Universität für Bodenkultur Wien

University of Natural Resources and Life Sciences, Vienna

Department of Water, Atmosphere and Environment

Institute of Sanitary Engineering and Water Pollution Control

INVESTIGATION OF WATER RESOURCES IN THE MUNICIPALITY OF TECOLUCA AND EVALUATION OF WATER SUPPLY IN EL MILAGRO, EL SALVADOR

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LIEMBERGER, MARION

Supervisor: Langergraber, Günter, Priv.-Doz. Dipl.-Ing. Dr.nat.techn.

Co-Supervisor: Leroch, Klaus, Dipl.-Ing. Dr.nat.techn.

Student number: 01040650

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ABSTRACT

The supply of safe drinking water is a central topic of interest as well as concern within the Municipality of Tecoluca, El Salvador. Insufficient quantity and quality of drinking water is the result of inadequate catchment of water and the unsatisfying state of the distribution networks as well as their management. The aim of this research was set on documenting the state of water resources within the Municipality and determining if community management is a viable solution for the target community and thereby setting a basis for future planning on water resources management. Data collection took place during a five month stay in Tecoluca, during which water resources used for drinking water were visited and further knowledge was gathered by the means of structured interviews and observations. Fieldwork included the mapping of the water sources and respective in situ measurements on water quantity and water quality. Furthermore, an in-depth study in the rural community of El Milagro was undertaken to gain information on the actual water use, water demand and water consumption at household level and the management of the drinking water distribution. The results on water resources show that more data is necessary to make a concrete statement about the potential decrease of spring discharge alongside changes in water quality. The point measurements conducted, while providing basic insight into the availability of water from particular sources, are not suitable for drawing long-term conclusions. Regarding water supply in El Milagro, findings show that currently enough water is available, however the design of the network does not allow for optimal distribution. The overall consumption is relatively high, considering that most households have only one tap and neither shower heads nor flushed toilets. Furthermore, water storage in open basins and other forms of containments is a potential health risk due to in-house contamination. Further steps for the improvement of the community water supply need to be taken.

Keywords:

Community Management, Rural Water Supply, Household water storage

KURZFASSUNG

Die Versorgung mit sauberem Trinkwasser ist ein zentrales Anliegen der Gemeinde Tecoluca, El Salvador. Unzureichende Menge und Qualität sind das Resultat von veralteten Quellfassungen einerseits sowie dem bedenklichen Zustand des Verteilungsnetzes und dessen Managements andererseits. Das Ziel dieser Forschung war es, den Zustand der Wasserressourcen in der Gemeinde zu dokumentieren und festzustellen, ob kommunale Wasserversorgung und -management eine hinreichende Option für dieses spezifische Dorf darstellen und somit eine Grundlage für zukünftige Planungen zum Wasserressourcenmanagement darstellen. Die Datenerhebung erfolgte während eines fünfmonatigen Aufenthalts in Tecoluca, bei dem Trinkwasserressourcen untersucht und weitere Erkenntnisse mittels strukturierter Interviews und Beobachtungen gesammelt wurden. Die Feldarbeit umfasste die Kartierung der Wasserquellen sowie entsprechende In-situ-Messungen der Wassermenge und -qualität. Darüber hinaus wurde in der ländlichen Gemeinde El Milagro eine eingehende Studie durchgeführt, um Informationen über den tatsächlichen Wasserverbrauch, die Wassernachfrage und -nutzung auf Haushaltsebene sowie das Management der Trinkwasserverteilung zu erhalten. Die Ergebnisse zu den Wasserressourcen zeigen, dass mehr Daten benötigt werden, um eine konkrete Aussage über die potentielle Abnahme der Quellschüttung oder Veränderungen der Wasserqualität treffen zu können. Die durchgeführten Punktmessungen liefern zwar einen grundlegenden Einblick in die Verfügbarkeit von Wasser aus bestimmten Quellen, sind jedoch nicht geeignet, langfristige Schlussfolgerungen zu ziehen. Bezüglich der Wasserversorgung in El Milagro zeigen die Ergebnisse, dass genügend Wasser zur Verfügung steht, das Design des Netzwerkes jedoch keine optimale Verteilung erlaubt. Der Gesamtverbrauch ist relativ hoch, wenn man bedenkt, dass die meisten Haushalte nur einen Wasserhahn haben und weder Duschköpfe noch Spültoiletten. Darüber hinaus birgt die Wasserspeicherung in offenen Becken und anderen Behältnissen ein Gesundheitsrisiko aufgrund von potentieller Kontamination auf Haushaltebene. Es bedarf weiterer Maßnahmen um die kommunale Wasserversorgung zu verbessern.

Stichwörter:

Kommunale Wasserversorgung, ländliche Wasserversorgung, Wasserspeicherung auf Haushaltsebene

Abbreviations

ANDA	*Administración Nacional de Acueductos y Alcantarillados*
	National Administration for Water and Sanitation Services
BOKU	*Universität für Bodenkultur, Wien*
	University of Natural Resources and Life Sciences, Vienna
JMP	Joint Monitoring Programme
LAC	Latin America and the Caribbean
LMIC	Low and middle-income countries
NGO	Non-governmental organisation
MDGs	Millennium Development Goals
MARN	*Ministerio de Medio Ambiente y Recoursos Naturales*
	Ministry of Environment and Natural Resources
MINSAL	*Ministerio de Salud y Asistencia Social*
	Ministry of Public Health and Social Assistance
O&M	Operation and maintenance
pH	Potential of Hydrogen
UCA	Universidad Centroamericana
UN	United Nations
UNICEF	United Nations Children's Fund
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization
WIS	Water Information System

1. Introduction

The Municipality of Tecoluca has made the supply of sufficient and safe water to its rural population a main priority in its fight against poverty. Despite all efforts in previous years, continuous supply of clean and safe drinking water to its rural population is still not possible. In urban areas, piped water supply, regulated and monitored by the National Administration for Water and Sanitation Services (ANDA) is the norm. In rural communities, local water boards are in charge of managing water supply and face many different challenges, such as lack of funds and know-how etc. The Municipality is rich in natural springs, yet locals claim that the amount of water is decreasing and therefore distribution to the communities is more challenging. In addition to less water, most of El Salvador’s grey and black water is discharged untreated into water bodies, contaminating potential water sources. In the case of limited water suitable for domestic use, a well-planned and managed distribution system paramount to ensure sustainability.

This thesis is a continuation of research previously conducted by BOKU students in 2015, whom were closely engaged in the planning phase. The initial purpose of this research project was to establish a continuous monitoring network for springs in the Municipality. However, due to difficulties on-site, this topic had to be abandoned and a new approach was chosen. For this reason, this thesis contains two parts. Firstly, the collection and comparison of water quantity and quality data of water resources within the Municipality. The second part comprises an in-depth analysis of the water supply system in the community of El Milagro. The researcher attempted to ensure that all collected data was used. Research on-site took place during a four month period from February to June 2016, during which data collection took place. Results were not separated but combined to illustrate how the different topics are interlinked and strongly dependent on each other. Work from other students was used to show similarities and differences within the Municipality to give a better understanding of the complexity of municipal water supply and management.

In 2000 the ‘Regionalkooperation Salzburg-San Vicente’ was created. A cooperation supporting projects in organic farming, health, education, advancement of women, water and wastewater management. Emphasis was placed on improving water supply as well as sanitation. Thus, an additional cooperation between the University of Natural Resources and Life Sciences, Vienna (BOKU) in particular the Institute of Sanitary Engineering and Water Pollution Control and the Municipality of Tecoluca through the Austrian NGO INTERSOL was established to enhance and facilitate this process. Austrian students contributed to the development of the water and waste water situation in Tecoluca through a number of Master thesis projects. The presented thesis is an outcome of this collaboration.

2. Research gap, aim and objectives

Community managed water supply may offer a good solution for rural communities in the Municipality of Tecoluca, but whether it comprehensively and suitably meets the needs and expectations of the people must be determined. Currently, most rural communities are in charge of their own water supply systems. From building spring captures, operating and maintaining the supply network to billing its consumers. However, specific and contextual investigation is imperative to determine if these water resources are properly managed and the respective management systems are suitable for the communities in the Municipality of Tecoluca.

The researcher notes that the documentation and analysis of water sources in comparison with previously gathered information as well as a specific study on rural water supply in El Milagro has not yet been conducted and therein lies a knowledge gap.

This study aims to fill this knowledge gap with findings from field work carried out from February to June 2016 in the Municipality of Tecoluca and more detailed investigation in the rural community of El Milagro.

Aim and objectives

The aim of this research is to document the state of water resources within the Municipality and to determine if community run management is a viable solution for the target community. By offering insight into the different water resources and supply schemes as well as more detailed information based on the case study of El Milagro, the perception of the management scheme and how it can be optimised are explored.

The objectives are:

- To document the state of different water resources in the whole Municipality of Tecoluca, their quality and the comparison to previously gathered information, as well as
- to analyse the water supply and assess user needs and possible future research in a particular target community, El Milagro.

Thesis structure

This thesis is divided into four main chapters:

- Chapter “Fundamentals”, provides an introduction into the topic of rural water supply, its different aspects as well as an overview and interrogation of the status quo of the country and the community of interest.
- Chapter “Methodology” explains the methods and tools used for data collection and analysis of the water supply in the target community.
- Chapter “Results and Discussion” presents the collected information with a comparison to previously gathered information on water resources in the study area as well as documentation and analysis of the water supply in El Milagro.
- Chapter “Conclusion and Outlook” gives a summary of the results and of the study alongside recommendations for future studies.

3. Fundamentals

This Chapter contains three main sections which help to examine the fundamentals and present the state of science and research in the field of this thesis.

1. The first section (Chapter 3.1) gives an overview of water in an international context, the fundamentals of water as well as its distribution in rural communities.
2. The second section (Chapter 3.2) introduces water supply in the region, as well as an introduction to the country and its water resources at the time of the study.
3. The third section (Chapter 3.3) gives insight to the study area and the rural community El Milagro, the focal point for the Case study of this thesis.

3.1 Background information on water

3.1.1 Water in an international context

3.1.1.1 Sustainable Development Goal 6

The United Nations (UN) created 17 broad and interdependent goals, called Sustainable Development Goals (SDGs). The SGDs include aspirational global targets to achieve universal access to basic services and to replace the former Millennium Development Goals (MDGs). The MDGs were developed by the UN in 2000, with 8 goals to meet the needs of the world's poorest and to enhance the fight against extreme poverty. The targets were set with a deadline of 2015 and included actions on education, health, gender equality and environmental sustainability. Regarding water and sanitation, the MDG Goal 7 (see Box 1) was replaced by a more specific goal (Goal 6 "Clean Water and Sanitation").

Box 1: Millennium Development Goal 7

Millennium Development Goal 7 – Environmental Sustainability

Target 7c: *Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation.*

A safe drinking water source is by nature of its construction or through intervention likely to be protected from outside contamination, particularly from faecal matter. Basic sanitation is hygienically separating human excreta from human contact. The world met the target 5 years ahead of schedule, 2.6 billion people gained access to improved drinking water and 2.1 billion people gained access to improved sanitation. However, 2.4 billion people remained using unimproved sanitation facilities, including open defecation. Source: (UN, 2015)

The Sustainable Development Goal 6 (SDG 6) was developed to ensure availability and sustainable management of water and sanitation for all (United Nations, 2015) and to progressively improve the standard of water, sanitation and hygiene (WASH) services by 2030. The goal consists of 8 targets with corresponding target indicators. For the purpose of this thesis, targets 6.1, 6.4 and 6.B are of most relevance (see Box 2).

Box 2: Sustainable Development Goal 6

Sustainable Development Goal 6

Target 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all.

Target indicator:

6.1.1: Proportion of population using safely managed drinking water services

Target 6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

Target indicator:

6.4.1: Change in water-use efficiency over time

6.4.2: Level of water stress: freshwater withdrawal as a proportion of available freshwater resources

Target 6.B: Support and strengthen the participation of local communities in improving water and sanitation management.

Target indicator:

6.B.1: Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management.

Source: (United Nations, 2015)

The Joint Monitoring Programme for Water and Sanitation (JMP) by World Health Organization (WHO) and United Nations Children's Fund (UNICEF) has since 2016 been officially tasked to monitor progress towards the SDG 6. Previously it was tasked to monitor MDG 7, Target 7c related to drinking water and sanitation (JMP, 2017b). The JMP developed a service ladder (see Table 1) to benchmark and compare service levels across countries. The term *"drinking water services"* refers to the accessibility, availability and quality of the main source used by households for drinking, cooking, personal hygiene and other domestic uses.

Table 1: JMP Drinking water ladder[1]

SERVICE LEVEL	DEFINITION
SAFELY MANAGED	Drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination.
BASIC	Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing.
LIMITED	Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing.
UNIMPROVED	Drinking water from an unprotected dug well or unprotected spring.
SURFACE WATER	Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal.

It is important to note that improved drinking water sources are those which by nature of their design and construction have the potential to deliver safe water. These include piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater and packaged or delivered water (JMP, 2017b).

3.1.1.2 The Human Right to Water

Following the UN General Assembly in 2010, access to water and sanitation was declared a human right through the Resolution 64/292, acknowledging its importance in the realisation of all human rights. The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses (UHCHR and WHO, 2010).

- **Sufficient for personal and domestic use:** Including drinking, sanitation and hygiene as well as food preparation. The amount should meet basic needs and sustain life and health and varies between 50 – 100 litres per day per person according to the WHO.
- **Safe and acceptable for personal and domestic use:** Water has to be free from micro-organisms, chemicals or radiological hazards. Limit values can be found in national and international standards such as the WHO guidelines for drinking water quality.
- **Physically accessible:** Within 1 km from a home or 30 min walking distance, roundtrip.
- **Affordable and available for everyone:** Water should be affordable even to the poorest and water prices should not exceed 5% of the household income.

(UHCHR and WHO, 2010; Lasser, 2018)

[1] Source: (JMP, 2017b)

3.1.2 Water quantity and quality

Measuring water quantity helps to manage water resources because it has a direct relationship with water quality. For the purpose of this thesis, two aspects of water quantity and quality are emphasised, such as the importance of continuous water supply, its metering as well as the importance of appropriate water storage to guarantee safe water at a household level.

3.1.2.1 Essentials

According to the World Health Organisation a minimum of 7.5 l/c/d will provide sufficient water for hydration and incorporation into food, however a consumption of 20 - 50 l/c/d for basic (within 1 km/within 30 min round-trip) to intermediate access (Water provided on-plot through at least one tap (yard level)) to water can be expected. Optimal access, meaning supply of water through multiple taps within the house is estimated to be on average 100 – 200 l/c/d (WHO, 2011a).

Water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics. The essential parameters for monitoring springs are discharge, water temperature, electric conductivity, turbidity and pH (BMLFUW, 2009; WHO, 2011a).

Discharge

The discharge is the amount of water a spring releases over a specific time. It is mostly measured in l/s and forms the most important parameter.

Temperature

El Salvador does not have limits for drinking water temperatures within the national Drinking Water Standards (CONACYT, 2009). According to the WHO (2011a) it is recommended to keep water temperatures outside the range of 20 – 50°C to prevent microbial growth. In addition to microbiological growth, higher water temperatures can affect inorganic constituents and chemical contaminants that may increase problems related to smell, taste, colour and corrosion.

Electrical conductivity

The electrical conductivity of spring water and groundwater varies greatly due to geological effects. It is used as an indicator for the concentration of dissolved ionic substances and a sudden change in a water body can indicate pollution. The time-variation gives information about the lithology of the aquifer, the storage dynamic of the catchment area, the surface runoff dynamic of the spring and the behaviour regarding rainfall. It is therefore recommended as a parameter that should be used in operational monitoring for source waters (WHO, 2011b). Approximate values that can be expected in raw and tap water to range between 50 and 500 µS/cm ((Hauser, 2002) as cited in Schaidreiter, 2016).

Turbidity

Turbidity is the reduction in transparency of a liquid. Undissolved matter, such as suspended sediments or living organisms can increase turbidity, further consequences include problems with disinfection.

pH

Although it is not a regulated parameter for drinking water, pH has to be considered in the operational aspects of water supply in order to ensure proper clarification and disinfection (Schaidreiter, 2016). The Drinking Water Standards from the Ministry of Public Health and Social Assistance (MINSAL) El Salvador, states that pH has to be within a range of 6.0 and 8.5 (CONACYT, 2009). According to the WHO Drinking Water Guidelines (2011a), pH levels closer to 8 are more suitable for effective operation in water treatment. Higher pH values reduce the effectiveness of disinfection with chlorine, thereby causing the need for higher chlorine concentrations. However, values less than 7 can lead to corrosion of distribution pipe materials. Therefore, it is recommended that pH levels should lie in the range of 6.5 and 8.5 (WHO, 2011a).

3.1.2.2 Guaranteeing water quality through appropriate water storage

Storing water becomes essential when water supply is not continuous. However, if the supplied water is of good quality but not continuous, it is necessary for the residents to store water in their homes, where it is exposed to potential contamination. Unless a continuous water supply can be established, it is recommended to educate the public on appropriate household water storage (WHO, 2011b). Water which is stored should either come from a clean source or must be treated (e.g. boiling or filtering), prior to storage. Water should be stored in an appropriate container such as earthenware or plastic (WHO, 2012). Schouten and Moriarty (2003) emphasise the importance of covering a storage facility to prevent contamination. Furthermore, water should be stored beyond the reach of children and animals and storage facilities should be cleaned at least once a year. In addition it is important to note, contamination of treated water at household level often results from poor hygiene (e.g. hand dipping of cups) (WHO, 2012). To prevent this, fitting a tap to the storage container for drawing clean water can prevent contamination by dirty cups, ladles, or hands.

3.1.2.3 Measuring water quantity through water meters

Water meters are the only continuous way to establish how much water is being consumed by communities and individual households. Based on consumption data costumers can be billed accordingly. However, water meters can also help to identify water losses in a network by simply determining how much input and output a water network has[2]. To ensure continuous and correct measurements it is important to note that incorrect installation, inappropriate meter type, lack of maintenance as well as replacement of deteriorated water meters can impact on the registered water volume (Arregui, Enrique Cabrera and Cobacho, 2006). Depending on the type of used water meter it is recommended to replace household water meters every 10 years (Arad Group, 2015).

3.1.3 Community based rural Water Management

Community management, like many other approaches for rural water supply, has its roots in the International Decade for Drinking Water and Sanitation in the 1980s (WHO, 1981), when access to rural water and sanitation was rapidly increased (Moriarty *et al.*, 2013). This was a measure taken due to the lack of centralised government service delivery and commitment in many countries (Harvey and Reed, 2007). The basic principles of community water management are that the benefitting community should have a major role in the development of its system, ownership over it and willingness and ability of the community to carry out operation and maintenance (O&M) (Moriarty *et al.*, 2013). These principals are based on a set of assumptions including community cohesion, *"sense of ownership"* being a meaningful proxy for legal ownership, as well as willingness and ability to form institutions and voluntarism to manage the technical systems. However, these assumptions have often proven to be myths ((RWSN, 2010) as cited in Moriarty *et al.*, 2013) and are based on the cultural idealisation of rural communities. In general, community management is carried out through setting up a management committee responsible for water tariffs and O&M (Harvey and Reed, 2007). Limited demand, lack of affordability or acceptability among communities as well as limited community education are amongst the reasons for low levels of sustainability (Carter, Tyrrel and Howsam, 1999). Community management was an *"easy way out"* for NGOs to shift responsibility for O&M to the community (Harvey and Reed, 2007). This fact is directly related to the situation in El Milagro where a water distribution system was built by an NGO[3] but responsibility for O&M was left with the community.

[2] The researcher notes, that determining water losses is more complex than simply analysing input and output. However, this is not emphasised on in the context of this thesis.
[3] Name of the NGO could not be established.

3.2 Water supply in the Americas

According to the JMP, rural Latin America and the Caribbean (LAC) have made large advances in improving drinking water coverage since 1990. These were driven by an expansion of piped water supply. However, whilst coverage of piped water with 89% is high in South America, in Central America and Mexico it is significantly lower with 27%, as well as in rural Caribbean with 38%. Whereas the use of unimproved drinking water sources is not common in South America, approximately one in five households rely on these sources in Central America and Mexico as well as the Caribbean. In urban areas of LAC, coverage of piped water with 9 out of 10 urban dwellers is much higher. The use of unimproved sources in urban areas is very rare, however, with 5% it is the highest in Central America and the Caribbean (WHO/UNICEF JMP, 2016). Figure 1 shows the trends in rural and urban drinking water of LAC from 1990 to 2015.

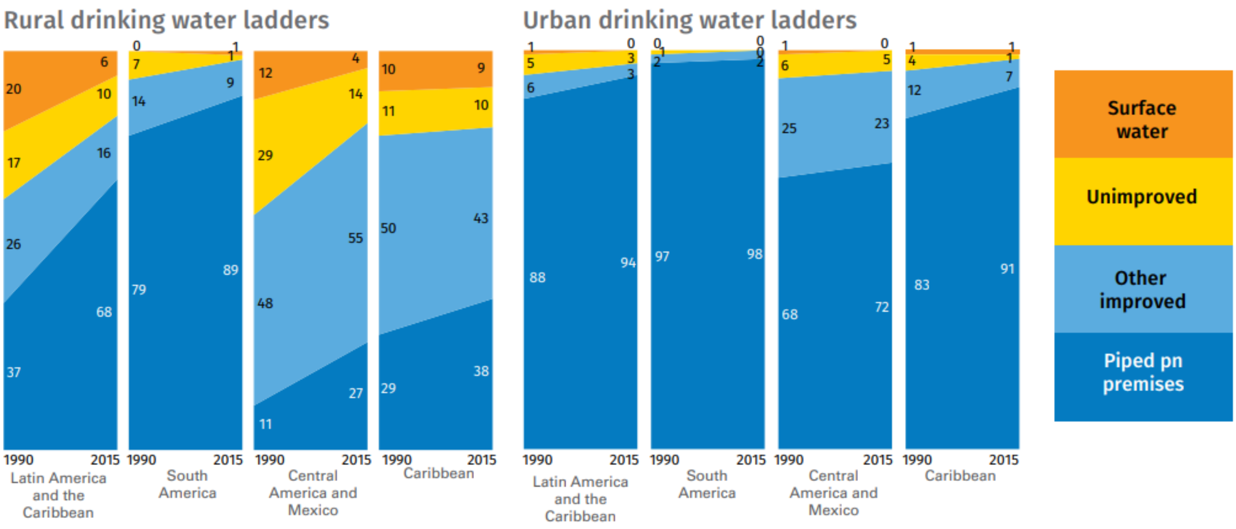


Figure 1: Trends in rural and urban drinking water in LAC, 1990 – 2015[4]

3.2.1 El Salvador at the time of the study

El Salvador is a country in Central America, bordering the North Pacific Ocean between Guatemala and Honduras (CIA, 2017). With a population of over 6 million and an area of 21,040 km², El Salvador has 291.2 inhabitants per km² and is the most densely populated country in Central America (The World Bank, 2016). About 70% of the population lives in urban areas (FAO, 2017) and according to current indicators, 3 out of 10 homes are living in poverty. 24% of these households have no access to piped water and 50% have no access to a private toilet (Gobierno de El Salvador, 2016). The country's climate is considered tropical in coastal regions and temperate in the highlands (CIA, 2017). The average temperature ranges from 24.2°C to 25.9°C

[4] Source: (WHO/UNICEF JMP, 2016)

and the average annual rainfall per year is 1,784mm (MARN, 2017), ranging from 1,200mm in coastal zones, up to 2,500mm in the highlands (Loures and Rieu-Clarke, 2013). 93% of the annual rainfall occurs during the rainy season from May to October (MARN, 2017). The dry season from November to April is characterised by severe droughts (Loures and Rieu-Clarke, 2013).

3.2.2 Water in El Salvador

The country has 10 hydrological regions, and 360 rivers (MARN, 2017), 59% of the country's surface area is part of shared catchments. El Salvador shares three catchments, Rio Lempa, Rio Paz and Rio Goascorán with neighbouring countries. With a size of 18,240 km², the Rio Lempa is the most important catchment (Tábora *et al.*, 2011). Furthermore, El Salvador has 71 aquifers with approximately 6 million m^3 of water, which represents the most important water source (Tábora *et al.*, 2011). The total internal renewable water sources are estimated to be 15.63×10^9 m³/a (FAO, 2017). Currently, with 18,252 million m³ of available water per year and a yearly demand of 1,844 million m³, the country uses only 10% of its available water. However, despite the fact that El Salvador has sufficient water, due to biological contamination only 17% of all water bodies are considered to be of good quality, therefore the effective available water is only 3,000 million m³/a (Tábora *et al.*, 2011), resulting in approximately 500 m³/c/a. The main sources of contamination are untreated domestic and industrial waste such as human excreta, solid waste and agricultural waste. 85% of the water is used for agricultural purposes and the remaining 15% for human consumption (Tábora *et al.*, 2011). A report conducted by the Ministry of Environment and Natural Resources (MARN) on river water quality in El Salvador, concludes that all tested rivers are generally in a bad state (see Table 2). According to the report the main reason for the poor water quality is the discharge of untreated wastewater and solid waste into water bodies ((MENA, 2013) as cited in Schütz, 2018).

Table 2: River quality in El Salvador[5]

WATER QUALITY	USES	PERCENTAGE OF OBSERVED SITES
EXCELLENT	Facilitates the development of aquatic life	0
GOOD	Facilitates the development of aquatic life Limits	5
REGULAR	Limits the development of aquatic life	73
BAD	Limits the development of aquatic life	17
POOR	Precludes the development of aquatic life	5

[5] Source: ((MENA, 2013) as cited in Schütz, 2018)

The Rio Lempa is one example of poor water quality in water bodies. It has shown high levels of contamination (Schaidreiter, 2016). The plentiful aquifers are in general a safe water source. Springs and deep wells are the most reliable, however many of the shallow aquifers show signs of contamination and salt water intrusion in coastal regions (Loures and Rieu-Clarke, 2013). Deforestation, agriculture and urbanisation are contributing factors for a changing environment, leading to increased surface runoff and lower aquifer recharge rates (Schaidreiter, 2016). In the dry season, smaller groundwater fed water bodies dry up (Tábora *et al.*, 2011) causing water shortages and water stress. In addition, demographics indicate another challenge, as El Salvador is the smallest but most densely populated country in Central America, putting pressure on its water resources. It is estimated that El Salvador, by the year 2030, will show low levels of water stress close to 13.3% (Tábora *et al.*, 2011) and could even rise to 30% by the year 2050 (Loures and Rieu-Clarke, 2013).

3.2.2.1 Water quality and access

In 1996, it was reported that only 45% of the population had access to safe drinking water, making it the country with the lowest coverage in Central America at the time ((Direccion General de Estadistica y Censos (1996)) as cited in Perez-pineda and Quintanilla-armijo, 2012). National data shows, that *“a significant majority”* (World Bank, 2006, p. 23) of the population has access to improved water and sanitation services. However, the World Bank (2006) criticises that *“improved”* in this regard means anything from a poorly maintained community well to a household connection. The JMP estimates that in 2015, 12% of the rural population in El Salvador used surface water as drinking water source (JMP, 2017a). According to Global Development Indicators of the World Bank, El Salvador increased access to drinking water from 70% in 1990 up to 98% in 2015 and has met the MDG 7 (see Box 1) for Water and Sanitation (World Bank, 2017; Seynabou, 2018). Private household connections increased from 42.2% in 1991 to 76.6% in 2013 (Gobierno de El Salvador, 2016). Local and international NGO’s played a major role in implementing water projects across the country (Perez-pineda and Quintanilla-armijo, 2012). Low coverage, intermittent supply and poor or no treatment are contributing factors for poor public health. At the national level, according to statistics from studies carried out in 2008, 29% of piped water samples in homes contain faecal coliforms, a figure that rises to 85.4% in homes that are supplied with wells (Tábora *et al.*, 2011). In 2011, more than 5% of the population in El Salvador was affected by diarrheal diseases caused by contaminated drinking water (UN El Salvador, 2014). In 2006, 53% of poor children in rural areas suffered from 1 to 15 days per month from stomach diseases (World Bank, 2006). This results from the lack of treatment facilities, because, apart from a few primary treatment facilities in urban areas, all domestic and industrial effluent is released into the environment without any form of treatment (Loures and Rieu-Clarke, 2013).

Furthermore, statistics show that only 11.2% of the water in homes has residual chlorine (Tábora *et al.*, 2011) and that diarrhoea amongst children in rural areas was very high (Perez-pineda and Quintanilla-armijo, 2012). This is directly linked to the fact that inadequate water supply, sanitation and hygiene practices are leading causes for disease, and children are particularly vulnerable (Prüss-Üstün *et al.*, 2014). Water-borne diseases are known to cause gastrointestinal infections which account for the majority of deaths in El Salvador (USAID and FUNDE, 2009; Tábora *et al.*, 2011).

3.2.2.2 Organisation of the water sector and its service providers

The water sector in El Salvador is a patchwork of laws, standards and regulations which are mostly adapted from international standards. Responsibilities for water supply are shared amongst many stakeholders (see Figure 2), namely ANDA and more than 1,000 local providers in rural areas and small towns[6].

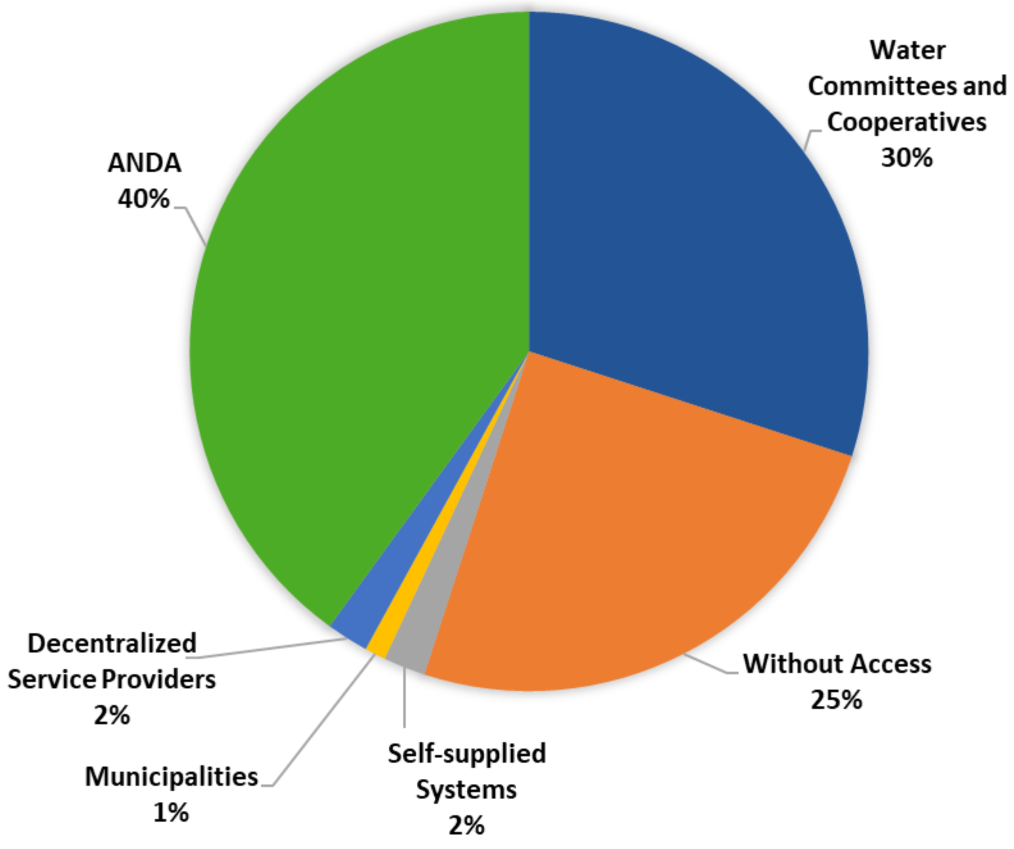


Figure 2: Share of population served by different categories of water service providers[7]

[6] No mention of the definition of 'rural' or 'small'
[7] Adapted from (World Bank, 2006)

ANDA is responsible for the provision of services in urban areas to 40% of the population, covering 149 of 262 municipalities, alongside privately-run decentralized service systems. These systems obtained the right to provide services but the assets are owned by ANDA (World Bank, 2006). As a result of lack of service provision by ANDA, developers of new housing developments have implemented their own water supply networks. However, a lack of finances and expertise have led to poor quality systems with no funding for O&M (World Bank, 2006). In rural parts of the country, 79% of its population is supplied by municipalities, housing developers and rural cooperatives (World Bank, 2006; Tábora *et al.*, 2011; Schaidreiter, 2016). Municipalities operate independently, set their own water tariffs and handle finances. Technical assistance is partly provided through national agencies and international NGOs (Ortiz and Piedrafita, 2006; World Bank, 2006). No national institution is responsible for rural water supply, leaving the *"rural population basically to its own means"* (World Bank, 2006, p. 172), with regard to installing water committees, financing the system through limited funding provided by NGOs and maintaining such a system (World Bank, 2006). Water committees or so-called water boards comprise community members that are elected by the community. These board members often receive no or only a marginal salary. Water boards provide administrative support, deal with payments and O&M of the water supply scheme. Water boards charge a fee for services (electricity (in the case of pumping), chlorination, material, inspections), which is included in the water tariff. The money received from tariffs sometimes does not cover the running costs (mainly due to high operation costs in pumping systems). As a result, water is supplied in some communities for only a few hours a day. Many of these rural water systems, administered by the local municipalities show large signs of deficits, such as insufficient infrastructure and lack of administrative and financial expertise and capacity. For more details on national laws and regulations of the El Salvadorian water sector please refer to *"Establishment of a GIS database for water resources management: a case study in Tecoluca, El Salvador"* (Schaidreiter, 2016).

3.3 Description of the study area

3.3.1 Municipality of Tecoluca

Tecoluca, with an area of 284.65 km^2 is the fifth largest Municipality in El Salvador. The Rio Lempa is the natural boundary to the East (Trigueros, 2016). Its capital is Tecoluca Town, located approximately 73 km East of the country's capital San Salvador. The Alcaldía is the municipal administration located in the capital of the Municipality, in Tecoluca Town. For its local administration the Alcaldía has divided the Municipality in seven sectors: North, San Nicolás, Costa, Santa Cruz, Center, Pueblo and The Volcano, which brings together 22 cantons of the rural and the urban area with its neighbourhoods, colonies and subdivisions (COEM, 2004). The volcano San Vicente (altitude 2,170 m), located in the North of the Municipality, is the highest elevation. The north-eastern part of the Municipality is defined by hills and mountains, the central part is characterised by alluvial planes and the South is defined by alluvial and costal planes (FUNDE, 2015).

Municipal water resources and drinking water supply

The Municipality of Tecoluca is rich in water resources such as 41 rivers, 20 streams and creeks, 2 lagoons, 5 small lagoons, 6 ravines, as well as two main groundwater reservoirs. Furthermore, the annual mean precipitation rate is 1,900 mm. Despite a large number of water resources, high level of contamination of such alongside insufficient water production and distribution leads to shortages of water and the estimated total annual water demand of about 1,140,638 m^3 cannot be met (FUNDE, 2015). For further information regarding water resources and drinking water supply in Tecoluca please refer to Schaidreiter (2016).

3.3.2 Case study: El Milagro

3.3.2.1 Location and general information

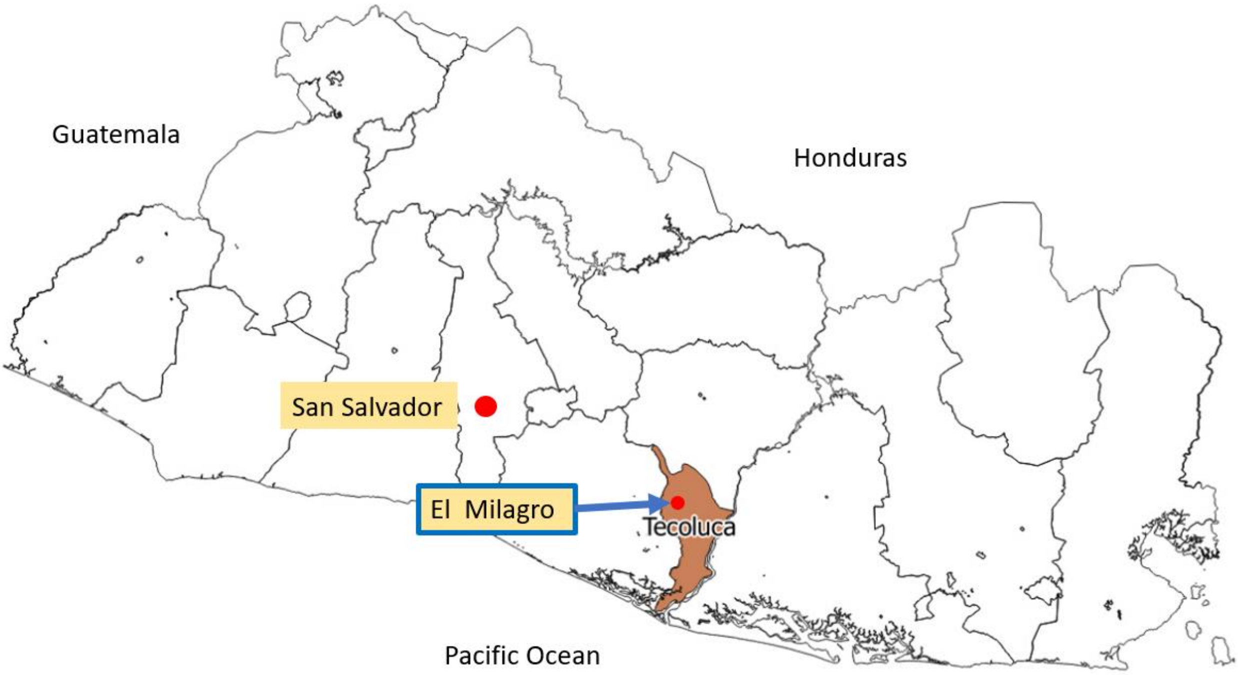


Figure 3: Location of El Milagro in relation to El Salvador[8]

El Milagro is one of the rural communities in the Municipality of Tecoluca. It is located in the Cantón San José Llano Grande, 4 km south-west of Tecoluca Town (see Figure 3), off the main road, called *Litoral*, connecting San Vicente and Zacatecoluca. The community has partially paved and unpaved roads. The paved roads are the result of a former NGO[9] project (information from villagers). The community consists of 105 houses inhabiting 475 people. The size of the households ranges from 1 to 16 people, on average 4.5 people per household. Figure 4 shows the relatively even age and gender distribution, with the biggest age group being 25 to 44, the majority of which work in agriculture. The community is equiped with a primary school including a sports field, a number of small shops and a dairy production facility.

[8] Adapted from (Rossman, 2017)
[9] Name of the NGO unknown

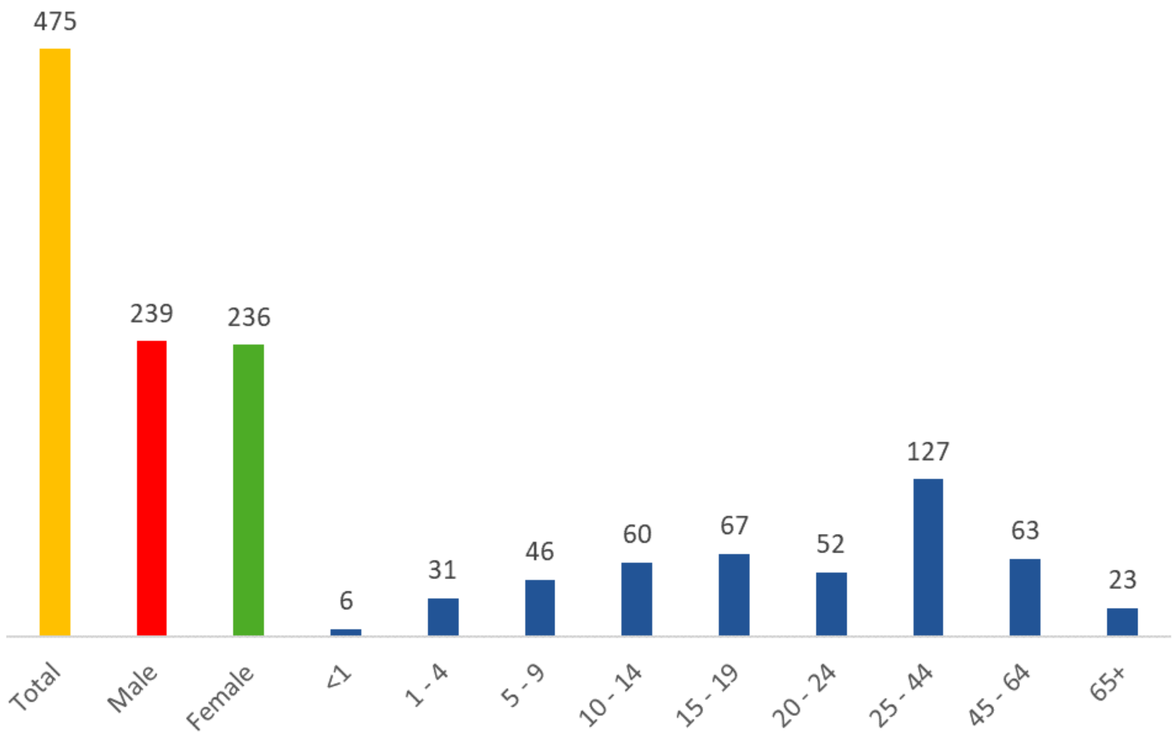


Figure 4: Demographics distribution in El Milagro[10]

3.3.2.2 Institutional organisation and finances

The water supply in El Milagro, like in the majority of the rural communities in the Municipality, is managed entirely by the community residents themselves. A water board is elected every 2 years, which is responsible for reading of water meters, billing of customers, and O&M. At the time of this study the water board had just been newly elected and it was observed that some members had more knowledge about the system in addition to management skills, than others. Reading water meters once a month and issuing bills is one of the tasks carried out by members of the water board. The current water tariff is 3.0 US$/month for 15 m^3 and 0.15 US$ for each additional cubic meter consumed. If a consumer does not have a water meter, only the monthly fee of 3.0 US$ has to be paid. The money collected is used to pay O&M costs, such as electrical energy for the pump and chlorine tablets for disinfection. However, if expenses exceed the monthly budget an ad hoc community meeting is held to inform the entire community of the situation and to find solutions to resolve the matter. During the course of the field study, good data availability, accessibility and community cooperation were contributing factors for El Milagro to be announced as a *“model community”*, where not just water supply but in addition, waste water, solid waste and other issues are being targeted and solutions are developed. For more details on waste water

[10] Adapted from (Schütz, 2018)

and solid waste in El Milagro, please refer to *“Evaluation of the sanitary situation in the communities of El Milagro and San Francisco Angulo, El Salvador”* (Schütz, 2018).

3.3.2.3 Water supply and treatment

There are two community water sources located in El Milagro. A deep well and a spring capture. The deep well was designed[11] to be the main water supply for the communities of El Milagro, San Francisco Angulo and Cantarrana. It was designed for future demand in 20 years. With its depth of 125 m it was planned to provide 150 l/c/d to all three communities. However, the well had only been in operation until 2012 due to high manganese and iron contents[12]. Furthermore, electricity costs for the operation of the pump were too high to maintain (information from a former member of the water board). It is unknown whether water treatment had been considered or attempted. Nowadays, the three water supply systems are not joined anymore. San Francisco Angulo and Cantarrana form an individual system. More information can be found in *“Hydraulic Water Balance Calculation and Water Quality Analysis of the drinking water supply system of San Francisco Angulo and Cantarrana, El Salvador” by (Kern, 2018).* El Milagro has its own water supply system, fed by a spring located in the southeast of the community. It is located next to a small river and consists of the spring chamber, an outlet to a public basin and a transmission pipe to a ground reservoir on the other side of the river (see Figure 5).

[11] Date of project unknown.
[12] No report on water quality was available.

Figure 5: Spring capture and local women washing clothes in public basin (El Milagro)

The reservoir is equipped with an electric pump, used for distributing the water. The pump does not turn on automatically but is operated manually three times a day (morning, midday and evening). According to the pump operator, during storms, the pump cannot be operated because it does not have a lightning rod and the potential risk of damaging it and having to buy a new pump would be too expensive. The water is being pumped through the entire community and at the end, in the northeast of the community, at a point of much higher elevation, a storage tank is located. There is no direct pipe from the reservoir to the tank and according to locals, the water only reaches the tank during rainy season. According to the 2015 census every household had an individual water connection and used chlorination for disinfection (DIGESTYC, 2015), however water board members stated that chlorine, if available, is being applied directly into the spring tapping chamber therefore ensuring the chlorination of the entire network.

4. Methodology

This Chapter describes the methodological approach that was applied to achieve the aim of this thesis (see Chapter 2).

The body of work consists of three major sections:

1. The first section (Chapter 4.1) gives an overview on the preparatory work that had to be undertaken prior to field data collection.
2. The second section (Chapter 4.2) explains the process of field data collection.
3. The third section (Chapter 4.3) provides an overview of how data was processed and analysed using MS Word® and MS Excel® to achieve the objectives and meet the aim of the thesis.

4.1 Preparatory work

The preparatory work for this thesis took place in two stages. Stage one took place prior to departure for El Salvador and included an extensive literature review, consultation with former MSc students and selection of tools for stage two. The purpose of this initial stage was to develop a deeper understanding of previous work and local circumstances, such as cultural aspects, alongside research restrictions and limitations, as well as to trace previous research conducted on this particular matter to ensure key subjects and questions were defined and included, respectively. Stage two of the preparatory work included orientation on-site and meetings with the Head of the Department for Water and Sanitation at the Alcaldía, representatives of the Universidad Centroamericana (UCA) and members of local water committees. The purpose of this second phase was to develop a deeper understanding of local authorities and their responsibilities.

Demographics and information on drinking water

Information on demographics was acquired from the 2015 Census of the Municipality of Tecoluca, published by MINSAL. This document incorporates demographic information as well as information regarding water supply and treatment in all 107 communities of the Municipality (see Table 3).

Table 3: Census 2015 categories

DEMOGRAPHICS	NUMBER OF	DRINKING WATER SOURCES AND TREATMENT	NUMBER OF FAMILIES
	• Households • Families • Male and female • Total population		• Piped on premises • Public tap or standpipe • Protected well • Surface water or river • Other • Walk more than 300m to reach water source • Application of water treatment • Chlorine or puriagua • Boiling of water • Other method of water treatment

4.2 Field data collection

Data collection took place in two segments. The first segment included collecting quantitative data of water resources within the boundaries of the Municipality of Tecoluca. The second segment comprised a quantitative and qualitative assessment of the water supply in the rural village El Milagro. The project takes up aspects of a formative evaluation approach, which is designed to discover information that will facilitate advantageous change and improve the implementation of projects where there are existing problems (Ritchie and Lewis, 2003) thereby helping to identify the most important aspects for a particular target population (Devine, 2009).

4.2.1 Investigation of water sources in the Municipality of Tecoluca

To assess the status quo of water resources and supply schemes, field visits were conducted and data was collected on water parameters, such as discharge, water temperature, electrical conductivity and pH, as well as general information about the state of the existing infrastructure (see Table 4). The collection of data on water sources was based on previous fieldwork conducted by Schaidreiter (2016). The researcher notes, that turbidity is also an important indicator for water quality, however no measuring equipment was available and could therefore not be included in this research.

Table 4: Overview of gathered information at investigated sites

AREA OF CONCERN	QUESTIONS
WATER PARAMETERS	Discharge, Temperature, pH, electrical conductivity
TREATMENT	Yes/No, Type of treatment
WATER SOURCE	Spring/Well, additional sources
STORAGE	Yes/No, Type of storage
DISTRIBUTION	Number of communities/households

Identical sampling techniques to the ones used by Schaidreiter (2016) were applied to facilitate comparison of data and building of databases. Measurements should be repeated several times to ensure the results are more accurate than any single measurement (Taylor, 1982), therefore all measurements were executed a minimum of three times to mitigate errors and ensure consistency and congruency. To ensure that gathered information would be accessible in the future, GPS locations of newly captured sites were recorded and data was captured in the Water Information System (WIS) of Tecoluca, established by Schaidreiter (2016) and further developed by Rossmann (2017). In total, 36 (see Table 5) site visits were carried out, including investigations of springs (n= 14), wells (n= 8) and tanks (n= 16).

Table 5: Visited water sources

NUMBER	NAME	TYPE	ADMINISTRATION
1	Las Pampas	Spring	Local water board
2	Parque Tehuacan	Spring	Local water board
3	Guajoyo	Spring	Local water board
3.1	Granzazo	Tank	Local water board
3.2	Guajoyo	Tank	Local water board
4	Nueva Tehuacan	Spring	Local water board
4.1	Nueva Tehucan	Tank	Local water board
4.2	Brisas del Volcan	Tank	Local water board
4.3	Sinaí San Francisco	Tank	Local water board
5	Marcial Gavidia 1	Spring	Local water board
5.1	Achiotes	Tank	Local water board
6	Marcial Gavidia 2	Spring	Local water board
6.1	El Socorro	Tank	Local water board
7	Marcial Gavidia 3	Spring	Local water board
7.1	Betania	Tank	Local water board
8	Santa Monica	Well	Local water board
8.1	Santa Monica	Tank	Local water board
9	19 de Junio	Spring	Local water board
10	Trinidad	Well	Local water board
11	Noventa y Dos	Well	ANDA
11.1	Noventa y Dos	Tank	ANDA
12	Porrillito	Well	Local water board
13	Santa Fe	Well	Local water board
14	El Milagro	Spring	Local water board
14.1	El Milagro	Tank	Local water board
15	San Jose Llano Grande 1	Spring	Local water board
16	San Jose Llano Grande 2	Spring	Local water board
16.1	San Jose Llano Grande 2	Tank	Local water board
17	San Francisco-Angulo	Spring	Local water board
17.1	San Francisco-Angulo	Tank	Local water board
18	Madre Tierra	Well	ANDA
18.1	Madre Tierra	Tank	ANDA
19	El Puente	Well	Local water board
20	El Casino	Spring	Local water board
20.1	El Casino	Tank	Local water board

4.2.1.1 Water parameters

Discharge of springs

Discharge measurements were taken at all the above-mentioned locations as far as possible. The term *"possible"* in this context means that the researcher had to be able to physically access the source in order to take measurements. The methods actioned by the researcher include, the bucket method and water level measurements. The bucket method can be used at locations, where it possible to collect all the water from a source. It can be captured by a bucket over a precisely known time period (taken by a stopwatch), after determining the volume of the water, the discharge can be calculated (ETH, 2016). A cylinder with a volume of 21 litres[13] was used and discharge was either measured in spring captures or water tanks, depending on accessibility. The water discharge was measured as the volume of water in litres per second, determined with the following equation:

$$Q = V/t \tag{1.1}$$

Q = Discharge (l/s)

V= Volume of water (l)

t = Time (s)

Each measurement took on average 10 – 15 seconds and was repeated 3 to 5 times to ensure minimal errors. The bucket was placed on a level surface and the water height was measured using a measuring tape (see Figure 6). The volume was determined by the height and the given bucket dimensions. The measurements were averaged. In order to use the bucket method, it has to be possible to capture water (e.g. from an inlet pipe). Where this was not possible and therefore the bucket method was not applicable (n= 4) the rising water level was measured with a folding rule over a certain time period (taken by a stopwatch). In some locations (n= 2) it was not possible to measure the discharge directly at the inlet and therefore necessary to sum up several partial measurements, including overflow pipes, to determine the total water discharge. Subsequently, the measured water discharge data was used to determine the per capita water availability (see Chapter 5.1.2).

[13] Height: 33.5 cm, Diameter: 28.3 cm

Figure 6: Field data collection

Electrical conductivity, temperature and pH

Electrical conductivity, temperature and pH measurements were taken in situ. Electrical conductivity and water temperature were determined by using the WTW ProfiLine Cond 197 Portable Conductivity Meter. The pH was measured using Hydrion pH paper strips, ranging from 0.0 to 13.0 by colour indication.

4.2.1.2 Key Informant interviews

Key Informant interviews are conducted to obtain a better understanding of a certain topic. In case of this thesis, the topic of intertest was the Municipality's water supply, its problems and challenges. Key Informants are individuals of the community who are particularly knowledgeable about certain matters (Nichols, 1991) or specialists in the particular field of interest. In the Municipality of Tecoluca, Key Informants included members of the community water boards, municipal water technicians and other members of the community with organisational roles.

4.2.2 Data collection in El Milagro

In addition to the investigation of the water sources (as described in Chapter 4.2.1), the community of El Milagro, which was later announced as a *"model community"* (as described in Chapter 3.2.2.2) was chosen for an in-depth study. On site, a simplified transect walk, i.e. an initial systematic walk across the community (CatCom, no date; Conradin, Kropac and Spuhler, 2010), provided the researcher an initial and important insight into the study area and enabled the researcher to gather preliminary information, such as location of spring tapping, state of houses and general infrastructure. Data collection was carried out in the company of a member of the El Milagro water board, providing valuable insight into the community and especially facilitating household visits.

4.2.2.1 Collection of water network data

In order to assess the condition of El Milagro's water distribution system, information on consumption, pressure and infrastructure was required. Firstly, consumption was addressed for which data was needed. El Milagro's properties are equipped with water meters which are used for monthly billing. One member of the water board, who reads the community's water meters every month, provided readings and from previous years (2012 – 2016). Due to the lack of pressure loggers it was not possible to obtain continuous pressure data. Only point pressure readings with a simple pressure gauge were obtainable. Access restrictions and personal security concerns did not allow the researcher to take the readings herself, however assistance was provided by a former member of the water board. Pressure readings were obtained from three randomly selected households[14] in the community. A map (see Figure 7) of the piped network was available and gave insight of pipe diameter and length.

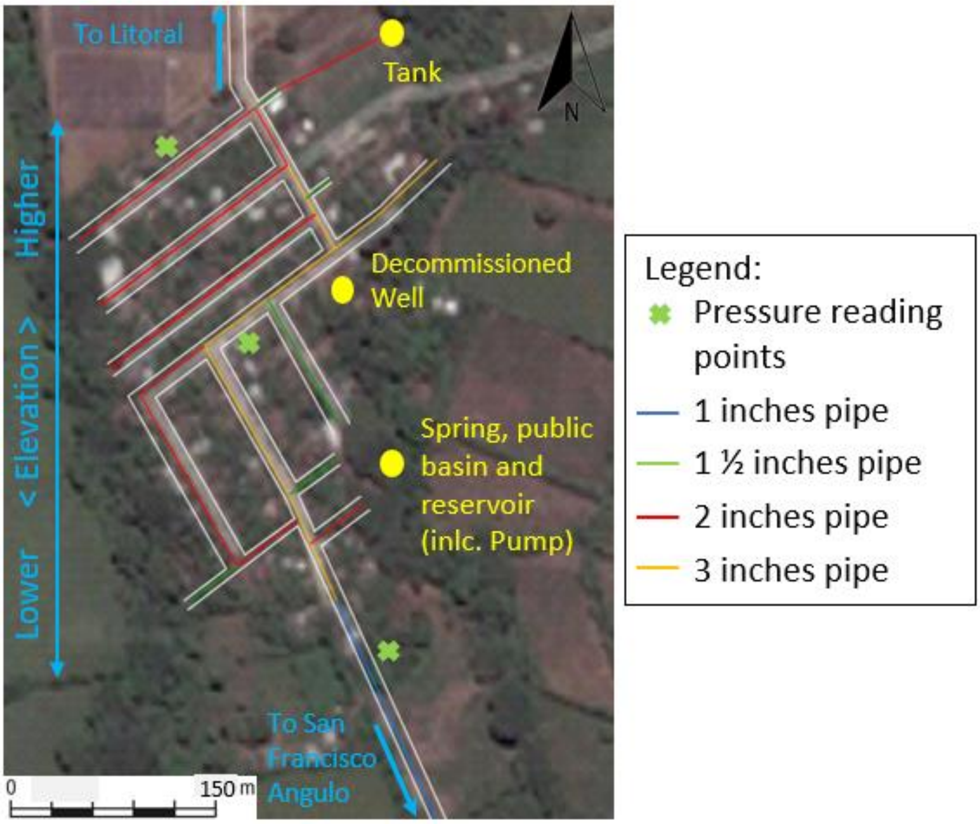


Figure 7: Digitalised network map of El Milagro distribution system

4.2.2.2 Household surveys

In addition to Key Informant interviews (see Chapter 4.2.1.2), further information from local customers was logged via household surveys conducted in El Milagro. Despite the fact that

[14] The households were selected by the resident taking the pressure readings.

individual interviews are time consuming, this technique enabled the researcher to generate more in-depth knowledge about current water use, consumption and demand at household level and the community's water distribution. Further issues such as potential problems including the perceived reduction of amount of water and quality, failing infrastructure, possible sources of contamination, lack of electricity and chlorination problems were elucidated. Household surveys were facilitated by a local water board member, accompanying the researcher. A questionnaire for the surveys was developed, summarised in Table 6, gathering knowledge on technical aspects, living conditions and information about water supply. The full questionnaire can be found in Appendix 8.1.

Table 6: Household survey questions

AREA OF CONCERN	QUESTIONS
TECHNICAL INFORMATION	Water meter: existence, reading, installation Other water source Water storage
LIVING CONDITIONS	Number of residents (children/adults), usage of drinking water
INFORMATION ABOUT WATER SUPPLY	Supply time, monthly quote, Number of taps/shower heads/toilets

4.2.2.3 Water consumption data from water meters

El Milagro has a total of 105 private household connections, most of which have functioning water meters. Therefore, data from household water meters was collected to gain further information on water consumption. Records of meter readings could be traced back to the year 2012, resulting in data collection and analysis for the period from 2012 to 2016.

For statistical analysis of the data collected from the water meters, only active users with a consumption of ≥ 1 m^3 (during the investigation period from 2012 to 2016) were considered. The average water consumption per household and month as well as the water consumption per capita was calculated. Data on the population from the 2015 Census was analysed to facilitate the calculation of the people/household ratio.

4.3 Data processing and analysis

All data collected from on-sight investigations regarding water parameters were imported into MS Excel and compared with data previously gathered by Schaidreiter (2016). The coordinate data from the GPS survey on the visited water sources and water distribution systems was conducted by the researcher. These data was imported into to QGIS by Rossmann (2017) as part of his MSc thesis, *“Further Development of the water information system in the municipality of Tecoluca, El Salvador”*. Information gathered through interviews and surveys was summarised and analysed with MS Excel®. Water meter readings were converted into MS Excel® files to enable further analysis.

5. Results and Discussion

This Chapter contains two sections, presenting and discussing the results obtained by applying the methodological approach (see Chapter 4).

1. The first section (Chapter 5.1) includes results of the visited communities water supply systems including results from the on-site measurements regarding water quantity and quality. Also included in this sections is a comparison, where possible, of newly generated data with data gathered by Schaidreiter (2016) in 2015.
2. The second section (Chapter 5.2) provides an insight of data gathered about water supply in El Milagro, including results from the household surveys.

5.1 Water sources in Tecoluca

5.1.1 Information on visited water sources

Table 7 to Table 23 above, show information on all 33 visited sites, including 14 springs, 5 wells and 14 tanks. Where available data from 2015 (from (Schaidreiter, 2016)) was included. Technical difficulties with the temperature sensor lead to fewer temperature measurements. Collected data of all sites are provided in Appendix 8.1.

Table 7: Las Pampas measurements

NAME	**LAS PAMPAS - SPRING**	
WATER SOURCE	Spring - under construction at time of visit	
STORAGE TANK	2 Tanks[15]	
SUPPLIED COMMUNITY	Las Pampas, San José La Ceiba	
SUPPLIED POPULATION	476 (282+194)	
DATE OF MEASUREMENT	**2015**	**2016**
	25.05.2015	26.02.2016
DISCHARGE	1.5 l/s	1.19 l/s
TEMPERATURE	31.4 °C	31.6 °C
ELECTRICAL CONDUCTIVITY	288 µS/cm	290 µS/cm
PH	7	8

[15] Tanks were empty due to ongoing construction of new spring capture

Table 8: Parque Tehuacan measurements

NAME	PARQUE TEHUACAN - SPRING	
WATER SOURCE	Spring	
STORAGE TANK	No tank	
SUPPLIED COMMUNITY	Parque Tehucan	
SUPPLIED POPULATION	No information	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	26.02.2016
DISCHARGE		5.44 l/s
TEMPERATURE		27.1 °C
ELECTRICAL CONDUCTIVITY		236 µS/cm
PH		7.5

Table 9: Guajoyo measurements

NAME	GUAJOYO - SPRING	
WATER SOURCE	Spring	
STORAGE TANK	2 Ground Level Storage Tanks	
SUPPLIED COMMUNITY	4 Communities: Flor de Fuego, Guajoyo, Miramar, Granzazo	
SUPPLIED POPULATION	1128 (648+145+113+222)	
DATE OF MEASUREMENT	**2015**	**2016**
	29.05.2015	29.02.2016
DISCHARGE	3.59 l/s	2.4 l/s
TEMPERATURE	27.6 °C	27.9 °C
ELECTRICAL CONDUCTIVITY	229 µS/cm	235 µS/cm
PH	7.5	7
	TANK - GRANZAZO	
SUPPLIED COMMUNITY	Granzazo	
SUPPLIED POPULATION	222	
DATE OF MEASUREMENT	**2015**	**2016**
	29.05.2015	29.02.2016
DISCHARGE	No measurement	Tank empty at time of visit
TEMPERATURE	31.3 °C	
ELECTRICAL CONDUCTIVITY	229 µS/cm	
PH	7.5	
	TANK - GUAJOYO	
SUPPLIED COMMUNITY	3 Communities: Guajoyo, Mirmar, Flor de Fuego	
SUPPLIED POPULATION	906 (648+145+113)	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	29.02.2016
DISCHARGE		2.41 l/s
TEMPERATURE		31.3 °C
ELECTRICAL CONDUCTIVITY		236 µS/cm
PH		8

Table 10: Nueva Tehuacan measurements

NAME	**NUEVA TEHUCAN - SPRING**	
WATER SOURCE	Spring	
STORAGE TANK	4 Ground Level Storage Tanks	
SUPPLIED COMMUNITY	5 communities: Monte Sinaí, San Francisco Tehuacán, Nueva Tehuacán, El Arco, Las Brisas	
SUPPLIED POPULATION	2546 (275+264+978+801+228)	
DATE OF MEASUREMENT	**2015**	**2016**
	14.04.2015	02.03.2016
DISCHARGE	16.2 l/s	11.51 l/s (Sum of the tanks, no direct measurement possible)
TEMPERATURE	27.0 °C	27.1 °C
ELECTRICAL CONDUCTIVITY	231 µS/cm	236 µS/cm
PH	7.5	7
	TANK - NUEVA TEHUACAN	
SUPPLIED COMMUNITY	Nueva Tehucan	
SUPPLIED POPULATION	978	
DATE OF MEASUREMENT	**2015**	**2016**
	14.04.2015	02.03.2016
DISCHARGE	No measurement	6.31 l/s
TEMPERATURE	27.1 °C	27.1 °C
ELECTRICAL CONDUCTIVITY	232 µS/cm	238 µS/cm
PH	7.5	7
	TANK - BRISAS DEL VOLCAN	
SUPPLIED COMMUNITY	Brisas del Volcan	
SUPPLIED POPULATION	228	
DATE OF MEASUREMENT	**2015**	**2016**
	16.06.2015	02.03.2016
DISCHARGE	No measurement	2.25 l/s
TEMPERATURE	27.1 °C	27.1 °C
ELECTRICAL CONDUCTIVITY	232 µS/cm	237 µS/cm
PH	7.5	7.5
	TANK - SINAÍ SAN FRANCISCO	
SUPPLIED COMMUNITY	2 Communities: Monte Sinai, San Francisco Tehucan	
SUPPLIED POPULATION	539 (275+264)	
DATE OF MEASUREMENT	**2015**	**2016**
	14.04.2015	02.03.2016
DISCHARGE	No measurement	2.95 l/s
TEMPERATURE	27.7 °C	28.0 °C
ELECTRICAL CONDUCTIVITY	232 µS/cm	237 µS/cm
PH	7.5	7.5

Table 11: Marcial Gavidia measurements

NAME	MARCIAL GAVIDIA - SPRING	
WATER SOURCE	3 Springs	
STORAGE TANK	3 Ground Level Storage Tanks	
SUPPLIED COMMUNITY	6 Communities: La Florida, Betania 1, Betania 2, El Socorro, San Andrés Los Achiotes, El Ojushte	
SUPPLIED POPULATION	2556 (302+190+119+185+151)	
	SPRING 1	
SUPPLIED COMMUNITY	Community Achiotes	
SUPPLIED POPULATION	151	
STORAGE TANK	Achiotes - Tank	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	09.03.2016
DISCHARGE		No measurement
TEMPERATURE		28.5 °C
ELECTRICAL CONDUCTIVITY		236 µS/cm
PH		8
	TANK - ACHIOTES	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	09.03.2016
DISCHARGE		1.45 l/s
TEMPERATURE		29.4 °C
ELECTRICAL CONDUCTIVITY		231 µS/cm
PH		7.5
	SPRING 2	
SUPPLIED COMMUNITY	Community El Socorro	
SUPPLIED POPULATION	185	
STORAGE TANK	El Socorro - Tank	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	09.03.2016
DISCHARGE		No measurement
TEMPERATURE		28. 4°C
ELECTRICAL CONDUCTIVITY		230 µS/cm
PH		7.5
	TANK - EL SOCORRO	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	09.03.2016
DISCHARGE		1.13 l/s
TEMPERATURE		30.5 °C
ELECTRICAL CONDUCTIVITY		232 µS/cm
PH		7

	SPRING 3	
SUPPLIED COMMUNITY	2 Communities: Betania 1, Betania 2	
SUPPLIED POPULATION	309 (190 + 119)	
STORAGE TANK	Betania - Tank	
DATE OF MEASUREMENT	**2015**	**2016**
	18.06.2015	09.03.2016
DISCHARGE	1.36 l/s	0.99 l/s
TEMPERATURE	28.7 °C	28.6 °C
ELECTRICAL CONDUCTIVITY	228 µS/cm	229 µS/cm
PH	8.5	8.5

	TANK - BETANIA	
DATE OF MEASUREMENT	**2015**	**2016**
DISCHARGE	No access possible. Measurements only possible at spring capture	
TEMPERATURE		
ELECTRICAL CONDUCTIVITY		
PH		

Table 12: Santa Monica measurements

NAME	SANTA MONICA - SPRING	
WATER SOURCE	Spring	
STORAGE TANK	1 Ground Level Storage Tank	
SUPPLIED COMMUNITY	Santa Monica	
SUPPLIED POPULATION	374	
DATE OF MEASUREMENT	**2015**	**2016**
DISCHARGE	Measurement only possible at storage tank	
TEMPERATURE		
ELECTRICAL CONDUCTIVITY		
PH		

	TANK - SANTA MONICA	
SUPPLIED COMMUNITY	Santa Monica	
SUPPLIED POPULATION	374	
DATE OF MEASUREMENT	**2015**	**2016**
	21.04.2015	10.03.2016
DISCHARGE	1.25 l/s	0.95 l/s
TEMPERATURE	30.0 °C	29.8 °C
ELECTRICAL CONDUCTIVITY	273 µS/cm	284 µS/cm
PH	7.5	7

Table 13: 19 de Junio measurements

NAME	19 DE JUNIO - SPRING	
WATER SOURCE	Spring	
STORAGE TANK	No storage	
SUPPLIED COMMUNITY	19 de Junio	
SUPPLIED POPULATION	141	
DATE OF MEASUREMENT	**2015**	**2016**
	17.06.2015	10.03.2016
DISCHARGE	0.9 l/s	No measurement
TEMPERATURE	29.5 °C	29.2 °C
ELECTRICAL CONDUCTIVITY	329 µS/cm	337 µS/cm
PH	7.5	7.5

Table 14: Trinidad measurements

NAME	TRINIDAD - WELL	
WATER SOURCE	Well	
STORAGE TANK	No storage Tank	
SUPPLIED COMMUNITY	5 communities: Milagro de Dios 2, El Playon, Santa Teresa 1, Santa Teresa 2, Progresso	
SUPPLIED POPULATION	1290 (187+181+487+435)	
	2015	**2016**
DATE OF MEASUREMENT	22.04.2015	11.03.2016
DISCHARGE	No measurement	No measurement
TEMPERATURE	32.4 °C	31.5 °C
ELECTRICAL CONDUCTIVITY	336 µS/cm	341 µS/cm
PH	7.5	7.5

Table 15: Porrillito measurements

NAME	PORRILLITO - WELL	
WATER SOURCE	Well - Handpump	
STORAGE TANK		
SUPPLIED COMMUNITY	Parque Tehucan	
SUPPLIED POPULATION	No information	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.03.2016
DISCHARGE		No measurement
TEMPERATURE		30.8 °C
ELECTRICAL CONDUCTIVITY		297 µS/cm
PH		8

Table 16: Noventa y Dos measurements

NAME	NOVENTA Y DOS - WELL	
WATER SOURCE	Well	
STORAGE TANK	1 Ground Level Storage Tank	
SUPPLIED COMMUNITY	12 communities: San Jose Porrillio 2, Buenavista, Noventa y uno, Noventa y Dos, El Cristal, San Luis los Altos, San Luis las Posadas, La Quinta, San Pedro El Gavilon, Cruzadilla de Vaqueranos, El Mojon, El Platanar	
SUPPLIED POPULATION	1992(227+76+115+274+465+252+96+64+242+181)	
DATE OF MEASUREMENT	**2015**	**2016**
DISCHARGE	Measurement only possible at storage tank	
TEMPERATURE		
ELECTRICAL CONDUCTIVITY		
PH		

	TANK - NOVENTA Y DOS	
SUPPLIED COMMUNITY	12 communities: San Jose Porrillio 2, Buenavista, Noventa y uno, Noventa y Dos, El Cristal, San Luis los Altos, San Luis las Posadas, La Quinta, San Pedro El Gavilon, Cruzadilla de Vaqueranos, El Mojon, El Platanar	
SUPPLIED POPULATION	1992(227+76+115+274+465+252+96+64+242+181)	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.03.2016
DISCHARGE		No measurement
TEMPERATURE		32 °C
ELECTRICAL CONDUCTIVITY		262 µS/cm
PH		7

Table 17: Santa Fé measurements

NAME	SANTA FÉ - WELL	
WATER SOURCE	Well	
STORAGE TANK	1 Ground Level Storage Tank	
SUPPLIED COMMUNITY	Santa Fe	
SUPPLIED POPULATION	420	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.03.2016
DISCHARGE		No measurement
TEMPERATURE		31.8 °C
ELECTRICAL CONDUCTIVITY		307 µS/cm
PH		7.5

	TANK - SANTA FÉ	
SUPPLIED COMMUNITY	Santa Fe	
SUPPLIED POPULATION	420	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.03.2016
DISCHARGE		No measurement
TEMPERATURE		33.3 °C
ELECTRICAL CONDUCTIVITY		311 µS/cm
PH		7.5

Table 18: El Milagro measurements

NAME	EL MILAGRO - SPRING	
WATER SOURCE	Spring	
STORAGE TANK	1 Elevated Storage Tank	
SUPPLIED COMMUNITY	El Milagro	
SUPPLIED POPULATION	482	
DATE OF MEASUREMENT	**2015**	**2016**
	17.04.2015	11.04.2016
DISCHARGE	0.84 l/s	0.84 l/s
TEMPERATURE	28.5 °C	28.5 °C
ELECTRICAL CONDUCTIVITY	247 µS/cm	256 µS/cm
PH	7.5	7
	TANK - EL MILAGRO	
SUPPLIED COMMUNITY	El Milagro	
SUPPLIED POPULATION	482	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.04.2016
DISCHARGE		Empty at time of measurement
TEMPERATURE		
ELECTRICAL CONDUCTIVITY		
PH		

Table 19: San Francisco - Angulo measurements

NAME	SAN FRANCISCO ANGULO - SPRING	
WATER SOURCE	Spring	
STORAGE TANK	1 Ground Level Storage Tank	
SUPPLIED COMMUNITY	2 communities: San Francisco Angulo, Cantarrana	
SUPPLIED POPULATION	426 (299+127)	
DATE OF MEASUREMENT	**2015**	**2016**
DISCHARGE	Measurement only possible at storage tank	
TEMPERATURE		
ELECTRICAL CONDUCTIVITY		
PH		
	TANK - SAN FRANCISCO ANGULO	
SUPPLIED COMMUNITY	2 communities: San Francisco Angulo, Cantarrana	
SUPPLIED POPULATION	426 (299+127)	
DATE OF MEASUREMENT	**2015**	**2016**
	21.04.2015	13.04.2016
DISCHARGE	1.7 l/s	1.13 l/s
TEMPERATURE	29.6 °C	No measurement
ELECTRICAL CONDUCTIVITY	254 µS/cm	285 µS/cm
PH	7	8.5

Table 20: San Jose Llano Grande measurements

NAME	SAN JOSÉ LLANO GRANDE - SPRING	
WATER SOURCE	2 Springs	
STORAGE TANK	3 Ground Level Storage Tanks	
SUPPLIED COMMUNITY	San Jose Llano Grande	
SUPPLIED POPULATION	263	
	SPRING 1	
SUPPLIED COMMUNITY	San José Llano Grande 1	
SUPPLIED POPULATION	263	
STORAGE TANK	No tank	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	No measurement
DISCHARGE		No measurement
TEMPERATURE		32.8 °C
ELECTRICAL CONDUCTIVITY		364 µS/cm
PH		7
	SPRING 2	
SUPPLIED COMMUNITY	Community San José Llano Grande 2	
SUPPLIED POPULATION	65 families	
STORAGE TANK	San José Llano Grande 2 - Tank	
DATE OF MEASUREMENT	**2015**	**2016**
DISCHARGE	Measurement only possible at storage tank	
TEMPERATURE		
ELECTRICAL CONDUCTIVITY		
PH		
	TANK - SAN JOSÉ LLANO GRANDE 2	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	13.04.2016
DISCHARGE		No measurement
TEMPERATURE		31.4 °C
ELECTRICAL CONDUCTIVITY		261 µS/cm
PH		7.5

Table 21: El Puente measurements

NAME	EL PUENTE - WELL	
WATER SOURCE	Handpump - Well	
STORAGE TANK		
SUPPLIED COMMUNITY	El Puente	
SUPPLIED POPULATION	167	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	14.04.2016
DISCHARGE		No measurement
TEMPERATURE		No measurement
ELECTRICAL CONDUCTIVITY		425 µS/cm
PH		8

Table 22: Madre Tierra measurements

NAME	MADRE TIERRA - SPRING	
WATER SOURCE	Spring	
STORAGE TANK	1 Ground Level Storage Tank	
SUPPLIED COMMUNITY	Madre Tierra	
SUPPLIED POPULATION	147	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	14.04.2016
DISCHARGE		No measurement
TEMPERATURE		25 °C
ELECTRICAL CONDUCTIVITY		366 µS/cm
PH		8
	TANK - MADRE TIERRA	
SUPPLIED COMMUNITY	Madre Tierra	
SUPPLIED POPULATION	147	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	14.04.2016
DISCHARGE		1.12 l/s
TEMPERATURE		25 °C
ELECTRICAL CONDUCTIVITY		366 µS/cm
PH		7.5

Table 23: El Casino measurements

NAME	EL CASINO - SPRING	
WATER SOURCE	Spring	
STORAGE TANK	1 Ground Level Storage Tank	
SUPPLIED COMMUNITY	El Casino	
SUPPLIED POPULATION	175	
DATE OF MEASUREMENT	**2015**	**2016**
	28.05.2015	18.04.2016
DISCHARGE	1.17 l/s	No measurement
TEMPERATURE	28.7 °C	No measurement
ELECTRICAL CONDUCTIVITY	332 µS/cm	374 µS/cm
PH	7.5	7
	TANK - EL CASINO	
SUPPLIED COMMUNITY	El Casino	
SUPPLIED POPULATION	175	
DATE OF MEASUREMENT	**2015**	**2016**
	28.05.2015	18.04.2016
DISCHARGE	No measurement	0.4 l/s
TEMPERATURE	29.8°C	No measurement
ELECTRICAL CONDUCTIVITY	330 µS/cm	396 µS/cm
PH	7.5	7

5.1.2 Discharge

The water discharge[16] at the investigated sites (n=17), including springs, wells and tanks (where access to spring captures was not possible), was investigated between February and April 2016. Table 24 shows all results measured during this period in comparison with available data from 2015, published by Schaidreiter (2016). The discharge was measured in litres per second (l/s) and ranges from 0.4 to 11.51 l/s or 35 to 994 m³/day. The per capita water availability (litres/capita/day) in the communities served by these water sources was calculated based on the provided population data. It ranges from 33 to 853 l/c/d[17] (see Table 24 and Figure 8).

Table 24: Discharge for investigated springs in comparison with 2015 data[18]

	POPULATION	DISCHARGE					
		l/s		m³/day		l/c/d	
		2015	**2016**	**2015**	**2016**	**2015**	**2016**
SPRINGS							
LAS PAMPAS	476	1.5	1.19	130	103	272	216
PARQUE TEHUACAN	300		5.44		470		1567
GUAJOYO	1128	3.59	2.4	310	207	275	184
NUEVA TEHUACAN	2546	16.2	11.51	1400	994	550	391
MARCIAL GAVIDIA SPRING 3	309	1.39	0.99	118	86	380	277
EL MILAGRO	482	0.84	0.84	73	73	151	151
TANKS							
TANK – GUAJOYO	906		2.41		208		230
TANK – NUEVA TEHUACAN	978		6.31		545		557
TANK – BRISAS DEL VOLCÁN	228		2.25		194		853
TANK – SINAÍ SAN FRANCISCO	539		2.95		255		473
TANK – ACHIOTES	151		1.45		125		830
TANK – EL SOCORRO	185		1.13		98		528
TANK – SANTA MONICA	374	1.25	0.95	108	82	289	219
TANK – SAN FRANCISCO-ANGULO	426	1.7	1.13	147	98	345	229
TANK – MADRE TIERRA	147		1.12		97		658
TANK – EL CASINO	175		0.4		35		197

Note: empty fields indicate, that no data was available.

[16] The researcher notes, that in case of wells it is the yield, not the discharge but to simplify reading, the word discharge is used for available amount of water.
[17] The amount for Parque Tehuacan is not included in the range because the population is only estimated.
[18] Source population data: (DIGESTYC, 2015)

At all the above-mentioned investigated sites, water discharge was sufficient to meet the service levels recommended by WHO (for more detail see Chapter 3.1.2.1). It is important to note that not the entire population is supplied with water from the distribution network but also from or by different water sources such as private wells for example. However, to analyse the per capita water availability the calculations are based on the total population in each community.

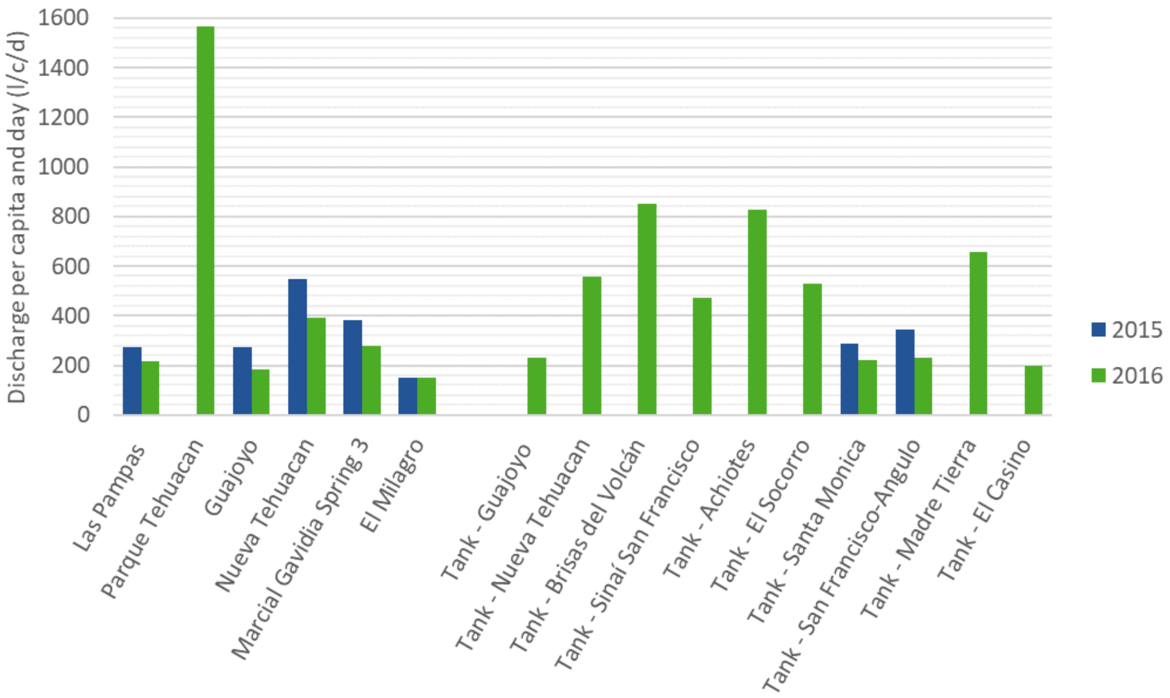


Figure 8: Per capita water availability

Regarding water discharge, it can be stated that the amount of water at the time of the study was sufficient to supply the individual communities. Hereby it is important to note, that not every community is supplied by an individual water source. In some cases, water sources are shared amongst multiple communities. For more information on water sources and their supplied communities please refer to the checklists in Appendix 8.1. It is apparent that the discharge is less in comparison to the data from 2015. It is not possible to make a more conclusive statement about potential reduction of water yield without having more data points over a longer time period as well as additional information about the precipitation in the respective years. Furthermore, water discharge measured in tanks does not directly reflect on the spring discharge itself. Losses occurring between the spring capture and the tank will decrease the measured discharge in the tank, however could not be investigated further. Losses after the points of measurement (spring captures or tanks) will result in less available water at household level and should therefore be investigated further. The discharge of the spring supplying El Milagro however, is the same as the previous year, which means that not the water availability but possibly the distribution thereof is the reason for fewer water available at household level.

5.1.3 Water temperature

Water temperature at the investigated springs (n=14) ranges from 25.0 to 32.8 °C, at wells (n=3) from 30.8 to 32.0 °C, whereas water temperature in tanks (n=10) ranges from 27.1 to 33.3 °C (see Figure 9).

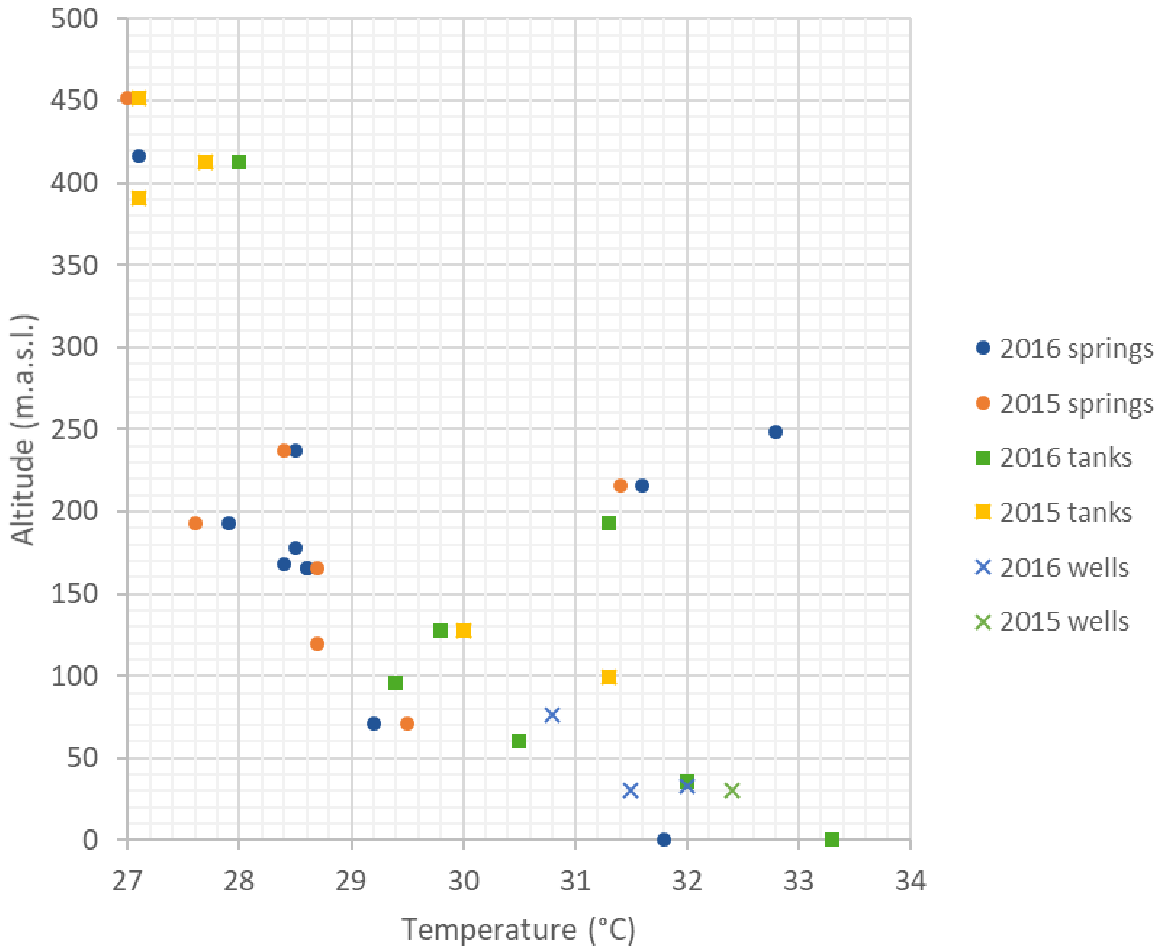


Figure 9: Water temperature at springs and tanks in comparison with 2015 data

It can be observed, that water temperatures are very similar to the previous year. Small differences can be interpreted as differences in weather conditions, measurement inaccuracies and tolerances. Sites located at higher altitudes tend to have slightly lower water temperatures. Furthermore, it can be observed that all temperatures exceed values recommended by the WHO for drinking water (2011a).

5.1.4 Electrical conductivity and pH

The electrical conductivity measured for springs, wells and tanks (n=31) ranges from 299 to 425 µS/cm. The pH at all measured sites ranges from 7.0 to 8.5. Measured values are within range of

MINSAL as well as WHO. The results of measured water temperature, electrical conductivity and pH in comparison with data from 2015 can be seen in Table 25 below.

Table 25: Water temperature, electrical conductivity and pH in comparison with 2015 data

	TEMPERATURE (°C)		PH		ELECT. CONDUCTIVITY (MS)	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
MEAN	29.0	29.5	7.4	7.5	267.4	286.5
STANDARD DEVIATION	1.59	2.23	0.17	0.45	41.54	56.68
MEDIAN	28.7	29.4	7.5	7.5	247	262
MINIMUM	27	25	7	7	228	229
MAXIMUM	32.4	33.3	7.5	8.5	336	425
COUNT	14	27	15	31	15	31

Regarding electrical conductivity and pH it can be stated, that all water samples (springs, wells and tanks) lie within the recommended range for raw and tap water ((Hauser, 2002) as cited in Schaidreiter, 2016) and pH values are within the range according to local and international recommendations (CONACYT, 2009; WHO, 2011a).

5.1.5 Additional findings

During the taking of measurements, additional information about the state of the spring captures was gathered. It was found that roots had started to grow or in some cases had intensively grown into the spring boxes (see Figure 10). Root growth is a sign of faulty construction as well as lack of maintenance. Trees and other vegetation with aggressive root systems must be cut in the surrounding area of the spring to prevent root growth (Umweltbundesamt, 2013).

Figure 10: Root growth in spring boxes

5.2 Water supply in El Milagro

5.2.1 Network infrastructure

5.2.1.1 Pipes

The water supply network of El Milagro has a total length of approximately 1900 m, which was determined by using an existing map as well as through a topographic survey conducted with the Unversidad de El Salvador in San Vicente. The map includes the originally built network, with pipe diameters (see Table 26). The topographic survey (Appendix 8.3) concluded that the network has a total length of approximately 1858 metres. The existing network was built to be supplied by the aforementioned deep well and was modified when the deep well was decommissioned and the spring capture was used as the single source of water supply in El Milagro. New, or replaced pipes, put in after the construction of the network are not documented and therefore no conclusive statement about the relation of pipe diameters and distribution can be made.

Table 26: Pipe diameters of the distribution system

PIPE DIAMETER (INCHES)	LENGTH (METERS)
1	210.13
1 ½	193.74
2	984.82
3	536.23
Total length	**1924.92**

5.2.1.2 Pressures

Water pressure readings were taken with a pressure gauge due to the absence of a pressure logger. However, even if a pressure logger would have been available it would not have been possible to connect it to a tap for 24 hours as most households only have one tap (see Chapter 5.2.4) on their premises meaning that a resident would have to sacrifice access to water. Pressure readings range from 0.3 bar in the elevated zone (Zone “Alta”) to 1.4 in the central zone (Zone “Media). However, due to different times, readings cannot be compared.

Table 27: Water pressure readings

ZONE	TIME	PSI	BAR
BAJA	09:42	14	1.0
BAJA	10:00	7	0.5
MEDIA	11:45	20	1.4
MEDIA	12:25	16	1.1
ALTA	12:00	4	0.3
ALTA	12:10	4	0.3

5.2.1.3 Water meters

In El Milagro it is common to have a water meter at each household connection. According to members of the water board many water meters were installed when the network was put in place at the time of construction of the deep well. Additional water meters were privately bought and installed and in the case of new houses or of broken water meters it is the responsibility of the homeowner to buy and install a new one. This is recommended by the water board, however when questioned about what happens if no water meter is bought, the representative of the water board said: *"Then we ask again to buy one",* meaning that there are no negative consequences for the inhabitants if no water meter is bought. This leads to a false perception of water consumption as well as the potential loss of income for the water board due to lower water bills. Water meters are read by a member of the local water board in charge of finances and billing. Meters were found in different states, ranging from hardly accessible/readable or poorly maintained (see Figure 11) to brand new.

Figure 11: Selection of water meters in El Milagro

During the analysis of the water meter readings for the period from 2012 – 2016 (to determine water consumption) (see Chapter 5.2.3.1) irregularities were found in the data, such as discontinuity of recordings which could be caused by a number of factors and can be classified into three different groups:

1. **Problems with the reading**
    - If the water meter is not accessible on the day of the reading, no reading gets recorded until the following month.
    - If the reading of the water meter is not clearly visible it is only estimated or does not get recorded at all.

2. Organisational problems

- No information about the water meter, such as serial number, brand or date of installation is documented.
- When a meter is broken and does not get replaced, the homeowner is only being charged the minimum fee of 3 US$/month, causing the water board to lose revenue.
- Bills are issued every month, therefore if water meter readings are not recorded at all or only estimated (see 1. Problems with the reading) the community loses revenue each month.
- Customers exchange water meters themselves and do not notify the water board.
- Water meters are private property and can[19] therefore be taken with when vacating the house.
- Water meter readings are not assigned to the serial number of the water meter, but the name of the homeowner, therefore if the name of the homeowner changes, a new data set is created and recordings cannot be traced back.
- If a person moves from one home to another within the community no new data set gets created, however the reading changes to another meter and is therefore not consistent.
- The readings are not checked and post-processed to correct any errors.
- Old data sets are not deleted and give a false impression on the number of customers.
- Change of property ownership leads to various data sets with the same name, however no readings are recorded.

3. Problems with network and water meter

- When the pipes are empty moving air can make the water meter record flow and therefore give wrong impressions of water consumption.
- Inaccurately installed meters can cause over or under registration of water flow, leading to wrong water meter readings.
- Poorly or none-maintained water meters can lead to malfunctioning.

[19] This has only been the case once, but due to its possible occurrence it is included.

5.2.2 Water sources

El Milagro has one spring supplying the community network with water. The discharge was 0.84 l/s at the time of investigation as well as in the previous year. Based on the assumption that the discharge is consistent, this results in a 26,490 m³ per year which are theoretically available for the water supply of the village.

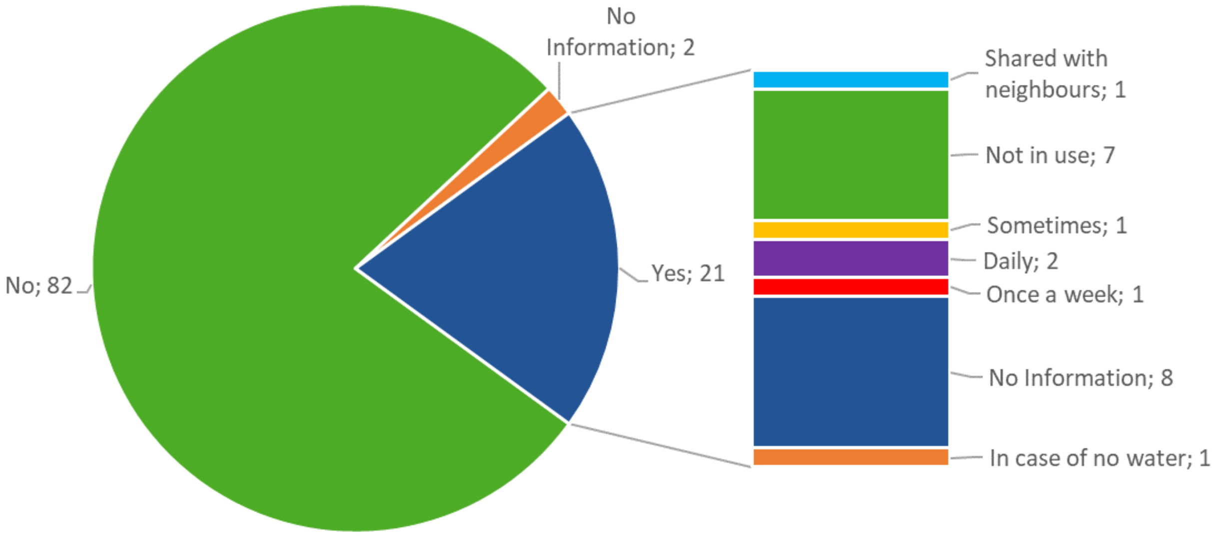


Figure 12: Existence and usage of private wells in El Milagro

In addition to the public water supply, individuals were found to have private wells on their property. Investigations showed that, 21 households are in possession of a private well but in only two cases was it confirmed that they are being used for daily water supply. One household declared to use it only once a week (see Figure 12). One homeowner stated to use it *“sometimes”* and in one case the answer was *“when there is no water*”, however not specifying how often these situations occur. In 7 cases the well was not in use. The state of the well however was not investigated, therefore no statement can be made about its potential usability. If the wells that are not used on a daily basis or at least once a week, are not considered as a main water source, which is highly likely, the findings show a similar distribution to the investigation of the different water sources carried out by Lasser (2018) (see Figure 13).

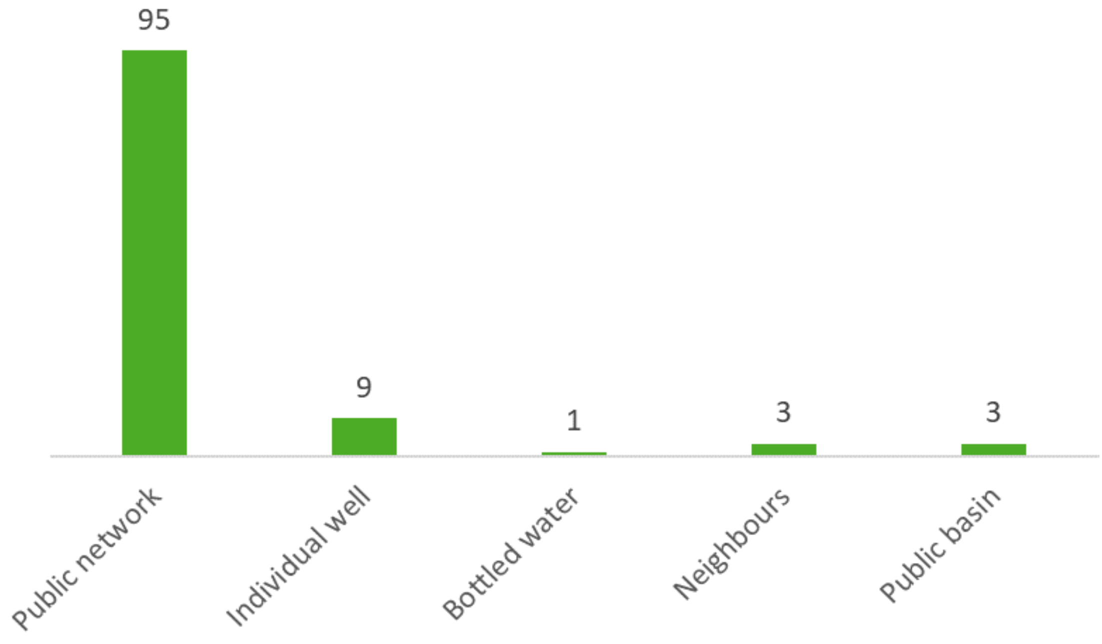


Figure 13: Water sources in El Milagro[20]

In addition to alternative water sources, the public basin in the river bed is irregularly used by families for personal hygiene, washing clothes and dishes.

5.2.3 Water consumption and storage

5.2.3.1 Water consumption

El Milagro had an average yearly consumption of 22,066 m^3 over the course of 4 years. Figure 14 illustrates the monthly per capita consumption for the period from 2012 to 2016. Water consumption over the entire period appears to be relatively stable without large seasonal fluctuations. The researcher notes, that in November and December 2015, water consumption is reduced by approximately 50% in comparison to the average consumption in these months. However, despite the obvious lower water consumption, no evidence was found explaining why this was the case.

[20] Adapted from (Lasser, 2018)

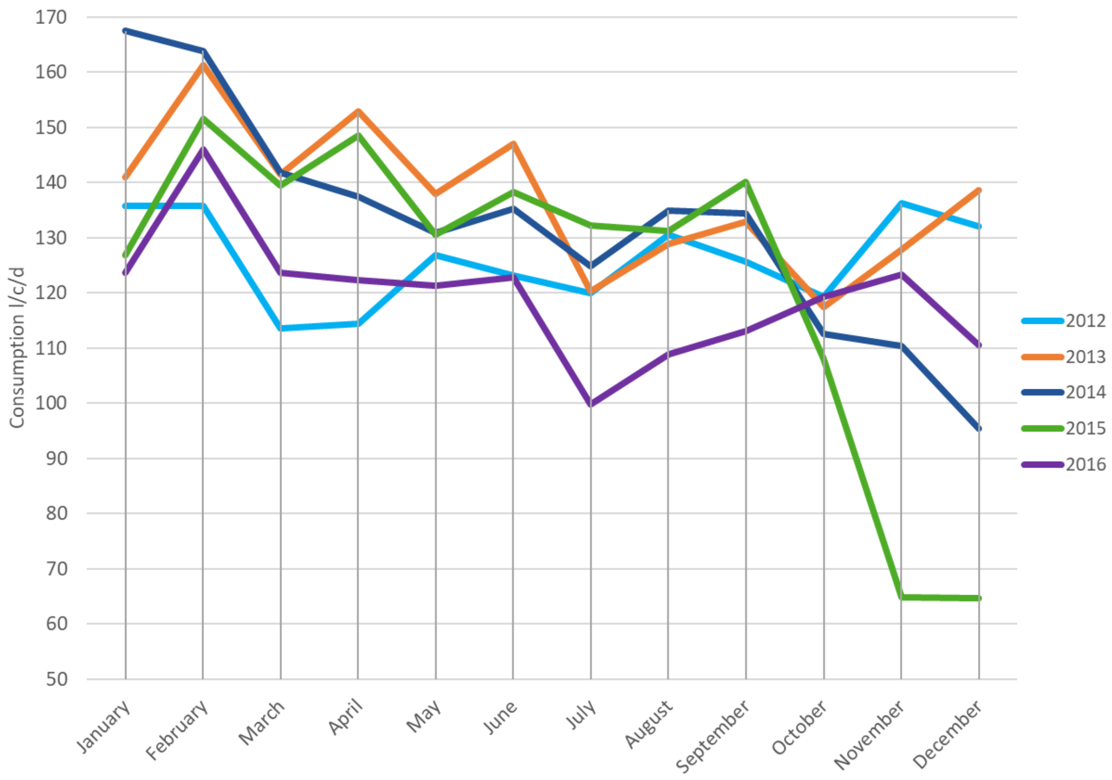
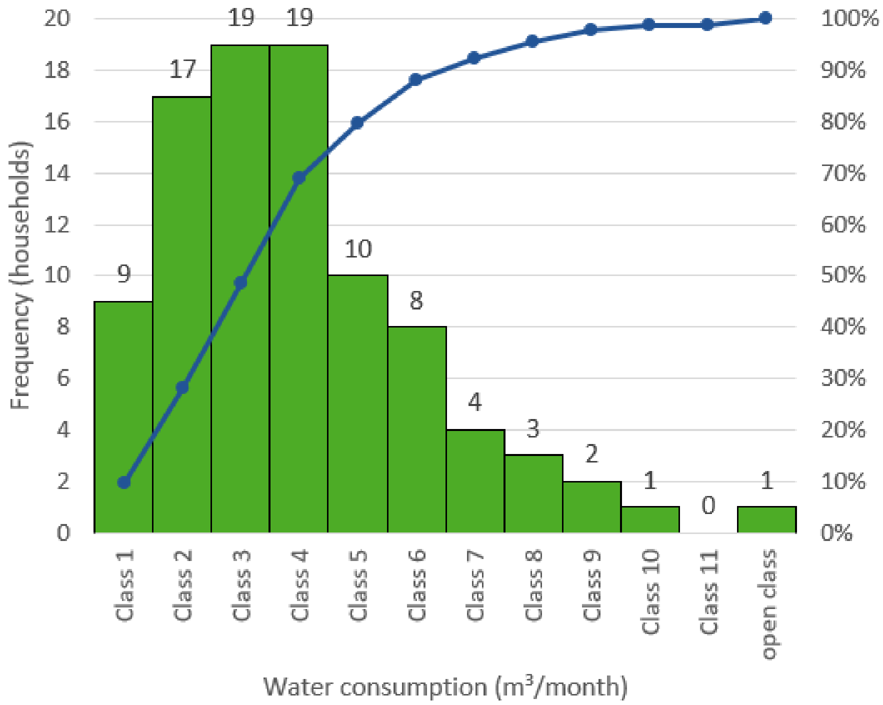


Figure 14: Water consumption January 2012 - December 2016

El Salvador has two distinct seasons, summer and winter. The rainy season (Winter) is between May and October and the dry season (Summer) is between November and April. Whilst the seasons seem to have only a marginal influence on the water consumption in El Milagro this is in contrast to findings from Kern (2018) in the nearby communities of San Francisco Angulo and Cantarrana, which state that per capita water consumption is directly related to seasonal variations. Generally, can be stated that if enough water is available throughout the year, water consumption is not influenced by seasonal changes.

Additionally, data on the water consumption per household and month was analysed (see Figure 15). Classes were formed and cumulated. The results show that 19 households have an average water consumption per month between 11 and 15 m³, another 19 households between 16 and 20 m³ and 17 households between 6 and 10 m³. Only one household was assessed as having water consumption higher or equal to 55 m³. For households falling under the category of Class 5 or higher, meaning that more than 20 m³ of water are being consumed monthly, assumptions can be made. It can be assumed that water is used for additional purposes such as commercial uses[21], irrigation or water for animals. Furthermore, can be assumed that leakages on the consumer side of the meter are very high or that water is in general being wastefully used.

[21] In case of the dairy production.



Class 1	1 – 5 m³
Class 2	6 – 10 m³
Class 3	11 – 15 m³
Class 4	16 – 20 m³
Class 5	21 – 25 m³
Class 6	26 – 30 m³
Class 7	31 – 35 m³
Class 8	36 – 40 m³
Class 9	41 – 45 m³
Class 10	46 – 50 m³
Class 11	51 – 55 m³
Open Class	≥55 m³

Figure 15: Average water consumption per household and month (2012 – 2016)

Furthermore, the average water consumption per household and per capita (n= 105), using household water metering data was calculated. Results of these calculations (see Table 28) show, that the average water consumption per household is 567 l/d or 17 m³/M. With an average of 4.5 people per household, the average per capita consumption is 126 l/d or 3.8 m³/M. Data shows that between households the consumption varied between 1 and 90 m³/hh/M, which is in a comparable range as the findings from Schaidreiter (2016), where per household water consumption in Bajo Lempa varied between 1 and 83 m³/hh/M. Both findings from El Milagro with an average consumption of 17 m³/hh/M and 14.8 m³/hh/M in Bajo Lempa respectively are within the estimated consumption levels per household, 15 to 23 m³/hh/M for rural areas in El Salvador (Ortiz and Piedrafita, 2006). The technical norms from ANDA (CONACYT, 2009) only provide information on the average water consumption per person in urban areas, suggesting a domestic consumption ranging between 80 and 350 l/p/d. There is no information for rural areas.

Table 28: Per household and per capita water consumption for the period from 2012 – 2016

	PER HOUSEHOLD CONSUMPTION		PER CAPITA CONSUMPTION	
	m^3/hh/M	l/hh/d	m^3/c/M	l/c/d
MEAN	17	567	3.8	126
MEDIAN	16	533	3.6	119
MAXIMUM	90	3000	20.0	667
MINIMUM	1	33	0.2	7.41

AVERAGE HOUSEHOLD SIZE: 4.5 PEOPLE/HOUSEHOLD

5.2.3.2 Hourly water availability

The interviewees were asked at which time of the day they have water. As shown in Figure 16, it was found that water becomes available three times a day. The first peak in the morning is between 3:00 and 4:00 am, for duration of approximately 4 hours. The second peak, at midday, is slightly lower and shorter than the first peak, it starts around 11:00 am for duration of approximately 3 hours. The last peak in the evening is considerably smaller than the first peak, starting at around 5:00 pm and lasts for duration of approximately 5 hours. The three peaks are in line with the information provided by the pump operation manager, stating that the pump is in use 3 times a day.

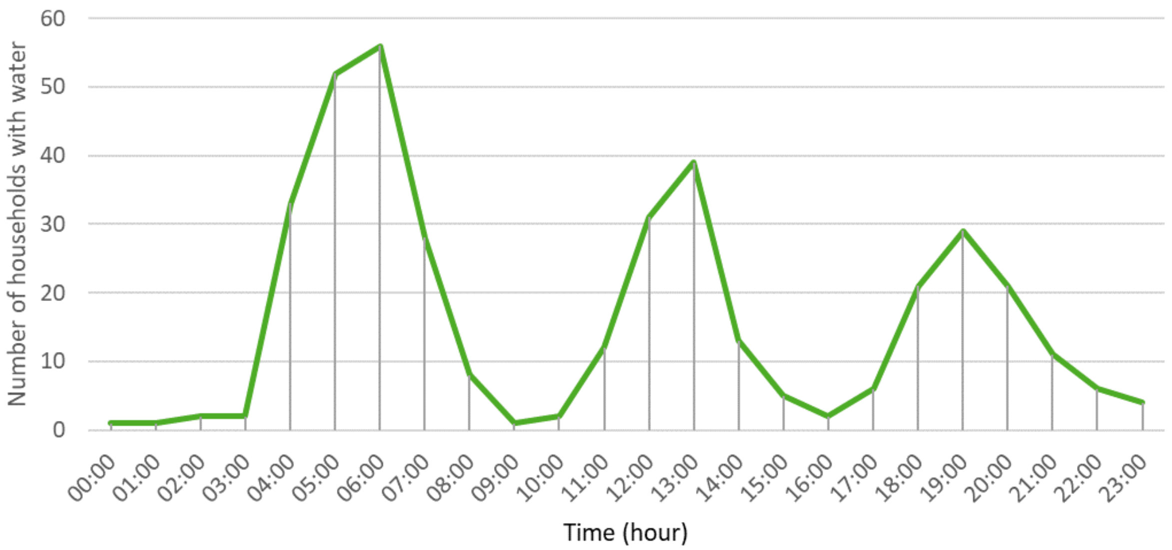


Figure 16: Hourly water availability

Customers in the topographically lower parts of the village did not have problems with water availability. However, in the higher zones or towards the end of the branch lines of the supply system, customers often stated that water is only available for a very short time during the morning. According to residents, in some cases only 30 minutes. This may explain why the second and the third peak are smaller, than the first one. However, this results in customers leaving their taps open, capturing water in large storage facilities (see Chapter 5.2.3.3), in case of water arriving. Because most costumers leave their taps open until storage facilities are filled the pressure is insufficient to supply water to higher zones or towards the end of the branch lines. Insufficient pipe diameters could be a potential reason for limited water availability, however, must be further investigated. The researcher notes, that this analysis is based solely on consumer information, rather than actual measurements, hence it is possible that actual water availability might differ from these findings. However, Schaidreiter (2016) and Kern (2018) made similar findings on average hourly water demand in both, 18 different communities in the Municipality of Tecoluca and the community of San Francisco Angulo, respectively.

5.2.3.3 Storage

87% of all households indicated that water is stored in either "Pilas", "Barrils", "Cubos" or a combination thereof (see Figure 17). A "Pila" is a bathtub-like topless concrete basin where water is stored. Often small fish are nurtured in these "Pilas" to prevent mosquito and other insect larvae to grow. A "Barril" is mostly a plastic drum or barrel with approximately 50 – 100 litres storage capacity. "Cubos" are small containers, such as buckets, cans, cups etc. This type of storage has only been reported to be used as permanent, rather than temporary storage in one house. The researcher endeavoured to establish why no Pila had been built, however, no information was provided by the homeowner.

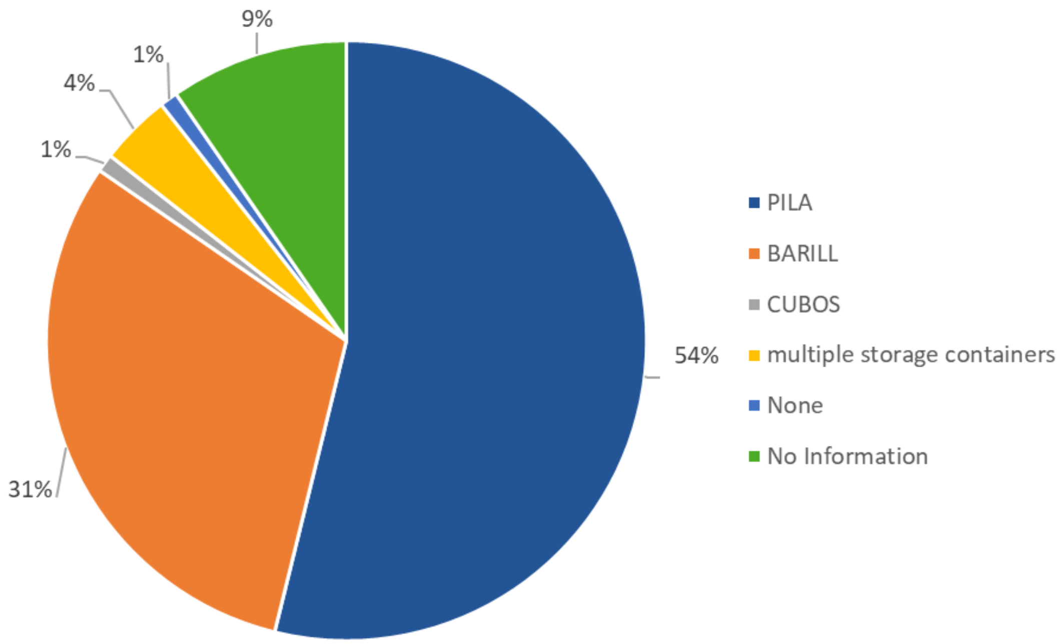


Figure 17: Household water storage in El Milagro

100% of the storage facilities in El Milagro were found to not fulfil the recommendations by the WHO (for more details please refer to Chapter 3.1.2.2) such as covering storage facilities, keeping them out of reach for children and animals or preventing recontamination through contact with hands, cups or other obstacles.

5.2.4 Points of access

83% of all households have only one (n= 77) or two (n= 10) taps as access points to the network. Only 8% (n= 8) use shower heads in their houses and in only 4% of all households (n= 4) is a flushed toilet available. Figure 18 below shows the distribution of water access points in El Milagro.

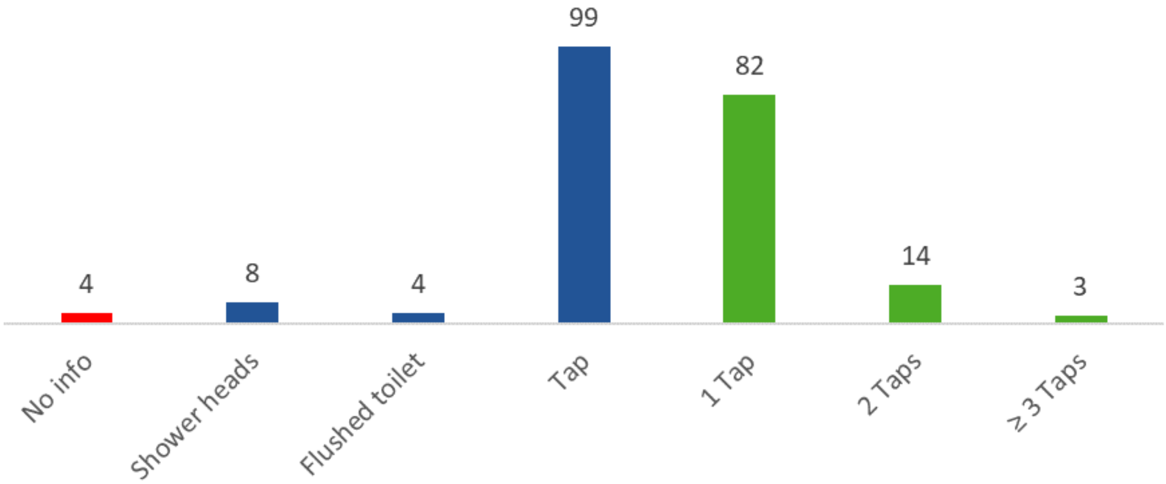


Figure 18: Number of water access points in El Milagro

5.2.5 Water use for domestic animals

In households with large numbers of domestic animals, water consumption can be expected to be higher. Therefore, the study included the question of domestic animals. 78 out of 105 households declared to have domestic animals, 5 of which have cattle as well. In the case of 3 households no information was recorded. The researcher notes that, the focus was not on animals and the questionnaire was therefore not designed to record different categories. Additionally, interviewees often did not consider animals such as chickens or pets[22] as animals, only cattle, hence denied possession of such. Lasser (2018) studied the distribution of domestic animals in more detail and recorded the different categories (see Figure 19), however, does not state how many households have more than one type of animal. Therefore, it is not possible to compare the findings of both studies.

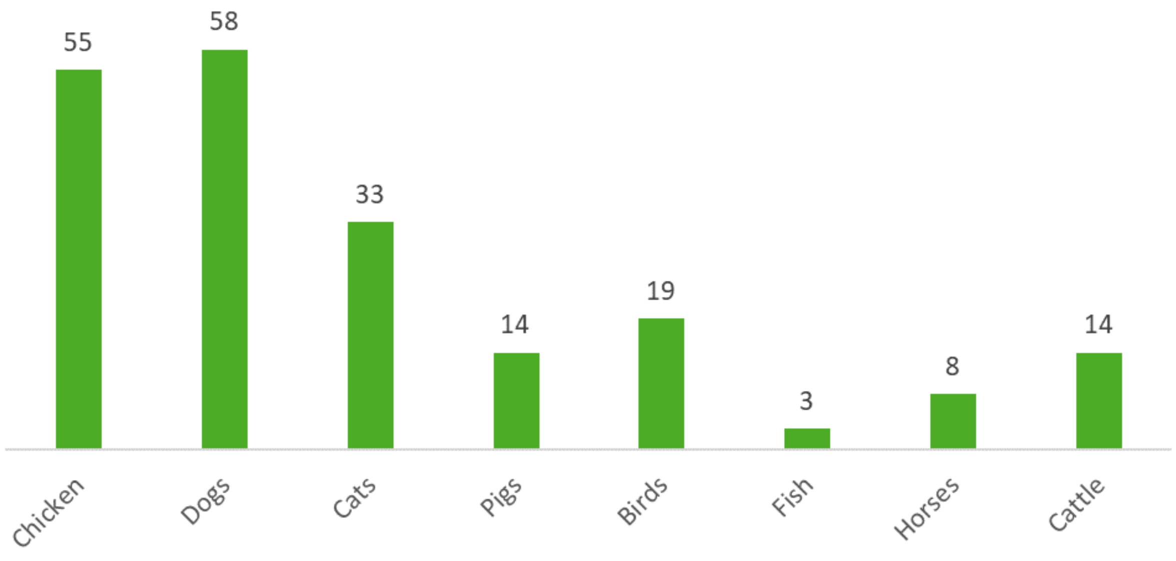


Figure 19: Domestic animals in El Milagro[23]

Despite the lack of recorded findings, personal observations by the researcher confirm that most households are in possession of domestic animals, especially chickens and dogs, which corresponds with Lasser's findings. Regarding higher water consumption in households with large number of domestic animals no concrete findings could be recorded and therefore no general statement can be made.

[22] The term “pet” in this context means dogs, cats or birds
[23] Adapted from (Lasser, 2018)

6. Conclusion and Outlook

The overall goal of this thesis was to scientifically document and analyse the state of the water resources in the Municipality of Tecoluca and describe the current situation of the water supply system in the rural village El Milagro. This was accomplished by collecting data on water quantity and quality by means of measurements as well as via structured interviews and observations. Additionally, data was analysed to illustrate water consumption in El Milagro for the period from 2012 to 2016. By means of these methods, the study identified the state of 12 selected water sources (6 directly and 6 indirectly, measured at storage tanks) within the municipal area of Tecoluca as well as the characteristics of distribution and management of El Milagro's water supply.

Regarding water resources, it is important to note that, to estimate the discharge of springs over the year as well as to detect changes in water quality, measurements must be taken over a longer period. In only 7 out of the 12 sites have measurements been conducted in 2015. Hence no conclusive deductions can be made regarding the available water quantity and quality. Overall it has been found that the status of the water resources in the Municipality of Tecoluca is still largely unknown. The point measurements conducted, while providing basic insight into the availability of water from particular sources, are not suitable for drawing long-term conclusions.

In the case of El Milagro, the spring discharge in conjunction with the water meter readings should be enough to theoretically determine where the problem lies. However, due to the poor quality of consumption data this does not facilitate making a general statement. Therefore, additional information regarding water distribution is essential to determine whether the problem lies with the yield of the spring, the distribution network or elsewhere. Residents complained about very limited and intermitted water supply. However, it was found that the water supplied by the spring has a discharge of 26,490 m^3 per year and the average consumption of the village is estimated to be 22,066 m^3 per year. Based on these facts, El Milagro should be able to supply all residents with sufficient water at this point. However, due to the unreliability of consumption data it may well be, that consumption is much higher than the current spring discharge. The overall consumption is relatively high, considering that most households have only one tap and neither shower heads nor flushed toilets. Therefore, consumption should be expected to be around 50 l/c/d. Additionally, it is important to note that, an increase in the population, a decrease of the spring discharge or solely the installation of additional shower heads or flushed toilets will increase the consumption and is likely to put further stress onto the water supply in El Milagro. The availability of water at this point is not the problem. The distribution network seems unsuitable for the provision of continuous water supply in the village. The system is not only dated, but has also been expanded without any proper hydraulic design and is poorly or non-maintained. Extensions and other changes to the network have not been documented making it difficult to analyse the system further. Furthermore, it was found that the unreliable water supply leads to the necessity of household water storage, which was detected as a potential health risk as none of the households in El Milagro were found to have appropriate water storage containers, posing a significant health risk to its population. These findings lead to the conclusion, that the distribution network and its management as well as individual water use on household level are of major importance in El Milagro.

The case of El Milagro shows that gaining more detailed insight into common water management practices in the villages of the Municipality of Tecoluca is crucial to understand problems and challenges regarding water supply, wastewater and hygiene. This study provides detailed information on only one village, while there are still 82 communities within the Municipality of Tecoluca, where not even basic data is available.

Outlook

The investigations carried out by the researcher demonstrated the poor state of some of the water resources in the Municipality of Tecoluca. Further steps need to be taken to increase the amount of data as well as to improve data quality, with specific focus on discharge and water quality. Regarding the water supply within the municipal area of Tecoluca it is crucial to continue investigations throughout the remaining communities by generating and following a standardised approach. Well-structured documentation will facilitate a simplified comparison of supply systems and practices. This will furthermore help to identify localised as well as culturally generalised problems (e.g. storing water in an open storage container, such as a “Pila”). The awareness of the situation on water resources and the willingness for improvement exists on the part of the management at the Alcaldía. If the willingness to cooperate on the part of the communities to ensure water supply as well as to change household behaviour exists, it is not clear and should be further investigated.

Recommendations

General

- Water quality and quantity measurements should be continued and ideally be automated.
- Carrying out training workshops for water board members on how to maintain spring captures and tanks to prevent contamination and root growth.
- Conducting further in-depth studies of rural communities.

Specifically, for El Milagro:

- Further investigations should be carried out regarding high water consumption and water tariffs.
- Setting awareness-raising measures related to water consumption, use, storage and hygiene.
- Carrying out an in-depth analysis of the water distribution network and if necessary design new infrastructure such as a pipe from the pump to the tank.
- Calculating a water balance and determining water losses including non-revenue water and carrying out leak detection.

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8. Appendix

8.1 Checklists

Table 29: Data Las Pampas Spring[24]

MANAGEMENT	**WATER BOARD LAS PAMPAS**	
WATER SOURCE	Spring (constructed in 1994, by IBASA)	
WATER SUPPLY	2 Communities: Las Pampas, San José La Ceiba	
POPULATION	476 (282+194)	
WATER TREATMENT	Chlorination	
WATER STORAGE	2 Elevated Storage Tanks (20m³, 50m³)	
WATER DISTRIBUTION	Distribution by gravity	
WATER ANALYSIS	No regular water analysis	
OTHER WATER SOURCES	New spring capture in construction (2015)	
WATER SERVICE FEES	US$1.50/household/month no limitation, no water metering	
COORDINATES	13° 31' 23.8" N 88° 46' 52.4" W | 215.6 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	25.05.2015	26.02.2016
DISCHARGE	1.5 l/s	1.19 l/s
WATER TEMPERATURE	31.4 °C	31.6 °C
CONDUCTIVITY	288 µS/cm	290 µS/cm
PH	7	8

Table 30: Data Parque Tehuacan Spring

NAME	**PARQUE TEHUACAN – SPRING**	
MANAGEMENT	Water Board Parque Tehuacan	
WATER SOURCE	Spring	
WATER SUPPLY	Parque Tehuacan	
USERS	depends on the number of guests	
WATER TREATMENT	No Water treatment	
WATER STORAGE	No Water storage	
WATER DISTRIBUTION	Distribution by gravity	
WATER ANALYSIS	No Water analysis	
OTHER WATER SOURCES	No other sources	
WATER SERVICE FEES	No fees	
COORDINATES	13° 33' 44.4" N 88° 47' 15.2" W | 416.2 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	26.02.2016
DISCHARGE		5.44 l/s
WATER TEMPERATURE		27.1 °C
CONDUCTIVITY		236 µS/cm
PH		7.5

[24] Adapted and further extended from (Schaidreiter, 2016)

Table 31: Data Guajoyo Spring and Tanks[25]

NAME	**GUAJOYO – SPRING**	
MANAGEMENT	Water Board Guajoyo	
WATER SOURCE	Spring (constructed by InterSOL in 2013)	
WATER SUPPLY	4 Communities: Flor de Fuego, Guajoyo, Miramar, Granzazo	
POPULATION	1128 (648+145+113+222)	
WATER TREATMENT	No water treatment; biofilter in spring capture	
WATER STORAGE	2 Ground Level Storage Tanks	
COMMENTS	Second tank at time of visit empty. It is counter reservoir	
WATER DISTRIBUTION	Distribution by gravity	
INLET	8in inlet pipe	
WATER ANALYSIS	Once per year (InterSOL)	
OTHER WATER SOURCES	Domestic wells in the communities (drinking water quality not sufficient), other springs in the surrounding area of spring capture	
WATER SERVICE FEES	US$1.00/household/month No limitation, no water metering applied	
COORDINATES	13° 31' 18.7" N 88° 41' 39.4" W | 193.2 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	29.05.2015	29.02.2016
DISCHARGE	3.59 l/s	2.4 l/s
WATER TEMPERATURE	27.6 °C	27.9 °C
CONDUCTIVITY	229 µS/cm	235 µS/cm
PH	7.5	7
	TANK GRANZAZO	
MANAGEMENT	Water Board Granzazo	
WATER SOURCE	Guajoyo	
CONSTRUCTION	1996	
WATER SUPPLY	Community Granzazo	
POPULATION	222	
WATER TREATMENT	No treatment	
CAPACITY	25 m³	
COORDINATES	13° 28' 25.5" N 88° 41' 07.6" W | 99.6 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	29.05.2015	29.02.2016
DISCHARGE	No measurement	Tank empty at time of visit
WATER TEMPERATURE	31.3 °C	
CONDUCTIVITY	229 µS/cm	
PH	7.5	
	TANK GUAJOYO	
MANAGEMENT	Water Board Guajoyo	
WATER SOURCE	Guajoyo Spring	
WATER SUPPLY	3 Communities: Guajoyo, Mirmar, Flor de Fuego	
POPULATION	906 (648+145+113)	
OUTLET	Tank has 2 outlets. One 1.5in pipe (constructed in 2005) and one 2in pipe (constructed in 1992)	
COORDINATES	13° 29' 47.1" N 88° 41' 03.9" W | 117.6 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	29.02.2016
DISCHARGE		2.41 l/s
WATER TEMPERATURE		31.3 °C
CONDUCTIVITY		236 µS/cm
PH		8

[25] Adapted and further extended from (Schaidreiter, 2016)

Table 32: Data Nueva Tehuacan Spring and Tanks[26]

NAME	NUEVA TEHUACAN – SPRING	
MANAGEMENT	Water Boards, 4 different water supply systems	
WATER SOURCE	Spring (constructed by InterSOL in 2008)	
WATER SUPPLY	5 communities: Monte Sinaí, San Francisco Tehuacán, Nueva Tehuacán, El Arco, Las Brisas	
POPULATION	2546 (275+264+978+801+228)	
WATER TREATMENT	Chlorination; Biofilter in spring capture	
WATER STORAGE	4 Ground Level Storage Tanks	
WATER DISTRIBUTION	Distribution by gravity	
WATER ANALYSIS	Once per year (InterSOL)	
OTHER WATER SOURCES	Domestic wells in the communities	
WATER SERVICE FEES	US$1.50/household/month no limitation, no water metering	
COORDINATES	13° 33' 44.3" N 88° 47' 15.5" W | 433.5 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	14.04.2015	02.03.2016
DISCHARGE	16.2 l/s	11.51 l/s
WATER TEMPERATURE	27.0 °C	27.1 °C
CONDUCTIVITY	231 µS/cm	236 µS/cm
PH	7.5	7

	TANK NUEVA TEHUACAN	
MANAGEMENT	Water Board Nueva Tehucan	
WATER SOURCE	Spring Nueva Tehucan	
CONSTRUCTION	2000	
WATER SUPPLY	Community Nueva Tehucan	
POPULATION	978	
WATER TREATMENT	Chlorination	
COORDINATES	13° 33' 32.1" N 88° 47' 4.5" W | 395.3 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	14.04.2015	02.03.2016
DISCHARGE	No measurement	6.31 l/s
WATER TEMPERATURE	27.1 °C	27.1 °C
CONDUCTIVITY	232 µS/cm	238 µS/cm
PH	7.5	7

	TANK BRISAS DEL VOLCAN	
MANAGEMENT	Water Board Nueva Tehucan	
WATER SOURCE	Spring Nueva Tehucan	
CONSTRUCTION	2000	
WATER SUPPLY	Community Brisas del Volcán	
POPULATION	228	
INLET	1.5in inlet pipe	
COORDINATES	13° 33' 30.1" N 88° 47' 02.5" W | 390.6 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	16.06.2015	02.03.2016
DISCHARGE	No measurement	2.25 l/s
WATER TEMPERATURE	27.1 °C	27.1 °C
CONDUCTIVITY	232 µS/cm	237 µS/cm
PH	7.5	7.5

[26] Adapted and further extended from (Schaidreiter, 2016)

	TANK - SINAÍ SAN FRANCISCO	
MANAGEMENT	Water Board Nueva Tehucan	
WATER SOURCE	Spring Nueva Tehucan	
CONSTRUCTION	2000	
WATER SUPPLY	2 Communities: Monte Sinai, San Francisco Tehucan	
POPULATION	539 (275+264)	
WATER TREATMENT	Chlorination	
CAPACITY	23 m³	
COORDINATES	13° 33' 34.8" N 88° 47' 06.5" W | 413.2 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	14.04.2015	02.03.2016
DISCHARGE	No measurement	2.95 l/s
WATER TEMPERATURE	27.7 °C	28.0 °C
CONDUCTIVITY	232 µS/cm	237 µS/cm
PH	7.5	7.5

Table 33: Data Marcial Gavidia Springs and Tanks[27]

NAME	**MARCIAL GAVIDIA - SPRING**	
MANAGEMENT	Water Board Marcial Gavidia	
WATER SOURCE	3 Springs (constructed 1992)	
WATER SUPPLY	6 Communities: La Florida, Betania 1, Betania 2, El Socorro, San Andrés Los Achiotes, El Ojushte	
POPULATION	2556 (185+151+302+190+119)	
WATER TREATMENT	No water treatment; biofilter in spring capture	
WATER STORAGE	3 Ground Level Storage Tanks	
WATER DISTRIBUTION	Distribution by gravity	
WATER ANALYSIS	Once per year (InterSOL)	
OTHER WATER SOURCES	Domestic wells in the communities (drinking water quality not sufficient), other springs in the surrounding area of spring capture	
WATER SERVICE FEES	US$2.00/25m³/household/month No water metering applied	
	SPRING 1	
WATER SUPPLY	Community Achiotes	
POPULATION	151	
STORAGE TANK	Achiotes - Tank	
COORDINATES	13° 30' 47.9" N 88° 42' 46.0" W | 178.1 m.a.s.l.	
COMMENTS	bad smell, white spots, maybe mould, appearently poor water quality and water borne diseases	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	09.03.2016
DISCHARGE		No measurement
WATER TEMPERATURE		28.5 °C
CONDUCTIVITY		236 µS/cm
PH		8

[27] Adapted and further extended from (Schaidreiter, 2016)

		TANK ACHIOTES
MANAGEMENT	Water Board Achiotes	
WATER SOURCE	Marcial Gavidia Spring 1	
CONSTRUCTION	2000	
COORDINATES	13° 29' 51.9" N 88° 42' 58.1" W | 95.7 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	09.03.2016
DISCHARGE		1.45 l/s
WATER TEMPERATURE		29.4 °C
CONDUCTIVITY		231 µS/cm
PH		7.5

		SPRING 2
MANAGEMENT	Water Board Marcial Gavidia	
WATER SOURCE	Spring	
WATER SUPPLY	Community El Socorro	
POPULATION	185	
STORAGE TANK	El Socorro Tank	
COORDINATES	13° 30' 47.6" N 88° 42' 46.1" W | 167.9 m.a.s.l.	
COMMENTS	very dirty spring capture	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	09.03.2016
DISCHARGE		No measurement
WATER TEMPERATURE		28. 4°C
CONDUCTIVITY		230 µS/cm
PH		7.5

		EL SOCORRO TANK
MANAGEMENT	Water Board El Socorro	
WATER SOURCE	Marcial Gavidia Spring 2	
CONSTRUCTION	2000	
COORDINATES	13° 28' 41.3" N 88° 42' 54.2" W |60.4 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	09.03.2016
DISCHARGE		1.13 l/s
WATER TEMPERATURE		30.5 °C
CONDUCTIVITY		232 µS/cm
PH		7

		SPRING 3
MANAGEMENT	Water Board Marcial Gavidia	
WATER SOURCE	Spring (constructed by InterSOL in 2011)	
WATER SUPPLY	2 Communities: Betania 1, Betania 2	
POPULATION	309 (190 + 119)	
STORAGE TANK	Tank Betania	
COORDINATES	13° 30' 47.0" N 88° 42' 45.8" W | 165.6 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	18.06.2015	09.03.2016
DISCHARGE	1.36 l/s	0.99 l/s
WATER TEMPERATURE	28.7 °C	28.6 °C
CONDUCTIVITY	228 µS/cm	229 µS/cm
PH	8.5	8.5

		TANK BETANIA
MANAGEMENT	Water Board Marcial Betania	
WATER SOURCE	Marcial Gavidia Spring 3	
CONSTRUCTION	2000	
COORDINATES	13° 27' 22.0" N 88° 44' 53.5" W | 37.9 m.a.s.l.	
COMMENTS	No tank, water goes directly	
DATE OF MEASUREMENT	**2015**	**2016**
DISCHARGE	No access possible. Measurements only possible at spring capture	
WATER TEMPERATURE		
CONDUCTIVITY		
PH		

Table 34: Data Santa Monica Spring and Tank[28]

NAME	SANTA MONICA - SPRING	
MANAGEMENT	Water Board Santa Monica, ADESCO	
WATER SOURCE	Spring (constructed by InterSOL in 2011)	
WATER SUPPLY	Community Santa Monica	
POPULATION	374	
WATER TREATMENT	Distribution by Gravity	
WATER STORAGE	1 Ground Level Storage Tank (15m³)	
WATER DISTRIBUTION	No water treatment; biofilter in spring capture	
WATER ANALYSIS	Once per year (InterSOL)	
OTHER WATER SOURCES	No other water sources	
WATER SERVICE FEES	US$1.50/household/month No limitation, no water metering applied	
COORDINATES	13° 29' 46.0" N 88° 45' 58.1" W | 128.0 m.a.s.l.	
COMMENTS	Spring capture too deep to measure discharge but all water goes straight to tank	
DATE OF MEASUREMENT	**2015**	**2016**
DISCHARGE	Measurement only possible at storage tank	
WATER TEMPERATURE		
CONDUCTIVITY		
PH		
		SANTA MONICA TANK
MANAGEMENT	Water Board Santa Monica	
WATER SOURCE	Spring Santa Monica	
CONSTRUCTION	2011	
WATER SUPPLY	Community Santa Monica	
POPULATION	374	
WATER TREATMENT	Chlorination	
CAPACITY	15 m³	
INLET	4in pipe	
COORDINATES	13° 29' 44.4" N 88° 45' 56.9" W | 116.3 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	21.04.2015	10.03.2016
DISCHARGE	1.25 l/s	0.95 l/s
WATER TEMPERATURE	30.0 °C	29.8 °C
CONDUCTIVITY	273 µS/cm	284 µS/cm
PH	7.5	7

[28] Adapted and further extended from (Schaidreiter, 2016)

Table 35: Data 19 de Junio Spring[29]

NAME	19 DE JUNIO - SPRING	
MANAGEMENT	Water Board 19 de Junio Water	
WATER SOURCE	Spring (constructed in 2008/2009)	
WATER SUPPLY	Community 19 de Junio	
POPULATION	141	
WATER TREATMENT	Chlorination	
WATER STORAGE	No water storage	
WATER DISTRIBUTION	Distribution by gravity	
INLET	4in pipe; valve broken, always open	
WATER ANALYSIS	No regular analysis	
OTHER WATER SOURCES	Domestic wells, drinking water quality not sufficient	
WATER SERVICE FEES	US$1.00/household/month	
	No limitation, no water metering applied	
COORDINATES	13° 28' 24.2" N 88° 45' 52.7" W | 71.0 m.a.s.l.	
COMMENTS	Cracks in the concrete, root ingrowth, sand sediments,	
SURROUNDINGS	Sugar cane plantations with use of fertilizer	
DATE OF MEASUREMENT	**2015**	**2016**
	17.06.2015	10.03.2016
DISCHARGE	0.9 l/s	No measurement
WATER TEMPERATURE	29.5 °C	29.2 °C
CONDUCTIVITY	329 µS/cm	337 µS/cm
PH	7.5	7.5

Table 36: Date Trinidad Well[30]

NAME	TRINIDAD - WELL	
MANAGEMENT	Trinidad Water board	
WATER SOURCE	Well (constructed in 2007 by NGOs)	
DETAILS	83m deep water level at 35m (at time of construction at 18m)	
WATER SUPPLY	5 communities: Milagro de Dios 2, El Playon, Santa Teresa 1, Santa Teresa 2, Progresso	
USERS	1290 (187+181+487+435)	
WATER TREATMENT	Chlorination	
WATER STORAGE	No water storage	
WATER DISTRIBUTION	Distribution by pump	
WATER ANALYSIS	Analysis by Laboratorio ProVida	
OTHER WATER SOURCES	No information gathered	
WATER SERVICE FEES	US$4/household/month for 20m³	
COORDINATES	13° 26' 34.3" N 88° 45' 14.5" W | 30.2 m.a.s.l.	
COMMENTS	estimated illegal consumption: US$ 300 - 500 /month; regular checks for leaks, immediate repairs	
DATE OF MEASUREMENT	**2015**	**2016**
	22.04.2015	11.03.2016
DISCHARGE	No measurement	No measurement
WATER TEMPERATURE	32.4 °C	31.5 °C
CONDUCTIVITY	336 µS/cm	341 µS/cm
PH	7.5	7.5

[29] Adapted and further extended from (Schaidreiter, 2016)
[30] Adapted and further extended from (Schaidreiter, 2016)

Table 37: Data Porrillito Well

NAME	**PORRILLITO - WELL**	
MANAGEMENT	Water Board Porrillito	
WATER SOURCE	Well (constructed by Living Water)	
WATER SUPPLY	Community Porrillito	
POPULATION	193	
WATER TREATMENT	No information gathered	
WATER STORAGE	No water storage	
WATER DISTRIBUTION	Handpump	
WATER ANALYSIS	No information gathered	
OTHER WATER SOURCES	No information gathered	
WATER SERVICE FEES	No information gathered	
COORDINATES	13° 27' 57.9" N 88° 47' 17.1" W | 76.7 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.03.2016
DISCHARGE		No measurement
WATER TEMPERATURE		30.8 °C
CONDUCTIVITY		297 µS/cm
PH		8

Table 38: Data Noventa y Dos Well and Tank

NAME	**NOVENTA Y DOS - WELL**	
MANAGEMENT	ANDA	
WATER SOURCE	Well (constructed in 2013 by ANDA, AECID)	
WATER SUPPLY	12 communities: San Jose Porrillio 2, Buenavista, Noventa y uno, Noventa y Dos, El Cristal, San Luis los Altos, San Luis las Posadas, La Quinta, San Pedro El Gavilon, Cruzadilla de Vaqueranos, El Mojon, El Platanar	
POPULATION	1992(227+76+115+274+465+252+96+64+242+181)	
WATER TREATMENT	Chlorination	
WATER STORAGE	Elevated Water Storage Tank	
WATER DISTRIBUTION	No information gathered	
WATER ANALYSIS	No information gathered	
OTHER WATER SOURCES	No information gathered	
WATER SERVICE FEES	No information gathered	
COORDINATES	13° 26' 18.8" N 88° 46' 45.9" W | 33.3 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
DISCHARGE	Measurement only possible at storage tank	
WATER TEMPERATURE		
CONDUCTIVITY		
PH		

	NOVENTA Y DOS - TANK	
MANAGEMENT	ANDA	
WATER SOURCE	Spring Noventa y Dos	
COORDINATES	13° 26' 18.4" N 88° 46' 45.8" W | 35.3 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.03.2016
DISCHARGE		No measurement
WATER TEMPERATURE		32 °C
CONDUCTIVITY		262 µS/cm
PH		7

Table 39: Data Santa Fé Well and Tank[31]

NAME	SANTA FÉ - WELL	
MANAGEMENT	Water board Santa Fé	
WATER SOURCE	Well (constructed in 2001)	
DETAILS	90m deep water level 36m	
WATER SUPPLY	Community Santa Fé	
POPULATION	420	
WATER TREATMENT	Chlorination	
WATER STORAGE	Ground level storage tank	
WATER DISTRIBUTION	Distribution by pump (3h/day)	
WATER ANALYSIS	No information gathered	
OTHER WATER SOURCES	No information gathered	
WATER SERVICE FEES	Water meters non-functioning	
COORDINATES	13° 26' 14.9" N 88° 45' 29.8" W | - m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.03.2016
DISCHARGE		No measurement
WATER TEMPERATURE		31.8 °C
CONDUCTIVITY		307 µS/cm
PH		7.5

	SANTA FÉ TANK	
MANAGEMENT	Water Board Santa Fe	
WATER SOURCE	Spring Santa Fe	
WATER SUPPLY	Community Santa Fe	
POPULATION	420	
WATER TREATMENT	Chlorination	
COORDINATES	13° 26' 14.9" N 88° 45' 30.0" W | - m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.03.2016
DISCHARGE		No measurement
WATER TEMPERATURE		33.3 °C
CONDUCTIVITY		311 µS/cm
PH		7.5

[31] Adapted and further extended from (Schaidreiter, 2016)

Table 40: Data El Milagro Spring and Tank[32]

NAME	EL MILAGRO - SPRING	
MANAGEMENT	Water board El Milagro, ADESCO	
WATER SOURCE	Spring	
WATER SUPPLY	Community El Milagro	
POPULATION	482	
WATER TREATMENT	Chlorination	
WATER STORAGE	1 Elevated Storage Tank (25m²)	
WATER DISTRIBUTION	Ditribution by pump (1 pump, 1.6 kW)	
WATER ANALYSIS	No regular water analysis	
OTHER WATER SOURCES	Domestic wells	
	Small springs along the river Angulo	
WATER SERVICE FEES	US$3.00/15m³/household/month; additional: US$0.15/m³ water meters at all households	
COORDINATES	13° 31' 02.1" N 88° 48' 17.9" W | 237.1 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	17.04.2015	11.04.2016
DISCHARGE	0.84 l/s	0.84 l/s
WATER TEMPERATURE	28.5 °C	28.5 °C
CONDUCTIVITY	247 µS/cm	256 µS/cm
PH	7.5	7

	EL MILAGRO TANK	
MANAGEMENT	Water board El Milagro, ADESCO	
WATER SUPPLY	Community El Milagro	
POPULATION	482	
CAPACITY	25 m³	
COORDINATES	13° 31' 13.2" N 88° 48' 20.2" W | 259.3 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	11.04.2016
DISCHARGE		Empty at time of measurement
WATER TEMPERATURE		
CONDUCTIVITY		
PH		

32 Adapted and further extended from (Schaidreiter, 2016)

Table 41: Data San Francisco-Angulo Tank[33]

NAME	SAN FRANCISCO ANGULO - TANK	
MANAGEMENT	Water Board San Francisco Angulo	
WATER SOURCE	Spring	
CONSTRUCTION	2012	
WATER SUPPLY	2 communities: San Francisco Angulo, Cantarrana	
POPULATION	426 (299+127)	
WATER TREATMENT	Distribution by pump	
WATER STORAGE	1 Ground Level Storage Tank (2100L)	
CAPACITY	2.1 m³	
WATER DISTRIBUTION	No chlorination	
WATER ANALYSIS	No regular analysis	
OTHER WATER SOURCES	Springs with sufficient discharge in surrounding area	
WATER SERVICE FEES	US$3.00/15m³/household/month; additional: $0.20/1m³	
	water metering applied	
COORDINATES	13° 30' 50.2" N 88° 48' 24.0" W | 228 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	21.04.2015	13.04.2016
DISCHARGE	1.7 l/s	1.13 l/s
WATER TEMPERATURE	29.6 °C	No measurement
CONDUCTIVITY	254 µS/cm	285 µS/cm
PH	7	8.5

Table 42: Data San José Llano Grande 1 Spring

NAME	SAN JOSÉ LLANO GRANDE 1 SPRING	
MANAGEMENT	Water Board San Jose Llano Grande	
WATER SOURCE	Spring	
WATER SUPPLY	Community San Jose Llano Grande 1	
POPULATION	263	
WATER TREATMENT	No information gathered	
WATER STORAGE	No information gathered	
WATER DISTRIBUTION	No information gathered	
WATER ANALYSIS	No information gathered	
OTHER WATER SOURCES	No information gathered	
WATER SERVICE FEES	No information gathered	
COORDINATES	13° 31' 50.6" N 88° 47' 14.6" W | 248.2 m.a.s.l.	
COMMENTS	Many roots in the spring capture	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	No measurement
DISCHARGE		No measurement
WATER TEMPERATURE		32.8 °C
CONDUCTIVITY		364 µS/cm
PH		7

[33] Adapted and extended from (Schaidreiter, 2016)

Table 43: Data San José Llano Grande 2 Spring[34]

NAME	WATER BOARD SAN JOSÉ LLANO GRANDE 2 - SPRING	
MANAGEMENT	Water Board San José Llano Grande 2	
WATER SOURCE	Spring (constructed in 2013, by Solidar Suiza)	
WATER SUPPLY	Community San José Llano Grande 2	
USERS	65 families	
WATER TREATMENT	Chlorination	
WATER STORAGE	1 Elevated Storage Tanks (3400L) Distribution	
WATER DISTRIBUTION	Distribution by gravity	
WATER ANALYSIS	Free chlorine residual measured by Water Board every 15 days	
OTHER WATER SOURCES	5 wells for irrigation within community, small springs in surrounding area	
WATER SERVICE FEES	US$1.50/15m³/month water metering	
COORDINATES	13° 31' 18.3" N 88° 47' 22.8" W | 232.3 m.a.s.l.	
COMMENTS	often no water in the afternoon	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	26.02.2016
DISCHARGE		5.44 l/s
WATER TEMPERATURE		27.1 °C
CONDUCTIVITY		236 µS/cm
PH		7.5

Table 44: Data El Puente - Well

NAME	EL PUENTE - WELL	
MANAGEMENT	No information gathered	
WATER SOURCE	Well (constructed in 2016 by Living Water)	
WATER SUPPLY	Comunity El Puente	
POPULATION	167	
WATER TREATMENT	No information gathered	
WATER STORAGE	No information gathered	
WATER DISTRIBUTION	Handpump	
WATER ANALYSIS	No information gathered	
OTHER WATER SOURCES	No information gathered	
WATER SERVICE FEES	No information gathered	
COORDINATES	13° 30' 51.2" N 88° 49' 0.4" W | 219.7 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	14.04.2016
DISCHARGE		No measurement
WATER TEMPERATURE		No measurement
CONDUCTIVITY		425 µS/cm
PH		8

[34] Adapted and further extended from (Schaidreiter, 2016)

Table 45: Data Madre Tierra Spring and Tank

NAME	**MADRE TIERRA - SPRING**	
MANAGEMENT	Water Board Madre Tierra	
WATER SOURCE	Spring	
WATER SUPPLY	Community Madre Tierra	
POPULATION	147	
WATER TREATMENT	No information gathered	
WATER STORAGE	No information gathered	
WATER DISTRIBUTION	No information gathered	
WATER ANALYSIS	No information gathered	
OTHER WATER SOURCES	No information gathered	
WATER SERVICE FEES	No information gathered	
COORDINATES	13° 30' 24.9" N 88° 45' 38.5" W | 163.1 m.a.s.l.	
COMMENTS	Spring capture totally overgrown, risk of root growth inside	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	14.04.2016
DISCHARGE		No measurement
WATER TEMPERATURE		25 °C
CONDUCTIVITY		366 µS/cm
PH		8
	MADRE TIERRA TANK	
MANAGEMENT	Water Board Madre Tierra	
WATER SOURCE	Spring Madre Tierra	
WATER SUPPLY	Community Madre Tierra	
POPULATION	147	
COORDINATES	13° 30' 20.0" N 88° 45' 55.2" W | 153.2 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	No measurement	14.04.2016
DISCHARGE		1.12 l/s
WATER TEMPERATURE		25 °C
CONDUCTIVITY		366 µS/cm
PH		7.5

Table 46: Data El Casino Spring and Tank[35]

NAME	EL CASINO - SPRING	
MANAGEMENT	Water Board El Casino	
WATER SOURCE	Spring (constructed in 1994, by the EU)	
WATER SUPPLY	Community El Casino	
POPULATION	175	
WATER TREATMENT	Chlorination	
WATER STORAGE	1 Ground Level Storage Tank	
WATER DISTRIBUTION	Distribution by gravity	
WATER ANALYSIS	No regular analysis	
OTHER WATER SOURCES	Other springs in the surrounding area of spring capture	
WATER SERVICE FEES	US$1.00/household/month	
	No limitation, no water metering applied	
COORDINATES	13° 29' 24.5" N 88° 46' 56.0" W | 119.6 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	28.05.2015	18.04.2016
DISCHARGE	1.17 l/s	No measurement
WATER TEMPERATURE	28.7 °C	No measurement
CONDUCTIVITY	332 µS/cm	374 µS/cm
PH	7.5	7

	EL CASINO TANK	
MANAGEMENT	Water Board El Casino	
WATER SOURCE	El Casino	
CONSTRUCTION	1994	
WATER SUPPLY	Community El Casino	
POPULATION	175	
CAPACITY	16.5 m³	
COORDINATES	13° 28' 52.4" N 88° 46' 35.8" W | 103.9 m.a.s.l.	
DATE OF MEASUREMENT	**2015**	**2016**
	28.05.2015	18.04.2016
DISCHARGE	No measurement	0.4 l/s
WATER TEMPERATURE	29.8°C	No measurement
CONDUCTIVITY	330 µS/cm	396 µS/cm
PH	7.5	7

[35] Adapted and further extended from (Schaidreiter, 2016)

8.2 Household survey questions

NOMBRE DEL BENEFICIARIO	
Número	**Zona**

1) Información tecnica

1) Hay un medidor?

☐ SI

☐ NO

NÚMERO DEL MEDIDOR:	
Lectura actual:	
Por qué no?	
Desde cuando no hay?	
Como se cobra?	

2) Funciona?

☐ SI

☐ NO

Desde hace cuanto tiempo?	
Como se cobra?	

3) Está instalado de la manera horizontal?

☐ SI

☐ NO

Como?	

4) Hay otro tipo de suministro de agua?

☐ SI

Cual/Qué tipo?	
Donde esta?	
Para qué?	
Cuanto tiempo?	

☐ NO

5) Hay un tipo de almacenamiento de agua(tanque)?

☐ SI

Cual/Qué tipo?	
Donde esta?	
Cual es el volumen?	
Como se llena?	
Como se cierra?	
Tiene una bomba?	

☐ NO

2) Información de la casa

6) Cuantas personas viven en la casa:

No de adultos	
No. de niños	

7) Hay uso de agua para:

	SI	NO
Jardín	☐	☐
Animales	☐	☐
Agricultura	☐	☐

3) Información del agua

8) De que horas a que horas tienen agua?

Ahora	
En Verano	
En Invierno	

9) Cuanto pagan normalmente por mes?

10) Estan contentos con el sistema del abastecemiento del agua?

☐ SI

☐ NO

11) Estarían dispuestos a colaborar en mejorar el sistema?

☐ SI ☐ Trabajo

☐ Dinero:

☐ NO

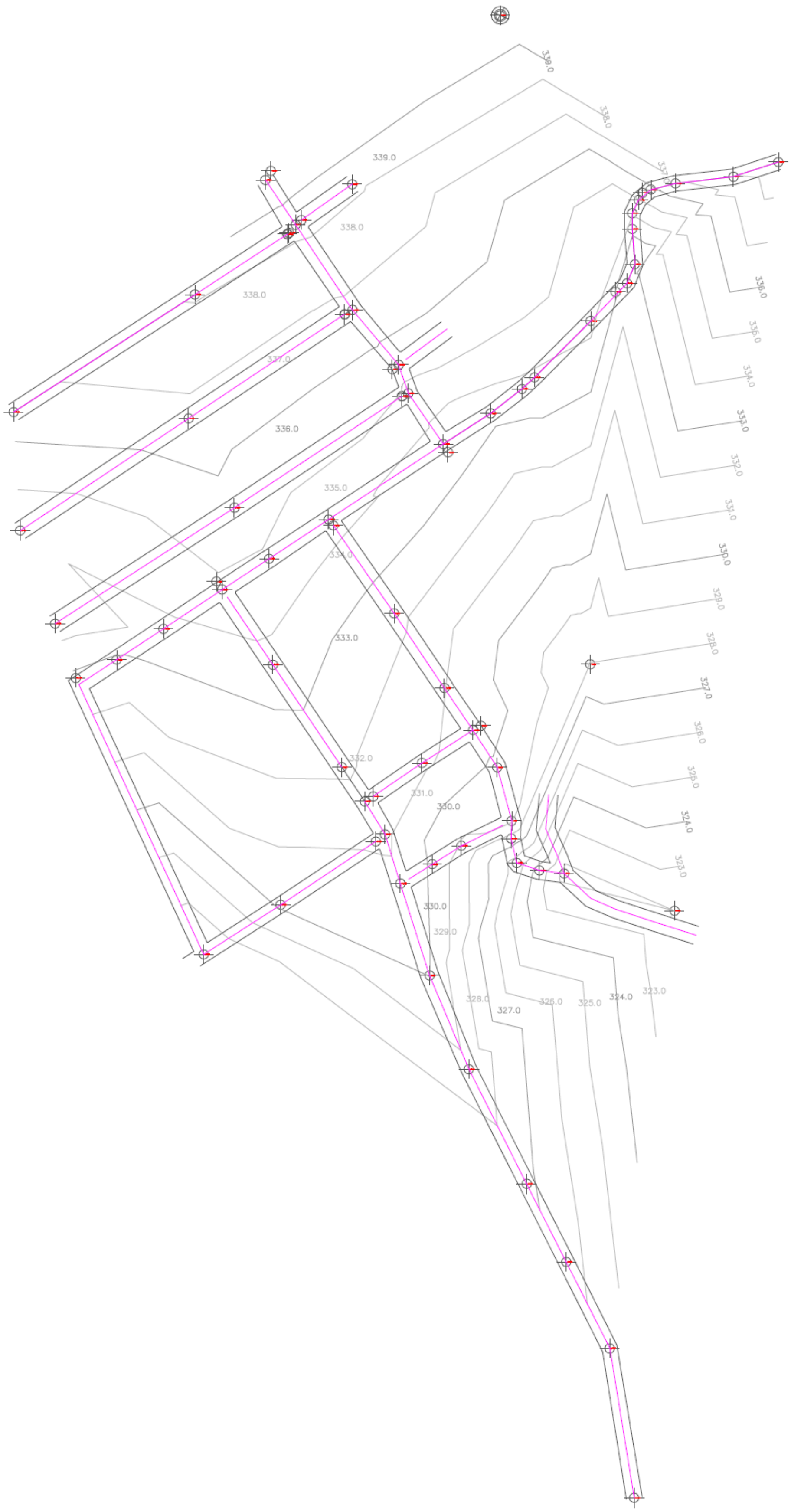
12) Para que usan el agua?

	SI	NO
Tomar/Cocinar	☐	☐
Bañar	☐	☐
Lavar Ropa	☐	☐
Limpiar Casa	☐	☐
Regar	☐	☐
Animales	☐	☐

13) Acceso al agua

No. de grifos	
No. de duchas	
No. de banos	

8.3 Topographic map of El Milagro



Affirmation

I certify, that the master thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Vienna, Austria on 2nd of November, 2018 *Marion Liemberger, MSc*