Baseline assessment for efficient irrigation of oil palm in the Sevilla basin, Colombia

REPORT 211

CLIENT RVO

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Baseline Study Report

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Summary

This baseline assessment is part of a feasibility study on the adoption of more efficient irrigation techniques by oil palm farmers in Colombia. The baseline assessment includes characterization of the local environment (e.g. climate, water, soils, land use, and topography) in the Sevilla basin, agronomy and field management of the oil palm areas, and costs and benefits associated to efficient irrigation, fertigation and water harvesting.

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1 Introduction

1.1 Background

The Sierra Nevada de Santa Marta, a UNESCO-declared Biosphere Reserve, is an isolated mountain complex encompassing approximately 17,000 km^2, set apart from the Andes chain that runs through Colombia. The Sierra Nevada has the world's highest coastal peak (5,775 m above sea level), just 42 kilometres from the Caribbean coast. The Sierra Nevada is a landscape of biological juxtapositions. Palms, cacti and tropical dry forest fringe the park's northern border along the Caribbean coast, while tropical rain forests, treeless plains, and snow-capped peaks are found in the interior. The mountain's isolation has allowed for many plant and animal species found nowhere else on Earth. The Sierra Nevada is considered a precious natural barrier that avoids the passing of Caribbean hurricanes in the Colombia.

The Sierra Nevada is the source of 36 watersheds, making it the major regional 'water factory' supplying 1.5 million inhabitants as well as vast farming areas in the surrounding plains used principally for the cultivation of banana and oil palm. The flow from the rivers of the massive mountain complex amounts to approximately 10,000 million cubic meters of water annually.

The Frio-Sevilla and Tucurinca-Aracataca river basins host the major agricultural activities in the Sierra Nevada. Agricultural crops from the river basins contribute substantially to the regional GDP and employment. The specific crops are crucial for regional food security and dominate the export portfolio of the Magdalena and Cesar region.

Key issues that the region is facing in the basins from rivers originating in the Sierra Nevada, are:

- Declining availability of water for irrigation of plantations;
- Declining availability and quality of water for human consumption;
- Increasing salinization of groundwater and soils;
- Increasing incidence of floods.

These issues generate a number of negative impacts:

- Declining productivity of oil palm plantations;
- Declining palm oil extraction rate;
- Flood damage to crops, infrastructure and homes;
- Water contamination and receding groundwater threatening drinking water availability;
- Decreasing soil quality due to salinization.

To mitigate these impacts, the palm oil sector is increasingly interested in adopting more efficient water management technologies. A feasibility study is being carried out by a consortium of Delphy, Solidaridad, Cenipalma and FutureWater. The **objective** of this feasibility study is to characterize the local environment at basin scale and current cultivation practices, and assess the feasibility of possible interventions regarding efficient irrigation, fertigation and water harvesting in oil palm areas.

The **project area** is located south of the departmental capital Santa Marta, spreads across five municipalities of Magdalena department: Zona Bananera, Pueblo Viejo, Aracataca and parts of Ciénaga and El Retén. The five municipalities have a combined population of 257,000 people – of which at least 145,000 live inside the project area. 53% of the people in the project area do not have their basic needs satisfied (health, education, food), which is well above the national poverty index (NBI) of 28%)[1]. The Sevilla river basin is the main focus of the feasibility study.

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[1] Poverty index refers to the indication developed by United Nations which assesses three elements:

- Longevity, which is defined as the probability of not surviving to the age of 40.

1.2 This baseline assessment

This baseline assessment was developed for the Sevilla basin. The Sevilla river basin is part of the hydrographic subzone Ciénaga Grande de Santa Marta. The Ciénaga Grande de Santa Marta is the largest and most important coastal lagoon of the country with an area of 3,487 km^2 (of which 730 km^2 is water) and belongs to the outer delta system of the Magdalena River, which is responsible for 60% of its sweet water inflow; the balance of 40% comes from rivers draining the western flank of the Sierra Nevada, principally the rivers Frio, Sevilla, Tucurinca, Aracataca and Fundación.

The river length of the Sevilla river is 89.36 km. This basin includes approximately 41,562 hectares and its main tributaries streams are: El Chorro, Cebolleta, Venado, Gallina river, Sevillita river, Caño Mocho, Cherua river and Maquencal. The most populated urban centres located in this basin are: Palmor, San José de Kennedy, Seville, Estación Sevilla, Guacamayal and Palomar (CORPAMAG, 2016).

The baseline assessment concerns a characterization of the local environment (e.g. climate, water, soils, land use, and topography) at basin scale, agronomy and field management of the oil palm areas, and costs and benefits associated to efficient irrigation technology (e.g. fertigation, water harvesting).

- Knowledge, which is assessed by looking at the adult literacy rate.
- A 'decent' standard of living (% of the population not using an improved water source and % of children under-weight for their age).

2 Data and information

2.1 Environmental data and information

Local environmental information was collected from a range of GIS, satellite-based, and local data sources (Table 1). Soil information is the basis for a proper environmental baseline study. Since local soil maps of good quality are often not available, global soil maps with a lower resolution are used (1km resolution). Furthermore, soil maps do not include information about soil hydraulic properties, which are of importance to evaluate irrigated agriculture. Hence, the soil hydraulic properties in the Sevilla basin were obtained from HiHydroSoil (de Boer, 2016), filling this data gap. Also the latest information about land cover (2015) from Copernicus was used (Buchhorn et al., 2019) to separate between forest and agriculture areas in the basin.

The historical patterns on precipitation, temperature, and evapotranspiration were obtained from global datasets CHIRPS, WorldClim and MODIS. CHIRPS (Funk et al., 2015) is a merged precipitation product using ground stations and remote sensing, and has been proven to be accurate for its application in tropical regions such as in Colombia (Kaune et al., 2019). WorldClim (Hijmans et al., 2005) is a set of global climate layers including temperature (gridded climate data) which has been used extensively by FAO, researchers and consultants for mapping and spatial modelling. MODIS (Mu et al., 2013) is an actual evapotranspiration product supported by NASA based on the logic of the Penman-Monteith equation, which includes inputs of daily meteorological reanalysis data along with MODIS remotely sensed data products such as vegetation property dynamics, albedo, and land cover.

Combining the collected climate information, a drought hazard map was developed for the Sevilla basin for the dry season and the wet season to evaluate the risks on water harvesting to support efficient irrigation (see section 3.6). Also, information from previous studies done in the region were collected to determine the location of oil palm areas, cultivars and nutrient management at field level.

Table 1. Data and information collected for baseline assessment

Type	Layer	Source
Soil	Available water content	HiHydroSoil
Soil	Organic matter content	HiHydroSoil
Soil	Soil texture class	HiHydroSoil
Soil	Saturated hydraulic conductivity	HiHydroSoil
Landcover	Landcover classification	Copernicus
Landcover	Vegetation greenesss index	MODIS
Topography	Digital elevation model	SRTM
Landcover	River network	SRTM
Climate	Precipitation	CHIRPS
Climate	Temperature	WorldClim
Climate	Evapotranspiration	MODIS
Climate	Drought hazard	CHIRPS/MODIS
Climate	Station-based variables	Local information
Agronomy	Cultivars	Local information
Agronomy	Nutrient management	Local information
Water	Current irrigation practices	Local information
Water	Distance to river	SRTM

Information about the oil palm areas, including agronomy and water management, in the Sevilla basin was obtained by a literature study and professional knowledge of Cenipalma.

2.2 Economic data and information

According to Alvarez et. al. (2017), the potential yield of oil palm is limited, among other factors, due to the water deficit. This situation determines a relevant gap between the potential offered by the developed genetic materials and the yield finally obtained for the oil palm growers. Consequently, the water deficit is the climatic factor that probably most affects the yields of this crop. Based on Woittiez et al. (2017), oil palm performance is reduced with rainfall levels lower than 2,000 mm / year, or months with rainfall less than 100 mm. Calliman & Southworth (cited in Corley & Tinker, 2003), concluded in their study that a water deficit of 600 mm experienced in a single year, reduces the yield of palm crops by 8 to 10% for the first year, and between 3 and 4% for the second year, after presenting the stress situation.

Therefore, several studies have researched the impact of the water deficit on the yield of oil palm crops. Then, one of the alternatives for mitigating this impact is adopting irrigation systems. Section 3.10 includes an analysis about the costs and benefits regarding efficient irrigation, fertigation and water harvesting.

3 Baseline assessment

3.1 Hydro-meteorolgical setting

The Sevilla basin is located in the Magdalena-Cauca Macrobasin (MCMB) in the northeast of Colombia (Figure 1). The MCMB is the primary river basin system in Colombia, draining an area of around 257,000 km², which is about 25% of the total territory of the country. It has its headwaters high up in the Colombian Andes at the Magdalena Lagoon at an elevation of about 3700 m.a.s.l. which is located in the south. The Magdalena River flows northward for about 1600 km through the western part of the country before reaching the Caribbean Sea. The mean annual river discharge at Calamar, which is the gauging station closest to the mouth before the diversion of the Canal del Dique, is approximately 7200 m³/s, with mean maximum discharges occurring in November (10,200 m³/s), and minimum average flows in March (4050 m³/s). Due to the movement of the Intertropical Convergence Zone (ITCZ), the upper and mid MCMB experience a bimodal annual precipitation cycle with two wet periods (April – May, and October – November) and two interspersed dry periods, while the lower MCMB has a unimodal cycle, with a wet period between May and November, and a dry period between December and April (Rodríguez et al., 2019).

The Sevilla River originates in the *Sierra Nevada de Santa Marta* at an elevation of about 3900 m.a.s.l. and flows westward for about 60 km reaching a large marshland called *Cienaga Grande de Santa Marta* (Figure 2). The Sevilla basin area is located approximately between the coordinates: 10° 39'N and 10° 55'N latitude, and 73°51'W and 74° 20'W-longitude (CORPAMAG, 2016), having an area of 713 km² and extensive oil palm areas in the lower part of the basin at an elevation below 280 m.a.s.l.

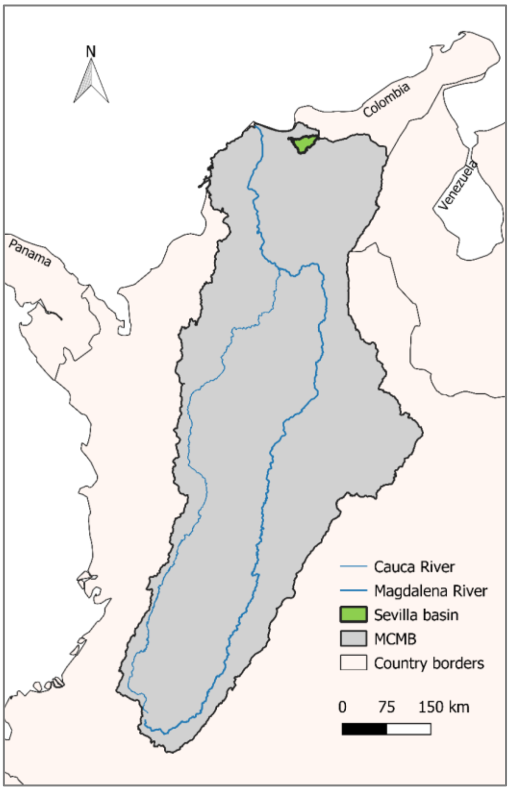

Figure 1. Magdalena-Cauca Macrobasin (MCMB) and Sevilla basin, Colombia (Source: SRTM).

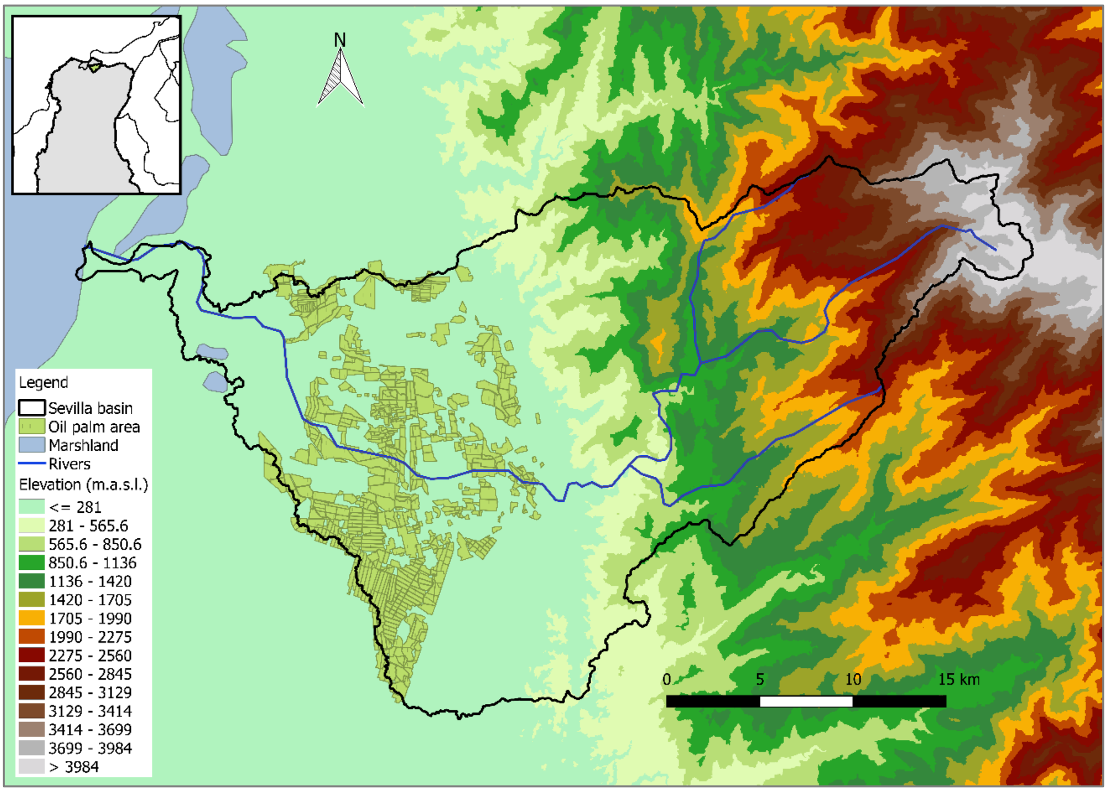

Figure 2. Oil palm area, major rivers and elevation in the Sevilla basin, Colombia (Source: SRTM, CENIPALMA). The Sevilla basin is located in the Magdalena-Cauca Macrobasin (MCMB).

3.2 Land cover

According to remote sensing land cover information (Buchhorn et al., 2019) the major land cover type in the Sevilla basin consists of evergreen closed forest with broadleaf trees (Closed forest ebl), making up 66% of the basin area. This means that the broadleaf trees remain green all year round and canopy is never without green foliage. Other main land cover types are other forest types (22%), and herbaceous vegetation (9%). Apparently, cropland is only 1% of the basin area, however, it is known that in the lower part of the basin oil palm trees are cultivated. Copernicus, 2015 may have quantified the oil palm trees as a forest type. Based on actual information from CENIPALMA, the total area of oil palm fields in the Sevilla basin is 101 km². This represents 14% of the basin area. Figure 3 displays the land use / land cover map of the basin including the actual oil pam area provided by CENIPALMA.

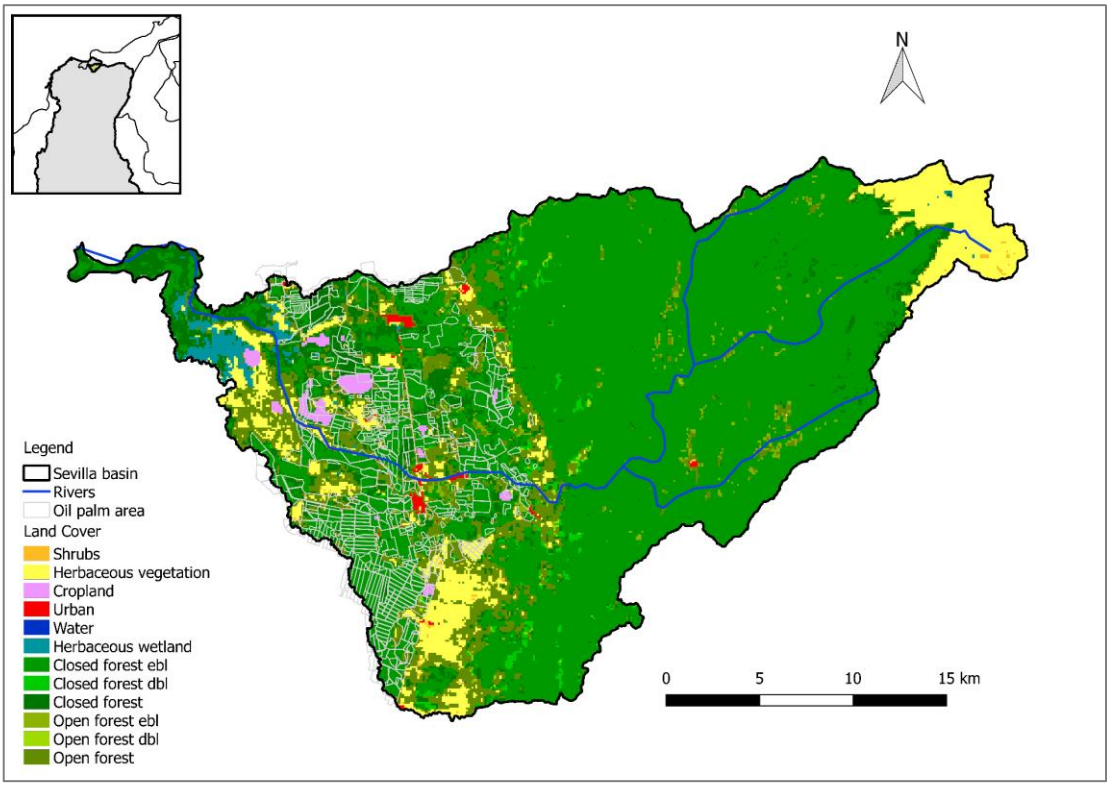

Figure 3. Land cover / land use in the Sevilla basin, Colombia (Source: Copernicus, 2015). Oil palm area is delineated in light grey (Source: CENIPALMA).

3.3 Soils

Soil information was collected from the HiHydroSoil product (de Boer, 2016) based on SoilGrids1km (Hengl et al., 2014) for average outputs at 1 meter soil depth. In the Sevilla basin, the soil water storage capacity, SWC varies between 197 mm and 317 mm, with the lowest values in the oil palm area (Figure 4). Still 197 mm per meter of soil depth is considered as a relatively high storage capacity associated to loamy soils (FAO, 2012). The saturated hydraulic conductivity, Ksat varies between 39 mm/day and 155 mm/day in the basin, with the highest values in the lower part of the basin, especially in the right margin of the river in the oil palm areas (Figure 5). Higher Ksat values mean better soil drainage. Also, the percentage of organic matter content, ORMC in the soil is shown in Figure 6 with relatively low percentages (1 to 6%) and the lowest values in the lower part of the basin. A summary of the range of SWC, Ksat and ORMC values in the oil palm areas is shown in Table 2.

Table 2. Range of soil water storage capacity, SWC, hydraulic conductivity, Ksat and organic matter content, ORMC in the oil palm areas.

	SWC (mm/m)	Ksat (mm/day)	ORMC (%)
Oil palm areas (lower basin)	197 - 257	68 - 155	1 - 3

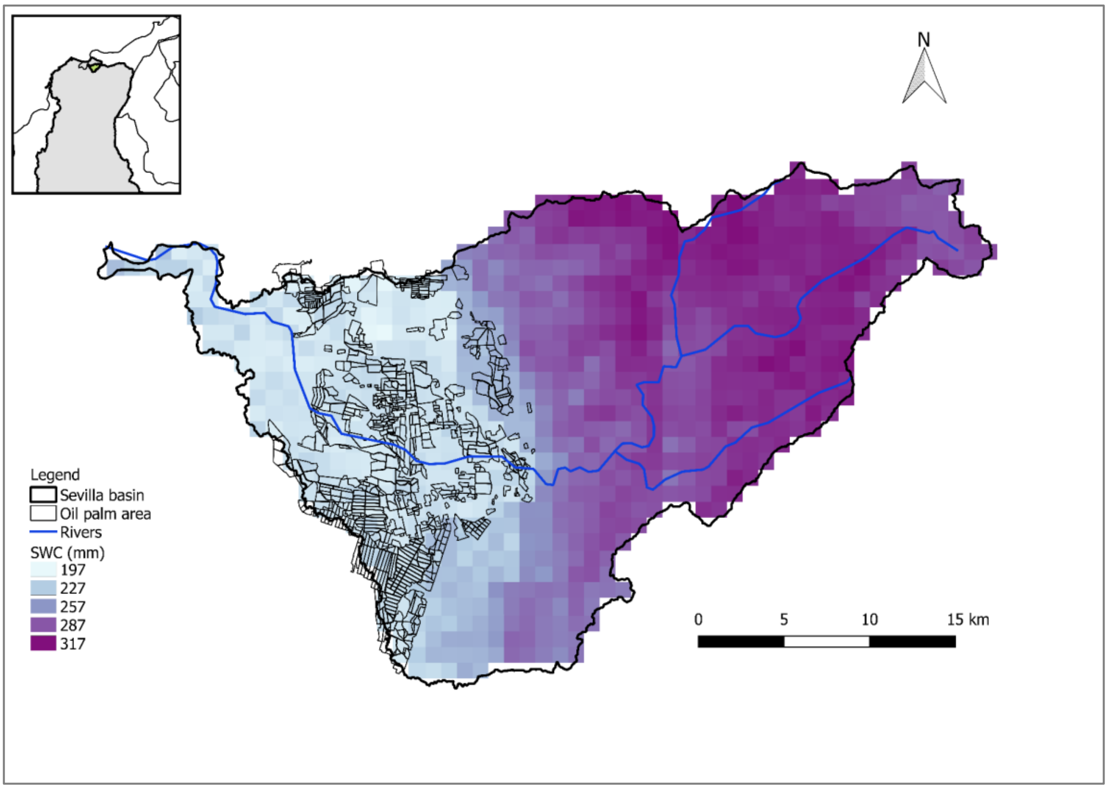

Figure 4. Soil water storage capacity (mm) in the Sevilla basin, Colombia (Source: HiHydroSoil). Oil palm area is delineated in light black (Source: CENIPALMA).

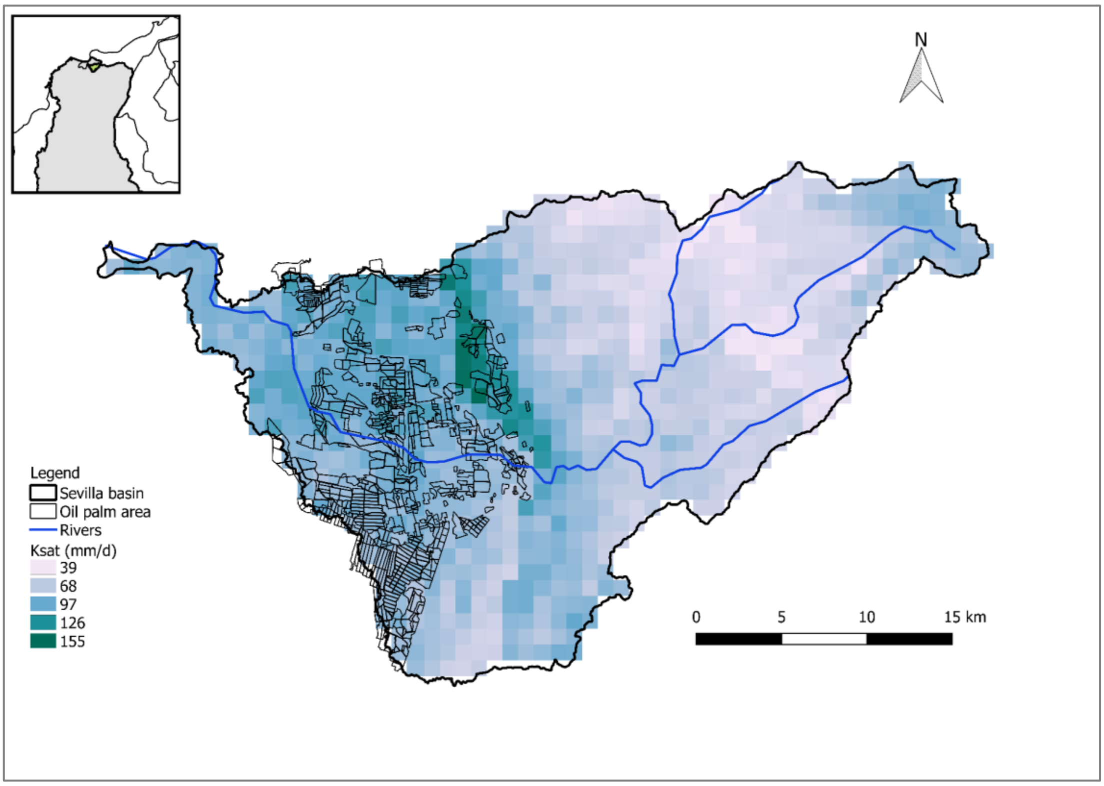

Figure 5. Saturated hydraulic conductivity (mm/day) in the Sevilla basin, Colombia (Source: HiHydroSoil). Oil palm area is delineated in light black (Source: CENIPALMA).

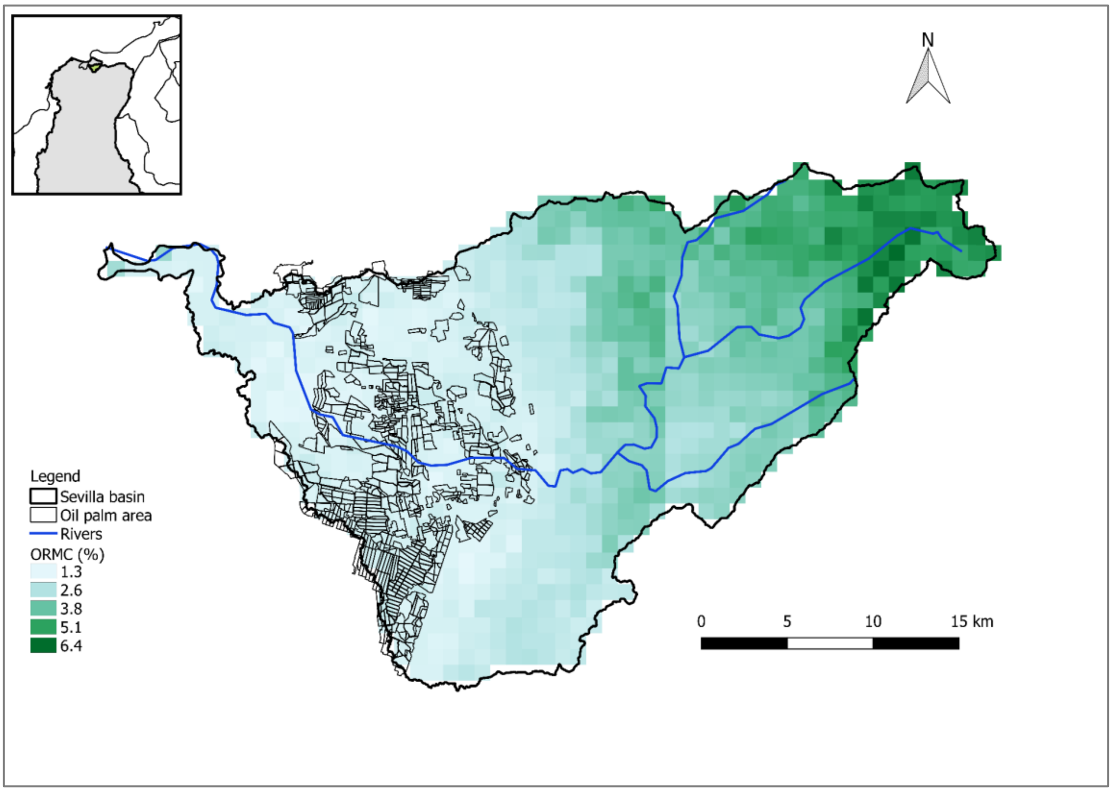

Figure 6. Organic matter content (%) in the Sevilla basin, Colombia (Source: HiHydroSoil). Oil palm area is delineated in light black (Source: CENIPALMA).

3.4 Precipitation, temperature and evapotranspiration

Temperature and precipitation information is available from meteorological stations located close to the Sevilla basin (GSI, 2015). The average temperature range in a year is between 27 °C and 29 °C. The precipitation information shows a dry season between December and March, and a wet season between April and November (Figure 7). In September, average precipitation is 88 mm/month in the Aeropuerto Simon Bolivar located in the Caribbean coast, but can reach up to 400 mm/month in San Lorenzo located 20 km inland from Aeropuerto Simon Bolivar.

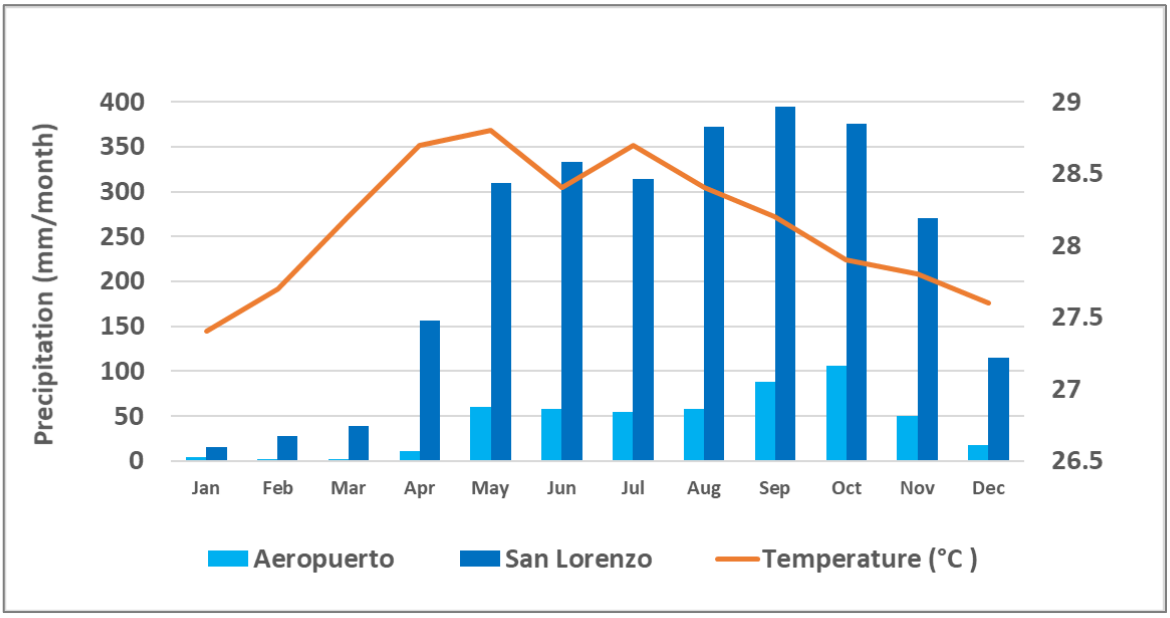

Figure 7. Average monthly precipitation and temperature as recorded in stations *Aeropuerto Simón Bolivar and San Lorenzo* located close to the Sevilla basin (Source: GSI, 2015).

Precipitation, temperature and evapotranspiration in the Sevilla basin were obtained from historical spatial products available online: i) CHIRPS (Funk et al., 2015); ii) WorldClim (Hijmans et al., 2005) and iii) MODIS (Mu et al., 2013), to evaluate the spatial variability in the dry season and in the wet season. The dry season was defined between December and March, and the wet season was defined between August and November. In the basin, the temperature varies from 4.5 °C to 28 °C in the wet season, and 3.4 °C to 27.4 °C in the dry season (no significant change between seasons, Figure 8 and Figure 9) with the highest values in lower part of the basin. The relative humidity presents minimum values between January and April, close to 70% in the lower and middle basin, while the rest of the year remains constant with values close to 90% (CORPAMAG, 2016).

Precipitation varies from 565 mm/season to 2128 mm/season in the wet season (Figure 10), and varies from 31 mm/season to 250 mm/season in the dry season (Figure 11), with the lowest values in the lower part of the basin which is typical for a mountainous basin. The actual evapotranspiration varies from 35 mm/season to 477 mm/season in the wet season (Figure 12), and varies from 140 mm/season to 739 mm/season in the dry season (Figure 13), with higher values in the lower part of the basin. In the lower part of the basin, the evapotranspiration in the dry season (739 mm/season) is higher than in the wet season (477 mm/season) because of irrigation in the oil palm area. In the wet season inaccuracies in evapotranspiration estimates happen in the higher part of the basin due to clouds.

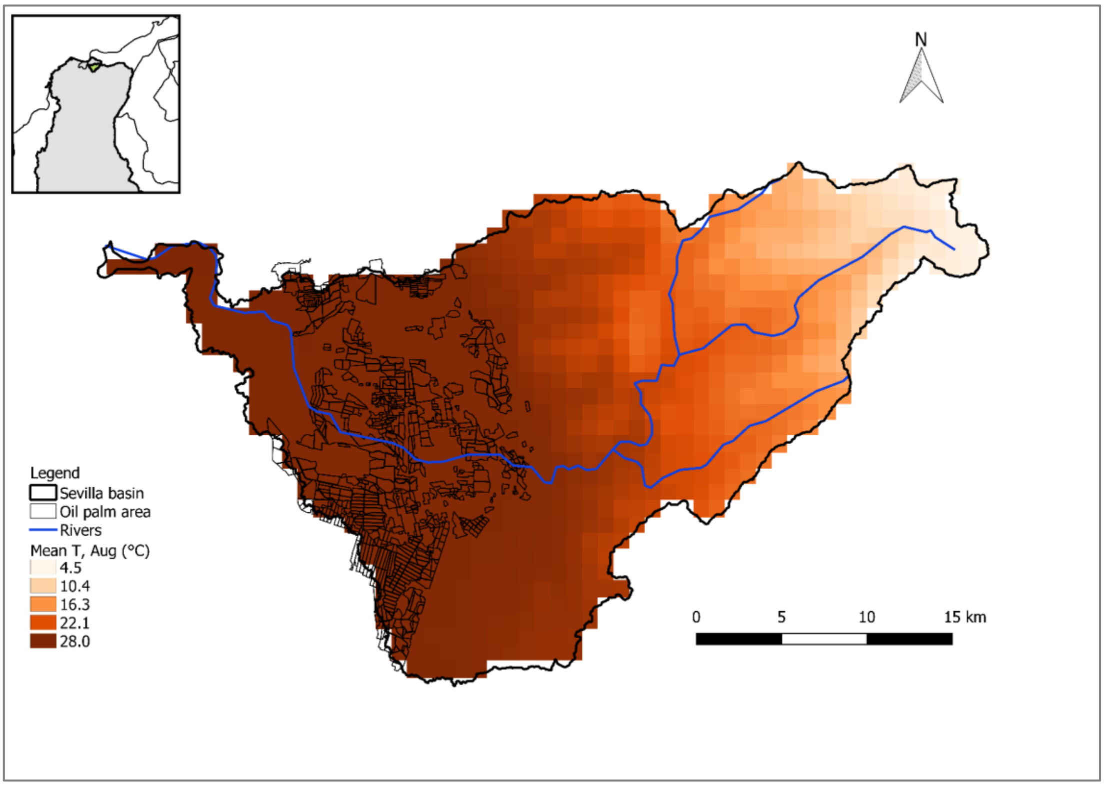

Figure 8. Mean temperature from August to November (wet season) in the Sevilla basin, Colombia (Source: WorldClim). Oil palm area is delineated in light black (Source: CENIPALMA).

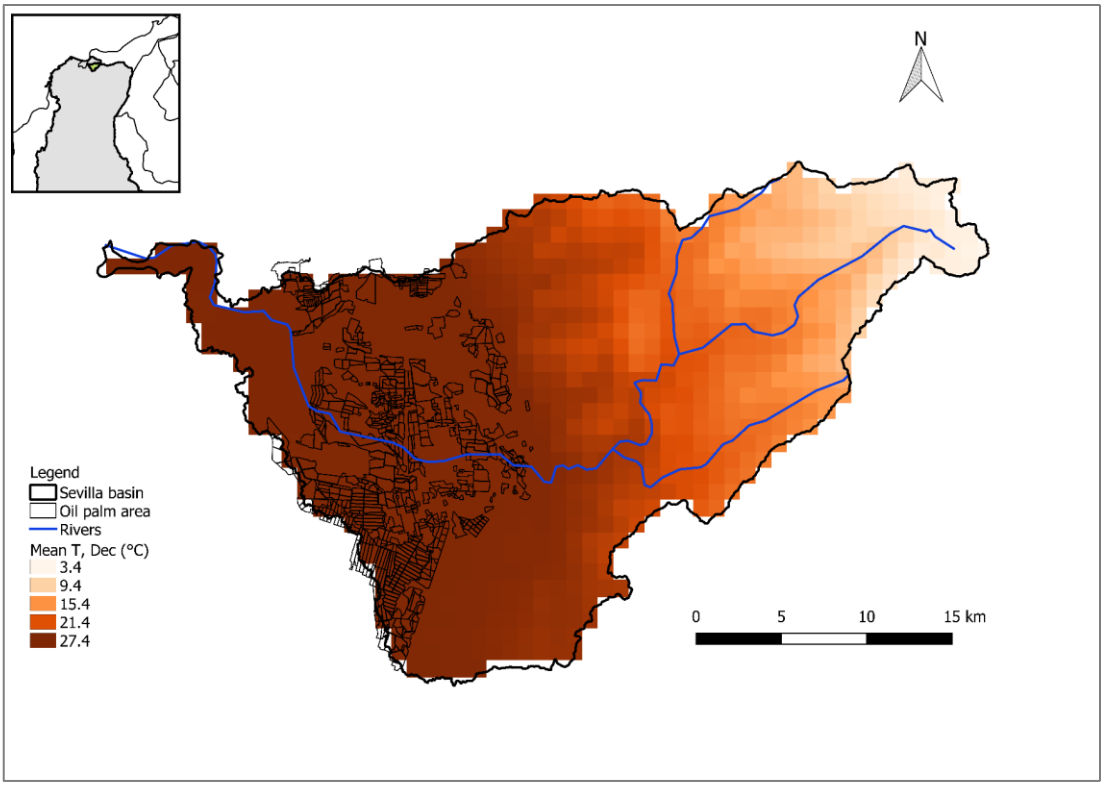

Figure 9. Mean temperature from December to March (dry season) in the Sevilla basin, Colombia (Source: WorldClim). Oil palm area is delineated in light black (Source: CENIPALMA).

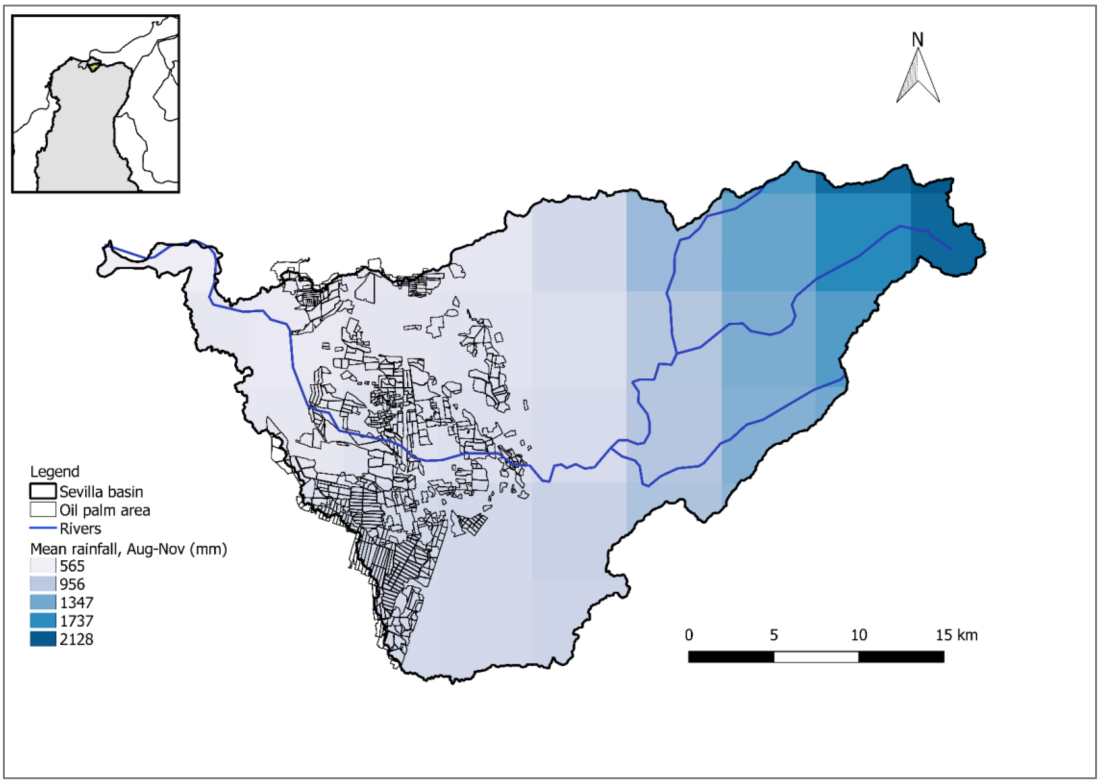

Figure 10. Mean total precipitation from August to November (wet season) in the Sevilla basin, Colombia, period 1981-2019 (Source: CHIRPS). Oil palm area is delineated in light black (Source: CENIPALMA).

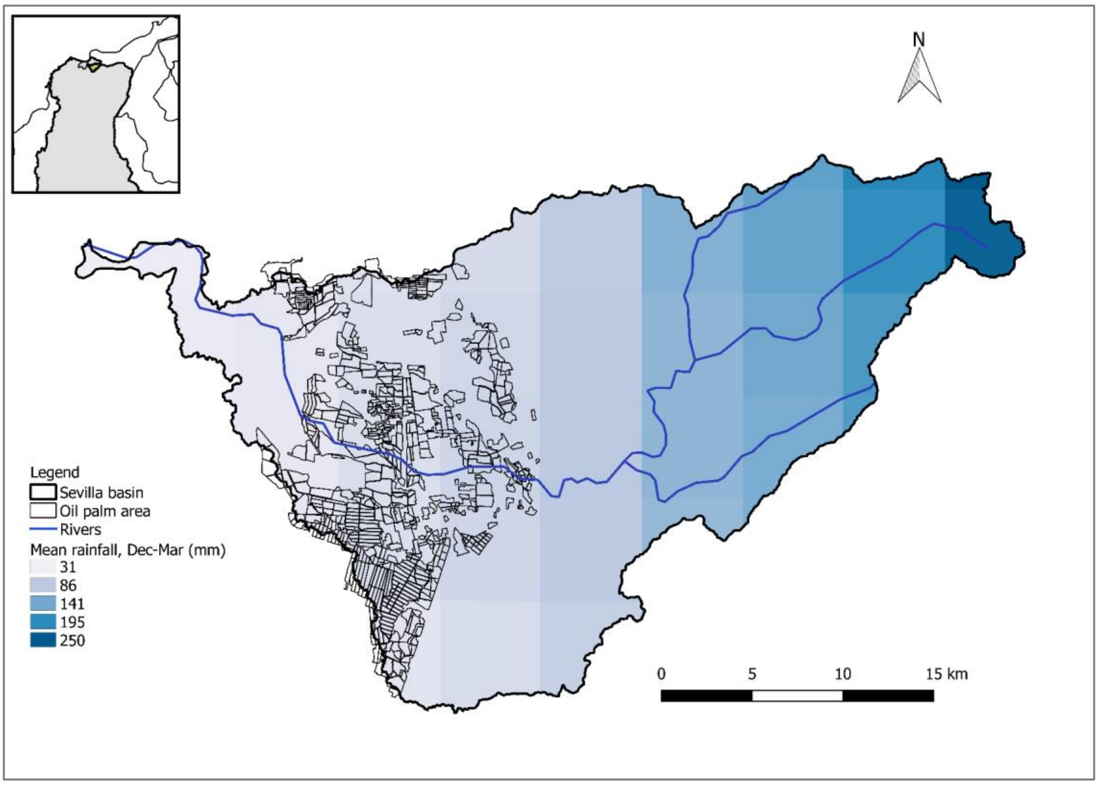

Figure 11. Mean total precipitation from December to March (dry season) in the Sevilla basin, Colombia, period 1981-2019 (Source: CHIRPS). Oil palm area is delineated in light black (Source: CENIPALMA).

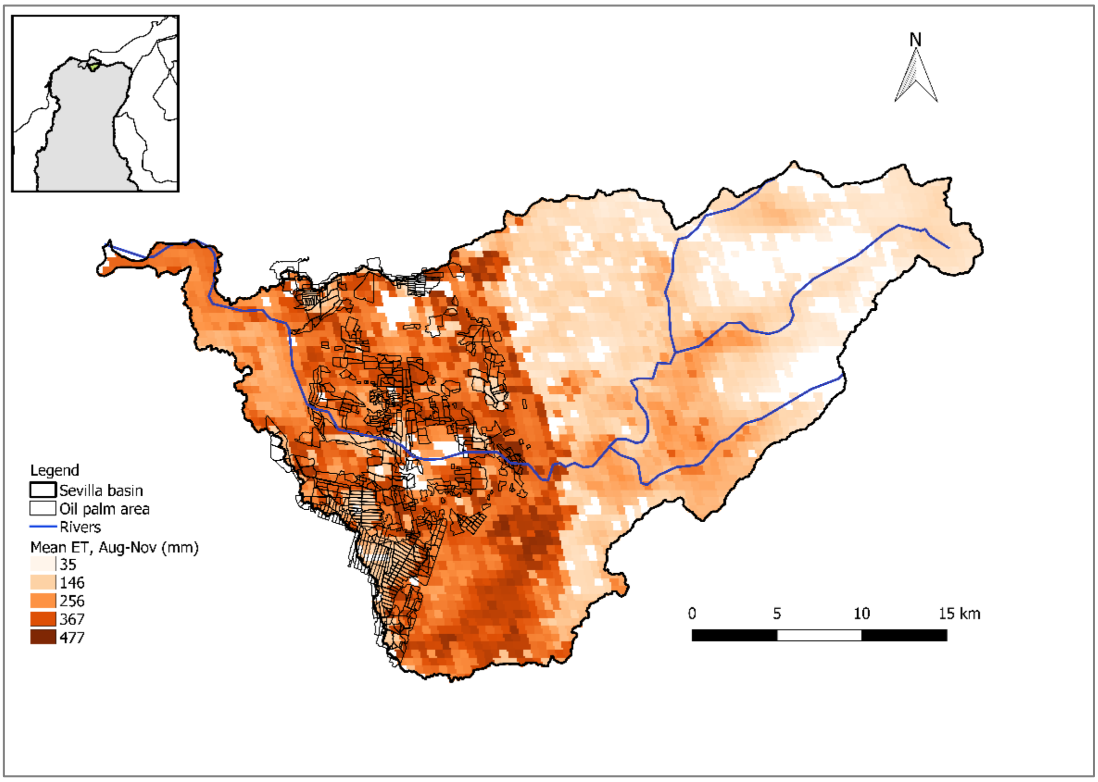

Figure 12. Mean total ET from August to November (wet season) in the Sevilla basin, Colombia, period 2010-2019 (Source: MODIS). Oil palm area is delineated in light black (Source: CENIPALMA).

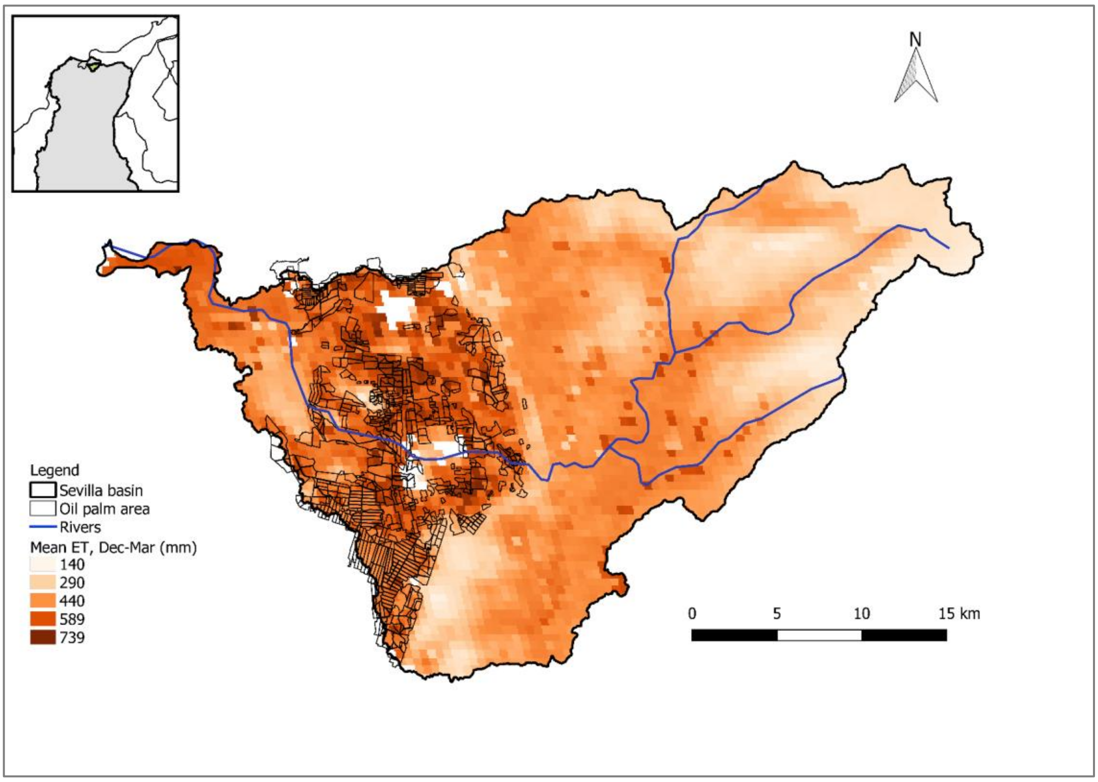

Figure 13. Mean total ET from December to March (dry season) in the Sevilla basin, Colombia, period 2010-2019 (Source: MODIS). Oil palm area is delineated in light black (Source: CENIPALMA).

3.5 Water yield

The water yield is an indicator of water availability in the basin, subtracting the actual evapotranspiration from precipitation (P-ET). If the water yield is higher (lower) than zero, then water is (not-) available. Figure 14 shows the historical monthly water yield in the Sevilla basin for the period 2000-2019. The historical data shows a clear pattern of water deficit between December and March and water surplus between August and November. The year 2015 was the year with the lowest water yield in the basin with water deficit in most of the months. Only between October and November (2015) the water yield was higher than zero (49 mm/month and 11 mm/month, respectively), but lower than the normal values which are expected in these months (wet season). This extreme event is important to consider when planning for water harvesting in the basin. Water harvesting allows the water to be stored during the wet season to be used later in the dry season for satisfying urban or irrigation demands. However, if the water available in the wet season is lower than expected, then the harvested water will not satisfy the water demands leading to water scarcity and agricultural losses.

In Figure 15 and Figure 16, the spatial variability of the water yield is shown for the drought event of 2015. In the wet season (August 2015 – November 2015), a pattern of water deficit is found only in the lower part of the basin (Figure 15), but in the dry season (December 2015 – March 2016), the pattern of water deficit extends over the entire basin (Figure 16). These results show the potential of water harvesting in the higher part of the basin between the months of August and November even during a drought event such as the one in 2015.

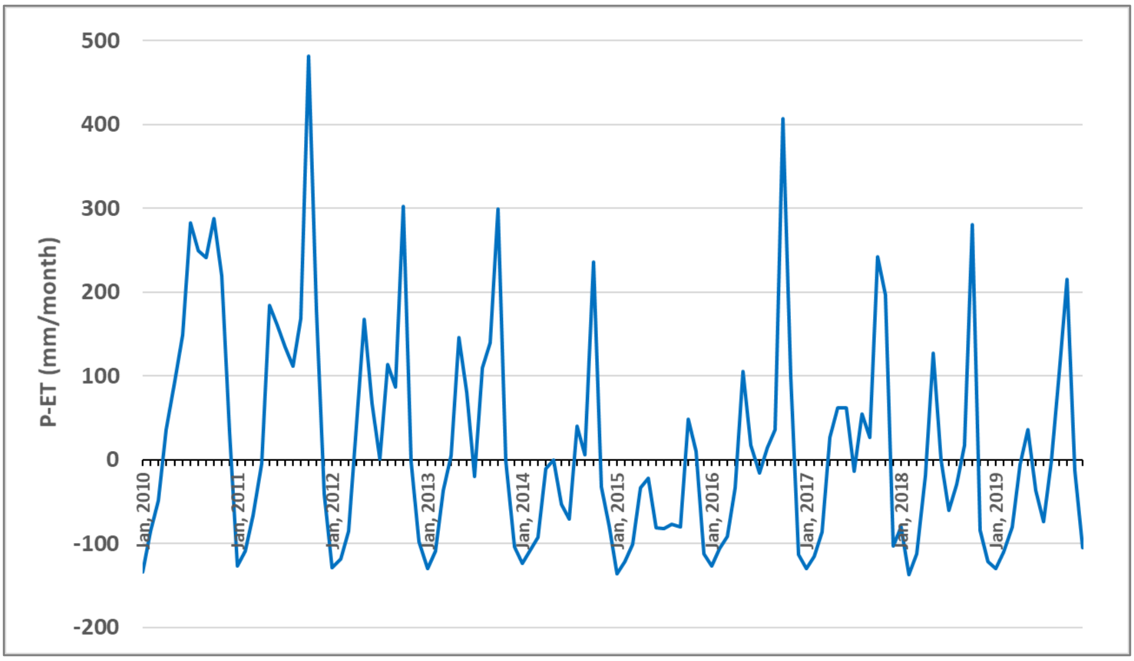

Figure 14. Historical monthly water yield, P-ET in the Sevilla basin, Colombia, period 2000-2019 (Source: CHIRPS and MODIS). Drought event in 2015.

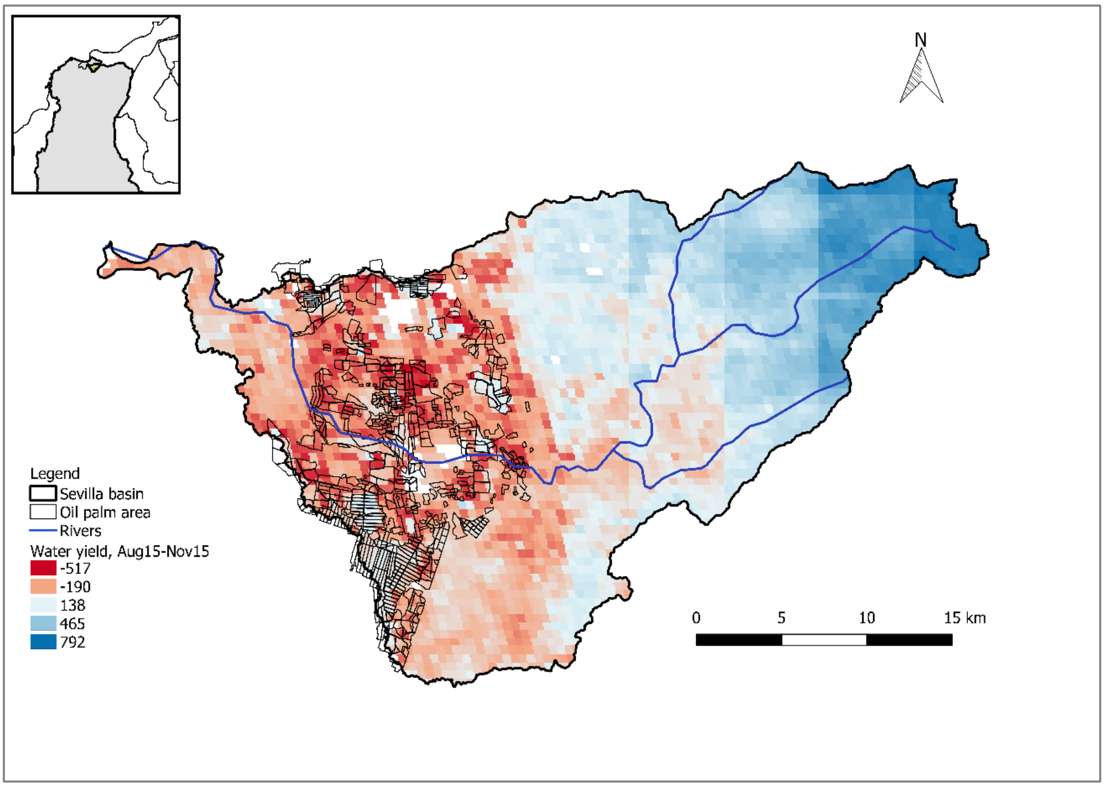

Figure 15. Water yield (mm), for the period August 2015-November 2015 (wet season), in the Sevilla basin, Colombia (Source: CHIRPS and MODIS).

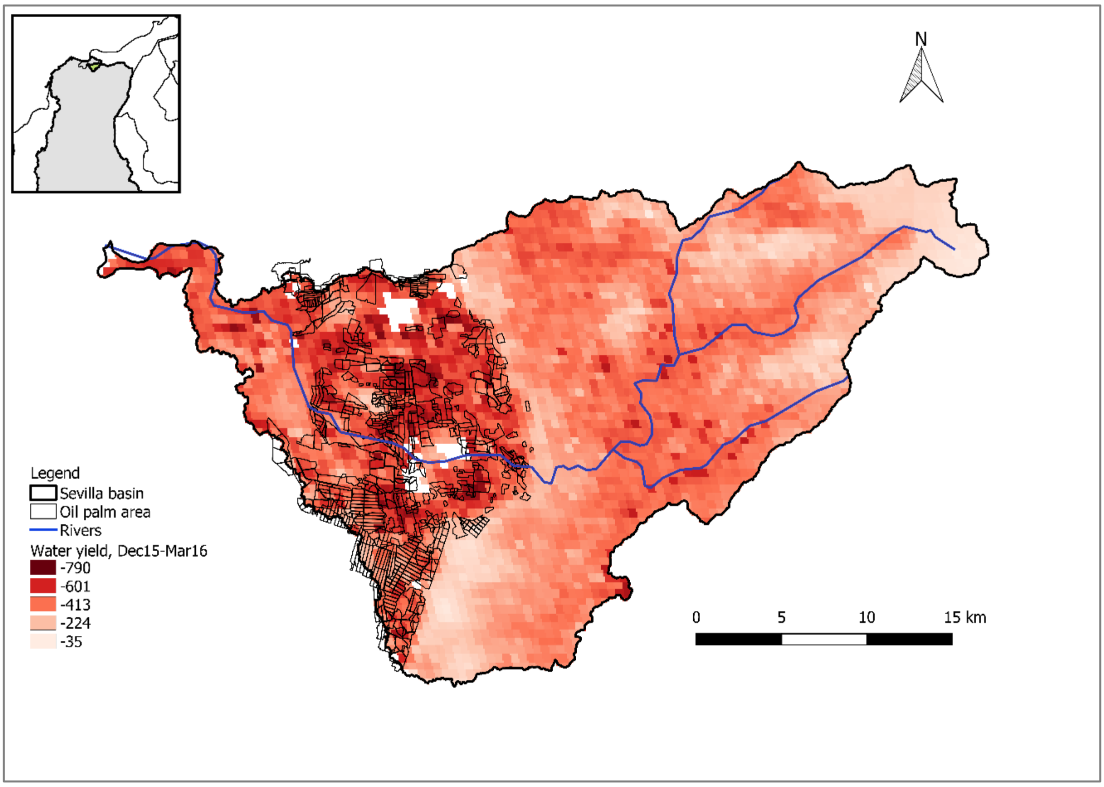

Figure 16. Water yield (mm), for the period December 2015-March 2016 (dry season), in the Sevilla basin, Colombia (Source: CHIRPS and MODIS).

3.6 Drought hazard index

Future droughts can affect water harvesting and available water for irrigation and urban areas in the Sevilla basin. Hence it is crucial to evaluate the drought hazard in the basin. The approach of Terink et al., 2011 and JBA Consulting (2020) was used which integrates five hazard indices into an overall drought hazard index (DHI):

1. Average precipitation
2. Coefficient of variation of precipitation
3. Average NDVI
4. Coefficient of variation of NDVI
5. Average temperature

The overall DHI results in values between 0 and 1. Values close to (0) 1 means a (low) high drought hazard. In Figure 18 and Figure 17 the drought hazard index, DHI is shown for the Sevilla basin in the wet season and in the dry season, respectively. For both seasons, the highest drought hazard was found in the lower part of the basin. In the wet season the drought hazard index provides information about where is the lowest risk of water scarcity for installing water harvesting facilities. In the dry season the drought hazard index provides information about where is the highest risk of water scarcity which helps to decide where to use the harvested water from the wet season.

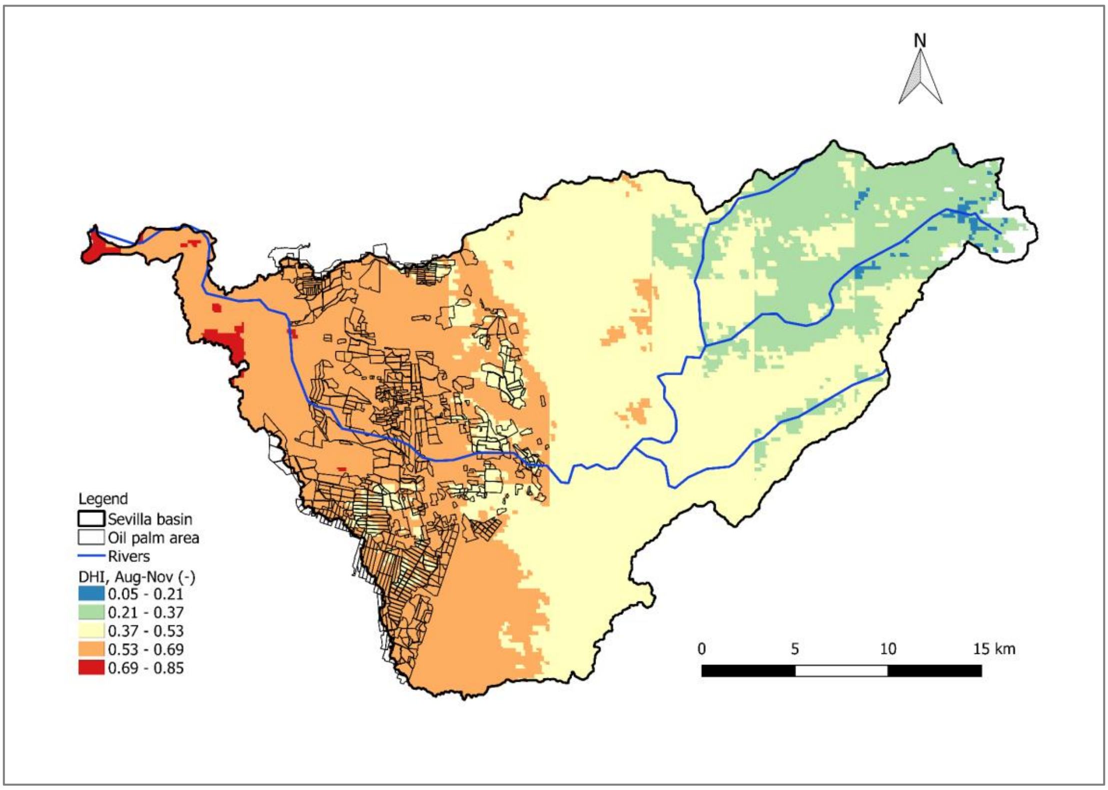

Figure 17. Drought hazard index, DHI from August to November (wet season) in the Sevilla basin, Colombia, period 2000-2019 (Source: CHIRPS, MODIS).

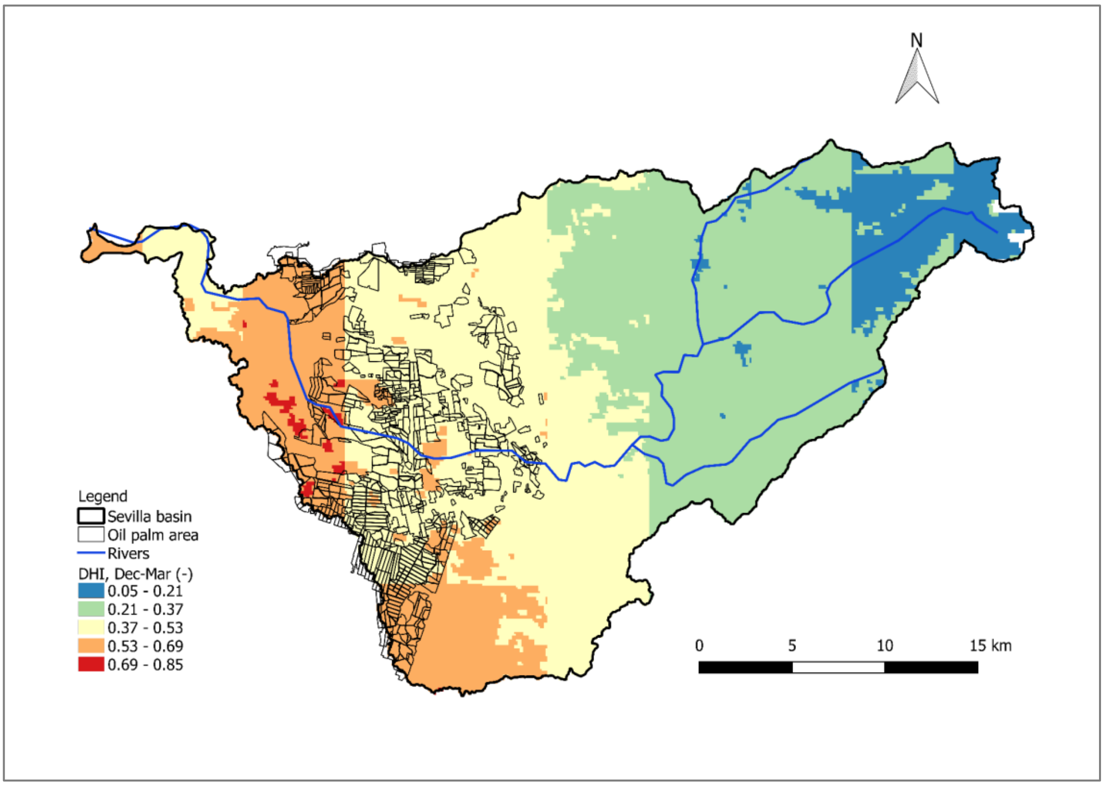

Figure 18. Drought hazard index, DHI from December to March (dry season) in the Sevilla basin, Colombia, period 2000-2019 (Source: CHIRPS, MODIS).

3.7 River discharge and irrigation demand

The monthly river discharge in the Sevilla River, available water for irrigation and irrigation demand of Asosevilla is shown in Table 3 based on a previous study (GSI, 2015). The available water for irrigation is established by considering an environmental flow. The irrigation demand is an allowed water concession of 7 m³/month. The available water for Asosevilla is supplied mainly to Oil Palm areas (GSI, 2015). In February and in March the available water does not satisfy the irrigation demand, thus in these months water shortage can occur.

Table 3. Monthly river discharge in the Sevilla River, available water for irrigation, and irrigation demand of Asosevilla (Source: GSI, 2015). The months with the lowest river discharge are between December and April. The units are in millions of m³/month.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
River discharge	17	11	12	16	32	39	39	42	53	60	49	27
Available water	8	5	6	8	15	19	19	20	26	29	24	13
Demand Asosevilla	7	7	7	7	7	7	7	7	7	7	7	7

3.8 Water quality and sediment conditions

According to a previous study (GSI, 2015) the water in the Sevilla River is not suitable for recreational uses due to coliforms. In addition, high levels of sediments, BOD and organic matter are reported.

The regional environmental authority, CORPAMAG (Corporación Autónoma Regional de Magdalena) defined in 2012, the quality objectives of the Sevilla River for the period 2013–2023. As a result of the monitoring activities,

Table 4 includes the available quality indicators of three river sections: river source (Palmor town), mid-section (Puente Sevilla-Guacamayal) and river mouth.

Table 4. Quality indicators of the Sevilla Basin.

Quality indicators	Units	River source section (Palmor town)		Puente Sevilla – Guacamayal section (Zona Bananera municipality)		River mouth section (Zona Bananera municipality)	
		2012	2014	2012	2014	2012	2014
pH	U of pH	7.25	7.35	7.04	7.24	7.15	8.18
Dissolved Oxygen (DO)	mg/L	10.53	7.19	9.53	5.35	9.34	6.71
Suspended solids	mg/L	10.2	< 10	71.2	23.2	47.8	< 10.0
Biological Oxygen Demand (BOD)	mg/L	< 5	< 2.0	< 5	< 2.0	< 5	< 2.0
Fats, Oils and Grease (FOG)	mg/L	< 10	< 15.0	< 10	16.7	< 10	< 15.0
Total Coliforms	Most Probable Number (MPN) /100 mL	17230	16100	36540	26130	46110	15800
Escherichia Coli	Most Probable Number (MPN) /100 mL	200	200	3930	3640	3640	3100

The parameters evaluated in the Sevilla basin indicate that the physicochemical variables have a similar performance throughout the river (pH, BOD). As result of the comparison between 2012 and 2014, it is evident the quality conditions have been affected in terms of Dissolved Oxygen (OD), as well as Fats, Oils and Grease (FOG). The concentration of Total Coliforms and Escherichia Coli has been reduced substantially in the Puente Sevilla-Guacamayal section and the river mouth. Based on CORPAMAG report, Dissolved Oxygen indicator does not meet the quality objectives for 2014 (target level of > 8).

3.9 Oil palm management practice

3.9.1 Cultivars

About the established cultivars, there is information registered through CENIPALMA for about 40% of the established areas (Figure 19). The most predominant cultivar is Deli x Avros (Table 5, Dami las Flores is the commercial name) which is highly productive in terms of tons of fruit and the amount of oil/ha.

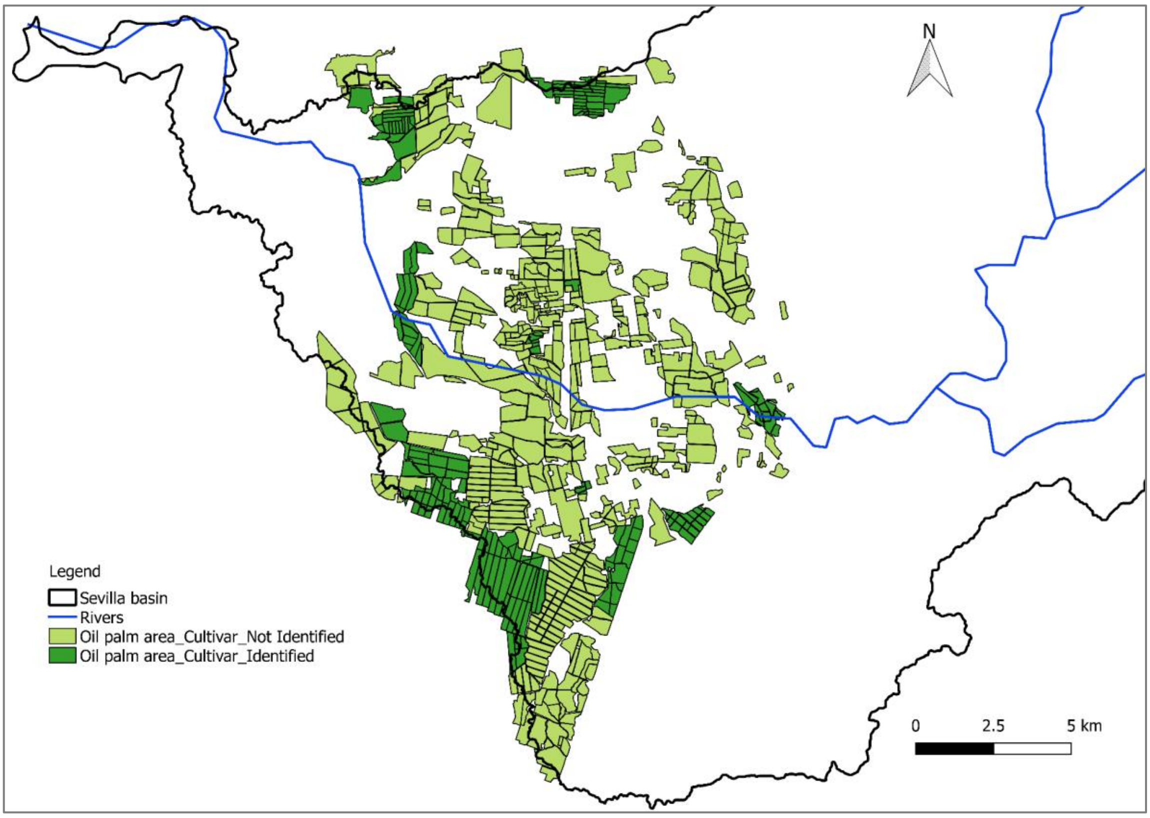

Figure 19. Oil palm area in the Sevilla basin. Light green is Not Identified Cultivar, and dark green is Identified Cultivar (Source: CENIPALMA).

Table 5. Surface area in hectares of different cultivars of Oil Palm in the Sevilla basin (Source: CENIPALMA).

Status	Cultivar of Oil Palm	Area (ha)
Identified	*Dami Las Flores (Generico)*	1,341
	Hibrido no identificado	219
	Compacta x Ghana	201
	Tenera	123
	Deli x Ghana	120
	Avros + Malasia	89
	Angola x Probador + Tanzania x Ekona	21
	Compacta x Nigeria	15
	Nigeria x Ghana	11
	Avros	11
	Others	78
Total Identified		2,228
Total Not Identified		7,916
Grand total		10,145

Research is currently being carried out in the Experimental Field of Palmar de La Sierra with the aim of determining the water requirements of the most predominant cultivars (Deli x Avros, Coari x La Mé and Deli x Ghana). The impact is evaluated in terms of vegetative variables, physiology, and fruit and oil yields.

3.9.2 Nutrient management

Mass balance is the most frequently used concept for the nutrition of oil palm in Colombia. According to this concept, to maintain the balance and sustainability of the crop, it is necessary to quantify both the entry and exit of nutrients in the production system and replace those missing nutrients to guarantee the nutritional balance of the plant. Under this scheme, the soil is considered a source of nutrients and for the conditions of the Sevilla River these are particularly relevant since the natural fertility of the soils tends to be moderate to high, with high saturation of bases and pH values close to neutrality, which has affected that the amounts of nutrients applied, in general, are lower with respect to the other three palm areas of Colombia.

Regarding the application forms, the most used is the application of fertilizers in solid form (granules or powders) aimed at the soil around the palm, having the highest root activity. This area corresponds to the site around the plate and where the pruning and harvesting leaves are located, and which stimulate the development of roots. The application of nutrients through irrigation systems is absent. This is associated with the low knowledge of the technology and the irrigation system used, generally done by surface irrigation.

Fertilizer is most often applied manually, with the help of livestock or tractors for the transport of the sources of nutrients to or inside the plots. For cost and logistical reasons, inorganic (chemical) fertilizers are the most frequently used. The fertilizers are generally applied in four fractions per year and in the months in which there is adequate availability of water in the soil. Secondly, the use of sub-products of the agro-industrial process, such as empty bunches and fibre, are used. Lastly, plant residues (i.e. prunes and harvested leaves) supply nutrients through recycling, in addition to the cover legume establishments that supply nitrogen through biological fixation.

Using fertigation systems to provide oil palms with fertilizer is not a common practice.

3.9.3 Crop protection

In oil palm cultivation, the use of fungicides or bactericides is not frequent, and when they are used they are not applied in a generalized way to crops. The main diseases are Bud Rot (BR) and Lethal Wilt. For BR the main management is agronomic and when the disease appears, the diseased tissue is removed and the wounds are protected with fungicides and bactericides. As Lethal Wilt is lethal deadly for the palm trees, the management consists in the timely detection of symptoms and the eradication of the affected palms. There are other diseases such as Red Ring and stipe rots, in which the same management is also applied with respect to Lethal wilt.
Eventually there are insect attacks that defoliate the crop and some insecticides are applied, but it is not a routine task and years can go by without making applications.

3.9.4 Irrigation and drainage practices

Water deficit does occur in the lower basin of the Sevilla River, thus the application of supplementary irrigation is necessary to achieve yields greater than 30 t of fresh fruit bunches (RFF) per year. Not applying irrigation implies obtaining yields that do not exceed 12 t of RFF/ha/year and this is a common denominator for the majority of the plantations established in the North Palm zone of Colombia. On the other hand, the distribution of rainfall implies that for at least eight of the twelve months of the year it would be necessary to apply irrigation to mitigate the water deficit.

Palm oil farmers pay two rates for their water use, a fixed one and a volumetric one. The fixed rate is paid every 2 months (23,861 Colombian pesos). The volumetric rate is paid according to the concession (57 Colombian pesos/m^3). Farmers have to apply for a concession by AsoSevilla, who will evaluate whether or not they can give the concession according to the availability of the water resource. If they approve, they make a visit to the plantation and verify if they have flow meters in the pressurized irrigation system or if they must make gauges in the irrigation canal that is delivered to the farmers. The concession is always based on the application of 1 L / sec / ha, in pressurized irrigation. And if it is surface irrigation, it is based on irrigation modules of 30 or 50 ha.

Delivering the concession according to the area of the property. The farmers’ concessions last for one year. AsoSevilla itself also has a concession to take water from the Río Sevilla, which is granted CORPAMAG, and this concession is for 10 years.

According to the information available in CENIPALMA, there are around 11,000 hectares with oil palm crops which are physically located in the Sevilla River basin, with information stored and being updated in GIS (see Figure 19 and Table 5). Of this area, more detailed information is provided for around 4700 hectares (Table 5). According to this information, prepared jointly with the palm nuclei of the area (Table 6), the following stand out:

- The Sevilla River is the main water source for irrigation, supplied by the Asosevilla irrigation district. In some cases, deep or shallow wells are used. However, this information needs to be specified through field work.
- More than 90% of the producers apply surface irrigation (Table 6) which consists of the diversion of water, in open channels and on the ground, from the canal of the Riego Asosevilla district to the plantation and subsequent diversion to the cultivation plots.
- For the characterized area, less than 10% of the producers use some type of pressurized irrigation. This is especially true for producers who use deep or surface groundwater. This is also the case of the Palmar de La Sierra Experimental Field, which collects water from the main channel of the irrigation district and is transported through pipelines to the palm plots.
- Regarding the way of applying irrigation, in the case of surface methods the most frequently used is basin irrigation (the entire field is flooded) and in some cases partial wetting with the help of furrows or ridges around the palm. This is known as furrow or trench irrigation. With respect to pressurized irrigation, there is sprinkler irrigation, mainly both partial and total coverage, and in the case of Palmar de La Sierra, there is also high-flow drip irrigation.
- Rainwater harvesting is no common practice in the study area.

According to Cenipalma efficiencies for surface irrigation can go as low as 8%, however, the average could be around 30%. In the case of pressurized systems, the efficiency of high-flow drip irrigation is close to 90% and for sprinkler irrigation 80% with average values close to 70%.

Irrigation can affect the proliferation of diseases. With surface irrigation, farmers have the challenge of unevenness in application and infiltration of water, there are soils with low aeration, which affects the root system, nutrient uptake and susceptibility of the palm to pathogen attack (i.e. Bud Rot). When farmers apply sprinkler irrigation, there can be problems with diseases in the first years if the water falls directly on the crown or bud of the palms.

In relation to drainage, the soils of the basin generally have adequate natural drainage and it is a condition that would require management especially for around four months of the year. On the other hand, the water table levels tend to be below the limiting depth for cultivation, which is fifty centimetres. Exceptions are those areas that may have the influence of lakes. Although it is necessary to quantify the density of the drains around and inside the plantations, it is assumed that there is a low density of drains and that in some cases these drains are also used as ways to conduct irrigation and are plugged or blocked with the purpose of retaining water in palm lots. In general, the main focus of the producers regarding water management is irrigation, as they observe the impact of this practice on yields. Drainage would be considered a ‘secondary’ practice and contrary to the first. However, due to the impact of Bud Rot and its relationship with soils with low aeration; it has sparked interest in knowing the state of soil aeration, the measurement of the fluctuation of groundwater levels and the execution of drainage on a regional scale and in each of the plantations.

Table 6. Oil palm producers and some characteristics of their plantations in the Sevilla River basin (Source: CENIPALMA).

PLANTACIÓN	AREA (ha)	NÚCLEO	TIPO DE CULTVO	ZONA	TIPO DE RIEGO
1	652	EL ROBLE	INDEPENDIENTE	SEVILLA	Superficie
2	130	EL ROBLE	INDEPENDIENTE	SEVILLA	Superficie
3	7	EL ROBLE	ALIANZAS	SEVILLA	Superficie
4	134	GRADESA	PROVEEDORES	ORIHUECA	Superficie
5	99	FRUPALMA	PROVEEDORES	ORIHUECA	Superficie
6	85,5	PALMACEITE	PROVEEDORES	SEVILLA	Superficie
7	20	EL ROBLE	ALIANZAS	ORIHUECA	Superficie
8	24	PALMACEITE	SOCIOS	ORIHUECA	Superficie
9	25	EL ROBLE	ACCIONISTA	ORIHUECA	Superficie
10	60	GRADESA	PROVEEDORES	ORIHUECA	Superficie
11	14	PALMACEITE	PROVEEDORES	LA GRAN VIA	Superficie
12	38	EL ROBLE	ALIANZAS	SEVILLA	Superficie
13	8	EL ROBLE	ALIANZAS	ORIHUECA	Superficie
14	13	EL ROBLE	ALIANZAS	ORIHUECA	Presurizado
15	44	PALMACEITE	SOCIOS	ORIHUECA	Superficie
16	78	EL ROBLE	INDEPENDIENTE	SANTA ROSALIA	Superficie
17	45	PALMACEITE	PROVEEDORES	LA GRAN VIA	Superficie
18	7	EL ROBLE	ALIANZAS	ORIHUECA	Superficie
19	20	FRUPALMA	PROVEEDORES	ORIHUECA	Superficie
20	9	EL ROBLE	ALIANZAS	SEVILLA	Superficie
21	305	FRUPALMA	SOCIOS	ORIHUECA	Superficie
22	9	EL ROBLE	ALIANZAS	ORIHUECA	Superficie
23	8	EL ROBLE	ALIANZAS	SEVILLA	Superficie
24	15	EL ROBLE	ALIANZAS	SEVILLA	Superficie
25	7	FRUPALMA	PROVEEDORES	ORIHUECA	Superficie
26	15	EL ROBLE	ALIANZAS	SANTA ROSALIA	Superficie
27	14	PALMACEITE	SOCIOS	SANTA ROSALIA	Superficie
28	54	ACEITES	SOCIOS	SEVILLA	Superficie
29	5	EL ROBLE	ALIANZAS	ORIHUECA	Superficie
30	240	FRUPALMA	SOCIOS	ORIHUECA	Superficie
31	26	PALMACEITE	PROVEEDORES	SEVILLA	Superficie
32	30	EL ROBLE	ACCIONISTA	SANTA ROSALIA	Superficie
33	162	FRUPALMA	SOCIOS	ORIHUECA	Superficie
34	6	EL ROBLE	ALIANZAS	SANTA ROSALIA	Superficie
35	14	PALMACEITE	SOCIOS	ORIHUECA	Superficie
36	8	EL ROBLE	ALIANZAS	PALOMAR	Superficie
37	6	EL ROBLE	ALIANZAS	PALOMAR	no riega
38	150	GRADESA	PROVEEDORES	SANTA ROSALIA	Superficie
39	10	EL ROBLE	ALIANZAS	ORIHUECA	Superficie
40	5	EL ROBLE	ALIANZAS	PALOMAR	Superficie
41	7	EL ROBLE	ALIANZAS	SEVILLA	Superficie
42	30	EL ROBLE	ALIANZAS	LA GRAN VIA	Superficie
43	7	EL ROBLE	ALIANZAS	PALOMAR	Superficie
44	263	ACEITES	SOCIOS	ORIHUECA	Superficie
45	10	FRUPALMA	SOCIOS	SEVILLA	Superficie
46	280	EL ROBLE	INDEPENDIENTE	SANTA ROSALIA	Superficie
47	18	EL ROBLE	ALIANZAS	SEVILLA	Superficie
48	4	EL ROBLE	ALIANZAS	SEVILLA	Superficie
49	130	EL ROBLE	INDEPENDIENTE	ORIHUECA	Superficie
50	22	EL ROBLE	ALIANZAS	SEVILLA	Superficie
51	106	EL ROBLE	INDEPENDIENTE	SEVILLA	Superficie
52	7	EL ROBLE	ALIANZAS	SEVILLA	Superficie
53	4	EL ROBLE	ALIANZAS	ORIHUECA	Superficie
54	5	EL ROBLE	ALIANZAS	SEVILLA	Superficie
55	6	EL ROBLE	ALIANZAS	SEVILLA	Superficie
56	73	PALMACEITE	PROVEEDORES	SEVILLA	Superficie
57	4	EL ROBLE	ALIANZAS	SEVILLA	Superficie
58	102	FRUPALMA	SOCIOS	SEVILLA	no riega
59	6	EL ROBLE	ALIANZAS	SEVILLA	Superficie
60	18	EL ROBLE	ALIANZAS	SEVILLA	Superficie
61	12	EL ROBLE	ALIANZAS	LA GRAN VIA	Superficie
62	18	EL ROBLE	ALIANZAS	SEVILLA	Presurizado
63	6	EL ROBLE	ALIANZAS	PALOMAR	Presurizado
64	17,5	EL ROBLE	ALIANZAS	SEVILLA	Presurizado
65	11	EL ROBLE	ALIANZAS	PALOMAR	Superficie
66	36	PALMACEITE	PROVEEDORES	SEVILLA	Superficie
67	182	FRUPALMA	SOCIOS	ORIHUECA	Superficie
68	73	FRUPALMA	SOCIOS	SEVILLA	Superficie
69	48	FRUPALMA	SOCIOS	ORIHUECA	Superficie
70	5	EL ROBLE	ALIANZAS	ORIHUECA	no riega
71	14	EL ROBLE	INDEPENDIENTE	SANTA ROSALIA	Superficie
72	20	PALMACEITE	SOCIOS	SAN JOSE	Presurizado
73	5	EL ROBLE	ALIANZAS	SEVILLA	Superficie
74	182	PALMACEITE	SOCIOS	SEVILLA	Presurizado
Total caracterizado	4633				

3.10 Costs and benefits regarding efficient irrigation, fertigation and water harvesting

Case study: Palma de la Sierra - Cenipalma

Research is conducted in the Palmar de la Sierra Experimental Field to evaluate the efficiency of irrigation systems and the costs associated with the implementation and management of: sprinkling, high-flow dripping and surface irrigation through gates (Figure 20a-c).

Figure 20. Sprinkler irrigation (a), high flow drip (b) and surface drip through windows (c).

Based on the research done, the application efficiency has been 86% for dripping, 60% for sprinkler and 18% for surface irrigation. The efficiency of the systems affects the accumulated water deficit (Figure 21). For the first six months of 2020, the highest accumulated deficit is for surface irrigation (greater than 540mm), while, with sprinkler and drip irrigation, it is less than 200mm, the deficit with the drip system being less high flow.

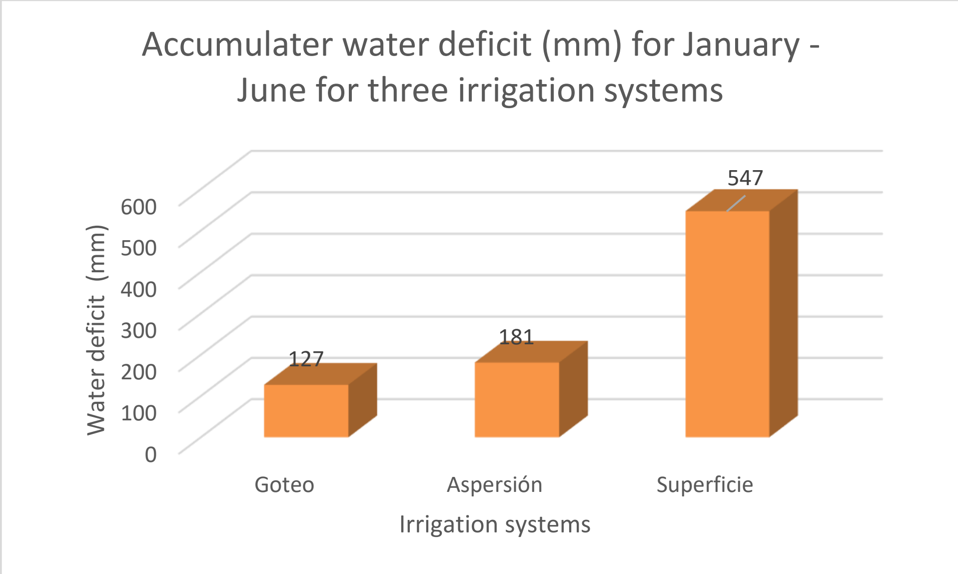

Figure 21. Water deficit based on irrigation systems used in the Palmar de La Sierra Experimental Field. Goteo: drip irrigation, aspersion: sprinkler irrigation and superficie: surface irrigation.

Regarding the costs of the systems, high-flow sprinkling and dripping have the highest initial investment (Table 7), however, operating costs (Table 8 and Table 9) can be up to four times higher for surface irrigation when you try to dispose the same amount of water to meet the requirements of the crop.

Table 7. Costs of establishing the irrigation systems.

Description	Costs (COL$/ha)
Surface irrigation	4,244,388
Drip and sprinkler irrigation	7,295,890

Table 8. Costs of operating the irrigation systems (to supply the water requirement of the crop and taking into account the efficiency of each system).

Irrigation system	Total costs (COL$/ha/year)
Surface irrigation	11,102,788
Sprinkler irrigation	2,170,983
Drip irrigation	1,797,697

In the real scenario of plantations, in which the efficiencies of the systems are not taken into account, the operating costs are presented in Table 8.

Table 9. Operating costs of three irrigation systems in Palmar de La Sierra (without considering the total contribution of the water requirement of the crop – CEPS 2018-2019).

Irrigation system	Water	Energy	Labour	Total costs (COL$/ha/year)
Surface irrigation	521,620	388,357	1,107,686	2,017,663
Sprinkler irrigation	463,503	419,712	394,286	1,277,501
Drip irrigation	393,148	336,685	424,581	1,154,414

Even in this case, operating costs are higher in surface irrigation systems and the accumulated water deficit is four times higher than in drip and sprinkler irrigation systems.

Case study: FARM SAN CARLOS – ACEITES S.A. CLUSTER

Within the framework of the water management system promoted by ACEITES S.A., a protocol is being developed, which seeks to implement a sprinkler irrigation system to supply the water needs of oil palm plantations, which are hardly met by the rainfall even if it does not reach 700 mm per year, according to local references between 2016 and 2019. This situation reflects the need to take advantage of this valuable resource efficiently. In addition, a photovoltaic plant was implemented to save up to 58% of the regular energy consumption (Electricaribe ESPSA) of the high-pressure pump for irrigation, which is based on the use of renewable energy that does not pollute the environment.

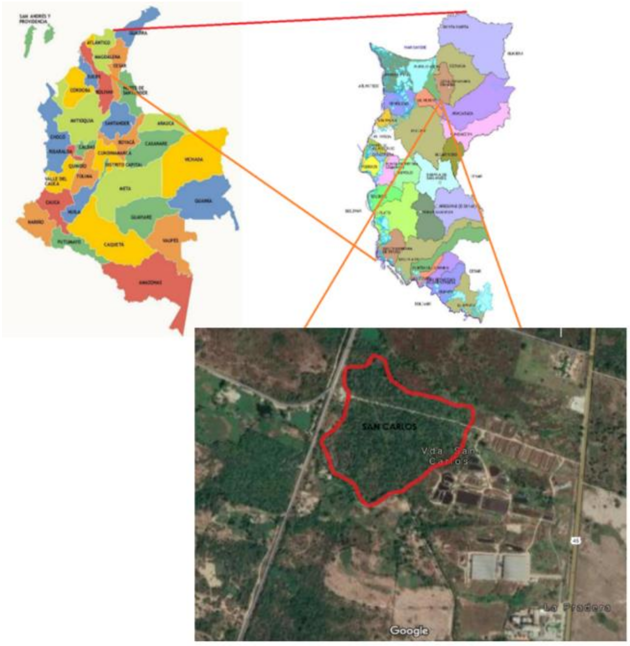

Figure 22. Geographic location of San Carlos plantation.

San Carlos farm, part of the company ACEITES S.A., is located in the municipality of Aracataca in the department of Magdalena, ninety kilometers from its capital Santa Marta (Figure 22). Its georeferencing corresponds to the following coordinates at 10° 37' 34.8" North latitude and 74° 10' 27.1" in West longitude, with an average altitude of 20 m.a.s.l. The plantation has an area of 20.36 hectares dedicated to the cultivation of oil palm.

Strategy

1.1 Design and installation of a pressure irrigation system

In Figure 23 the design of a pressurized irrigation system is shown. Irrigation blocks are designed to apply water for 4 hours.

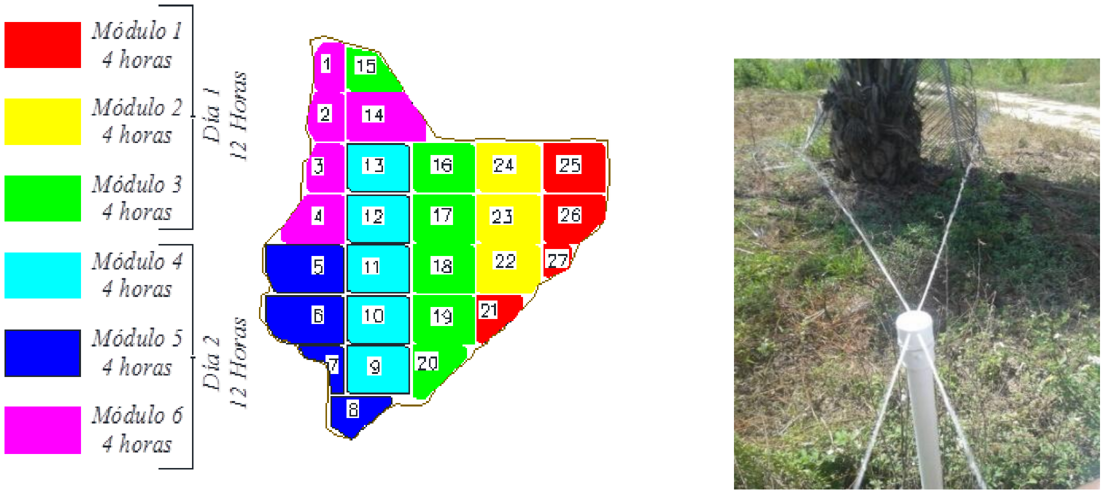

Figure 23. Design of a pressure irrigation system and irrigation system with PVC stopper.

This system is designed to apply the water requirement of 350 to 370 L /day/palm, that is, a 5 mm/day irrigation sheet is applied, which corresponds to 5% of the irrigation sheet of a surface irrigation system.

1.2 Photovoltaic plant

The photovoltaic plant is a solution interconnected to the grid, that operates through a system without a battery, where the energy consumed comes simultaneously from the solar system and the electrical grid. This plant has two components: solar panels and inverters (Figure 24).

Figure 24. Solar panels (left panel) and grid-tie inverter (right panel).

Solar panels or photovoltaic modules are responsible for capturing energy from the sun in the form of solar radiation and transforming it into electrical energy. This system consists of eighty solar panels of 255 Watt each.

The inverter is the electronic equipment that allows the energy produced by the photovoltaic generator to be injected into the electrical network (Figure 24). Its main function is to convert the direct current from the photovoltaic panels into alternating current.

The performance of the photovoltaic plant since its operation in 2018, 2019 and so far in 2020 is described below: During the year 2018, the photovoltaic plant was working during the summer months (January - April) until the start of the rains, in this period the irrigation system in San Carlos operated 742 of the 859 working hours (86%) time in which 11,123 kW of energy were consumed. The photovoltaic plant contributed 6,468 kW, which represents 58% of total energy consumption (Figure 25).

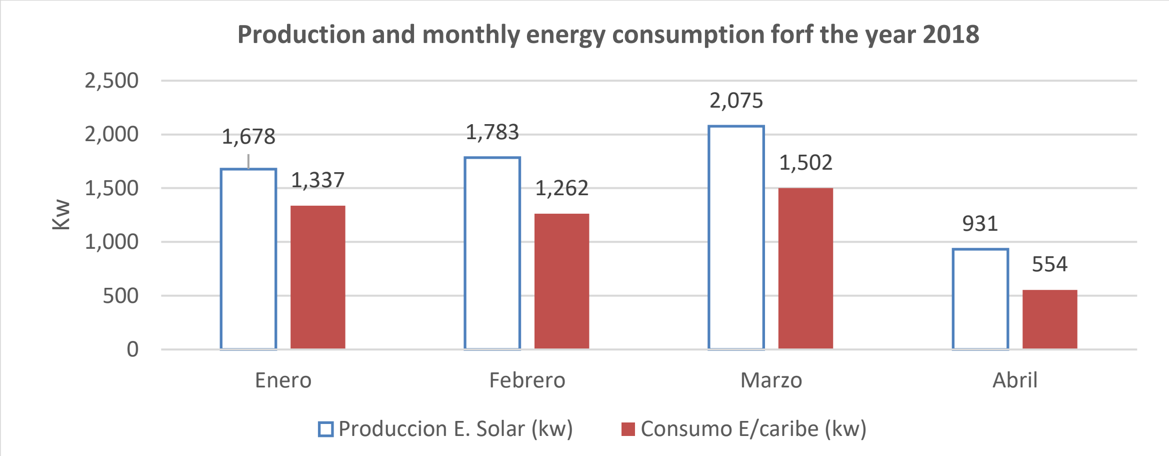

Figure 25. The production and monthly energy consumption of the photovoltaic plant for the year 2018.

During 2019, the photovoltaic plant was working also in the summer months (January - April and July - August) until the start of the rains, a period in which the irrigation system operated 970 of the 1,289 working hours (75 %), time in which 14,550 kW of energy were consumed. The photovoltaic plant contributed 7,867 kW, which represents 54% of total energy consumption (Figure 26). Due to inverter operating problems, the energy savings were not greater.

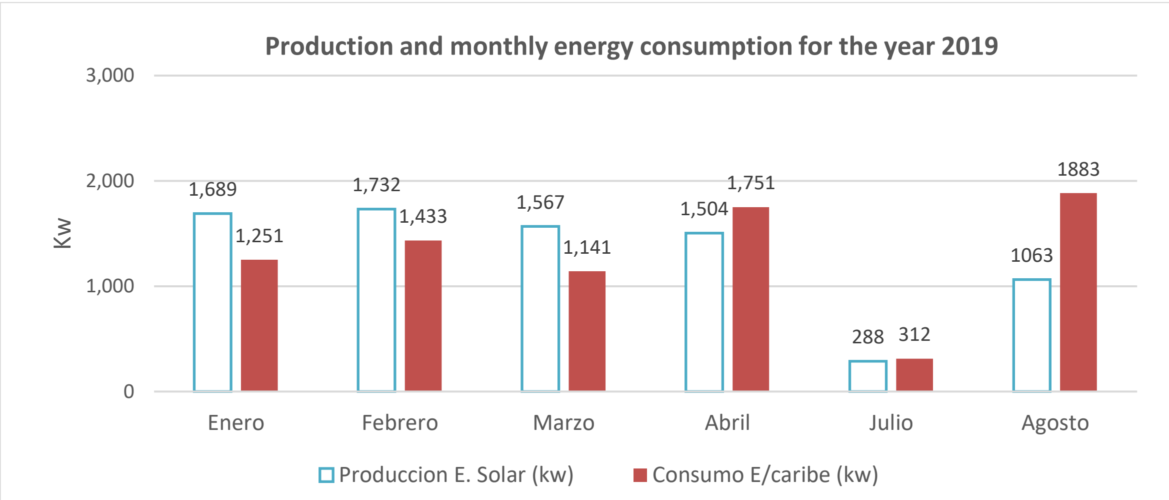

Figure 26. The production and monthly energy consumption of the photovoltaic plant for the year 2019.

So far in 2020, the irrigation system has operated 589 hours out of the 1,176 hours scheduled until June, which means that the operation of the system so far is 50%, taking into account that the rainy season began from the month of May and the hours of operation of the system decrease.

During 2020, the photovoltaic plant has generated 3,639 kW of the 8,172 KW of the consumption for the irrigation pump (Figure 27). In the last months they have had an energy saving rate greater than 50%, which means that the main objective of the project is being met; as long as all the components of the photovoltaic plant are operating in optimal conditions.

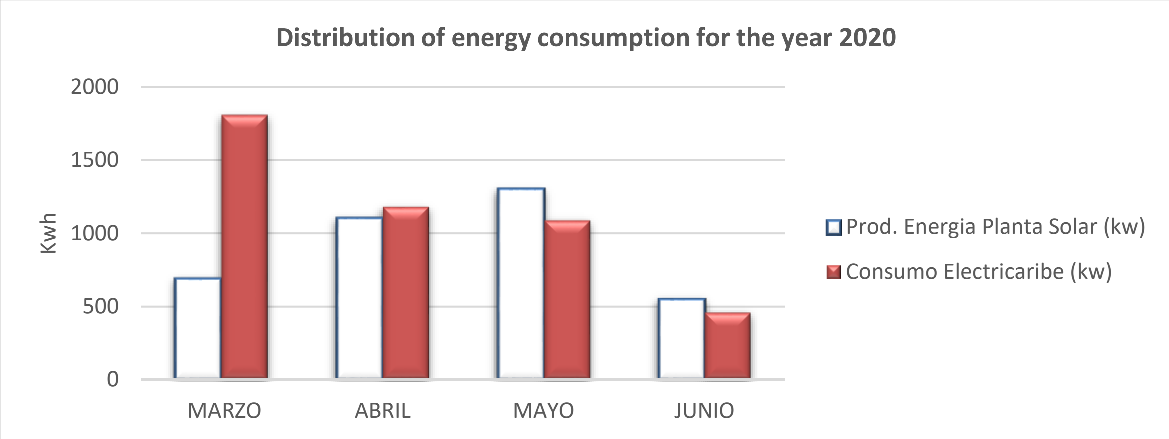

Figure 27. The production and monthly energy consumption of the photovoltaic plant for the year 2019.

As there is an energy saving, this is reflected in the billing costs of the electricity provider company, as long as the photovoltaic system is operating without any problem (Figure 28). Moreover, the climatic conditions that may occur during the operating time that affect the performance of the system must be taken into account.

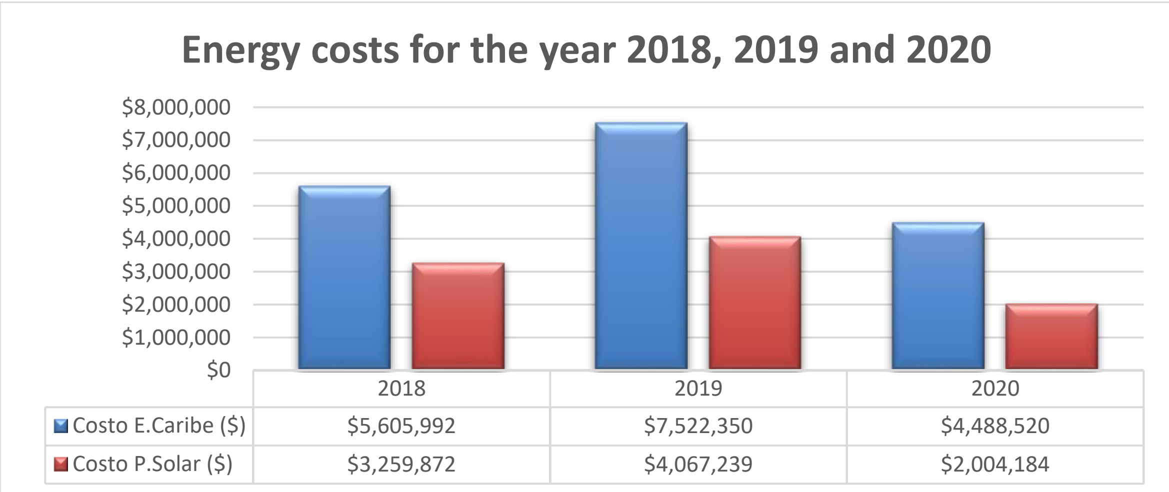

Figure 28. Energy costs (COL$) for the photovoltaic plant for the year 2018, 2019 and 2020.

1.3 Fertigation system

ACEITES S.A. has the conclusion that this project has fulfilled its objective of efficiently use the resources to produce fresh fruit bunches while increasing the productivity. By implementing pressurized irrigation and fertigation systems, the necessary water supply for oil palm cultivation is guaranteed in an efficient and rational manner (Figure 29, Figure 30 and Figure 31).

Sistema de fertirriego	
Caudal de bomba (LPS)	2
Presión de la Bomba (PSI)	80
Tasa de inyección (LPM)	6
Tiempo de inyección (min)	41,7
Flujometro (LPM)	10
Tanques para la mezcla (L)	250
Bomba de aire (Blower 900w)	1
Cantidad de tanques (und)	4

Figure 29. Fertigation system.

Figure 30. Monthly production for 2015, 2016, 2017, 2018 and 2019. Application of irrigation and fertigation are indicated.

SISTEMA DE RIEGO POR TAPON DE PVC PARA UNA BOMBA ELECTRICA CON ENERGIA SOLAR (SOLAR PLUS)				
1. BOMBA ELECTRICA				
DESCRIPCION	**UNIDAD**	**CANTIDAD**	**VR UNITARIO**	**VR TOTAL**
GE 3B 200 - 1B0037- 20 HP- 220/440V	UND	1	$ 4,930,000	$ 4,930,000
SUBTOTAL				**$ 4,930,000**
2. ENERGIA SOLAR				
DESCRIPCION	**UNIDAD**	**CANTIDAD**	**VR UNITARIO**	**VR TOTAL**
PLANTA FOTOVOLTAICA DE 20.4KW, ESTRUCTURA, TRANSPORTE E INSTALACION (SOLAR PLUS)	UND	1	$ 133,408,000	$ 133,408,000
SUBTOTAL				**$ 133,408,000**
3. MANO DE OBRA Y MATERIALES DEL SISTEMA DE RIEGO				
DESCRIPCION	**UNIDAD**	**CANTIDAD**	**VR UNITARIO**	**VR TOTAL**
MANO DE OBRA EN INSTALACION DEL SISTEMA	ha	22	$ 1,001,618	$ 22,035,603
COMPRA DE TUBERIAS	ha	22	$ 1,868,246	$ 41,101,417
COMPRA DE TALADRO DE COLUMNA	UND	1	$ 269,900	$ 299,900
FILTROS PARA EL SISTEMA DE RIEGO	UND	4	$ 1,007,460	$ 4,029,840
SUBTOTAL				**$ 67,466,760**
4. ENERGIA ELECTRICA				
DESCRIPCION	**UNIDAD**	**CANTIDAD**	**VR UNITARIO**	**VR TOTAL**
TRANSFORMADOR TRIFASICO DE 75 KVA	UND	1	$ 6,801,161	$ 6,801,161
INSTALACION DE TRANSFORMADOR, MALLA A TIERRA, TRANSPORTE Y COLOCACION POSTE.	UND	1	$ 5,274,500	$ 5,274,500
MATERIALES PARA CONEXIÓN Y ARRANCADOR SUAVE	UND	1		$ 2,409,942
INSTALACION DE LA BOMBA (ELECTRICISTA)	DIA	2	$ 47,441	$ 94,882
SUBTOTAL				**$ 14,580,485**
5. MANO DE OBRA Y MATERIALES PARA LA CASETA DE BOMBEO				
DESCRIPCION	**UNIDAD**	**CANTIDAD**	**VR UNITARIO**	**VR TOTAL**
AMPLIACION DE LA CASETA DE BOMBEO	UND	1	$ 5,550,000	$ 5,550,000
EMPARRILLADO Y REJA PARA LA SEGURIDAD DE LA CASETA	UND	1	$ 712,120	$ 712,120
MATERIALES PARA CONSTRUCCION	UND	1	$ 13,563,207	$ 13,563,207
SUBTOTAL				**$ 19,113,207**
6. TRANSPORTE				
DESCRIPCION	**UNIDAD**	**CANTIDAD**	**VR UNITARIO**	**VR TOTAL**
TRANSPORTE DE INSUMOS	UND	1	$ 908,577	$ 908,577
SUBTOTAL				**$ 908,577**
COSTO TOTAL DEL PROYECTO				**$ 240,407,029**
COSTO TOTAL (BOMBA + ENERGIA SOLAR + SISTEMA DE RIEGO)				**$ 205,804,760**

Figure 31. Total costs (COL$) of the research project.

3.11 Water harvesting potential

Water harvesting is defined as "The collective term for a wide variety of interventions which are primarily or secondarily intended to collect natural water resources which otherwise would have escaped from human reach, and buffer them through storage and/or recharge on or below the soil surface" (UNEP, 2019; Ouessar et al., 2012). The large set of practices embraced by this definition can be generally classified in the two main groups of "ex-situ", "in-situ" measures potentially applicable in the Sevilla basin.

Ex-situ water harvesting includes practices that collect runoff water from an area external to the farm, a farmland generally used for irrigation (e.g., small dams and check dams, road water harvesting, dugout ponds) such as the farms in the Oil palm region in the Sevilla basin. In-situ water harvesting refers to in-field soil and vegetation management practices applied to increase infiltration and reduce runoff and evaporation (e.g., micro-catchment, mulching, conservation tillage, vegetative strips). This can be applied in the oil palm farms, with lower costs compared to ex-situ water harvesting. However, building Ex-situ structures such as check dams in areas with lower drought risk in the wet season to transport the water to oil palm farms with higher drought risk in the dry season can be beneficial. Further evaluation in the area has to be made to see if hydraulic structures are already built (including canals to transport the water) and potentially just need to be rehabilitated increasing the net benefit. In Table 10, a list of water harvesting techniques (Piemontese et al., 2020), potentially applicable in the Sevilla basin is shown.

Table 10. Water harvesting techniques potentially applicable in the Sevilla basin for improving water management in the oil palm areas.

Water harvesting Group	Subgroup	Definition
Ex-Situ (Collection of runoff from an area > 10 larger than the farm size)	Dams/Check Dams	Water ponds realized by a damming wall in impluvium and gullies
	Diversion Canal	Floodwater diversion by canal
	Diversion Weir	Floodwater diversion by weir
	Dugout Ponds	Excavated in-situ water ponds
	Road Water Harvesting	Water harvested from roads
	Sand dams	Damming of dry riverbed to store sand in artificial aquifers
	Micro-catchment	in-situ techniques to increase infiltration and prevent evaporation (pits, semi-circular bunds)
In- Situ (Retention of runoff from an area < 10 larger than the farm size)	Conservation Tillage	Conservation Tillage
	Mulching	Soil cover for reducing evaporation
	Rooftop	Water harvested from rooftops
	Vegetative strips	Strips of vegetation on contour lines and/or in gullies

4 Conclusions and further work

This baseline assessment was developed for the Sevilla river basin in Colombia, which is the basin selected for the feasibility study on efficient irrigation for oil palm areas. The objective of this baseline assessment was to collect data on the local environment at basin scale, the current cultivation practices and identify suitable interventions regarding efficient irrigation, fertigation and water harvesting in oil palm areas.

In summary, oil palm plantations in the project area cover around 14% of basin area and are located in the downstream area of the basin. Smallholders have up to 20 hectares each, medium farmers 20-50 hectares and large farmers may have hundreds of hectares of oil palm plantations. Oil palm farmers are generally organised by palm oil mill, owned by companies in which they tend to be shareholders. Currently the water association called Asosevilla manages the water supply for the irrigated oil palm farms. The water concession from the Sevilla River is 7 Mm^3/month. In February and March, the available water is lower than the water concession.

The Sevilla basin has two distinctive seasons; a dry season from December to March and a wet season from April to November. In the wet season the highest rainfall occurs between August and November. These months are thus selected for the evaluation of the potential of water harvesting techniques which will be carried out in the next months. The drought hazard was determined to provide a better understanding of the risk of water scarcity in the basin. The highest drought hazard was found in the lower part of the basin (in the oil palm areas). Installing water harvesting facilities in the oil palm areas would help in reducing the impact of future drought events.

The soils in the oil palm areas have a high soil water storage capacity (SWC); even in the areas with low values there is still 197 mm of storage capacity per meter depth of soil, which is associated to loamy soils appropriated for in-situ water harvesting techniques. Specific farm conditions must be inspected (including the soil water storage capacity and saturated hydraulic conductivity) to confirm the appropriate soil characteristics for water harvesting and application of specific techniques. The exact location and specific water harvesting techniques (e.g. ex-situ or in-situ) have to be decided at farm level considering soil and climate conditions and associated costs.

The main practices regarding cultivation management in the area are manual application of (predominantly) chemical fertilizers, and crop protection is done reactively and kept to a minimum. The most predominant cultivar is Deli x Avros, which is highly productive in terms of tons of fruit and the amount of oil/ha. Irrigation is required for obtaining good yields, as water deficit can occur. The Sevilla River is the main water source for irrigation, supplied by the Asosevilla irrigation district. In some cases, deep or shallow wells are used. More than 90% of the producers apply surface irrigation which consists of the diversion of water, in open channels and on the ground, from the main canal of Asosevilla to the plantation and subsequent diversion to the cultivation plots. Regarding the way of applying irrigation, in the case of surface methods the most frequently used is basin irrigation and in some cases furrow or trench irrigation.

For the study area, less than 10% of the producers use some type of pressurized irrigation. This is especially true for producers who use deep or surface groundwater. With respect to pressurized irrigation, there is sprinkler irrigation, mainly both partial and total coverage, and in the case of Palmar de La Sierra, there is also high-flow drip irrigation. Efficiencies for surface irrigation can go as low as 8%, however, the average is estimated to be around 30%. In the case of pressurized systems, the efficiency of high-flow drip irrigation is close to 90% and for sprinkler irrigation 80% with average values close to 70%. The low uniformity of surface irrigation and the implications of prolonged waterlogging of some cultivation areas in terms of loss of soil oxygenation, nutrient imbalance and its impact on the appearance and development of diseases such as Bud Rot. In general, the main concern of the producers regarding water management is irrigation, as they observe the impact of this practice on yields. Drainage is considered a non-priority practice.

Based on research going on in the region, some initial cost and benefit analysis has been done which is presented in this report. High-flow sprinkling and dripping have the highest initial investment, however, operating costs can be up to four times higher for surface irrigation when you try to dispose the same amount of water to meet the requirements of the crop. Further cost-benefit analysis should reveal when these technologies can become attractive with a good expected return on investment.

This baseline assessment is the first output of the feasibility study. A number of activities and outputs will follow such as measuring field characteristics in selected oil palm farms, get insight in the limiting factors for the adoption of efficient irrigation technology, fertigation and water harvesting, and develop an action plan for the implementation phase. This will result in the final feasibility study for efficient irrigation techniques in the Colombian palm oil sector.

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