Social and Ecological Interactions in the Galapagos Islands

Amanda L. Thompson
Valeria Ochoa-Herrera
Enrique Teran *Editors*

Water, Food and Human Health in the Galapagos, Ecuador

"A Little World Within Itself"

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Social and Ecological Interactions in the Galapagos Islands

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The Galapagos Islands are a "living laboratory" for the study of evolution, environmental change, and conflicts between nature and society. Free of human predators for almost all its history, these islands have developed some of the most unique life forms on the planet, adapted to their harsh surroundings and living in ecological isolation. It was not until Charles Darwin's famous visit in 1835, which helped inspire the theory of evolution that this Archipelago began to receive international recognition. The Galapagos Archipelago encompasses 11 large and 200 small islands totaling approximately 8,010 sq. km. This series will focus on the entire island archipelago, and it will emphasize the study and documentation of human-environment interactions on the four inhabited islands in the Galapagos: Isabela, Santa Cruz, San Cristobal, and Floreana. Together they constitute a well-defined "natural laboratory" for the study of human-environment interactions as they vary in fundamentally important ways.

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ISSN 2195-1055 ISSN 2195-1063 (electronic)
Social and Ecological Interactions in the Galapagos Islands
ISBN 978-3-030-92410-2 ISBN 978-3-030-92411-9 (eBook)
https://doi.org/10.1007/978-3-030-92411-9

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Cover illustration: The image shows the deck of a barge delivering supplies to San Cristobal, Galapagos. Beth N.H. Katz, 2011

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Preface

Tourism and migration have ignited economic growth, environmental change, and urban development on the Galapagos Islands. While much research has examined the impact of population and economic growth on the health and biodiversity of the islands' plants and animals, the impacts on human health and well-being have not received as much widespread attention. Yet, these social and economic changes have transformed human health, nutrition, and well-being on the islands as well. The geographic isolation of the islands impacts the quantity and quality of available food, the range of healthcare services available, and the mental health and well-being of island residents. In addition, climate change and the current COVID-19 pandemic are important challenges that the population of the Galapagos islands are facing and could have a major impact on the health and economy of the islands in the short and long term. Therefore, the development and implementation of adaptative measures together with improved infrastructure are essential to assure the sustainability of this fragile ecosystem. As Charles Darwin in his book *Origin of Species* offered a compelling answer to the outstanding question of biology, which was "how life on earth had evolved," the ultimate goal of this book is to put in perspective the human health-related topics that can be addressed in the Galapagos Archipelago and to inspire further analysis.

In this book, we bring together interdisciplinary scholars and clinicians in medicine, public health, anthropology, nutrition, environmental sciences and engineering, and geography from several institutions in different countries, all doing research in the Galapagos Archipelago. Together, these authors provide a comprehensive description of the factors shaping water quality, food availability, and health services on the islands, the interactions between human health and the health of animals and the environment, the implications of these factors for human health and well-being, and potential avenues for intervention.

The volume has four key parts and several chapters within each: Part I, "The Water Environment", has chapters that include water security and supply, water quality and access, climate change and its impacts, and the current COVID-19 pandemic. Part II, "The Food Environment", includes chapters on how water and food insecurity impact the dual burden of diseases, how poor diet quality and processed

food consumption contribute to overweight and obesity, and how the spatial distribution of food resources may shape household decision making around diet. Part III, “The Environment, Animals and Human Health”, includes several chapters on One Health, which links humans, animals, and the environment, the “Galapagos Paradox,” antibiotic resistance among humans and animals, and how human development may compromise wildlife and the environment. Part IV, “Health Problems and Services”, includes a chapter on the first 1000 days of life (pregnancy through the infant's second birthday); how Galapagos may be a unique setting for HIV/STI infections, based on island networks and tourism; a chapter that explores the “lived experience” of residents who experience type 2 diabetes; a chapter on health-seeking behavior to understand the underutilization of the new hospital and its services; and another on how academia and the Ministry of Health worked together through professional development of hospital staff and the engagement of the community to improve health services.

Finally, we would like to thank the many people who have made human health research and this volume possible. In particular, we would like to thank Steve Walsh and Carlos Mena for their continued support throughout this project. We also thank the faculty and staff of the Galapagos Science Center, the Center for Galapagos Studies, GAIAS, all the volunteers for their contributions to field work in the Galapagos, and to the research assistants for their support in the different laboratories. Most importantly, we would like to thank the local authorities and the residents of the Galapagos Islands for their participation.

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Chapter 1
Introduction

Margaret E. Bentley and Jaime Ocampo

Abstract While much research has examined the impact of population and economic growth on the health and biodiversity of the islands' plants and animals over several decades, the impacts on human health and well-being have not received as much widespread attention. Social and economic changes have transformed the environment of the islands with important consequences for human health and well-being. As this chapter describes, population growth, tourism, and limited infrastructure pose health challenges for island residents, who experience high levels of chronic and infectious illnesses. The geographic isolation of the islands also places constraints on the health services available. This chapter provides an overview of human health research on the islands, a discussion of the history of the health system, and a description of current collaborative initiatives to improve human health. This overview highlights the need for interdisciplinary research teams to work alongside community members to identify programs and policies that can help to improve human well-being while preserving this unique and important world heritage site.

Keywords Health services · Human population · Health · Tourism · Dual burden of disease

This volume on human health in the Galapagos Islands reflects the evolution of more than 10 years of research in the archipelago. While several publications are

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A. L. Thompson et al. (eds.), *Water, Food and Human Health in the Galapagos, Ecuador*, Social and Ecological Interactions in the Galapagos Islands,
https://doi.org/10.1007/978-3-030-92411-9_1

already in the literature on this topic by some of the authors in this volume, the book represents new research completed in the last few years across a broad set of topics related to water, food, and human health. The authors are faculty, students, and staff from the University of North Carolina at Chapel Hill and the Universidad San Francisco de Quito, and authors from other universities and staff and the hospital on San Cristobal and the Ministry of Health. These two universities have been collaborating as part of the UNC-USFQ Galapagos Science Center (GSC), on the island of San Cristobal, which was dedicated in 2011 with its own research building, consisting of research offices, laboratories, and educational rooms. The mission of the GSC is to *improve the scientific understanding of the social, terrestrial, and marine sub-systems of the Galapagos; to understand the linkages between the population of the archipelago, its health, and the environment; and to focus on the competing challenges of conservation and economic development.* The GSC is situated right next to USFQ's international training and educational school (a satellite campus of USFQ), the Galapagos Academic Institute for the Arts and Sciences (GAIAS). Students and faculty from the two universities and around the world participate in research related to population, health, and the environment, and several short-term and study abroad opportunities exist for the students and faculty.

The Galapagos, consisting of 14 islands, is a part of Ecuador, located nearly 1000 km off the coast of the mainland. One may see this book title and ask, "Why Galapagos? Do people live there?" Indeed, one of the first studies on human health, published as part of the first book in the Springer series, was titled "People live here: Maternal and Child Health on Isla Isabela, Galapagos" (Page et al. 2013). The UNC authors who led this small study were asked this question repeatedly, hence the title of their chapter.

So, what do people think about when they think of the Galapagos? Why, Charles Darwin of course. This is where he stepped off the ship HMS Beagle in 1835 and whose collections of flora and fauna led to the theory of evolution, which was published in 1851 (Barlow 1935). The islands were then a stopping point for pirates and other sailing ships, such as whaling ships, nearly decimating the highland tortoises and Galapagos sea turtles, because they could be turned on their backs and would survive for months and provide a food source for the sailors (Bassett 2009). Many other species were left to evolve as distinct species without human settlements or disruption, except by changes in climate and the warming and cooling temperatures of the Pacific Ocean surrounding the archipelago.

A small influx of migrants began settling on small farms and establishing a fisheries industry in the late 1800s, coming primarily from Scandinavia and Europe (Quiroga 2013). With them they brought animals for husbandry, such as goats and cattle, and the promise of prosperity. Soon, blackberry bushes and guava trees were planted, and these and others became invasive species that still threaten the environment and survival of some of the native species.

The four habitable and populated islands are Isabela, at the westernmost part of the archipelago; Santa Cruz, where the population is currently by far the largest; San Cristobal, the government seat and easternmost island; and Floreana, with a very small population but a dramatic history (Instituto Nacional de Estadistica y Censos 2015). Satellite imagery of the most populated island, Santa Cruz, tells the story

over the last five decades (Pizzitutti et al. 2020). In 1974, the resident population on Santa Cruz was 1577, which grew to 11,000 in 2007. In 2018, there were more than 28,000 residents in the Galapagos, living on the four populated islands, primarily along the coasts but also in the highlands (Instituto Nacional de Estadistica y Censos 2015). Although tourists with private boats and yachts occasionally stopped in the Galapagos over the decades, tourism did not begin in earnest until the 1980s. Residents migrated primarily from coastal and highland Ecuador to work in the tourism industry, where livelihoods are better than the mainland. Tourism has supplanted fishing as a major driver of population growth and the economy (Hoyman and McCall 2013). The government of Ecuador and the Galapagos National Park do restrict migration and tourism; more than 97% of the island is protected by the Galapagos National Park, and tourists are not free to roam anywhere and they must have certified guides (Wolford et al. 2013). However, tension between conservation and economic development remains one of the most political and challenging issues facing preservation of the archipelago.

In 2015, more than 225,000 national and international tourists visited the islands, primarily arriving by air from the mainland to the most populated island, Santa Cruz, and, to a lesser extent, a smaller airport on San Cristobal Island (Izurieta 2015). The majority cruise around on small and medium boats and yachts and on large cruise ships, while others stay in small hotels. This influx of tourists places great pressure on the islands to meet the needs of both residents and visitors. With the population of the Galapagos nearly quadrupling in the past decade and the exponential growth of tourism, there is a substantial strain on available water and food resources (Hoyman and McCall 2013). Water and sanitation services have not been able to keep up with the demands placed on the system by expanding urban development and the tourism industry. Island residents are concerned about the quality of municipal water and often resort to buying expensive bottled water for drinking and cooking (Page et al. 2013). Food availability, particularly the availability of fresh foods, is also a critical issue. The designation of most of the island as parkland limits the amount of food that can be grown in the highlands, leaving residents and visitors dependent on food shipped from the mainland by sea and, to a lesser extent, air. The distance of the islands from the mainland means that produce arriving by barge is not fresh (Page et al. 2013; Pera et al. 2019). Residents tend to rely on more heavily processed foods, which are also viewed as less expensive. This combination of exposure to environmental pathogens through unclean water and high-energy, high-fat diets contributes to a dual burden of disease on the islands, with infections persisting alongside micronutrient deficiency and overweight and obesity rates among children and adults that are the highest in Ecuador (Freire et al. 2018; Thompson et al. 2019). Accompanying these are noncommunicable diseases (NCDs), such as diabetes, cardiovascular disease (CVD), and hypertension. Reproductive health issues are also a major concern, with gynecological infections, and requirements for adequate and timely antenatal, birth, delivery, and postpartum care (Page et al. 2013). Prior research by the team has documented substantial rates of anxiety, stress, and depression, particularly among women, who experience isolation living

far from the mainland (Page et al. 2013). A substantial proportion of women also experience domestic violence often related to alcohol abuse, particularly among males.

What is the history and current situation of the health system and services on the islands, in light of these known health issues?

Historically, since Galapagos was inhabited by national and international settlers, the region's medical system has not been constant nor has it been of good quality, which has put the population's well-being at risk, especially that of children and pregnant women. The prevalence of diseases such as upper respiratory and intestinal infections and influenza, among others, is similar to that in continental Ecuador. However, throughout the Galapagos Archipielago, as noted above, there is a high prevalence of metabolic syndrome and its consequences such as overweight, hypertension, diabetes, and cardiovascular diseases.

The Ministry of Health has been in the Galapagos since the 1960s implementing medical units for ambulatory care. At the beginning of the 1970s, in cooperation between the Ministry of Health and an order of priests, the Oskar Jandl Hospital was founded on San Cristobal Island. The physical structure of the hospital was always deficient with scarce or null technology, medicines and medical supplies, and very limited quality care from doctors. The medical professionals and nurses were mostly general practitioners, young professionals with very little experience and no specialty. Specialists, such as pediatricians or gynecologists, visited the islands a few times a month. These many limitations encouraged residents to incur high expenses and travel the mainland to seek medical help. Private medicine, although it exists in the islands, is very limited due to lack of supplies.

In the past 10 years, a new hospital was constructed on San Cristobal, and it has improved with new technology, some permanent specialists, permanent emergency care, and better trained doctors. Despite these improvements, some of the population are reluctant to use the hospital's services due to a lack of trust of Cuban doctors, who were hired by the Ministry of Health. In 2014, a cooperation agreement was signed between Oskar Jandl Hospital, Universidad San Francisco de Quito, and the University of North Carolina at Chapel Hill to complement the medical activities that nurses and physicians perform daily. The cooperation agreement has three parts:

Training: This part of the agreement supposed that both universities are able to develop training plans in professional aspect that doctors and nurses from the hospital need to improve. For example, since 2014, the UNC School of Nursing has sent a group of nursing faculty and advanced graduate students fluent in Spanish each summer to cooperate with local nurses for developing protocols in the emergency room, hospitalization, and pediatric intensive care units. In addition, there are training resources for hospital administrators in leadership and hospital and financial management.

Telemedicine: This section of the agreement is directed to develop a "second opinions" model in different specialties that do not exist in the island. For example, dermatologists, radiologists, cardiologists, and gastroenterologists from the USFQ Medical System advise local doctors in how to handle some diseases and conditions. During the time of the cooperation with the hospital, more than 400 cases were discussed between physicians of both institutions through telemedicine.

Research: This section of the agreement is to increase knowledge of important determinants of health in the islands, for the purpose of addressing community health needs. For example, researchers for both universities and local professionals from the hospital investigate the supply, quality, and access to water. In addition, studies about nutrition and breastfeeding have been performed as described in this volume.

1.1 Conclusion

While much research has examined the impact of population and economic growth on the health and biodiversity of the islands' plants and animals over several decades, the impacts on human health and well-being have not received as much widespread attention. Yet, these social and economic changes have transformed the environment, human health, nutrition, and well-being on the islands as well. The geographic isolation of the islands impacts the range of health care services available. While the islands are served by two hospitals, a small one on Santa Cruz and a larger, more modern hospital on San Cristobal, residents continue to worry about the lack of specialists to manage health emergencies or ongoing chronic conditions. Residents report spending considerable amounts of money to travel to the mainland for health care. The sense of isolation also impacts mental health and well-being. Mothers of young children often suffer from depressive symptoms, and substance abuse is also relatively common among men. Despite these considerable challenges, the majority of residents perceive their quality of life on the islands to be fair to good. Economic development and tourism have brought about a standard of living and education higher than that on the mainland. Rates of unemployment are low and literacy high.

It is clear that the Galapagos Islands *are* a "little world within itself" and are a perfect laboratory for research on human health and the environment – and how their interrelationships affect outcomes. This research is well underway, and we hope this volume and the publications that came before it will generate interest in future research. This should include interdisciplinary teams for implementing intervention research that will lead to community engagement and programs and policy that can help to preserve this unique and important world heritage site.

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Part I
Water Environment

Chapter 2
Analysis of Water Supply and Demand Management Strategies in Overcoming Water Scarcity in Santa Cruz

Maria Fernandes Reyes

Abstract Water resources in the Galapagos Islands have been severely strained by exponential increase in tourist visitors. Santa Cruz Island, the main tourism hub in the Galapagos, is facing significant challenges of too many people and not enough available water. There are no permanent freshwater resources on this island, and the municipal water supply system provides only (untreated) brackish water, intermittently.

In view of the scarce data found on water demand, this study involved extensive fieldwork with the aim of generating water-consumption figures from different types of premises (common households, hotels, restaurants and laundries), in order to assess current water demand. Several methodologies were used including 400 surveys and the installation of water meters, aiming to quantify water figures. The study quantified water demand from different categories and sources of water using several methodologies as means to create mitigation options regarding the fragility of the ecosystem.

Results indicated that domestic water demand varies between 163 and 428 litres per capita per day (lpcpd), which is extremely high for such a water-scarce island. Also, total water supply, without taking into account any losses, suggests around 350 lpcpd, which is also a high figure considering water scarcity threats in Santa Cruz Island. The results also suggest the that the presence of non-registered tourist accommodations or excessive water wastage from domestic premises is presenting a significant issue in the total water balance, leaving some premises without water.

This study provides scientific insights for the improvement of water resources management and further contributes for the creation of effective policies to preserve these resources.

Keywords Water demand · Water consumption · Water resource management · Tropical insular environment · Tourism

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A. L. Thompson et al. (eds.), *Water, Food and Human Health in the Galapagos, Ecuador*, Social and Ecological Interactions in the Galapagos Islands,
https://doi.org/10.1007/978-3-030-92411-9_2

2.1 The Island of Santa Cruz

Santa Cruz is the main island (economic and tourism centre) of the archipelago and has a surface area of 985 km^2. Brackish water is supplied by the municipality of Santa Cruz to the settlements, where the technical capacities continue to be limited. The biggest town is Puerto Ayora, located on the south coast, followed by the village of Bellavista, located at 180 m of elevation and 7 kms inland (GADMSC 2012a). Puerto Ayora has approximately 12,000 inhabitants (INEC, 2010), holding 61.3% of the total population of the archipelago, and Bellavista has a rural population of approximately 2500 inhabitants. Over the past 10 years, the rate of development in the highlands has been very high.

The population density in Puerto Ayora is the highest in the archipelago, with approximately 80 inhabitants per km^2 (INEC 2010). On the other hand, Bellavista is practically a suburb of Puerto Ayora, and it is a popular part of the island characterized by private properties distinguished by tranquillity and silence. Currently, there are new developments taking place further than Bellavista which cause additional problems, as the public network does not reach there yet.

The main driver for the significant increase in population (from the mainland) over the last years has been to support the tourism industry and to generate income. Consequently, there has been a noteworthy increase in the number of travel agencies, restaurants, hotels, bars, etc., stressing the water resources and environment in general (GADMSC 2012b). The growth in the local population and tourism in Santa Cruz has increased the demand for basic services, such as water supply without concurrent ways to cover the costs of these services, overwhelming the municipalities and so resulting in deficient services and untrained staff (Guyot-Tephiane et al. 2012).

Because of this exponential increase, low-cost hotels have also increased significantly, as well as the number of backpackers. This has also boosted the creation of small private accommodations with no environmental consideration. In addition, more restaurants (also informal) have started, as well as the number of local tourist agencies, offering day tours of occasionally questionable quality. The problem of tourism is further enhanced by the lack of monitoring by the Ministry of Tourism (MINTUR). Consequently, the lack of control and regulation boosts these illegal accommodations. According to the MINTUR, as of December 2013, there were 106 unregistered accommodations out of a total of 159 (Reyes et al. 2017a, b). Moreover, according to the Department of Potable Water and Sewage (DPWS), there are only 40 service connections belonging to the category of hotels (Sarango 2013).

Similarly, the number of laundries has grown as well. However, in the land cadastre of Santa Cruz, there are no premises categorized as laundries, while according to the DPWS, there are only five service connections of this category. An update of the land cadastre is lacking and stricter control over this type of premises regarding operating licenses. It is commonly known that laundries are a profitable business.

The main source of supply in Santa Cruz, which is extracted from the basal aquifer, is non-potable due to high concentration of chlorides (800–1200 mg/L) and is

further distributed without any prior treatment (d'Ozouville and Merlen 2007). In addition, the water is also contaminated with *Escherichia coli*, due to the lack of sewerage system (d'Ozouville et al. 2008). Wastewater is mainly disposed into septic tanks, which are installed individually by each household. It has been identified that most of these septic tanks are not constructed technically, resulting in infiltration to the water sources (Liu and d'Ozouville 2013).

As a consequence of uncontrolled urban growth, the local government councils are blocked of providing a permanent and optimal service to the local population. Furthermore, the water supply is intermittent and rationed, with an average supply of 2–3 h per day (Reyes et al. 2016), which has influenced inhabitants to build their own water storage in the form of cisterns and elevated tanks. Also, there is an excessive water loss in Puerto Ayora, which is caused by aging pipes and lack of maintenance along the distribution system. This problem has further worsened by the lack of water meters in the town of Puerto Ayora, which results in excessive water wastage within the households. This is also a consequence of the lack of water-saving practices or specific policies promoting water conservation in this fragile ecosystem. In addition, there are also financial constraints that contribute to the difficulties faced by the municipality to improve the water service.

On top of this, the lack of communication among different entities and unclear distribution of responsibilities within the institutions regarding water management contribute to the situation (Reyes et al. 2016). Lastly, there is a significant absence of data and information, causing difficulties in the assessment of the current situation and the future planning for the improvement of the water scarcity.

2.2 Quantification of Water Demand

The data for this study were collected from a survey carried out to 374 households in Puerto Ayora and Bellavista. This section reveals the daily average water demand per capita and how it differs between the two settlements, as well as the impact resulting from difference in the water tariff structures. Also, it analyses the type of consumer in the tourist category and how much it accounts of the total water demand within the island.

2.2.1 Research Methodology

In order to assess the water demand in Santa Cruz, a quantitative survey was carried out during the fieldwork conducted from November 2013 to January 2014 in Puerto Ayora and Bellavista. The minimum sample size was calculated based on the total number of land properties according to the 2012 cadastre from the municipality of Santa Cruz. With a total of 2460 properties in Puerto Ayora and 435 properties in Bellavista, the minimum sample size was calculated at 339, by applying the

confidence interval of 95% (DeVault 2014). Next, the actual sample size per consumption category was determined. The surveys were carried out during a period of 6 weeks.

The final version of the domestic survey contained five main parts: (i) general information about the location, (ii) family habits, (iii) water demand (bottled, municipal and/or from trucks), (iv) water-saving practices and (v) sanitation practices.

The surveys for other demand categories were less detailed and contained four groups of questions: (i) general information, (ii) average capacity of customers, (iii) water demand quantification regarding different type of sources and (iv) environmental awareness.

2.2.2 Analyses of Results in Puerto Ayora and Bellavista

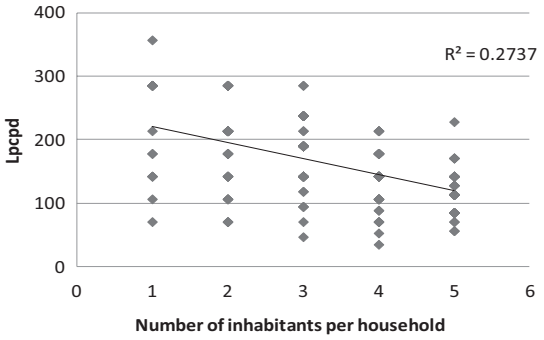
2.2.2.1 The Domestic Category

The results of the survey show several similarities and differences between the two settlements. Firstly, the percentage of connections to the municipal service is higher in Puerto Ayora (91%) than in Bellavista (81%), which could be attributed to the faster growth in the number of households in Bellavista and the consequent inability of the municipality to cope with it. The average annual increase of connections from 2005 to 2013 was approximately 9% in Bellavista, while in Puerto Ayora, it was only 2%. Furthermore, the frequency of service is worse in Bellavista, which differs from the information provided by the municipality, which claims that water is supplied every day.

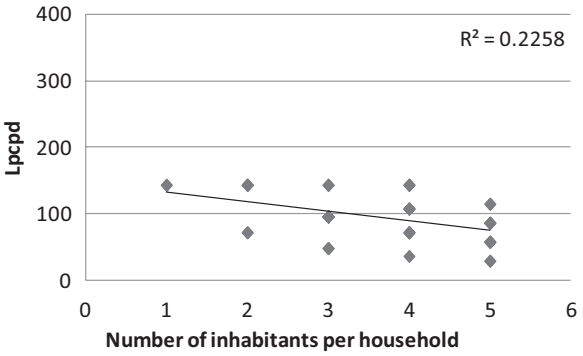
Using the capacity of household storage units (tanks or cisterns), the reported frequency of filling these and the number of users per household, an attempt was made to estimate the total water demand from the municipal supply system, as well as the specific demand per capita. This is shown in Fig. 2.1a for Puerto Ayora and in Fig. 2.2b for Bellavista.

From Fig. 2.1, it can be seen that larger households tend to have lower demand per capita. This can be explained by the fact that the water consumption for general activities like watering gardens, cleaning common areas and cooking is independent of the number of occupants. Furthermore, the figures for Puerto Ayora show a wider range of demand for the same number of inhabitants, suggesting diverse water use, probably due to different living standards and/or habits than in Bellavista. The average specific demand and standard deviation for Puerto Ayora is 163 ± 80 lpcpd and in Bellavista is 96 ± 34 lpcpd. This average differs significantly between the two settlements, probably due to different water tariff structures.

Puerto Ayora has fixed water fees per month for different categories established by the municipality. On the other hand, Bellavista has a metered system, with a consumption-based tariff structure (USD 1.21/m^3). As a consequence, the population in Bellavista tends to consume less than in Puerto Ayora. However, they



(a)



(b)

Fig. 2.1 Municipal water demand per capita and number of inhabitants per household in (**a**) Puerto Ayora and (**b**) Bellavista

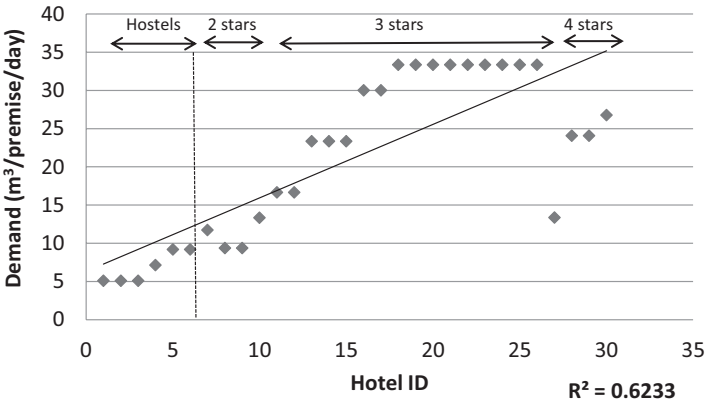


Fig. 2.2 Demand per surveyed hotel regarding rating

supplement their demand with rainwater, increasing the total water demand per capita. In Bellavista, customers are more aware of the value of water, unlike in Puerto Ayora, where higher wastage of water is evident with spilling of tanks. The fixed monthly fees in Puerto Ayora seem to be the main reason for such behaviour. According to the municipality, the biggest losses occur at the moment of filling household storage when faucets are not closed when tanks are full, resulting in significant overflow of water. It was observed during the fieldwork that these overflowing tanks were left unattended for more than half an hour in some cases. Lack of metering and low tariffs in Puerto Ayora appear to encourage the population to waste water. However, some households have shown to use much lower quantities of water than the others, for the same number of occupants, which in broader terms reflects different styles of living and/or habits. The high standard deviation on both settlements suggests that locals use water randomly per household, and there is no obvious tendency regarding social stratum or number of occupants, or the neighbourhood.

A high percentage of responses in Puerto Ayora (32%) identified leaks within their households. Unfortunately, these leaks are rarely fixed, probably due to the fact that the water lost is not charged to the consumer. On the other hand, the leaks within premises in Bellavista are much lower (reported in 15% of responses), meaning that the tariff structure influences the decision to fix them. The majority of leaks were reported to be in old and inefficient toilets, suggesting high losses since toilets account for major water use in a household of nearly 30% of total water consumption (EPA 2012). Finally, the less frequent spilling of individual tanks in Bellavista confirms overall higher awareness of the customers, which can be also explained by the difference in water tariff.

2.2.2.2 Total Demand Quantification for Domestic Sector

The quantification of domestic water demand was done for all types of sources used. This was possible based on the questions regarding the frequency of service/purchase and volumes of the different sources for every household. The results are shown in Table 2.1 with total demand per capita calculated for both settlements.

Table 2.1 Water demand per different sources of water in Santa Cruz

Settlement	Municipal supply (m^3/year)	Bottled water (m^3/year)	Water trucks[a] (m^3/year)	Rainwater[b] (m^3/year)	Total demand (m^3/year)	Approximate population[c] (no. of inhabitants)	Specific demand (lpcpd)
Puerto Ayora	712,188	7243	57,518	N/A*	776,949	12,000	177
Bellavista	82,481	2683	48,307	97,444	30,914	2500	253
Total	794,669	9925	105,825	97,444	1,007,863	15,000	190

Note: [a]Water from trucks refers to partial pumping from 'private' crevices. [b]Rainwater was not considered in Puerto Ayora for it is practised by less than 10% of surveyed households. [c]Based on the last national census carried out in 2010

Table 2.1 indicates relatively high specific demand in view of the widespread intermittency and scarce water sources. The public perception in both settlements is clearly that additional water next to that supplied by the municipality is necessary. Nevertheless, rainwater is barely collected in Puerto Ayora. One reason is lower precipitation levels than in Bellavista, but also that this practice is considered archaic (Guyot-Tephiane et al. 2012). Oppositely, people in Bellavista collect rainwater regularly and use it for all types of household activities. Furthermore, in both settlements, the bottled-desalinated water is used mainly for drinking and for personal hygiene, while brackish groundwater is used for other domestic activities such as cooking, dish washing, laundry, toilet flushing and showers.

Moreover, the supply by water trucks has high contribution to the high total demand in Bellavista, which could be explained by lower number of municipal service connections. In summary, the average per capita consumption is considerably higher in Bellavista than in Puerto Ayora. It is however to be noted that all the results are based on the personal assessments of the respondents; this certainly needs to be verified by more accurate measurements.

2.2.2.3 Analysis of Tourist and Laundry Category

The total demand was also assessed for tourist facilities in Puerto Ayora: private apartments, hotels and restaurants as shown in Table 2.2. The figures have been derived based on the survey questions regarding the volume of storage facilities and the frequency of refilling of storage tanks, as well as the amount of bottled-desalinated water and water supplied by trucks.

Figure 2.2 shows the daily demand of surveyed hotels; the horizontal axis represents each hotel, given by a serial number. For example, from 1 to 6 are hostels with capacity of 25 to 45 people to be accomodated per day, from 7 to 9 are two-star hotels with capacity of 20 to 25 people, from 10 to 26 are three-star hotels with

Table 2.2 Water demand quantification for hotels and restaurants in Puerto Ayora

Type of accommodation	Average capacity (customers)	Municipal water (m^3/day)	Water trucks (m^3/day)	Bottled water (m^3/day)	Specific demand (lpcpd)
Hostel	40	8.1	0	0	205
2-star hotel	35	4.0	12.3	0.1	470
3-star hotel	45	6.0	29.7	0.3	667
4-star hotel	35	9.6	9.0	0.1	535
Average	**38**	**7.0**	**11.3**	**0.1**	**469**
Restaurants	15	0.2	0.9	0.1	126
	25	0.5	1.7	0.1	158
	45	0.4	0.9	0.2	46
	50	0.4	1.8	0.3	79
Average	**34**	**0.4**	**1.3**	**0.2**	**102**

capacity of 10 to 50 people and from 26 to 30 are four-star hotels with capacity of 25 to 50 people. The water demand varies according to the type of accommodation (hotel rating) and the average capacity.

The majority of the hotels and restaurants are connected to the municipal supply, but some hotels (mainly three stars) and virtually all restaurants are mainly supplied by water trucks. The four-star hotels mostly have their own purification systems (by desalination) and are less dependent on the municipal supply, using it less than lower class tourist accommodations do. Moreover, three-star accommodations use more water because of higher occupancy. In Galápagos, the tendency is towards middle-class tourists, therefore, those who cannot afford luxurious accommodations at average rate of 350 USD/night (which seem to be more careful with water use).

The average water demand per bed, estimated by the survey respondents, was 168 lpcpd, which is far from reality, since the calculated average is 469 lpcpd, i.e. almost three times higher. Furthermore, in 10 out of 30 restaurants, the water demand estimate was approximately 0.5 m^3 per day.

Finally, the total water demand for Puerto Ayora was calculated based on the average consumption derived from the survey, multiplied by the total number of premises per category according to the land cadastre of the municipality. Table 2.3 shows the highest demand from the hotels for municipal water and from trucks. Approximately 24% of total demand of municipal water is from unregistered accommodations, which account for 66% of the total in the category of hotels. As in many other tropical islands, the biggest consumers are tourist accommodations, proportionally to the ranking of the hotel. The restaurants and laundries do not contribute significantly to the total demand in Santa Cruz, although the total number of registered restaurants and laundry premises in the land cadastre may be higher than reported.

Table 2.3 Total water demand quantification considering all categories

Category	Municipal supply (m^3/day)	Bottled water (m^3/day)	Water trucks[a] (m^3/day)	Total demand (m^3/day)
Domestic	1951.2	19.8	157.6	2128.6
Hotels	1107.2	20.6	1788.8	2916.6
Restaurants	69.3	7.6	51.1	128.0
Laundries	28.5	0	20.1	48.6
Total	3156.2	48.0	2017.6	5221.8

Note: [a]Water trucks refers to pumping from ‘private’ crevices

2.3 Assessment of Domestic Consumption in Puerto Ayora's Intermittent Supply Network

The intermittent water supply system, which is caused mainly by the lack of proper management and by sensitive political issues (Reyes et al. 2016), promotes a perception that the system is unreliable. The previous sections suggested the average total municipal water demand ranges from 40 lpcpd to 380 lpcpd. The possible subjectivity and uncertainty of some of the responses in the surveys from Sect. 2.2, pointing the extreme ranges of consumption, question the real effectiveness of the intermittent mode of supply in Puerto Ayora, where the estimates of the domestic consumption ranges from 163 to 177 lpcpd ±60 lpcpd.

WMI, a private organization financially supported by the German Cooperation G.I.Z, installed approximately 300 water meters in the period from 2013 to 2015, in three different pilot zones. Pilot Zone 1 (PZ 1), located in the northern part of the town, included 115 installed water meters. The readings took place in the period from August 2013 to June 2015. This zone was chosen by the municipality due to the prevalence of domestic premises. Furthermore, 140 water meters were installed in Pilot Zone 2 (PZ 2), located in the south-western part of the town. The readings in this zone correspond to the period from February 2014 to June 2015. Lastly, Pilot Zone 3 (PZ 3) was designed to cover the two main avenues of the town where most tourist facilities are located (Av. Baltra and Av. Charles Darwin). The readings in this zone were taken from 54 domestic water meters in the period from September 2013 to June 2015. All of these water meters were placed in the distribution network before the individual storage facilities, accounting also for spillage and wastage. The results from these readings indicate average specific demand ranging from 156 lpcpd to 568 lpcpd, for the different pilot zones and the different years.

This section aims to verify the findings of the survey conducted on water demand estimation presented in the previous section, as well as to establish domestic demand patterns using more accurate measurements. Also, it analyses the lack of equity in attempt to find a correlation between the schedules of intermittent distribution applied by the municipality and the water consumption. The preliminary findings showing extreme high figures of consumption raise the question whether the intermittency is really necessary.

2.3.1 Research Methodology

To get more insight and verify the data obtained in previous researches, a fieldwork was carried out from June to August 2015. In collaboration with the municipality, 18 water meters (Flodis-single jet turbine device) were installed in private premises based on their willingness to cooperate and accessibility to install the meters. Figure 2.3 shows the locations of the installed water meters. These were installed on the pipe after the individual storage facility, therefore not accounting for spillage of