a difference of one order of magnitude between cycles, due to the increase of blue water during the autumn-winter season. Considering only the indicators in table 8, continue sowing maize in the autumn-winter cycle with rain-fed should be evaluated, since its performance indicators are below than the regional average. The sustainable use of water in agriculture is not only the efficient use of irrigation water (blue), but also relies on a better use of rainfall (green).

Table 8. Summary of agriculture indicators for maize-grain broken down by cycle and modality (2017).

	Spring-Summer		**Autumn-Winter**	
	Irrigation	**Rain-fed**	**Irrigation**	**Rain-fed**
Harvested (ha)	5,918	339,234	7,656	14,397
Production (Mg)	23,976	614,047	30,319	15,947
Yield (Mg/ha)	4.05	1.81	3.96	1.11
Unit value (MXN/Mg)	3,920	4,223	3,757	3,603
Water footprint [blue] (l/kg)	62	184	437	1,268
Water footprint [green] (l/kg)	1,167	2,575	508	2,119
Value / BW (MXN/m^3)	63	23	9	3

In summary, MuSIASEM facilitates this complex and interdisciplinary analysis of sustainable water management, at different operational scales. Hierarchical structure and multilevel breakdown provided by this methodology give the possibility of continuing with the breakdown of information (provided sufficient data is available), either geographically or within the same sector. The division of the RHA-XII-YP at the municipal level, although it is a simple approach, serves to understand a complex problem. Water consumption varies according to the geographic level in which it is studied, but data management of a region can hide specific details of smaller local areas, where water consumption may have completely different characteristics. Our results suggest the overall necessity to change the strategies of consumption and water allocated in YP, which should give priority to resources conservation instead of economic growth.

5. Acknowledgments

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7. Supplementary information

Supplementary information 1. Crop data

Crop	**K_c ini**	**K_c med**	**K_c fin**	**Stage ini**	**Stage dev**	**Stage mid**	**Stage late**	**Planting / Green up day**	**Cycle**
Aloe	0.35	0.5	0.3	160	90	90	20	01-May	Perennes
Annona	0.6	0.85	0.75	20	70	120	70	01-May	Perennes
Anthuriums	0.95	1	0.75	30	30	15	15	01-May	Spring-Summer
Avocado	0.6	0.85	0.75	60	90	120	95	15-Jan	Perennes
Banana	1	1.2	1	120	60	180	5	01-Feb	Perennes
Basil	0.6	1.15	1.1	20	30	30	15	01-May	Spring-Summer
Bean	0.4	1.15	0.35	20	30	40	20	01-May	Spring-Summer
Bean	0.4	1.15	0.35	20	30	40	20	01-Nov	Autumn-Winter
Bean (green)	0.5	1.05	0.9	20	30	30	10	01-Oct	Autumn-Winter
Bean (green)	0.5	1.05	0.9	20	30	30	10	01-May	Spring-Summer
Breadnut	1	0.95	0.7	140	30	150	45	01-May	Perennes
Cabbage	0.7	1.05	0.95	40	60	50	15	01-May	Spring-Summer
Cabbage	0.7	1.05	0.95	40	60	50	15	01-Oct	Autumn-Winter
Caimito	0.6	0.85	0.75	20	70	120	70	01-May	Perennes
Carambolo	0.6	0.85	0.75	20	70	120	70	01-Apr	Perennes
Cashew apple	0.6	0.95	0.75	60	90	120	95	01-May	Perennes
Cassava	0.3	1.1	0.5	20	40	90	60	01-Apr	Spring-Summer
Castor oil plant	0.6	1.12	0.6	180	60	90	35	01-May	Perennes
Chayote	0.6	0.8	0.65	30	45	35	10	01-May	Spring-Summer
Chayote	0.6	0.8	0.65	30	45	35	10	01-Oct	Autumn-Winter
Chilies (green)	0.7	1.05	0.95	35	45	40	15	01-May	Spring-Summer
Chilies (green)	0.7	1.05	0.95	35	45	40	15	15-Oct	Autumn-Winter
Chrysanthemum	0.95	1	0.75	30	30	15	15	01-May	Spring-Summer
Chrysanthemum	0.95	1	0.75	30	30	15	15	01-Oct	Autumn-Winter
Cilantro	0.7	1.05	0.95	20	30	30	15	01-May	Spring-Summer
Cilantro	0.7	1.05	0.95	20	30	30	15	01-Oct	Autumn-Winter
Coconut	0.95	1	1	120	60	180	5	15-Feb	Perennes
Cotton	0.35	1.2	0.6	30	50	60	55	01-May	Spring-Summer
Cucumber	0.6	1	0.75	25	35	50	20	01-Jul	Spring-Summer
Cucumber	0.6	1	0.75	25	35	50	20	01-Nov	Autumn-Winter
Daisies	0.95	1	0.75	30	30	15	15	01-Oct	Autumn-Winter
Dragon fruit	0.35	0.5	0.3	160	90	90	20	01-May	Perennes
Dry Pepper	0.6	1.05	0.9	30	35	40	25	01-May	Spring-Summer
Eggplant	0.6	1.05	0.9	20	30	30	15	01-May	Spring-Summer
Eggplant	0.6	1.05	0.9	30	40	40	20	15-Oct	Autumn-Winter
Flowers	0.95	1	0.75	30	30	15	15	01-May	Perennes
Gerbera	0.95	1	0.75	30	30	15	15	01-May	Perennes
Gladiolus	0.95	1	0.75	30	30	15	15	01-May	Spring-Summer
Gladiolus	0.95	1	0.75	30	30	15	15	01-Oct	Autumn-Winter
Grape	0.55	0.9	0.6	20	70	120	60	01-May	Perennes
Grapefruit	0.7	0.65	0.7	60	90	120	95	15-Jan	Perennes
Groundnut	0.4	1.15	0.6	25	35	45	25	01-Jul	Spring-Summer
Groundnut	0.4	1.15	0.6	25	35	45	25	01-Oct	Autumn-Winter
Ground cherry	0.6	1.15	0.8	30	40	40	25	01-May	Spring-Summer
Ground cherry	0.6	1.15	0.8	30	40	40	25	15-Oct	Autumn-Winter
Guava	0.55	0.9	0.65	20	70	120	60	01-May	Perennes
Jackfruit	0.6	0.85	0.75	20	70	120	70	01-May	Perennes
Jamaica flower	0.65	1	0.6	30	30	15	15	01-May	Spring-Summer

Jamaica flower	0.65	1	0.6	30	30	15	15	01-Oct	Autumn-Winter
Jatropha	1	0.95	0.7	140	30	150	45	01-May	Perennes
Lemon	0.7	0.65	0.7	60	90	120	95	15-Jan	Perennes
Lettuce	0.7	1	0.95	20	30	15	10	01-May	Spring-Summer
Lettuce	0.7	1	0.95	20	30	15	10	01-Oct	Autumn-Winter
Lilies	0.95	1	0.75	30	40	40	20	01-May	Spring-Summer
Lilies	0.95	1	0.75	30	30	15	15	01-Oct	Autumn-Winter
Lilium	0.95	1	0.75	30	30	15	15	01-Oct	Autumn-Winter
Lime	0.7	0.65	0.7	60	90	120	95	01-May	Perennes
Lipstick tree	0.35	1.05	1.05	60	70	180	55	01-Jun	Perennes
Litchi	0.55	0.9	0.65	20	70	120	60	01-May	Perennes
Maize-grain	0.3	1.2	0.5	20	35	40	30	15-Jun	Spring-Summer
Maize-grain	0.3	1.2	0.5	20	35	40	30	01-Oct	Autumn-Winter
Mamey	0.9	1.1	0.9	90	90	90	95	15-May	Perennes
Mango	0.9	1.1	0.9	90	90	90	95	15-May	Perennes
Moringa	0.35	0.5	0.3	160	90	90	20	01-May	Perennes
Nanche	0.55	0.9	0.65	20	70	120	60	01-May	Perennes
Nard	0.95	1	0.75	30	30	15	15	01-May	Spring-Summer
Naseberry	0.9	1.1	0.9	90	90	90	95	01-May	Perennes
Neem	0.6	0.85	0.75	20	70	120	70	01-May	Perennes
Noni	0.6	0.85	0.75	20	70	120	70	01-May	Perennes
Nopalitos	0.35	0.5	0.3	160	90	90	20	01-May	Perennes
Oil palm	0.9	0.95	0.95	120	60	180	5	15-Feb	Perennes
Onion	0.7	0.9	0.85	25	30	10	5	01-May	Spring-Summer
Onion	0.7	0.9	0.85	25	30	10	5	01-Oct	Autumn-Winter
Orange	0.7	0.65	0.7	60	90	120	95	15-Jan	Perennes
Papaya	0.6	0.85	0.6	60	90	120	95	15-Jan	Perennes
Passion fruit	0.55	0.9	0.65	20	70	120	60	01-May	Perennes
Pastures	0.4	0.95	0.4	10	15	75	35	15-Apr	Perennes
Peas	0.4	1.15	0.35	20	30	40	20	01-Oct	Autumn-Winter
Pepper	0.6	1.12	0.6	180	60	90	35	01-May	Perennes
Pineapple	0.5	0.3	0.3	60	120	175	10	15-Jan	Perennes
Plum	0.55	0.9	0.65	20	70	120	60	01-May	Perennes
Pumpkin	0.5	1	0.8	20	30	30	20	01-May	Spring-Summer
Pumpkin	0.5	1	0.8	20	30	30	20	01-Oct	Autumn-Winter
Radish	0.7	0.9	0.85	10	20	30	10	01-May	Spring-Summer
Radish	0.7	0.9	0.85	10	20	30	10	01-Oct	Autumn-Winter
Rice	1.05	1.2	0.6	30	30	60	30	15-Jun	Spring-Summer
Rice	1.05	1.2	0.6	30	30	60	30	01-Oct	Autumn-Winter
Rose	0.95	1	0.75	30	30	15	15	01-May	Spring-Summer
Saramuyo	0.9	1.1	0.9	90	90	90	95	01-May	Perennes
Sisal	0.3	0.7	0.4	120	60	180	5	15-Feb	Perennes
Small vegetables	0.7	1.05	0.95	20	30	30	15	01-May	Spring-Summer
Small vegetables	0.7	1.05	0.95	20	30	30	15	01-Oct	Autumn-Winter
Sorghum	0.3	1	0.55	20	35	40	30	01-Jun	Spring-Summer
Sorghum	0.3	1	0.55	20	35	40	30	01-Oct	Autumn-Winter
Soursop	1	0.95	0.7	140	30	150	45	01-May	Perennes
Soy	0.4	1.15	0.5	20	30	60	25	01-Jun	Spring-Summer
Soy	0.4	1.15	0.5	20	30	60	25	01-Oct	Autumn-Winter
Stevia	0.6	1.15	1.1	20	30	30	15	01-May	Perennes
Sugar cane	0.4	1.25	0.75	35	60	170	100	15-Mar	Perennes
Sunflower	0.35	1.15	0.35	25	35	45	25	01-May	Spring-Summer
Sunflower	0.35	1.15	0.35	25	35	45	25	01-Oct	Autumn-Winter
Swede	1	1.4	1.2	20	30	20	10	01-May	Spring-Summer

Swede	1	1.4	1.2	20	30	20	10	01-Oct	Autumn-Winter
Sweet corn	0.3	1.2	0.5	20	35	40	30	01-May	Spring-Summer
Sweet corn	0.3	1.2	0.5	20	35	40	30	01-Oct	Autumn-Winter
Sweet melon	0.5	1.05	0.75	25	35	40	20	01-May	Spring-Summer
Sweet melon	0.5	1.05	0.75	25	35	40	20	01-Oct	Autumn-Winter
Sweet potato	0.5	1.15	0.65	15	30	50	30	01-Jun	Spring-Summer
Sweet potato	0.5	1.15	0.65	25	65	50	35	01-Oct	Autumn-Winter
Tamarind	0.35	0.5	0.45	200	50	60	55	01-May	Perennes
Tangerine	0.7	0.65	0.7	60	90	120	95	15-Jan	Perennes
Tomatoes	0.6	1.15	0.8	30	40	40	25	01-May	Spring-Summer
Tomatoes	0.6	1.15	0.8	30	40	40	25	15-Oct	Autumn-Winter
Vanilla	0.35	0.5	0.45	200	50	60	55	01-May	Perennes
Various fruit trees	0.9	1.1	0.9	90	90	90	95	01-May	Perennes
Watermelon	0.4	1.05	0.75	30	45	65	20	01-May	Spring-Summer
Watermelon	0.4	1	0.75	20	30	30	30	01-Oct	Autumn-Winter
Yam bean	0.5	1.1	0.95	25	30	25	10	01-May	Spring-Summer
Yam bean	0.5	1.1	0.95	25	30	25	10	01-Oct	Autumn-Winter
Zucchini	0.5	0.95	0.75	20	30	30	20	01-May	Spring-Summer
Zucchini	0.5	0.95	0.75	20	30	30	20	01-Oct	Autumn-Winter