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The feasibility of rainwater harvesting systems in Aruba

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CONSULTANCY REPORT

The feasibility of rainwater harvesting systems in Aruba

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1. Integrative executive summary

Aruba faces water scarcity due to its arid climate (Van Sambeek et al., 2000). Freshwater is currently supplied by the desalination plant; however, this method poses sustainability problems. The desalination process has a high carbon footprint, as it is powered by heavy fuel oil (Matos et al., 2024). Additionally, the marine ecosystems that surround the island are impacted negatively by this process (Marchena & Halman, 2018). Furthermore, water security can be compromised when the supply relies only on one water source and been vulnerable to external shocks. Moreover, the cost of water is relatively high (del Campo et al., 2023). To tackle this problem, a consultancy project has been done for Santa Rosa, the local name for the department of Agriculture, Livestock and Fisheries. Their goal is to eventually renounce the reliance on produce imports by increasing awareness about the importance of and supporting local production. One of their already existing services is the distribution of harvested rainwater.

The client strives for more sustainable water use to tackle the challenges mentioned above and to increase the water supply to meet the high demand of water for the farmers reducing and increase the resilience of the water production process. It is aimed to achieve this by integrating rainwater harvesting (RWH) systems in the existing water infrastructure in Aruba. Furthermore, there is interest in using rainwater from Santa Rosa and the general society, as more information on the practice of RWH has been requested from the members of Santa Rosa, and the research has shown positive perspectives within the Aruban community.

However, to date, no publicly available studies on RWH systems in Aruba have been conducted, and only a few studies on this topic have been conducted in similar, semi-arid, regions. This shows the lack of data available on this topic that would help Santa Rosa's goal of implementing RWH. Additionally, this research found that despite interest in RWH systems, there is a lack of awareness regarding the collection of rainwater. Therefore, this research gives practical, informative and feasible advice to Santa Rosa on the future implementation of RWH systems in Aruba. This will give the client an idea of which actions they have to undertake, why these actions are recommended and how they should proceed. Three main advice are given in this report:

1. Improve communication within the community of Aruba
2. Incorporate RWH systems in urban infrastructure, using community-based RWH
3. Combine proper use of natural water ways with the implementation of RWH systems

These recommendations are supported by research findings from two different approaches. Firstly, with a top-down approach, the influence and relevance of various environmental, socio-economic, and political factors on RWH systems implementation at the national level is examined. Secondly, with a bottom-up approach, an identification of the existing RWH practices, evaluation of their effectiveness, and exploration of possibilities for future implementation at the local level is carried out.

2. Integrative and Interdisciplinary Advice

2.1 Integrative Introduction

Aruba, a Caribbean small island state, faces a complex web of intertwined sustainability challenges. Due to the islands' small size, semi-arid climate, and limited freshwater resources, Aruba faces a challenge regarding water security (Van Sambeek et al., 2000). Throughout the year, the Caribbean Island experiences distinct rainy and dry seasons. In the rainy season, a substantial amount of precipitation falls on Aruba, but a significant portion of it typically drains into the sea (Marchena & Halman, 2018). Currently water for all purposes on the island is obtained through seawater desalination by Water- en Energiebedrijf Aruba (WEB), which is a highly energy-dependent process (Matos et al., 2024). However, the single-sourced water supply on the island creates a need to anticipate future challenges that can be caused by climate change. As there is limited groundwater on the island for an additional water supply, other solutions need to be considered, including rainwater.

Rainwater harvesting (RWH) involves the collecting, storage, and utilization of rainwater runoff (Reijtenbagh, 2010). As calculated in the paper by Montoya Rodriguez (2024), the annual amount of rainfall in Aruba is an estimated seven times of the amount of water produced yearly by WEB. This means that the volume of rainfall on the island could supply more than Aruba's own need. Additionally, according to Rahman et al. (2014), RWH is the most sustainable method for water supply. It is however important to note that rainwater is mainly suitable for non-potable uses, due to possible chemical, atmospheric, micro-biological and physical contamination (Van Houselt, 2021; Reijtenbagh, 2010).

The client for this consultancy project is the Department of Agriculture, Livestock, and Fisheries in Aruba (locally called Santa Rosa). Established in 1976 as an experimental governmental initiative, Santa Rosa aims to enhance its services, particularly in the agricultural, livestock, and fishery sectors. Their overarching objective is to increase awareness about the significance of locally produced goods, with the vision of reducing or eliminating the need for importing produce, relying solely on the island's farmers (Santa Rosa, n.d.). Santa Rosa supports farmers with e.g. financial help, various workshops, and distribution of self-harvested rainwater. Despite their notable efforts to harvest rainwater, the volume of water is not large enough for all farmers, creating a need for broader and more efficient RWH systems. Additionally, observations during the research have shown that RWH does not seem to be a common practice in Aruba, as not many houses have rain gutters. Therefore, Santa Rosa's goal is to increase the use of RWH systems in Aruba by integrating RWH with the existing water infrastructure and supply.

However, there is limited understanding how RWH systems can be integrated with the existing water infrastructure, specifically tailored to Aruba's semi-arid climate. This is also caused by the limited availability of data on the quantity and performance on existing RWH systems on the island, making it challenging to assess their effectiveness as well as predict the feasibility of future implementation of RWH system innovations. Additionally, investigating the potential of rainwater harvesting (RWH) systems to address water scarcity challenges in Aruba, it is necessary to elaborate into the dynamics of implementation and adoption across the national and local scale. Hence, the report will be structured in two subchapters, each one giving separate advice. This project's national perspective will investigate the influence and importance of various environmental, socio-economic, and political factors on RWH system

implementation. The local perspective will look at the existing RWH practices, their efficiency and future potential implementation on a small and large scale. The small scale includes individual households or small businesses¹, whereas large scale refers to farms registered with Santa Rosa. Ultimately, the result will be an integration of the findings from the national and local scale. The research approach will be community-based research (CBR), following the principles outlined by Strand (2003). CBR consists of connecting research and the community and has been proven to be effective in multiple studies (Salimi et al., 2012). As the project is based on consultancy, Santa Rosa has functioned as a connector with the community-level.

The overarching question that will be given advice on is: **How and which RWH systems excel in Aruba, considering the impact of environmental, socio-economic, and political factors on the effectiveness of these systems?** Answering this question will assist Santa Rosa in working towards a more sustainable, resilient future regarding water for Aruba. Together with Nathalie Maduro, the director of Santa Rosa, a commitment obligation has been agreed on (personal communication, 2024). This report is the commitment obligation and illustrates the research findings in the format discussed and agreed in the earlier stage of the investigation, giving practical, informative, and feasible advice. The following sub questions will contribute to answering the overarching research question:

Table 1: Research questions and sub questions of both the national and local level.

	National level	Local level
Research question	1. To what extent do environmental, socio-economic, and political factors influence the feasibility of rainwater harvesting (RWH) systems in Aruba?	2. Can business innovations, when integrated with rainwater harvesting systems (RWH), improve the efficiency of the sustainable water supply for stakeholders in Aruba?
Sub-question 1	1.1. How does the identification of climatic and environmental conditions affect possible RWH system implementation?	2.1 What innovations exist in RWH systems and how do they work?
Sub-question 2	1.2. How do societal perceptions and economic dependencies impact RWH system implementation in Aruba?	2.2 How efficient in terms of rainfall use, economic viability as well as ease of implementation and maintenance are these RWH system innovations?
Sub-question 3	1.3 What influence do past, and present water policies and political support	2.3 What is the perspective of the stakeholders, including farmers, small businesses, and households,

¹ Aruba classifies businesses with less than 10 full year equivalent employees as small enterprises (DEACI, 2018).

	<p>have on RWH system implementation?</p>	<p>regarding implementation and adoption of RWH systems and how does this influence current development?</p>
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The structure of this report is as follows: First, the integrative advice will be displayed. Second, the national level introduction, advice, methods, and results will be presented, followed by the same structure for the local level. Third, additional documents and information can be found in the Appendix.

2.2 Integrative Advice

This section answers the overarching question **“How and which RWH systems excel in Aruba, considering the impact of environmental, socio-economic, and political factors on the effectiveness of these systems?”** and provides four advice, each linked from the national and local findings. From previous discussions with Nathalie from Santa Rosa, she shared with us that she aims to advocate for a policy demanding integration of RWH systems to the existing water infrastructure in Aruba. Large buildings disturb the natural infiltration of rainwater into the ground as they cover large areas of nature with cement (Fenner et al., 2018). She suggests that these buildings should offset their water footprint by incorporating RWH systems. This could serve as a buffer during water scarcity, especially in dry seasons, fostering resilience and security for farmers by ensuring a consistent water supply.

Advice 1: Santa Rosa is recommended to improve communication within the community of Aruba

It is advised, before implementing RWH systems, to improve communication and information between Arubans, organizations as well as governmental departments and ministries. For example, by various collaborations between governmental departments or improving farmers’ cohesiveness. *(Advice 1)*

- There is a lack of knowledge among citizens on how to collect rainwater, how to maintain the systems, and how to finance it. *(Argument 1.1)*
 - Aruba’ citizens are partly uncertain about the technology and maintenance of RWH systems, see evidence 3.1.1 of the national level. *(Evidence 1.1.1)*
 - The financing of the collection of rainwater has been one of the most significant barriers for the implementation of RWH, see evidence 3.1.2 of the national level *(Evidence 1.1.2)*
 - The CBA analysis has estimations and lack of monetary values for agroforestry, check dams, and water pit/reservoir, see evidence 3.1.2 of the local level. *(Evidence 1.1.3)*
 - Clear information about costs and benefits is not available for individuals (farmers, households, and small businesses), as stated in interviews. See evidence 3.1.1 of the local level. *(Evidence 1.1.4)*
- The uncertainty about the quality of water makes the Aruban community hesitate about implementing RWH. The lack of shared data keeps the public uncertain. *(Argument 1.2)*
 - The interview with a governmental department affirmed that there is data on the water quality of the dams in Aruba but that it is not publicly available (I7N, personal communication, April 2, 2024). *(Evidence 1.2.1)*

- A farmer's organization representative mentioned that the dams are visibly polluted, "There's so much oil on the first surface, so you can physically see it" (I4N, personal communication, March 27, 20224). (*Evidence 1.2.2*)
- A farmer mentioned how farmers that collaborate with the hotel sector are not allowed to use water from the dams, due to its unknown quality (I2N, personal communication, March 26, 2024). (*Evidence 1.2.3*)
- Communication issues arise due to the lack of communication between different scales. There is interest for RWH in the Aruban population, but it does not reach higher scales such as the government. Between the government departments the communication is also low, similarly between individual Arubans. (*Argument 1.3*)
 - The lack of communication prevents the Aruban community and government to work more efficiently and help each other out, as explained by the representative of DOW and citizen (I2N, personal communication, March 22, 2024; I3N, personal communication, March 26, 2024) (*Evidence 1.3.1*)
- There is lack of a unified community representing agricultural practices to other institutions. Santa Rosa strives towards this; however, this is not what the stakeholders (farmers and households) perceive. (*Argument 1.4*)
 - Many interviewees identified the need for such a society or cited examples, such as the farming community of Curacao (Placci et al., 2022), as efficient farming communities that support each other. More information can be found in Appendix VII. (*Evidence 1.4.1*)

Advice 2: Santa Rosa is recommended to incorporate RWH systems in urban infrastructure, using community-based RWH.

It is advised to incorporate RWH systems in urban infrastructure by having several different RWH methods around the island, using community-based RWH systems (CBRWHS). CBRHWS differs to individual RWH as it is implemented and organized on a community scale and participants have a share in this project (Mukarram et al., 2023). This would create a sense of community in the neighborhoods. (*Advice 2*)

- The community can take advantage of large buildings for RWH. These buildings can incorporate RWH systems for the collection of water to then distribute to individual households or farmers around the island. (*Argument 2.1*)
 - RWH implemented on large buildings has been proven to be effective globally (Yannopoulos et al., 2019). (*Evidence 2.1.1*)
 - The infiltration rate around large buildings is disturbed by impermeable building material (Fenner et al., 2018). This can bring about floods as well as water stress due to the insufficient recharge of groundwater on the island (Fletcher et al., 2013). (*Evidence 2.1.2*).
 - Implementation of CBRWHS could decrease the need for individual households to obtain RWH infrastructure, as these systems can generally be expensive (Mukarram et al., 2023). (*Evidence 2.1.3*)

- A combination of totes with preferably aluminum rain gutters is, in terms of the MCA criteria, the most feasible and effective RWH system for large-scale implementation in Aruba. This is further explained in Advice 2 of the local level. (*Evidence 2.1.4*)
- If the roof of the large buildings exceeds a certain size, and its RWH capacity increases, the 3000-8000L dark plastic tanks should be utilized to store rainwater. Further elaboration on why this practice is optimal for higher water volumes is given in Advice 4 of the local level. (*Evidence 2.1.5*)
- Community-based RWH is a common practice in different places around the world. Kim et al. (2016) and Mukarram et al. (2023) illustrate several case-studies in Africa, Asia, and Bangladesh. (*Evidence 2.1.6*)
- When distributed to individual homes or farmers, this water could be stored in tanks and totes. (*Argument 2.2*)
 - Totes are, in terms of MCA criteria, the most feasible and effective RWH system for implementation in Aruba, this is further explained in Argument 2.2 of the local level. (*Evidence 2.2.1*)
 - Totes are the most economically viable; according to the CBA ranking based on the total costs of potential implementation (in AWG per liter), the totes scored first. (*Evidence 2.2.2*)
- Implementing communal nature-based solutions such as bioswales in urban planning for neighborhoods could help mitigate flood risks, increase infiltration and the efficient use of rainfall in urban areas. (*Argument 2.3*)
 - Van Houselt (2021) concluded that RWH can effectively reduce surface water runoff and help in flood risk management. (*Evidence 2.3.1*)
 - Currently, according to a governmental department, there is no infrastructure for flood management in Aruba (I2N, personal communication, March 22, 2024). (*Evidence 2.3.2*)
 - Bioswales efficiently utilize rainfall, enhancing soil and groundwater infiltration while reducing runoff and urban air temperatures. Additionally, rainfall infiltration in the soil, facilitated by the bioswale, will enable the soil to grow vegetation (Wright et al., 2015). A further description of this practice is given in Appendix III “Definitions of various RWH systems”. (*Evidence 2.3.3*)
 - Agroforestry can be implemented on top of bioswales to create more benefits. The MCA ranks agroforestry the highest for efficient use of rainfall, see argument 1.5 of the local level. (*Evidence 2.3.4*)

Advice 3: Santa Rosa is recommended to combine proper use of natural water ways with the implementation of RWH systems.

The proper maintenance and responsible use of the existing dry riverbeds and rainwater dams (locally called *rooien* and *tankis*) on the island in combination with the implementation of RWH structures in rural and urban areas, considering the ideal rainwater collecting methods for Aruba, can create a stable urban, rural and natural water supply as well as minimize the adverse environmental effects of heavy rainfall. (*Advice 3*)

- The *rooien* and *tankis* have worked as water management systems on the island since ancient times (Haviser & Hofman, 2015). They act as natural water retention and redirection areas, provide a water supply, and can help mitigate flooding and erosion on the island. (*Argument 3.1*)
 - The *tankis* allow for the collection of water for use by e.g. farmers for irrigation as well as water for construction on the island (I7N, personal communication, April 3, 2024). (*Evidence 3.1.1*)
 - Indigenous populations in the Caribbean have used water management systems such as *rooien* to mitigate for instance flooding (Finneran, 2017). (*Evidence 3.1.2*)
- Currently, the *rooien* and *tankis* on the island are improperly maintained (*Argument 3.2*)
 - Before the rainy season, the *rooien* and *tankis* are stripped free of sediment, trash and vegetation with heavy equipment, leading to increased erosion (I2N, personal communication, March 22, 2024). For elaboration, see Evidence 2.1.1 and 2.1.2 of the national level. (*Evidence 3.2.1*)
 - A DNM representative mentioned that “the plants they hold the structure around it”, when talking about the removal of vegetation around the *tankis* and *rooien* (I7N, personal communication, April 3, 2024). (*Evidence 3.2.2*)
 - The over-extraction of water from the *tankis* on the island could cause lower infiltration rates into groundwater reserves, which in turn could cause water stress (Van Houselt, 2021). (*Evidence 3.2.3*)
- Shifting the focus away from the water extraction from *tankis* and wells on the island by RWH implementation would allow for natural structures to recharge, possibly providing a richer supply of groundwater in the dry season. (*Argument 3.3*)
 - A hydrological study in Bonaire has concluded that the quality and quantity of groundwater can be increased through the retention of rainwater in e.g. dams, thus increasing infiltration rates (Borst & De Haas 2005). Due to Aruba and Bonaire’s geological similarities, this can be expected to work for Aruba as well. (*Evidence 3.3.1*)
 - A representative of DOW mentioned that the proper maintenance and use of *rooien* and *tankis* on the island can increase the infiltration rates (I2N, personal communication, March 22, 2024). (*Evidence 3.3.2*)
- Considering the ideal rainwater collecting methods for Aruba, a combination of totes and preferably aluminum rain gutters has been proven to be the most feasible and efficient implementation of RWH systems. See advice 2 of the local level for more information. (*Argument 3.4*)
 - The MCA and CBA results of the local level both show that this combination of RWH systems is the most efficient and feasible. They score high on accessibility of knowledge, material, and economic viability. For an elaboration on these results, see results section, evidence 2.1.1, and argument 2.4 of the local level. (*Evidence 3.4.1*)
 - If more locations on Aruba implement RWH, the demand for water from Santa Rosa’s basins will be lower during the rainy season. The basins will thus be less depleted, resulting in a bigger buffer of water supply during the dry season. (*Evidence 3.4.2*)



NATIONAL LEVEL

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3. National level

3.1 Introduction

This chapter dives deeper into the environmental, socio-economic, and political factors that influence RWH implementation in Aruba on a national scale. Due to the prominence of water scarcity in various Caribbean islands, it has become more common to implement RWH systems (Peters, 2016). This source states that rainwater is mostly used for potable and non-potable purposes. These uses could include drinking water, shower, laundry, irrigation, etc. However, it is not necessary to use the same water for all functions (National Academies of Sciences, Engineering, and Medicine, 2016). For now, the water supply in Aruba originates solely from the desalination plant on Aruba (Acevedo et al., 2023), which is an extensive process that uses mostly fossil fuels as energy source. The implementation of rainwater harvesting on a larger scale could transform Aruba to a more decentralized water supply (Sitzenfrei et al., 2017).

The backgrounds of the researchers for the national scale of this project are based on two tracks of the Global Sustainability Science bachelor at Utrecht University, namely Water, Climate & Ecosystems, and Governance & Societal Transformation. The Water, Climate & Ecosystems background has been beneficial in looking at various environmental aspects related to RWH feasibility, while the Governance & Societal Transformation background helps with the examination of societal and political elements like regulations and community perceptions of RWH. This research aims at understanding the elements that influence RWH implementation on a national scale. The main guiding research question is **“To what extent do environmental, socio-economic, and political factors influence the feasibility of rainwater harvesting (RWH) systems in Aruba?”**. Each factor has been divided into sub questions which have been defined the following way:

- 1.1 The environmental factors and advice will be discussed with the leading question *“How does the identification of climatic and environmental conditions affect possible RWH system implementation?”*
- 1.2 The socio-economic aspects are examined, answering the question *“How do societal perceptions and economic dependencies impact RWH system implementation in Aruba?”*
- 1.3 The political elements are illustrated and connected to the sub question *“What influence do past, and present water policies and political support have on RWH system implementation?”*

The next chapters start with the advice on the national level. After that, the methods are presented. Following the community-based research approach, several stakeholders needed to be considered for interviews regarding their relevance for the feasibility of RWH systems. For this research, the government is involved in the legal and infrastructural aspects and interests. The general citizen/farmer, farmers organization and consulting engineer represent the agricultural sector’s interests and the historical, business field. Hotels represent the tourism industry and the impact they have on water consumption. Considering the environmental components, the department of nature and environment (DNM) as well as other environmental specialists are included. The socio-economic elements are affected by the hotel industry, the desalination plant and individuals that do or want to implement RWH systems. The political factors are influenced by the governmental bodies and other specialists that work together with the

government. Some of the interviews were anonymous, for detailed explanation of the interviewees' citations and survey results, see methods section. In all three factors that have been researched, the Aruban community was involved through the survey. After the methods, the results of the interviews and survey are presented with the SWOT tool which was used to look at different advantages and disadvantages of RWH.

3.2 Advice

This section will explore the advice of the national level scale of the project. It is divided into five main advice based on the three themes of the abovementioned research sub-questions.

3.2.1 Environmental advice

Guiding question: How does the identification of climatic and environmental conditions affect possible RWH system implementation?

Advice 1: It is advised to initially identify and consider environmental factors such as rainfall, evaporation, infiltration rates and water quality that can facilitate or challenge rainwater harvesting implementation in Aruba before considering other dimensions. (*Advice 1*)

- Considering the environmental factors allows for the development of RWH systems adequate to present conditions and avoid possible negative environmental effects. (*Argument 1.1*)
 - If calculated, the annual rainfall volume in Aruba is estimated to be 7 times the volume of water produced yearly by WEB (Montoya Rodriguez, 2024). (*Evidence 1.1.1*)
 - Infiltration rate is important in replenishing groundwater reserves. So, by over-extraction of water from e.g. *tankis*, groundwater volume may be affected (I2N, personal communication, March 22, 2024). (*Evidence 1.1.2*)
 - Evaporation could, naturally, act as a barrier to water availability in water tanks and dams. A farmer mentioned that “The sun will evaporate the whole thing in a few months, and we won’t have any more water”, when asked about the *tankis* on the island (I3N, personal communication, March 26, 2024). Taking this into account could facilitate more effective RWH. (*Evidence 1.1.3*)
 - Respondents of the survey as well as interviewees 1N, 3N and 4N expressed that plants grow better with rainwater as opposed to tap water (I1N, personal communication, March 14, 2024); (I3N, personal communication, March 26, 2024); (I4N, personal communication, March 27, 2024). (*Evidence, 1.1.4*)

Advice 2: It is advised to investigate how water management, in terms of different RWH systems, could be implemented in natural, rural, and urban areas of Aruba to prevent flooding, increased runoff and erosion (*Advice 2*)

- Natural areas in Aruba, such as the Arikok national park face increased runoff and erosion during times of heavy rainfall. Maintaining the dry riverbeds and dams to work with nature, as well as possibly creating new collection structures (*tankis*) would decrease the degree of erosion and sediment release into the sea. (*Argument 2.1*)
 - The management of *rooiën* to prepare for the rainy season includes stripping the whole riverbed clear from not only sediment and trash but also vegetation. This could cause increased rates of erosion due to the increased speed of water flow (I7N, personal communication, April 2, 2024). (*Evidence 2.1.1*)

- A representative of DOW stated that “when rain season is coming, they do clean the dry riverbeds, [...] they go in with the heavy equipment and clean everything, also the plants. [...] that's also not the way to go because you create more erosion” (I2N, personal communication, March 22, 2024). (*Evidence 2.1.2*)
- The Caribbean Sea is under continuous stress from pollution, and a large cause in Aruba is the runoff of sediments and pollutants into the sea caused by heavy rainfall (Derix, 2016). (*Evidence 2.2.3*)
- In hydrological research on Bonaire, Borst & de Haas (2005) stated that “Groundwater quality and quantity can be improved by retaining more rainwater”. It was also mentioned that the proper maintenance of rainwater dams is crucial in decreasing the rapid runoff of rainwater into the sea. (*Evidence 2.2.4*)
- According to Hofman & Paalman (2014), various studies show that RWH can decrease stormwater runoff volume with 20-50%. (*Evidence 2.1.5*)
- In rural areas, construction on the *rooien* may have an adverse effect on the environment and the surrounding neighborhood due to the natural flow of water being disturbed. This can lead to flooding or property damage. (*Argument 2.2*)
 - “Unrestrained urban planning and house construction have an impact on the natural course of the rainwater, which comes with unpredictable costs during period of heavy rainfall” (Derix, 2016). This is often related to the blocking of the dry riverbeds (*rooien*). (*Evidence 2.2.1*)
 - A farmer mentioned that people drill holes in their concrete fence as a solution to the accumulated rainwater on their property. (I3N, personal communication, March 26, 2024). (*Evidence 2.2.2*)
- Due to impermeable infrastructure, Aruba repeatedly faces flooding and increased runoff in urban areas. This could be counteracted with effective rainwater redirection, harvesting systems, and allowing for infiltration with the help of e.g. bioswales (see local level MCA results). (*Argument 2.3*)
 - The development of impermeable infrastructure in urban areas can lead to a loss of infiltration, the accumulation of rainwater and flooding (Fletcher et al., 2013). (*Evidence 2.3.1*)
 - Certain areas and neighborhoods in Aruba are regularly faced with the consequences of flooding. This includes damage to properties, possible accidents, and traffic jams (Derix, 2016). (*Evidence 2.3.2*)
 - The survey conducted for this project showed that 78% of the respondents either agree or somewhat agree that flooding causes them problems (see Figure 5) (*Evidence 2.3.3*)
 - The study carried out by Van Houselt (2021) on the feasibility of RWH in Curaçao demonstrated how RWH can effectively reduce surface water runoff and thus help in flood risk management. It is expected that this has great potential for Aruba. (*Evidence 2.3.4*)
 - Nature-based solutions for RWH such as bioswales can enhance infiltration, reduce runoff, and even control urban air temperatures (see Integrated Evidence 3.2.3). (*Evidence 2.3.5*)

3.2.2 Socio-economic advice

Guiding question: How do societal perceptions and economic dependencies impact RWH system implementation in Aruba?

Advice 3: It is advised to resolve uncertainties and create awareness about rainwater harvesting within the Aruban community to amplify the opportunity of its implementation. (Advice 3)

- There is a lack of knowledge about the existing technology and maintenance of RWH systems. These concerns could be addressed for example with information on Santa Rosa’s website or in the form of a flyer. (*Argument 3.1*)
 - The survey conducted reveals that 14% of the respondents do not have knowledge on how to build and maintain RWH systems. (*Evidence 3.1.1*)
 - Mukarram et al. (2023) identified three principal barriers to RWH, namely financial insolvency, lack of technical skills, and insufficient education. (*Evidence 3.1.2*)
 - DNM’s representative shared possibilities on how to tackle the mosquito hurdle, which has also been a worry, mentioned by 13% in our survey. This would be by introducing fish as a natural solution approach or nets for a technological one (I7N, personal communication, April 2, 2024). (*Evidence 3.1.3*)
- Uncertainties on RWH have mostly risen due to the lack of communication. (*Argument 3.2*)
 - Today, RWH is allowed in Aruba but during the data collection interviewees gave opposing responses. The first six interviewees knew that it is allowed to build RWH tanks next to your house but interviewee 7, a representative of a governmental department, did not know this (I7N, personal communication, April 2, 2024). Additionally, an Aruban citizen shared the unawareness of existing legislation regarding RWH (I3N, personal communication, March 26, 2024). (*Evidence 3.2.1*)
- The lack of accessible data regarding rainwater quality and possible uses of rainwater has caused confusion among citizens on whether the collected rainwater can be used and what for. (*Argument 3.3*)
 - It is not necessary to use WEB’s potable water for e.g. car washing or irrigation, as the consultant expressed in the interview. Thus, there should be more education on water use possibilities for drinking water, rainwater, and wastewater (I1N, personal communication, March 14, 2024). (*Evidence 3.3*)
 - DNM’s representative affirmed that there is data on the water quality of several dams on the island. However, DOW’s representative, a farmer, and the representative of a farmer’s organization did not know of this data (I7N, personal communication, April 2, 2024). (*Evidence 3.3.1*)
- Another limiting factor for the implementation of rainwater harvesting is the lack of information regarding the financial and spatial aspect of RWH. RWH systems are a costly investment that not everyone can afford or knows of the prices of. In addition, it takes up space in the garden or next to the house. (*Argument 3.5*)

- 51% of the respondents in the survey indicated that they cannot afford to install RWH systems in their households. *(Evidence 3.5.1)*
- When asked for the largest barrier, 8% of the survey respondents indicated the spatial aspect as being a barrier and 16% said it was too expensive. *(Evidence 3.5.2)*
- The Interview with the consultant and one of the hotels revealed that to make sense for citizens, it is important for investments like RWH systems to provide a “return on investment” (I1N, personal communication, March 14, 2024; I6N, personal communication, April 2, 2024). *(Evidence 3.5.3)*
- As Mukarram et al. (2023) shared, financial insolvency is a large factor which is confirmed by the answers of the interviews and survey. *(Evidence 3.5.4)*
- For a successful implementation of RWH it is important to keep in mind the socio-economic factors (Peters, 2016). *(Evidence 3.5.5)*
- To convince the Aruban community to implement rainwater harvesting, the benefits of it need to be clear. *(Argument 3.6)*
 - The survey shows that respondents are conscious of a few benefits of RWH but not all of them. The answers were, among others: good for plant growth, lower water bill, resilience for water security, emergency water supply and different water usage. *(Evidence 3.6.1)*

3.2.3 Political advice

Guiding question: What influence do past, and present water policies and political support have on RWH system implementation?

Advice 4: It is advised for the governmental departments and ministries on the island to collaborate and create the necessary political support for various RWH implementation purposes. (Advice 4)

- Collaboration is possible based on a shared positive perception of RWH from the different departments, and it is necessary to coordinate the different tasks involved in RWH implementation. *(Argument 4.1)*
 - Besides Santa Rosa, representatives of DNM and DOW have shown support for RWH systems development (I7N, personal communication, April 2, 2024); (I2N, personal communication, March 22, 2024). *(Evidence 4.1.1)*
 - The governmental departments’ representatives explained that DNM measures the quality of nine dams, DOW manages the maintenance of these dams, and Santa Rosa distributes water to farmers. All these functions are relevant in the process of RWH development; thus, their coordination would be reasonable and beneficial (I7N, personal communication, April 2, 2024); (I2N, personal communication, March 22, 2024). *(Evidence 4.1.2)*
 - DOW in collaboration with DIP maintains some governmental buildings and gives the building permits, thus they could collaborate to set the implementation of RWH as a criterion for governmental buildings (I2N, personal communication, March 22, 2024). *(Evidence 4.1.3)*

- Political support in the form of political will is key to achieving RWH implementation. (*Argument 4.2*)
 - As explained by Robinson (2007), political commitment from the higher level of the government is important to have a more successful implementation of any governance reform, and to diffuse resistance. (*Evidence 4.2.1*)
 - Explicit support of government administrative processes is considered essential to creating change in the water sector (“Integrated Water Resources Management in the Caribbean: The Challenges Facing Small Island Developing States,” 2014). (*Evidence 4.2.2*)
 - In the case of Aruba, political will was identified as a barrier to translate the measures related to RWH that are in the planning phase into real implementation in the interview with DOW’s representative (I2N, personal communication, March 22, 2024). (*Evidence 4.2.3*)
 - Furthermore, when asking whether they saw a possibility for political support for larger RWH implementation in Aruba, DOW’s interviewee stated, “if you have the right people and the right pulling systems, I think you can do it” (I2N, personal communication, March 22, 2024). (*Evidence 4.2.4*)
 - 87% of the survey respondents think the government should initiate RWH implementation (see Results section). (*Evidence 4.2.5*)
- The main RWH potential purposes that have been identified for the island are agriculture development and flood management, both necessary for achieving the government’s sustainability goals, and collaboration and political support is needed in these specific RWH implementations. (*Argument 4.3*)
 - The flood management in place in Aruba is limited, thus should be improved (I2N, personal communication, March 22, 2024). (*Evidence 4.3.1*)
 - Agricultural development is key for the island’s sustainable development, contributing to achieving food security, and sustainable agriculture, and these are key elements of SDG 2 Zero Hunger: “End hunger, achieve food security and improved nutrition and promote sustainable agriculture” (United Nations, n.d.). (*Evidence 4.3.2*)
 - The agriculture and gardening sectors on the island are currently the largest rainwater consumers, as explained in the interview with and thus would benefit significantly from a political push to develop RWH systems in Aruba (I3N, personal communication, March 26, 2024). (*Evidence 4.3.3*)

Advice 5: It is advised to consider legislation regarding water on the island, including, for instance, water quality standards, or support mechanisms. (*Advice 5*)

- Legislation plays an important role in hindering or supporting rainwater harvesting in Aruba. (*Argument 5.1*)
 - From a historical perspective, the restriction set in place in the 1960s prohibiting the construction of regenbakken in new houses reduced greatly the practices of rainwater collection. And this scaling down is still visible nowadays, despite the abolition of this legislation, as most new houses do not have RWH systems anymore (I1N, personal

communication, March 14, 2024); (I7N, personal communication, April 2, 2024). (*Evidence 5.1.1*)

- Even today, three respondents of the survey had not considered RWH because they are not aware that this restriction is not in place anymore, showing the impact a governmental restriction can have on a population and their actions. (*Evidence 5.1.2*)
- Currently, there is an absence of a drinking water law in Aruba that sets the regulatory and institutional frameworks to establish quality standards and accountability for the current water management practices. (*Argument 5.2*)
 - In the interview with the consultant, it was explained that in Aruba there is no legislation on drinking water, and that water legislation should address two important areas: quality and security (I1N, personal communication, March 14, 2024). (*Evidence 5.2.1*)
 - Literature regarding the improvement of water governance affirms that the drafting and adoption of legislation is considered as a key element, as it contributes to having a facilitating environment and establishes an institutional framework (“Integrated Water Resources Management in the Caribbean: The Challenges Facing Small Island Developing States,” 2014). (*Evidence 5.2.2*)
- Rainwater quality standards or RWH practices should be addressed in legislation to support its management and further development. (*Argument 5.3*)
 - The representative of DOW, when asked if it was possible to develop larger scale RWH systems like in public buildings, stated: “I think I think it is possible, but we have to implement it in our laws, in our regulations” (I2N, personal communication, March 22, 2024). (*Evidence 5.3.1*)
 - In the case of *tankis*, the representatives of governmental departments identified the problematic management of these, as well as the overuse of the *tankis* and wells limiting the groundwater replenishment capacity, which could be effectively addressed in legislation (I7N, personal communication, April 2, 2024); (I2N, personal communication, March 22, 2024). (*Evidence 5.3.2*)

3.3 Methodology

In this research, the national scale defines our research boundaries, addressing political, environmental, and socio-economic factors affecting RWH national implementation. To obtain the necessary information to conduct this research, quantitative and qualitative data was collected, using literature review, a survey, and interviews.

3.3.1 Literature review

Firstly, a systematic literature review was conducted to gain an initial overview of RWH systems, and to find studies already done on the implementation conditions globally and in Aruba. The search engines Google Scholar and WorldCat were utilized. Due to the limited research on RWH in Aruba, to be able to find papers, backward snowballing was used (Wohlin, 2014). This means searching in the reference list of a paper found relevant to identify new papers related to the topic. Both grey- and academic literature were explored and compiled in an excel file organized per sub-questions. This can be found in Appendix VIII.

3.3.2 Survey

Next, an online survey was created on Google Forms to discover the perspectives of the local population on rainwater harvesting, following the community-based research approach. To reach a wide range of participants but initially having few contacts, snowball sampling was used as it means using these few initial contacts for obtaining contact with other participants (Bryman, 2012). The survey was sent to Santa Rosa, who posted it on their Facebook page; students at the University of Aruba, and other social groups, and each respondent shared the questionnaire forward. The questions mainly addressed opinions and knowledge on water use, RWH, water production, water management, and flooding, and were translated to three languages: Papiamentu, Dutch and English, to be more accessible. Open and closed questions, and Likert scale statements were utilized (see Appendix XI). A Likert scale is a five-option scale, ranging from 'agree' to 'disagree', used to measure people's perceptions or opinions (Batterton, 2017). The results were analyzed in excel with graphs and tables.

3.3.3 Interviews

In addition to the survey, seven semi-structured interviews were conducted with various stakeholders, based on fields and sectors relevant to each sub-question, reaching a broad and varied perspective on RWH in Aruba. The roles of the interviewees and examples of guiding questions are presented in Table 1. The interview questions were personalized for each interview due to their different background. The citation used throughout the report indicates the interviewee number and "N" clarifies that these interviews correspond to the national level research, to avoid confusion with the local level interviews.

Table 2: Interviewees' assigned number, their role or sector they work at, and examples of a personalized question asked in each interview.

Interviewee n ^o	Role or Sector	Example of personalized question
1N	Representative of Consulting Engineers firm	<i>What do you think was the intention behind the 1960s restriction on rainwater collection? Can you elaborate more on the effects this had, and why did it change?</i>

2N	Representative of DOW (Department of Public Works)	<i>What is the current flood management infrastructure on the island, and do you think RWH systems implementation can contribute to flood risk management and reduction? If so, in what way?</i>
3N	General citizen and farmer	<i>Do you think the government now ensures water security on the island (which means everyone has reliable access to sufficient clean water)?</i>
4N	Representative of farmer's organization	<i>Do you see any obstacles or barriers to having RWH, in your experience? And for the general society?</i>
5N	Sustainability manager in the hotel industry	<i>In your opinion are there any economic benefits for implementing RWH in the hotel? And financial barriers?</i>
6N	Quality assurance manager in the hotel industry	<i>What barriers are there today for the hotel industry in the implementation of RWH systems?</i>
7N	Representative of DNM (Directorate of Nature and Environment)	<i>Do you think it can be beneficial to have RWH in Aruba on a larger scale?</i>

The interviews were recorded, transcribed, and added into NVivo (Lumivero, 2023) for analysis. Several key themes corresponding to the sub-questions were identified in each interview and added to codes created in NVIVO. Grouping the themes together into codes made it possible to see how common they were in the interviews.

3.3.4 SWOT

The results were analyzed with the SWOT framework, classifying them into strengths, weaknesses, opportunities, and threats of the rainwater harvesting implementation (Benzaghta et al., 2021), which formed the basis for the advice given to the client. The results were based on the results of the survey, literature review and interviews.

3.4 Results

This section will explain the most relevant findings from the survey and interviews is provided, together with visual representations. The following subsections correspond to each of the data collection methods.

3.4.1 Interviews

The NVIVO coding made it possible to identify several themes common to the interviewees, based on literature and the Aruban context. Two layers of codes were used as there were sub-themes (e.g. economic dependencies included affordability, return on investment, etc.), presented in Table 2. In addition, a visual representation of the themes in the format of a mind map can be observed in Figure 1.

Regarding the environmental factors, dry riverbeds were mentioned 31 times, and their management was said to interfere with the natural processes of sedimentation of beneficial organic matter, causing erosion. The reduced capacity for the groundwater to replenish was highlighted, due to the intense use of the wells and impermeable water dams that limit the natural infiltration of water. Rainwater quality was perceived as more favorable for agriculture and gardening than desalinated water. Water pollution was expressed as a concern for using dams. Finally, flooding was identified nine times as an issue. Additionally, it was expressed that RWH can contribute to flood management, reducing runoff on the island.

Regarding socio-economic factors, all interviewees had positive opinions on RWH and believed it would be valuable for Aruba to have further development. One interviewee from the hotel sector, however, perceived RWH as less valuable, as their hotel has a sufficient water supply for gardening reusing grey water. All interviewees perceived that RWH is beneficial economically. Affordability and return on investment were mentioned eight and three times respectively when asked about financial barriers for RWH implementation on a more individual scale.

Finally, regarding political factors, past policies and the 1960s restriction for construction of RWH infrastructure in new houses were recognized to have reduced the possibility of using rainwater then and today. The dissolution of this restriction was not known to three interviewees in the agriculture and government sectors. The lack of a water law and specific RWH supportive legislation was identified three times. Also, political support, political will and collaboration between governmental departments was addressed eight times by the governmental and consultancy experts. Power relations and conflicting interests were asked about but were not considered influential.

Table 3. NVIVO analysis codes and number of references from the interviews.

Question	Code layer 1	Code layer 2		
Sub-Q1 <i>“How does the identification of climatic and environmental conditions affect possible RWH system implementation?”</i>	Arikok Park	3		
	Rain	2		
	Water wells	11		
	Dry riverbeds	31	Water dams	12
			Management	4
	Water quality	19	Water pollution	9
			DNM measurements	5
	Flood management	9		
Mosquitos	1			

	Environmental costs of rain gutters	1		
Sub-Q2 <i>“How do societal perceptions and economic dependencies impact RWH system implementation in Aruba?”</i>	Societal opinion on RWH	18	Negative	0
			Positive	8
			Not Know	8
	Economic dependencies	26	Economic benefits desalination	3
			Return on investment	3
			Economic consequences RWH	5
			Financial subsidies	3
			Affordability	8
			Financial barriers	4
Hotels perspective	6			
Sub-Q3 <i>“What influence do past, and present water policies and political support have on RWH system implementation?”</i>	Potentials for political support	52	Financial support	1
			Legislation	3
			Departments collaboration	8
			Awareness	1
			Societal perception of policies	17
	RWH use	12	Before 1960s restriction	6
			Now	6
			Past	2
	Power relations	8	Past	2
			Present	6
	Beneficiaries of RWH	8		
	Barriers to RWH	19		
	Conflicting interests	8		
	Past policies	19	Causes	11
Consequences			8	
Political priorities	18			
Stakeholders' support to RWH	20			

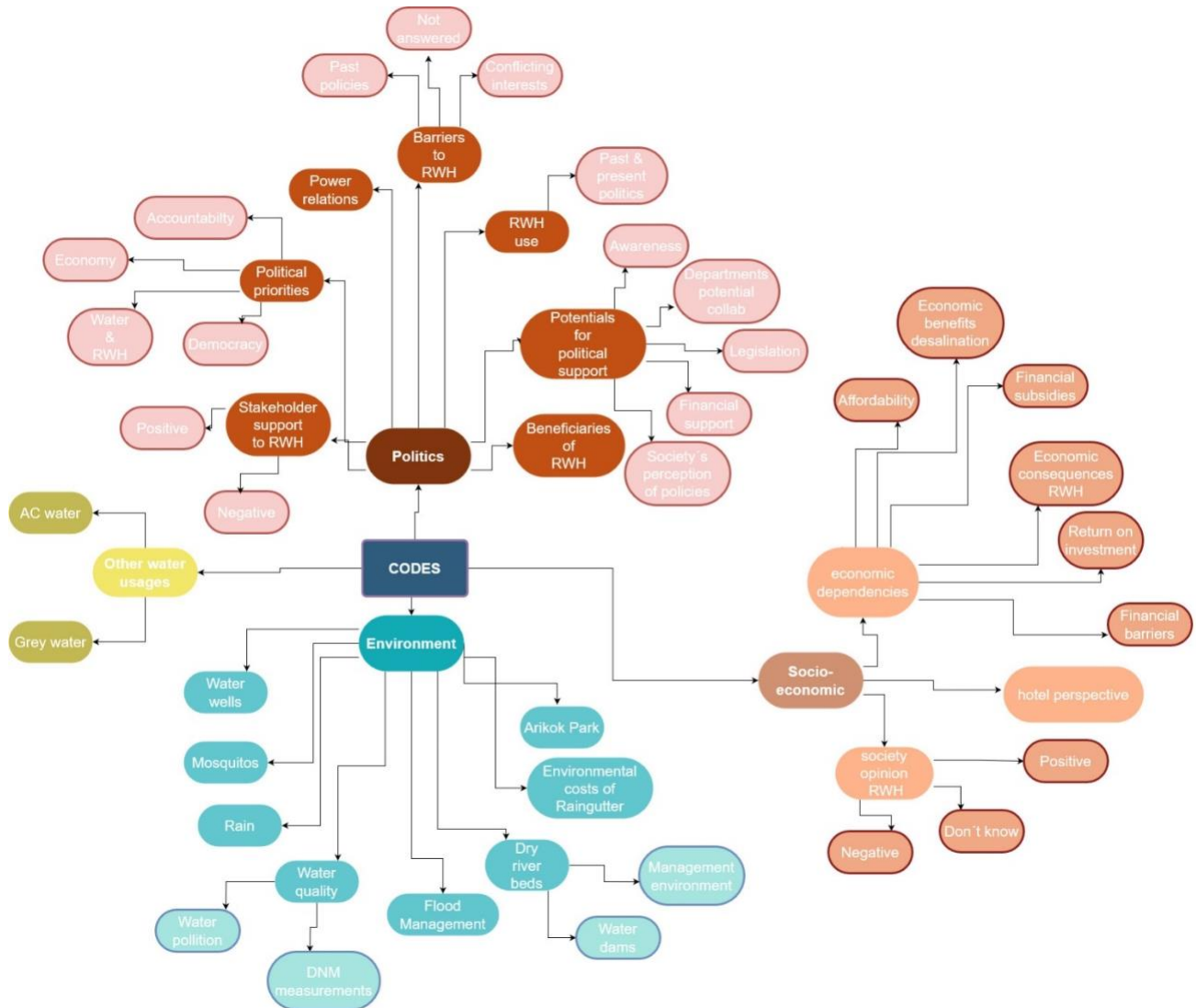


Figure 1; Overview of the codes used for the NVIVO analysis on the interview data. Blue corresponds to the environmental sub-question, coral-orange to the socio-economic, dark red to the political, and yellow represents themes not directly related to RWH.

3.4.2 Survey

The conducted survey has given an insight into different perspectives of the Aruban population on their general water use, RWH, water management on the island. 101 responses were received from different age groups, with 74% of the respondents being over 40 years old, working in a diverse range of fields. Examples of occupations of the respondents include airline pilot, doctor, shop owner, teacher, and bookkeeper. The distribution of male and female respondents in the survey was relatively equal, 44,6% and 54,5% respectively, and 96% of them have lived in Aruba for more than five years.

From the respondents, 53% stated that they collect rainwater for their households (See Figure 2). Still, as seen in Figure 3, 96% indicated that they get most of their water from WEB. An important barrier that was identified was the lack of financial support. Half of the respondents said that they cannot afford installing

RWH systems and that their water bill is too high (see Figure 4), and more than 80% believe that the government should initiate RWH through e.g. financial support and policies (Figure 6).

The lack of technical skills and knowledge became visible with 14% of the respondents indicating that they do not know how to build and maintain RWH systems. Still, many were aware that it boosts the growth of plants. All respondents indicated that they have noticed the flooding on the streets caused by rainfall, and 79% of the respondents indicated that it is a problem for them (see Figure 5). Finally, almost all respondents believe flood mitigation should be improved. For full survey data results, see Appendix X.

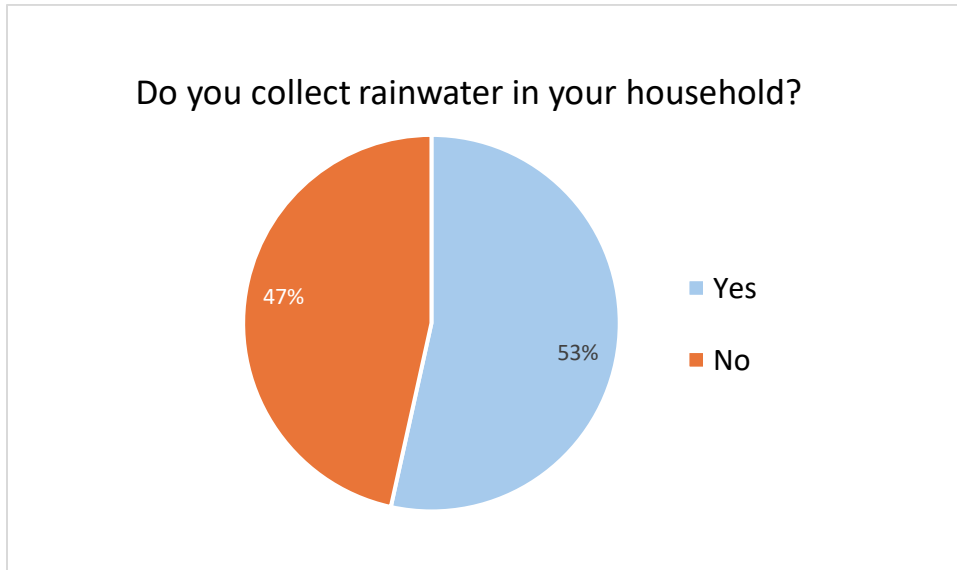


Figure 2. Pie chart showing the proportion of people that are, and are not collecting rainwater

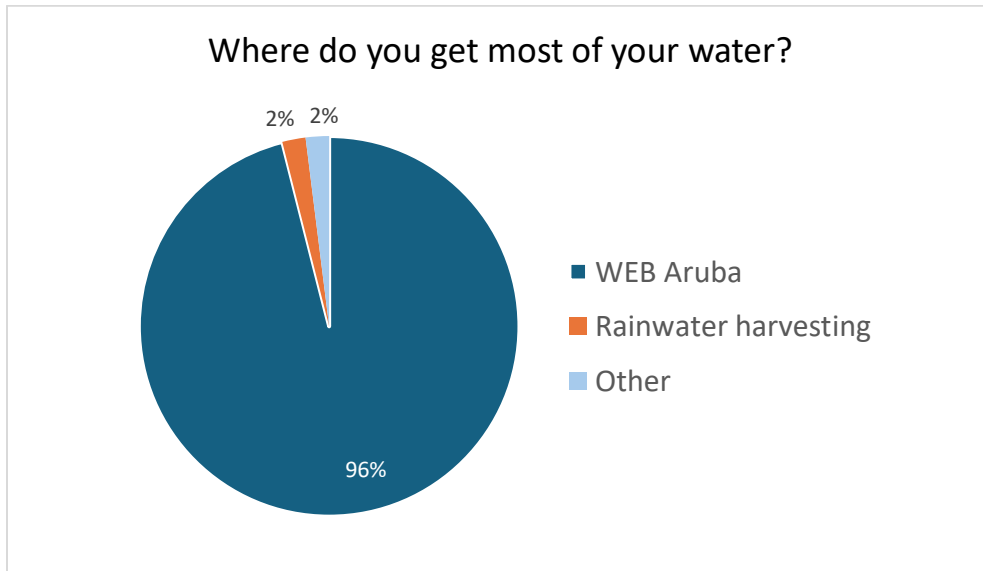


Figure 3. Pie chart showing where the respondents of the survey obtain most of their water.

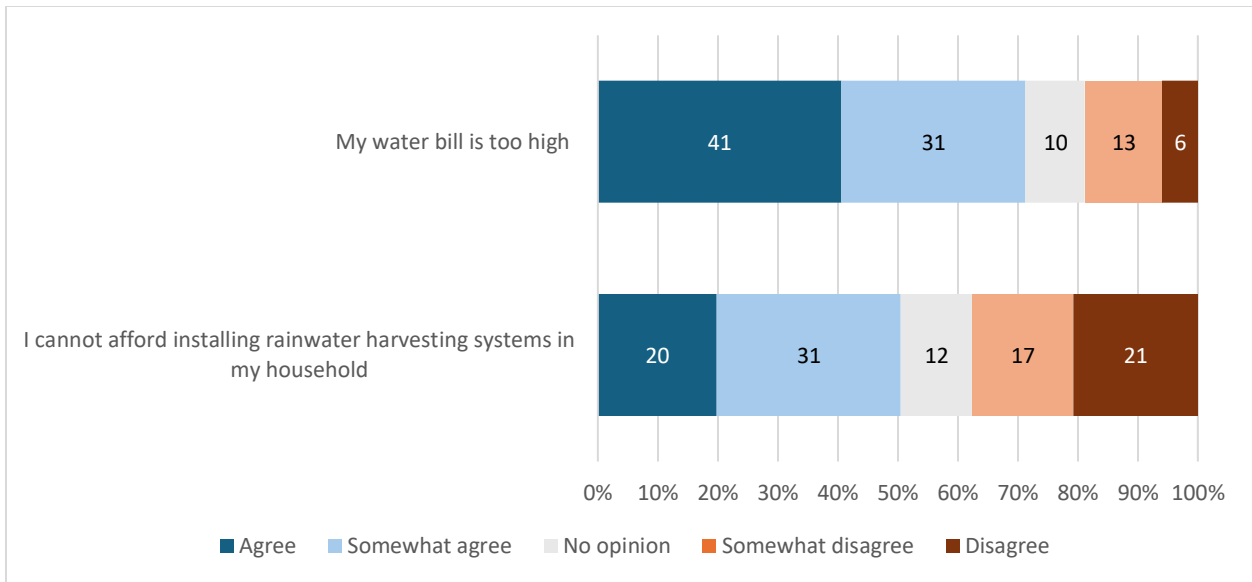


Figure 4. Likert scale survey results on the statements “My water bill is too high” and “I cannot afford installing rainwater harvesting systems in my household”. The X-axis shows the proportion of respondents in percentages, while the numbers on the bars reflect on the number of respondents for the specific answer.

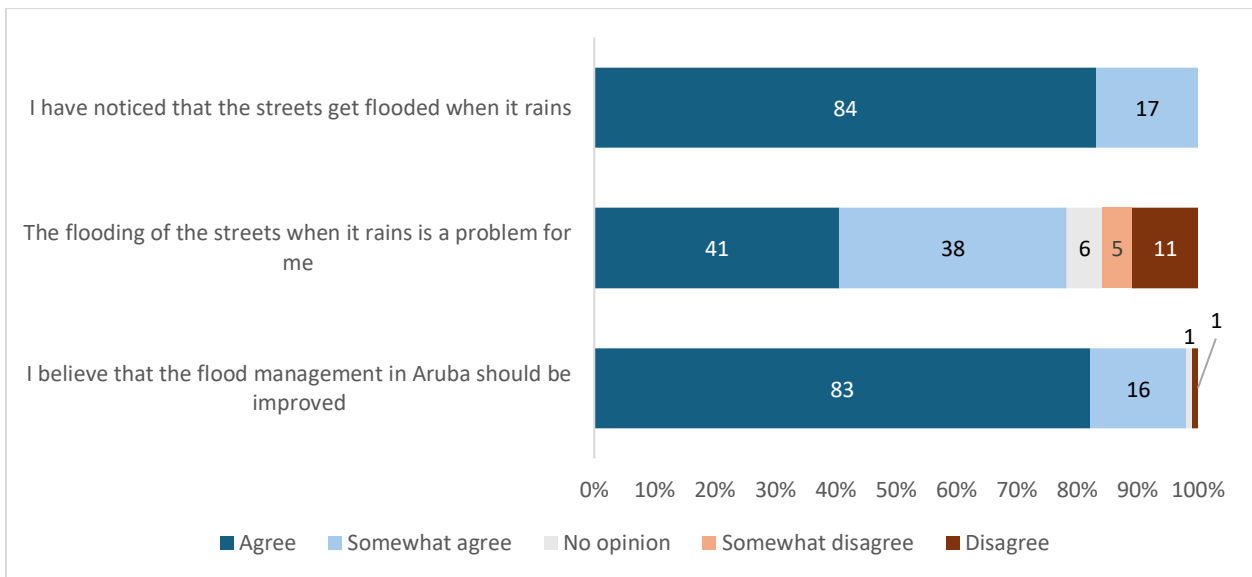


Figure 5. Likert scale survey results on the statements “I have noticed that the streets get flooded when it rains”, “The flooding of the streets when it rains is a problem for me” and “I believe that the flood management in Aruba should be improved”. The X-axis shows the proportion of respondents in percentages, while the numbers on the bars reflect on the number of respondents for the specific answer.

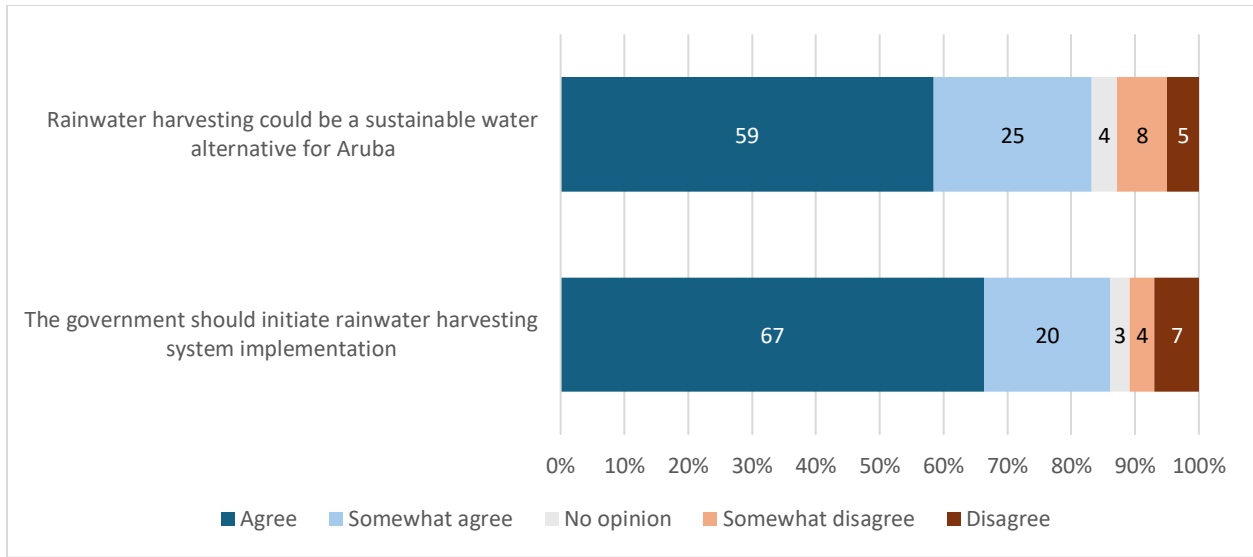


Figure 6. Likert scale survey results on the statements “Rainwater harvesting could be a sustainable water alternative for Aruba” and “The government should initiate rainwater harvesting system implementation”. The X-axis shows the proportion of respondents in percentages, while the numbers on the bars reflect on the number of respondents for the specific answer.

3.4.3 SWOT Analysis

In this section, the results of the SWOT analysis are presented. To better comprehend this analysis, the four components are defined as follows:

- **Strength:** Relates to the competitive advantages for RWH in Aruba. If RWH is adopted, the direct benefits indicate its strengths.
- **Weakness:** Direct disadvantages of the implementation of RWH systems.
- **Opportunity:** Represent the (external) conditions or strengths of the island that facilitate RWH.
- **Threat:** The barriers and difficulties that can hinder RWH implementation in Aruba.

Table 4. SWOT Table showing the Strengths, Weaknesses, Opportunities and Threats for RWH implementation in Aruba based on the conducted literature review, survey, and interviews. A full description of this table can be found in Appendix XII.

Strengths	Weaknesses
<ul style="list-style-type: none"> • Environmental: Lower pressure on natural RWH systems, allowing for sufficient groundwater recharge. • Socio-economic: Lowers water bill and dependency on desalination industry • Political: Less vulnerable to external shocks. 	<ul style="list-style-type: none"> • Environmental: Impermeable RWH impedes infiltration • Socio-economic: Short term economic loss • Political: Time and bureaucracy need for implementation process
Opportunities	Threats

<ul style="list-style-type: none">• Environmental: Rainfall volume, flood prevention, existing natural RWH structures• Socio-economic: Social awareness, willingness, and a positive outlook on RWH• Political: Department collaboration, political support by stakeholders. The possibility for implementing legislation.	<ul style="list-style-type: none">• Environmental: Irregular and short rainfall, polluted dams, the need to work around infrastructure• Socio-economic: Lack of awareness on benefits, need for investment• Political: Lack of political commitment, need for time and resources.
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LOCAL LEVEL

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4. Local level

4.1 Introduction

Historical evidence indicated that water collection was one of the primary water sources for early inhabitants (Marchena & Halman, 2018), suggesting the feasibility of water harvesting in Aruba. Until the introduction of the desalination plant, traditional Aruban homes used RWH through regenbakken, which are reinforced concrete water tanks designed to collect rainwater from roofs (Klomp, 1981). Since then, modern RWH systems have been introduced, including rain gutters made from various materials and advanced storage tanks. Additionally, natural solutions such as bioswales, offer nature-based urban water management (Pal, 2023). Check dams can be used to redirect water flow for irrigation purposes (Agoramoorthy et al., 2016). Furthermore, integrating agroforestry as nature based RWH system improves soil quality, infiltration, and overall water retention (Jose, 2009). Thus, these approaches contribute to the sustainable harvesting of rainwater.

Currently, RWH systems are not the primary water source in Aruba. Instead, WEB is the sole water producer on the island (Acevedo et al., 2023), making the population reliant on their services. Aruba, being a semi-arid island with limited water resources (Van Sambeek et al., 2000), would benefit by exploring more methods to improve water sustainability, and RWH is one of them. As mentioned before, the rainfall on the island is significant enough to put efforts into the capturing of it. By capturing and utilizing rainwater for non-potable purposes, such as irrigation, cleaning, or toilet flushing, water harvesting can diminish the need for freshwater purchased from WEB, lessening the economic burden on local entities.

Understanding how RWH systems can be implemented, while also considering the semi-arid climate of the country, remains an area requiring further research. This is also caused by limited availability of long-term data or any data on the performance of existing RWH systems in Aruba, which makes it challenging to assess their effectiveness and predict feasibility of future implementation of innovations of RWH systems.

As an interdisciplinary team of researchers, with expertise in energy & resources, business & innovation, and linguistics, the aim is to analyze the feasibility and efficiency of the existing and future potential implementation of RWH systems in Aruba, involving the preferences of the Aruban community. This research displays insightful findings and provides practical, informative, and feasible recommendations to the client and the involved stakeholders. This project's local perspective will look at the existing and future potential implementation of RWH systems on a small and large scale. To clarify again, the small scale includes individual households or small businesses, whereas large scale includes farms that are registered with Santa Rosa. The research question of this study is as follows: **Can business innovations, when integrated with rainwater harvesting systems (RWH), improve the efficiency of the sustainable water supply for stakeholders in Aruba?** The following sub questions will contribute to answering the overarching question:

1. What innovations exist in RWH systems and how do they work?
2. How efficient in terms of the use of rainfall, economic viability, and ease of implementation and are these innovations in RWH systems?

3. What is the perspective of the stakeholders, including farmers, small businesses, and households, regarding implementation and adoption of RWH systems and how does this influence current development?

By examining factors such as economic viability, volume, life span, accessibility, and ease of both implementation and maintenance, this research strives to be beneficial for potential implementation of RWH systems on a small and large scale. Economic viability refers to the capacity of a system to generate income and uphold its long-term sustainability. For a project to be economically viable, its benefits must outweigh its costs when considering societal impacts, including externalities and environmental factors (Cortes & Mayrhofer, 2019). Furthermore, the perspectives of the stakeholders regarding implementation and adoption of RWH systems will be used to enhance the community base research approach and the local level scope. The aim of this approach is to capture values shared by the communities. With the recognition of common purposes and a bottom-up approach, a more unified approach to the topic is achieved (Turner, 2009).

4.2 Advice

A disclaimer for the advice is that to be able to efficiently implement RWH systems, the client should assume the responsibility of having the role of centralized support entity for the community to rely on as center of information and support; more information is provided in Appendix VI. Without a stable, unified community, these RWH systems cannot be implemented on a larger scale.

This section will answer the question: “**Can business innovations, when integrated with rainwater harvesting systems (RWH), improve the efficiency of the sustainable water supply for stakeholders in Aruba?**” It offers four recommendations, each based on research findings. The first two advices propose specific systems to be implemented. Then considerations for larger storage volumes tailored to farmers or other large scale water users are mentioned. The final advice focuses on improving the distribution and availability of information on RWH systems. All of these draw from insights gained through the first sub question; What innovations exist in RWH systems and how do they work? The outcomes of the sub question on efficiency are used to justify the selection of these particular systems as the optimal choices, by using results from the Multi Criteria Analysis (MCA) and Cost and Benefit Analysis (CBA) analysis. Stakeholder perspectives on the implementation of RWH systems gathered through interviews are used to highlight the expressed needs and preferences.

Advice 1: Agroforestry should be promoted by Santa Rosa.

The department should continue to build understanding on agroforestry and function as an information center for the associated members. Agroforestry is the association of trees with farming practices, implementing farming practices that coexist with nature, fostering sustainable ecosystems (Living Soil Aruba - Agro Consultancy. (n.d.). The aim is to raise awareness of alternative systems for water harvesting, not as known among the local community. Moreover, Santarosa should provide, as already in act with common methods of plantation, support for the logistics of the preparation of the terrain and seeds and (rental) equipment. (*Advice 1*)

- Agroforestry improves the soil system; it enhances infiltration and water retention due to more extensive root systems, leading to increased nutrient use efficiency of the system. Agroforestry has a carbon sequestration potential, which is higher than any other RWH system (Kravchenko et al., 2019). Additionally, the integration of various crops and trees into this system improves biodiversity, soil fertility, and water quality (Jose, 2009). (*Argument 1.1*)
- One of the Agroforestry sub-categories, Syntropic farming, is an upcoming practice on the island. Recognizing the system by a part of the population predisposes the interest of other community members. (*Argument 1.2*)
 - There is already a movement present on the island regarding agroforestry. Living Soil Aruba is an agro-consultancy company that gives free presentations and workshops on this practice (Living Soil Aruba -Agro Consultancy, n.d.). “I am and a consultant on agroforestry, so more in a forest system on how to grow to me that's a system that you really regenerate the soil... in a way of syntropic forest means in the beginning yes i still

- get a lot of water but over time you need less and less because it's becoming more self-sustaining.' (I9L, personal communication, March 25, 2024). (*Evidence 1.2.1*)
- Three interviewees have mentioned the agroforestry company of the island company and one farmer have mentioned getting knowledge regarding the topic via a webinar 's a person from Brazil and he has agroforestry as that is that is the way they're doing replanting of trees, but also underneath the with the replanting Trees they're growing Products ..." (I8L, personal communication, March 26, 2024). (*Evidence 1.2.2*)
 - Interest and positive approach to agroforestry mentioned in four interviews out of ten (*Evidence 1.2.3*)
 - This solution is practical and applicable to household practice, every interested person with a backyard could implement it. (*Argument 1.3*)
 - An agroforestry site can be implemented in any garden; maintenance includes watering, weed control, and harvesting (Godsey, L. D., 2010). (*Evidence 1.3.1*)
 - There is a pilot project of the ministry of nature of Aruba already in place on the island: "*pilot projecto agroforestria na scolnan basico*" that will implement Syntropic farming in 12 schools on Aruba (I10L, personal communication, April 10, 2024)
 - The concept of agroforestry includes the respect of natural ecosystems hence it is natural to favorize planting climate adaptive plants. In some cases, these plants correspond with endangered native species, so the implementation of these systems could positively influence nature conservation on the island (*Advice 1.4*)
 - The book: *De inheemse bomen van de Benedenwindse eilanden, Curaçao, Bonaire and Aruba of John de Freitas, Jeff Simcox* 1996 can be used to select the species that better suite the necessity of the island and native repopulation specifically on the Dutch Caribbean Islands. (*Evidence 1.4.1*)
 - The use of other species: Cactus (Inglese et al., 2017), Mesquite flower, Pithecellobium dulce and Palo de Brasil (World Agroforestry, 2021). (*Evidence 1.4.2*)
 - An approach presented to us by a member of the department of Santarosa is forest gardening, successfully implemented in his garden show the feasibility of application on Aruba based on the work from Crawford (n.d). (*Evidence 1.4.3*)
 - The economic feasibility of this implementation is really convenient. Agroforestry merges two important aspects of RWH systems, a durable system and efficient water collector. (*Argument 1.5*)
 - The MCA score for agroforestry regarding efficient use of rainfall is a 9, due to it using rainfall to improve the soil system, enhancing infiltration and water retention (Jose, 2009). Improving soil quality can reduce risks of soil degradation and enhance the environment (Lal, 2015). (*Evidence 1.5.1*)
 - The CBA has reported that the costs necessary for implementation are the initial monetary investment that would depend on the availability of seeds and type of soil and time to maintain the garden understood with an economical value to it but no monetary one. (*Evidence 1.5.2*)

- The costs of this practice include ground preparation and investment in materials (Godsey, L. D., 2010). Materials required for agroforestry are land, soil, seeds, sunlight and the ability to water the field (University of Missouri Center for Agroforestry, 2021). In terms of money, this practice is economically viable. (*Evidence 1.5.3*)

Advice 2: Implementation of totes in combination with rain gutters should be promoted and made better available by Santa Rosa.

Santa Rosa should facilitate the implementation of totes in combination with preferably aluminum rain gutters. Totes are discarded Intermediate bulk containers (IBCs), an IBC water tank is a container designed to safely store large quantities of liquids. The facilitation of this system should be focused on the promotion of this combination and preferably with the aluminum rain gutters. Efforts should be made to further increase availability of totes, transparency on prices and informing about locations to purchase the totes as well as the (aluminum) rain gutters. This could be made more fruitful when a collaboration with WEB is established to form an agreement on the availability and supply of second-hand IBCs (totes). (*Advice 2*)

- Based on research observations, it is clear that this system is already known and present on the island. This fact is supported by the evidence. Therefore, this would not require devising an approach to RWH that has already been effectively done by using totes in combination with rain gutters. (*Argument 2.1*)
 - The MCA score for accessibility of knowledge of totes is an 8 and of aluminum rain gutters a 6. Implementation of rain gutters in general requires knowledge of roof structure and construction (I4L, personal communication, March 21, 2024). Any specific knowledge for operating a tote is not needed. (*Evidence 2.1.1*)
 - Survey data shows that these RWH systems are known and present on the island. Eight out of 15 respondents to the question “which type of RWH systems do you have?” had totes. Six had aluminum gutters and nine had PVC gutters. The rain gutters are always combined with a storage system. Six of the gutter systems were combined with totes and two with larger storage tanks. See Figure 7 in the results. (*Evidence 2.1.2*)
- This RWH system can be seen as the most feasible and effective for future potential implementation in Aruba. A combination of totes with gutters is required, as a harvesting system (the gutters) are of no use without a storage system (the totes). (*Argument 2.2*)
 - According to the MCA conducted for this consultancy report, the totes scored first based on equal weights for the criteria and second with the weights based on the preferences of the Aruban community, and the aluminum rain gutters ranked third for both the weighing methods. The PVC rain gutters ranked lower than the aluminum gutters for both. (*Evidence 2.2.1*)
- This RWH system is the most economically viable for implementation according to the CBA. (*Argument 2.3*)

- According to the ranking based on the total costs of potential implementation (in AWG per liter), the totes scored first, with costs ranging from 0.125 to 0.300 AWG per liter. (*Evidence 2.3.1*)
- These systems have a relatively high availability in terms of purchasing opportunities compared to other RWH systems. (*Argument 2.4*)
 - According to personal communication with Santa Rosa (2024) and E. Mijts (March 29, 2024) totes can be bought from Santa Rosa by registered farmers. Others can find these totes to be sold at Facebook or through other communication channels. They are discarded IBCs used for chemicals by for example Balashi and WEB. (*Evidence 2.4.1*)
 - The MCA score for accessibility of material required for implementation is a 6, however, none of the other RWH systems have scored higher than a 7. Which makes this system second best on the ranking for accessibility of material. (*Evidence 2.4.2*)
 - There is already a company present on the island that produces aluminum rain gutters and has the option of installment included (I4L, personal communication, March 21, 2024). (*Evidence 2.4.3*)
- Communication errors in pricing and lack of information on the location of purchase is confusing for the community. (*Argument 2.5*)
 - During the farm visits, different answers were given to the question what the price of the totes was. Santa Rosa has provided an overview of the costs through personal communication; however, these do not match the prices mentioned by the farmers and households. (*Evidence 2.5.1*)
 - Prices and/or costs are not mentioned on Santa Rosa's website or Facebook page, posing a challenge for individuals to determine the costs associated with implementing RWH systems. (*Evidence 2.5.2*)
- A combination of totes with rain gutters would facilitate not only getting rid of the nuisance that rainfall can cause, but also create an efficient use for the water. Nuisances caused by rainfall are for example overflowing or damaging property, roof leaks, and slippery surfaces. (*Argument 2.6*)
 - RWH systems improve sustainability on the island. A study by Rahman et al. (2014), states that rainwater harvesting is the most sustainable method for water supply. (*Evidence 2.6.1*)
 - According to the Departamento Meteorologico Aruba (2020), the average rainfall between 1981-2010 was 471,7 mm per year. This is a big amount, considering that Aruba faces challenges to water scarcity (Van Sambeek et al., 2000). As calculated by Montoya Rodriguez (2024), the annual amount of rainfall in Aruba is an estimated seven times the amount of water produced yearly by WEB. This highlights the urgency of sustainable water management practices. (*Evidence 2.6.2*)
 - Nuisance of water falling from your roof, mentioned by two interviewees "but they go ah I just want to get rid of the water. And they have the problem with the water" (I4L, personal communication, March 21, 2024) and "Because even if you're not capturing it like here and it goes off a flat roof, it can become a huge splash and a whole mess. Or it can overflow certain pieces of the garden. So the, uhm, I should call it avoiding

disturbances ... Both of the roof and the garden and how the garden flows to the street. You don't want your own house to be flooded" (I1L, personal communication, March 13, 2024) (*Evidence 2.6.3*)

Advice 3: Santa Rosa is recommended to improve RWH methods for agricultural or other high-volume water consumption practices by increasing accessibility and providing knowledge on larger storage volumes, such as the 3000-8000L dark tanks and other techniques.

They should facilitate the implementation of larger storage volumes, such as 3000-8000L dark tanks or a use of communicating vessels technique in combination with preferably aluminum rain gutters for farming practices or other practices that have large scale water use. Efforts should be made in further increasing the availability of these tanks, transparency on prices and informing about locations to purchase the tanks as well as the (aluminum) rain gutters. (*Advice 3*)

- Farming practices generally use more water than an average household. Therefore, these stakeholders would benefit by integrating a bigger storage volume with rain gutters. (*Argument 3.1*)
 - A communicating vessels technique could be used to store more water with implementation of totes. Totes are efficient and feasible according to the MCA. When using the communicating vessels technique, storage volume increases, as several totes are connected, and the water will then balance out to the same level in all the containers (De Luca & Faella, 2017) (*Evidence 3.1.1*)
 - The 3000-8000L dark tanks can store significantly more water than totes (1000L). (*Evidence 3.1.2*)
 - The larger tanks are already dark colored; therefore, no painting is required to prevent algae growth. Their lower MCA score on initial costs, accessibility of knowledge and ease of implementation compared to totes can be explained by bigger tanks being less common among small-scale water users, as they have no need for such large volumes. A solid foundation has to be constructed (The Caribbean Environmental Health Institute, 2009), however this also has to be done for totes. (*Evidence 3.1.3*)

Advice 4: Santa Rosa is recommended to provide more information on the economic viability of RWH systems.

The department can make the implementation of RWH more economically attractive for their stakeholders; specifically, for farmers regarding collection tanks and households for implementation in their garden. There is no easily accessible data available on the possible implementation of the different RWH systems in Aruba. Rosa could be the one that provides a clear overview of all the costs and benefits. (*Advice 4*)

- There is a lack of knowledge about the possible implementation of RWH systems, and the associated costs and benefits. People have no idea about the costs, and they cannot easily

estimate it themselves, because there is a lack of accessible data to make an accurate estimation. *(Argument 4.1)*

- As stated by an engineer: “So that balance I know, again and this is one of the issues, is all of this is completely opaque, not transparent, we don't know. Because those costs are buried within layers and layers of different other tasks that people are doing.” Clear information about the costs and benefits is not available (I5L, personal communication, March 21, 2024). *(Evidence 4.1.1)*
- Especially lack of information on the monetary benefits of implementation of various RWH systems in Aruba. Additionally, the costs of implementing agroforestry, check dams, and water pit/reservoirs are not presented in monetary values. *(Evidence 4.1.2)*
- The perspectives of the community on the economic viability of RWH systems. These systems are perceived as expensive. *(Argument 4.2)*
 - The transcription and coding of the interviews have identified the codes ‘money’ and ‘lack of economic viability’. *(Evidence 4.2.1)*
 - For other systems, prices on RWH systems are clear, but too expensive. As said by a governance consulting engineer: “There's innovation. So, I'm seeing in the stores more modern storage compartments, which is a very interesting development, but they're very expensive I found. So, I think they're too expensive, perhaps.” (I1L, Personal communication, March 13, 2024). *(Evidence 4.2.2)*
- A lot of people define WEB as costly and are more inclined to find an alternative. WEB has control over the pricing because it is a monopoly. If sources are diversified and WEB would breakdown, there will be more water resources when a crisis happens. Rainwater can be used for non-potable uses, such as showering, to limit the use of freshwater. *(Argument 4.3)*
 - Based on the results of the survey on Rainwater Harvesting in Aruba [Unpublished raw data], the biggest reason for implementation of RWH systems is reducing the water bill from WEB (Diaz-Maroto Knöfler et al., 2024). *(Evidence 4.3.1)*
 - As stated by a wastewater manager for international companies: “I only think that the people are... They have other problems, they say maybe, but the water is a problem for everybody, and if you have your bill, your water bill, you see, it's really expensive water.” (I7L, personal communication, March 25, 2024). *(Evidence 4.3.2)*

4.3 Methodology

Given the knowledge gap surrounding RWH systems in Aruba, the methodological framework is underpinned by Grounded Theory (Bryman, 2012). This approach allows for the simultaneous collection and analysis of data. Due to the lack of data availability, the research plan is structured as follows: The results has two sections, one for compensating the knowledge gap and another that displays collection of new data from the field.

Over a period of ten weeks, multiple data collection techniques were utilized, including a systematic literature review, content analysis of existing data, anonymous surveys, and semi-structured interviews. Of these, semi-structured interviews emerged as the primary source of data, focusing on stakeholders' perspectives (households, farmers, and small businesses) concerning RWH implementation and its developmental implications. These were chosen due to their relevance to the local scale and recommended by the consultancy client. Initiating contact with stakeholders involved organized visits in collaboration with Santa Rosa, facilitating community engagement and fellowship. A small sample was drawn from existing contacts, using a snowball approach (Naderifar et al., 2017). The semi-structured interviews followed predefined guidelines but allowed interviewees to deviate from these guidelines and perspectives on the topic (Bryman, 2012). Moreover, these visits enlarged the material for the content analysis that has allowed a better understanding regarding water collection and consumption on the island. Consent was secured from all interviewees, and recordings were transcribed using Word transcriber software. Additionally, a survey was utilized to gather data from households, farmers, and small businesses.

The interview transcripts underwent coding using NVivo software (Lumivero, 2023), facilitating the identification of key concepts and themes to ensure intercoder reliability. These codes are given in Table 9. A thematic analysis was subsequently done to identify patterns, which were then situated within established theoretical frameworks, thereby enriching our interpretation. This methodological approach gave an understanding of the perspectives held by the Aruban community regarding RWH implementation, effectively addressing the third research question: *What is the perspective of the stakeholders regarding implementation and adoption of RWH systems and how does this influence current development?* 10 semi-structured interviews are conducted as a sample for different kinds of stakeholders: households (4), farmers (4) and small businesses (2). In Appendix II the transcribed and fully coded interviews and the questions used as guidelines can be found.

Prior to conducting the CBA and MCA, an examination of existing and potential innovations in RWH systems was conducted, offering insights for the first research question: *What innovations exist in RWH systems and how do they work?* A CBA was selected as the optimal method for evaluating the economic viability of potential RWH system implementation (Table 6). CBA, as a systematic process, enables the assessment of financial costs and benefits associated with such initiatives (Hayes, 2024). It must be noted that some costs are converted into AWG, using the conversion of 1 US dollar being equal to 1,80 AWG (WorldData, 2024). Additionally, assumptions were made regarding the monetary benefits of bioswales, check dams, agroforestry, and water pit/reservoirs. There is too little information available about the monetary benefits of these RWH systems. Besides that, it is likely that if a stakeholder buys a large quantity, a lower unit cost could be negotiated, however no bulk purchase discount is assumed in this

analysis. Where possible, the monetary value was assigned to the factors, complementing the multi-criteria analysis (MCA). An MCA was chosen to evaluate the feasibility and efficiency of prospective business innovations within the Aruban context, as only partial data is available, and the criteria are difficult to quantify. It included establishing a framework for integrating various decision criteria within quantitative analysis, without assigning a monetary value to every factor. The objectives and criteria were obtained during the initial literature review. Amos et al. (2018) mentioned the environmental impacts and economic viability, including maintenance, and initial costs. A review on selection frameworks for RWH systems in arid and semi-arid ecosystems by Ahmed et al. (2023) used volume and the accessibility of materials and knowledge. System capacity of efficient use of water is an important aspect of RWH systems according to Toosi et al., (2020), this includes the volume and the efficient use of rainfall. The ease of implementation, ease of maintenance, and lifespan criteria were mentioned by Infrastructure Australia (2021). Then weights were assigned to criteria based on their relevance to Aruba's specific circumstances, reflecting the preferences of the decision makers, which is important for the MCA (Sijtsma, 2006), followed by the ranking of each system (Taherdoost & Madanchian, 2023). The weights were determined by matching criteria with codes, considering both frequency of code mentions and polarity (whether positive or negative). An explanation of the process of assigning weights is given in Appendix V. Subsequently, a radar diagram was constructed to visually represent the outcomes, as seen in Figures 8 and 9. This structured approach aims to identify energy-efficient solutions aligned with Aruba's socio-economic conditions, addressing the second sub question.

4.4 Results and Evidence

This section is a summary of all the material collected during the research. It explains the existing RWH systems, how they work, and goes further in depth on the efficiency and feasibility of RWH systems through analyses on data collected in the field combined with literature. The results are presented per research question to have more clarity of the reasoning behind this process.

4.4.1 What innovations exist in RWH systems and how do they work?

To answer this question, a systematic literature review was conducted in combination with literature added while visiting farmers associated with Santa Rosa. Most of the literature is not related to the island but categorized according to similar indicators such as climate or regional position (32 literature identified Caribbean or individualized systems (Appendix II)). Specifically, six sources are related to Aruba. The solutions identified with this method are suitable for the island in terms of climate, but some are possibly not applicable due to the development state of the current primary sector.

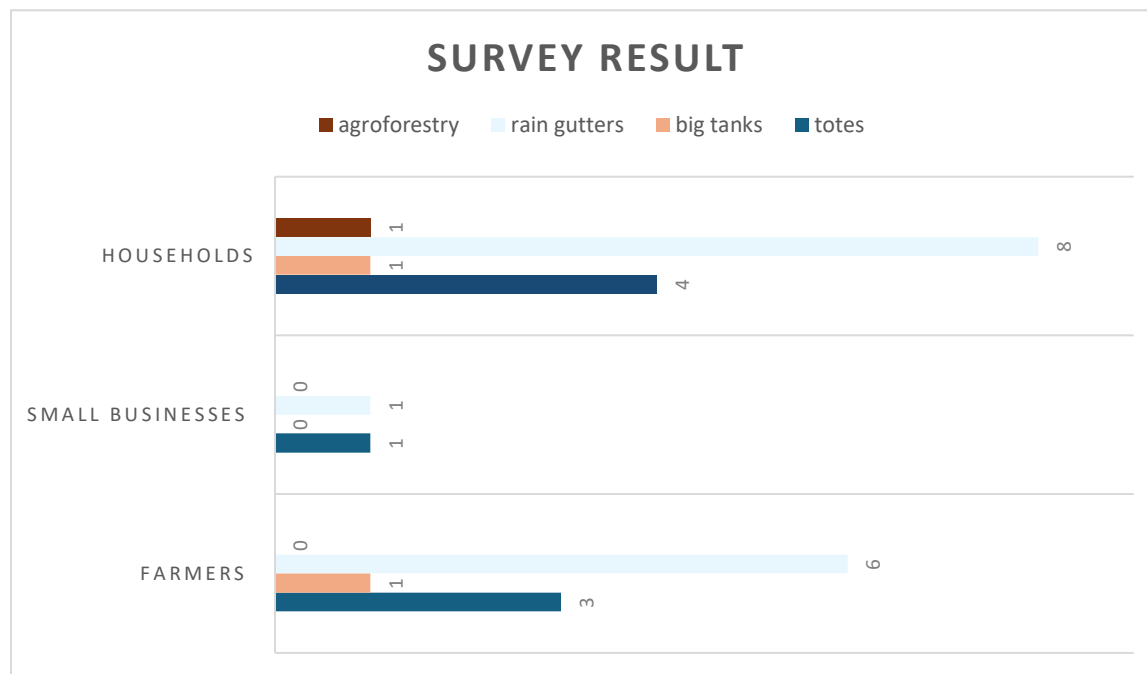


Figure 7: This shows which RWH systems are used by the stakeholders (households, small businesses and farmers). The numbers behind the bars correspond to the number of respondents of that stakeholder group that has that specific system implemented. For example, eight households have rain gutters. From this graph, the extent to which RWH are already present on the island can be seen.

The solutions that have been identified mostly from the literature review, and confirmed from the content analysis, are Demilunes, Bioswale and Check dams. All the solutions, from this theoretical analysis and the field research conducted (more detail: glossary in Appendix). Additionally, the visits to the farms and households that have implemented RWH systems, have shown which systems are already present. This research includes the traditional systems; regenbak, totes, 3000-8000L tank, rain gutters (PVC and aluminum), agroforestry, water pits/reservoirs. Moreover, the survey has allowed for collection of data regarding the presence of these systems on the island.

4.4.2 How efficient are these innovations in RWH systems?

The results are a combination of the systematic literature review, MCA and CBA. The literature used for these results focuses mostly on examples and guidelines on how to test effectiveness of these types of systems in a lack of data situation.

MCA results

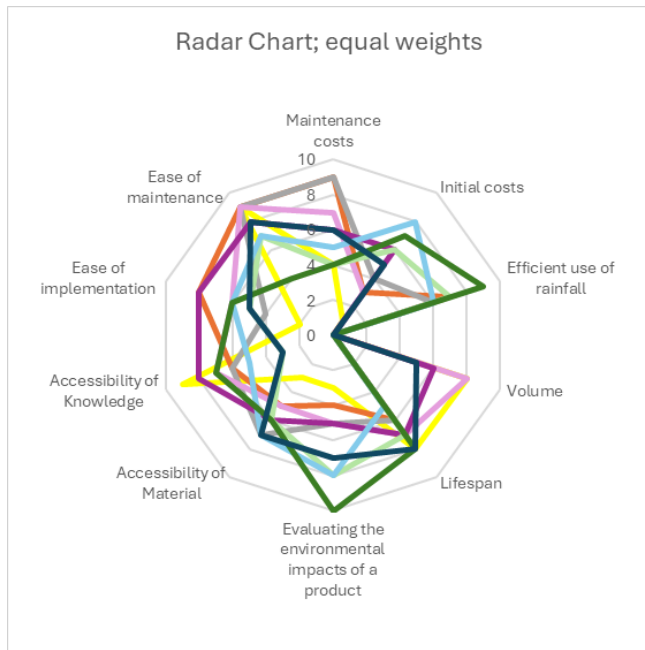
Rankings for both ,equal weights and for weights based on the Aruban community, were established. The total ranking and scores for both, including and excluding the communal weightings, are displayed in Table 5. These rankings indicate which system performs best overall, according to the criteria considered. In the weight-based ranking, the totes achieve the highest score, followed by agroforestry. When equal weights are applied, the ranking of the totes and agroforestry is reversed. The regenbak ranks the lowest, with the bioswale following, and the water pit/reservoir taking the third-to-last position in both rankings. In both rankings, rain gutters made from aluminum rank higher than those made from PVC pipes. The most significant divergence is seen in the ranking of the large PVC tank. Ranking 2 assigns it a lower rank compared to ranking 1. In terms of initial costs, which were prioritized by the Aruban community, aluminum gutters and large tanks both scored 5 points lower than check dams. Across the list of criteria, aluminum gutters and large tanks have similar scores, differing by no more than 1 point, except for ease of implementation, where aluminum gutters have an advantage by 2 points due to the possibility of having them installed by a specialized party. Check dams generally receive lower scores across other criteria.

Figure 8 and 9 represent radar diagrams for the RWH systems made with the scores for each criterion. Figure 8 shows how agroforestry excels in efficient use of rainfall and has the lowest environmental impacts. The dark purple line of the totes lays more to the border of the circle, scoring higher across all of the criteria. The yellow line, representing the regenbak, has a peak at ease of maintenance and accessibility of knowledge, but scores low in other areas. Figure 9 reveals outliers in the scores for initial costs of check dams and maintenance costs of rain gutters made from PVC and aluminum. Agroforestry demonstrates high scores across multiple criteria, in particular initial costs and efficient use of rainfall. Similarly, the totes score high across all criteria except for the environmental impacts.

Table 5: Ranking results of MCA. The score represents the sum of the scores assigned for every criterion per RWH system. The scores per criterion for ranking 2 were multiplied by the weights based on preferences of the Aruban community. These preferences are determined using corresponding codes for the criteria. Out of these final scores two rankings were created. RWH systems with an identical final score (rain gutters made from aluminum, 3000-8000L PVC tank, and check dams) share the same rank. The scores for both rankings cannot be compared, due to ranking 2 being weighted, and ranking 1 not. What can be compared is the ranking itself, so the specific place the RWH system has in the rankings.

Ranking 1	Score	Based on equal weights	Ranking 2	Score	Based on weights including the preferences of the Aruban community
1	61	Agroforestry	1	381	Totes (IBCs)
2	60	Totes	2	371	Agroforestry
3	57	Rain gutters made from aluminum	3	362	Rain gutters made from aluminum
3	57	3000-8000L PVC tank	4	359	Check dams

3	57	Check dams	5	362	Rain gutters made from PVC pipes
4	56	Rain gutters from PVC pipes	6	358	3000-8000L PVC tank
5	54	Water pit/reservoir	7	337	Water pit/reservoir
6	53	Bioswale	8	326	Bioswale
7	47	Regenbak	9	287	Regenbak



— Regenbak
— Rain gutters made from aluminum
— Rain gutters from PVC pipes
— Big PVC Tank
— Totes (IBC's)
— Bioswale
— Check Dams
— Agroforestry
— Water pit/reservoir

Figure 88; Radar Diagram with MCA results based on equal weights for the criteria. For both radar diagrams the criteria are placed on the outside of the diagram. The inside axis displays the values of the scores that the RWH systems received. A higher score (1-10) equals better performance on that criterion. The lines in different colors correspond with the analyzed RWH systems.

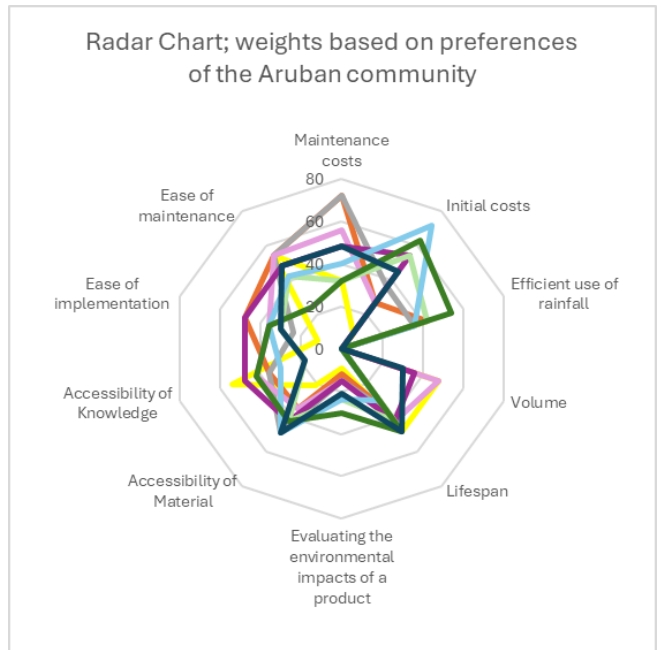


Figure 97; Radar Diagram with MCA results, the weights of the criteria based on preferences of the Aruban community. These preferences are determined using corresponding codes for the criteria. The inside axis displays the weighted score (0-100), thus the score multiplied by the weight assigned to the criterion. A score of 80 on this diagram corresponds with a score of 10 for Figure 8. The lines in different colors correspond with the analyzed RWH systems.

CBA results

Table 6; CBA results, showing the total costs of implementation of various RWH systems based on initial investment and operation & maintenance costs, both placed in the first column. Initial investment involves the starting capital required for the implementation of a system or project (Mitchell, 2024). The analyzed RWH systems are in the first row. The total monetary costs are converted to the same or similar unit to be able to compare the RWH systems. For example, the initial investment of a

'Regenbak' is 1.33 AWG per gallon which is converted to 0,35 AWG per liter (1 gallon = 3.785 liters (UnitConverters, 2024)). Thus, the initial investment of a 'Regenbak' is 1.33 AWG divided by 3.785 liters resulting in 0.35 AWG per liter.

	Regenbak (Cistern)	Rain gutters made from aluminum	Rain gutters made from PVC pipes	Big PVC tank	Totes (IBC's)	Bioswale	Check dams	Agroforestry	Water pit/reservoir
Initial investment	1,33 AWG per gallon	50 AWG per meter, including installation. 40 AWG per meter, excluding installation	90.95 AWG per 4 meters. However, material for connecting the separate gutters also has to be bought (35.36 AWG per gutter connection)	1000 – 1500 AWG per tank (3000 – 8000 liter)	75 – 150 AWG per tote (1000 liter)	104,40 AWG per linear ft for 9-16 ft wide patches, which is 32.04 AWG per m for 2.7 to 4.9 m wide patches	Preparation costs. Cost-effectiveness increases with lower height, larger number of check-dams is cheaper	Costs include ground preparation and planting crops	Costs of excavation, dependent on size of reservoir/pit
Operation & Maintenance (O&M) costs	Costs of maintenance can include repairing of cracks and re-coating the inside of the tank to prevent cracking and leakage	Smooth metal has higher runoff coefficients, we need less maintenance, due to less sediment accumulation	There is no need to regularly clean the gutters to reduce debris collection	Most PVC tanks are already dark colored. Therefore, no painting is required.	To prevent the tote from algae growth, it is advised to paint the outside of the tote in darker colors. This can be achieved with any dark-colored PVC paint, prices typically ranging from 50 AWG to 150 AWG	7.76 AWG per square ft, corresponding with 0.72 AWG per square meter	The sediment load must be removed after rainfall. Additionally, check dams less than 2 meters high have insignificant maintenance costs	Maintenance costs are expressed in time, as maintaining any type of garden costs time	Dependent on the size
Total costs	0.35 AWG per liter + O&M costs	40 AWG per meter or 50 AWG per meter + O&M costs	22.74 AWG per meter + 35.36 per gutter connection every 4 meters)	0.188 per liter (8000-liter tank) - 0.330 per liter (3000 liter tank)	0.125 – 0.300 AWG per liter	32.04 AWG per meter for 2.7 to 4.9 meter wide patches + 0.72 AWG per square meter	Preparation costs + O&M costs	Ground preparation and planting crops + O&M costs	Costs of excavation + O&M costs

Table 7: Rankings made based on the monetary values given in Table 6, however the monetary values go per different unit. Therefore two rankings are created. Ranking 1 is based on total costs in AWG per liter. Ranking 2 is based on total costs in AWG per meter.

Rank	1: Based on total costs in AWG per liter	2: Based on total costs in AWG per meter
1	Totes (IBC's)	Bioswale
2	Big PVC tank	Rain gutters (Aluminum)
3	Regenbak (Cistern)	Rain gutters (PVC)

The costs of the potential implementation of RWH systems in Aruba are shown in Table 2. Most costs are shown in monetary values; however, the costs of the potential implementation of check dams, agroforestry, and water pit/reservoir are not expressed in monetary values. For example, the operation & maintenance costs of an agroforestry are expressed in time, as time is considered as costly (Oxley & Baete, 2012). However, if time is not considered as costly, agroforestry is one of the cheapest RWH systems to implement.

Information about the monetary benefits of implementing the RWH systems is lacking in the CBA, due to the lack of data. As calculated in the paper Montoya Rodriguez (2024), mentioned in the average domestic use for a 4-person household in Aruba is about 21 m³ per month, which is equal to 215.70 Aruban Florin per month (WEB Aruba N.V. | Water- En Energiebedrijf Aruba N.V., 2024a). At the same time, the minimum wage in Aruba is 1893.40 Aruban Florin per month (Government of Aruba, 2023), which means that only the cost of water is already 11.4% of the monthly income for people receiving the minimum

wage. After having implemented RWH systems, there will be a decrease in the amount of water needed from WEB, which will decrease the monthly water bill. The exact monetary benefit depends on several factors, such as property area, storage capacity, and rainfall duration.

4.4.3 What is the perspective of the stakeholders regarding implementation and adoption of RWH systems and how does this influence current development?

The results from the coding used the most are the ones relating to our research, hence energy, resources, business and innovation. Economic viability within the limitation of implementation has been of great resource as well as the opinion on all the present rainwater harvesting systems such as rain gutters (widely accepted but mostly used to reduce disturbance) or agroforestry; most of our interviewees have identified the already present systems on the island as positive. We have collected a lot of opinions on governmental opinion and implementation that have been further used in the paper by Negrini (2024).

Table 8; Table with the number of the interviewee, a description of the interviewee role, type of personal communication and date. The citation used throughout the report indicates the interviewee number and “L” clarifies that these interviews correspond to the local level fieldwork. For context, all stakeholders were registered with Santa Rosa or knew about the department. Seven out of ten of the interviewees have RWH in place either in their houses or farm. Of the three that did not have a RWH, two are in commercial farms and use hydroponics and the third one focuses on agroforestry, proved by literature review to be a RWH system but not identified by the subject as such.

Interviewee n ^o	Role	Type of personal communication	Date
Interview 1L	Governance consulting engineer	Interview	13/3/2024
Interview 2L	Retired teacher	Interview	15/3/2024
Interview 3L	Elaborated product sold in small businesses	Interview	15/3/2024
Interview 4L	Rain gutter company	Interview	21/3/2024
Interview 5L	Professor and engineer	Interview	21/3/2024
Interview 6L	Retired businessman, commercial hydroponic farm	Interview	22/3/2024
Interview 7L	Wastewater manager for international companies	Interview	25/3/2024
Interview 8L	Syntropic forest implementation business	Interview	25/3/2024
Interview 9L	non-producing farmer	Interview	26/3/2024
Interview 10L	Commercial Hydroponics farmer	Interview	26/3/2024

Table 9: Table with codes used to analyze the transcripts of the interviews in NVIVO. The thematic analysis of the interviews gave a layered organization of the local RWH systems and the theme relation with the primary sector/sustainability/nature perspectives. The numbers next to the code summarize the number of citations per code. Note that the different layers are not supposed to add up to each other, the classification in a layer depends on the specificity of the citation with L1 being the least specific to L4 most specific. The final set of codes was determined by the group after initially independently coding the interviews.

Code layer 1		Code L2		Code L3		Code L4	
Background	8	Personal occupation	8				

	Knowledge		13				
National level	3						
Personal perspective	Limitation on implementation		26	Lack of knowledge	13		
				Lack of regulation	7		
				Lack of economic viability	15		
				Lack of aesthetic	7		
				No interest in water	4		
				Physical problems	6		
				Opinion		Santa Rosa	5
	Government	12					
	Web	14					
	Community	22	Farmers	3			
			Household	7			
			Business	7			
	Rainwater harvesting system	13	Agroforestry	4			
			Rain gutters	4			
		Regenbak	2				
Reason for implementation		15	Sustainability	11			
			Production	2			
			Money	5			
Solution	Examples		17				
	Innovation		22				
	Failed solutions		4				
	Positive on present solution		10				

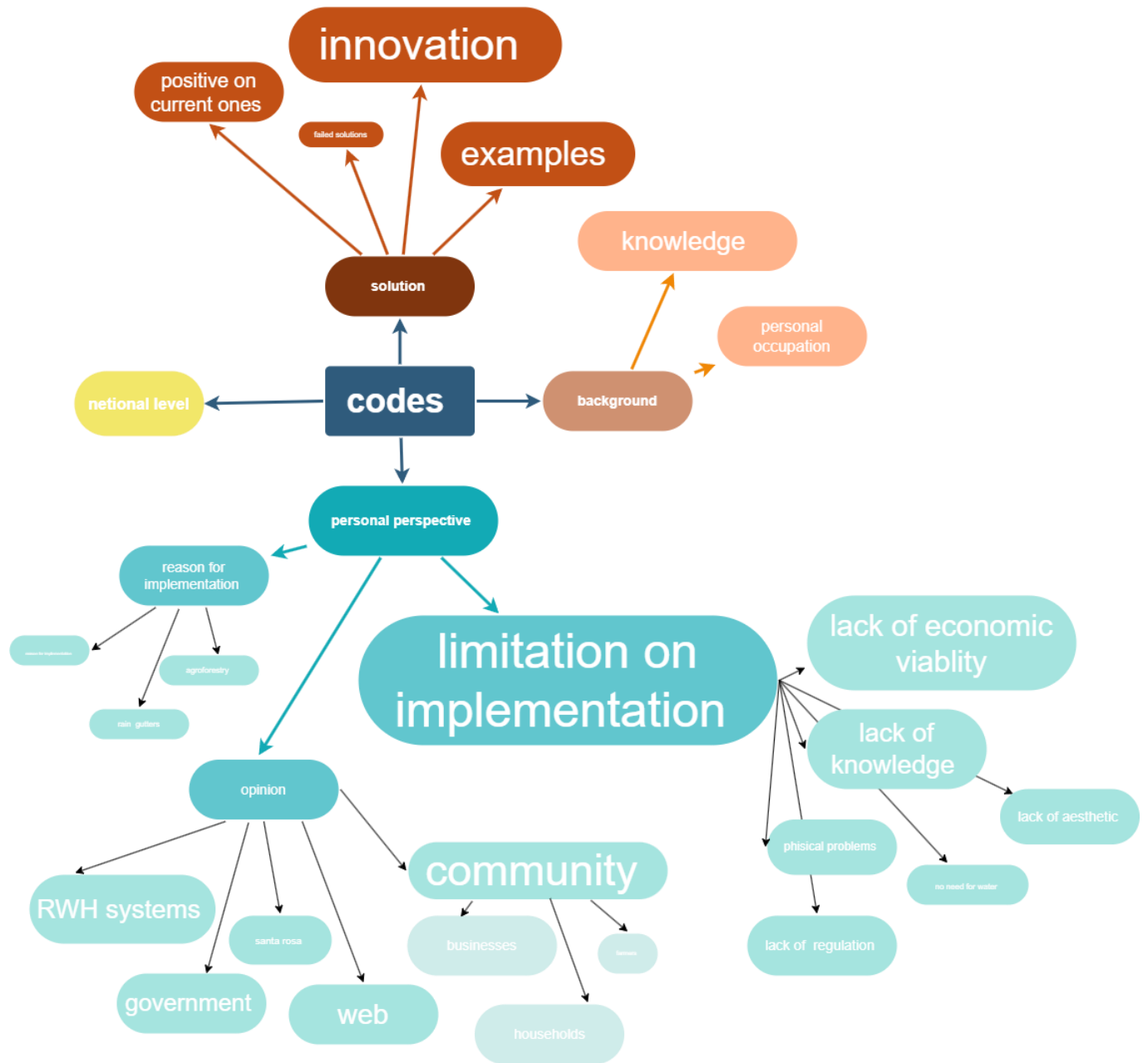


Figure 109: Visual representation of weighted codes. This flowchart represents the codes in a weighted format, with the largest codes being the most frequently mentioned during the interviews. The size has a linear relation with the frequency of the codes. The smaller, less readable boxes contribute to the visual by indicating that these codes were scarcely mentioned by the interviewees. Each color corresponds to the different codes in layer 1. For every subsequent layer, the colors assigned to the codes become lighter, enhancing the visual representation. The aim of the graph is to visually represent the most cited codes. Consequentially, the ones that have received too little will be present but not readable. The whole table of codes is presented in Table 9.

5. Appendices

Glossary

Link to Glossary: [Glossary](#)

Local Level

I. Interviews

Link to transcribed interviews in MS Word; [transcribed interviews](#)

II. Systematic Literature review

Link to the systematic literature review in MS Excel; [Systematic Literature Review in Excel](#)

Link to the systematic literature review in google spreadsheets; [Systematic Literature Review in Spreadsheets](#)

III. Definitions of various RWH systems

Link to document including the definitions of the various RWH systems, corresponding to sub question 1 in google documents; [Glossary](#)

IV. MCA Table;

Link to MCA Table in MS Excel; [MCA Analysis in Excel](#)

Link to MCA Table in google spreadsheets; [MCA Analysis in Google Spreadsheets](#)

V. Methods for MCA Table weights

The weights were determined by an analysis of the interviews conducted by the team for the consultancy project. In these interviews various opinions on the effectiveness and potential improvements were asked, as well as how the interviewee thought the general community of Aruba (of farmers) perceives the benefits and drawbacks of implementing RWH systems, what factors or incentives would motivate them or others to invest in an RWH system and why they themselves did or did not opt to implement an RWH system. The answers showed that economic viability in general was the most important factor, as most interviewees mentioned that current RWH systems maintenance and initial investment were too expensive. In particular, the initial costs were a barrier for many people to implement an RWH system. Therefore, both the maintenance costs are weighed with a with an 8, and the initial costs with a 9. Another insight from the interviews was that people thought implementation would be too much work and/or that they did not have the knowledge to do so. Therefore, both ease of implementation, maintenance and accessibility of knowledge are weighed with a 6. Accessibility of material goes accompanied by both economic viability as more accessible materials are generally cheaper and by ease of implementation. Therefore, this criterion is weighed with a 7, in between scores of both other criteria. The systems' ability of efficient use of the rainfall corresponds with the ability of actual production mentioned in the interviews. Thus, these criteria are weighed with a 6. The criterion of life span corresponds with economic viability and is mentioned often in the interviews. However, the lifespan specifically is not mentioned as the main motivation for implementing an RWH system, resulting in a weighing of 6. Lastly, environmental savings are weighed with a 3. Few interviewees mentioned sustainability as a driver for implementation of RWH systems, and stated from an interview as answer on if sustainability is a motivation for the Aruban society to implement these kinds of systems: " few Arubans would say it's sustainable". A Table with weights is displayed below.

Objectives	Sub Criteria and corresponding code	Weight based on preferences within the Aruban community
Economic viability (Amos et al., 2018)	Maintenance costs (<i>corresponding with code in L3; 'Money' as reason for implementation</i>)	8
	Initial costs (<i>corresponding with code in L3; 'Money' as reason for implementation</i>)	9
System Capacity of efficient use of water (Toosi et al., 2020)	Efficient use of rainfall (<i>corresponding with code in L3; 'Production' as reason for implementation</i>)	6
	Volume (Ahmed et al., 2023) (<i>corresponding with code in L3; 'Production' as reason for implementation</i>)	6
Life Span (Infrastructure Australia, 2021)	(<i>corresponding with code in L3; 'lack of economic viability' as reason for implementation</i>)	6
Environmental impacts (Amos et al., 2018)	Evaluating the environmental impacts (<i>corresponding with code in L3; 'Sustainability' as reason for implementation</i>)	3
Accessibility (Ahmed et al., 2023)	Accessibility of material	7
	Accessibility of knowledge (<i>corresponding with code in L3; 'lack of knowledge'</i>)	6
Ease of Implementation (Infrastructure Australia, 2021)	(<i>corresponding with code in L2; 'Limitation on implementation'</i>)	6
Ease of maintenance (Infrastructure Australia, 2021)	(<i>corresponding with code in L2; 'Limitation on implementation'</i>)	6

VI. CBA Table

The CBA Table with the sources included;

	Regenbak (Cistern)	Rain gutters made from aluminum	Rain gutters made from PVC pipes	Big PVC tank	Totes (IBC's)	Bioswale	Check dams	Agroforestry	Water pit/reservoir
Initial investment	1.33 AWG per gallon (The Caribbean Environmental Health Institute, 2009)	50 AWG per meter, including installation. 40 AWG per meter, excluding installation (I4L, personal communication, March 29, 2024)	90.95 AWG per 4 meters (Kooyman, n.d.). However, material for connecting the separate gutters also has to be bought (I4L, personal communication, 21 March, 2024). The price of a gutter connector	1000 – 1500 AWG per tank, with a volume ranging from 3000 liter to 8000 liter (Santa Rosa, 2024)	75 – 150 AWG per tote, with a volume of 1000 liter (Santa Rosa, 2024)	104.40 AWG per linear ft for 9-16 ft wide patches, which is 32.04 AWG per m for 2.7 to 4.9 m wide patches (Wright et al., 2015)	Preparation costs. Cost-effectiveness increases with lower height, larger number of check-dams is cheaper (Abbasi et al., 2020)	Costs include ground preparation and planting crops (Godsey, L. D., 2010)	Costs of excavation, dependent on size of reservoir/pit

			is 35.36 AWG (Kooyman, n.d.)						
Operation & Maintenance costs	Costs of maintenance can include repairing of cracks and re-coating the inside of the tank to prevent cracking and leakage (Austin, 2017)	Smooth metal has higher runoff coefficients, we need less maintenance, due to less sediment accumulation (The Caribbean Environmental Health Institute, 2009)	There is no need to regularly clean the gutters to reduce debris collection (The Caribbean Environmental Health Institute, 2009)	Most PVC tanks are already dark colored. Therefore, no painting is required (Santa Rosa, 2024)	To prevent the tote from algae growth, it is advised to paint the outside of the tote in darker colors (IBC Totes Authority, 2023 and Kooyman, 2024). This can be achieved with any dark-colored PVC paint, prices typically ranging from 50 AWG to 150 AWG (Kooyman, 2024)	7.76 AWG per square ft, corresponding with 0,72 AWG per square meter (Osouli et al., 2017)	The sediment load has to be removed after rainfall (Abbasi et al., 2020). Additionally, check dams less than 2 meters high have insignificant maintenance costs (Hassanli & Beecham, 2013)	Maintenance costs are expressed in time, as maintaining any type of garden costs time (Godsey, L. D., 2010)	Dependent on the size
Total costs	0.35 AWG per liter + O&M costs	40 AWG per meter or 50 AWG per meter + O&M costs	22.74 AWG per meter + 35.36 per gutter connection every 4 meters)	0.188 per liter (8000 liter tank) - 0,330 per liter (3000 liter tank)	0.125 – 0.300 AWG per liter	32.04 AWG per m for 2.7 to 4.9 m wide patches + 0,72 AWG per square meter	Preparation costs + O&M costs	Ground preparation and planting crops + O&M costs	Costs of excavation + O&M costs

VII. Advice out of the scope of RWH

Link to Advice out of the scope of RWH systems in MS Word; [Advice out of the scope of RWH.docx](#)

Link to Advice out of the scope of RWH systems in Google Docs; [Advice out of the scope of RWH in Google docs](#)

National Level

VIII. Systematic Literature review

[National level systematic literature review](#)

IX. Survey Questions

[National level survey questions](#)

X. Survey responses raw data

[National level raw survey data](#)

XI. Interview questions

[National level interview questions](#)

XII. SWOT analysis extended explanations

Strengths

One of the identified environmental strengths of RWH implementation is acquired through the implementation of RWH structures in urban areas. Implementing urban RWH structures could shift the focus away from and decrease the pressure on natural RWH systems such as *rooien* and *tankis*, further increasing the infiltration rate and recharge of groundwaters. Another identified environmental strength of RWH implementation is that rainwater is of better quality for gardening and other agricultural practices, leading to better growth of plants.

The socio-economic strengths of RWH implementation include a lower water bill, less dependency on the desalination industry and a broader supply of water on the island. In the survey, 47 out of 101 respondents mentioned a lower water bill, saving money and less dependence on WEB as benefits of implementing RWH. A broader water supply, despite not being mentioned by the survey's respondents, is a clear strength of the water supply on the island, since RWH would add resilience in the water supply and increase water security.

The political strengths follow along the socio-economic path, with RWH allowing for a less vulnerable, decentralized water supply, aligning with the government's goals for sustainable development on the island.

Because of the improved water quality for plants and reduced water bills, RWH implementation allows for a possibility for local food production to increase. This is directly related to the goals of our client, as Santa Rosa aims to encourage locally produced food, relying solely on the island's local farmers (Santa Rosa, n.d.).

Weaknesses

The environmental weakness of RWH implementation is the lack of infiltration into the soil to recharge groundwaters. This is the case when the RWH systems. Like *tankis*, have impermeable surface or bottoms, as mentioned by DOW as a problem. The socio-economic weakness of RWH implementation is the short-term economic loss due to investment in RWH systems. This is, however, only a temporary loss, as it has been identified that RWH systems can lower your water bill (see local level CBA). The political weaknesses of RWH implementation includes the extensive time and bureaucracy needs for the implementation process of RWH. Lastly, focusing solely on RWH implementation may overlook other possibilities of water reuse on the island, thus the sole implementation of RWH as an extra water supply may be a weakness.

Opportunities

There are many opportunities regarding RWH implementation in Aruba. Firstly, from an environmental perspective, the annual rainfall volume is large enough to supply the whole island (see Evidence 1.1.1 of the national level), RWH structures can help in flood mitigation for both rural and urban areas, and there are already existing natural RWH structures on the island that can act as a base for new innovations. Secondly, from a socio-economic perspective, the already existing urban and natural RWH structures on the island can be used as examples to achieve social awareness. This may further create a positive outlook on these systems and foster a will for people to implement such structures themselves. As seen in Figure

6, over 80% of the survey respondents already believe that RWH could be a sustainable water alternative for Aruba. Thirdly, from a political perspective, there is already political support from various governmental departments regarding RWH and a possibility for collaboration between these departments has been identified (see Evidence 4.1.1 of national level). Finally, implementing a legislation in support of RWH implementation would be a significant opportunity to benefit and support a decentralized water supply on the island.

Identifying these opportunities are key in RWH implementation, as a combination of for example governmental buildings with large rainwater capturing possibilities and households with a large demand for water could lead to a unified system where everyone benefits.

Threats

The environmental threats of RWH implementation in Aruba have been identified as the irregular and short rainfall, possible pollution of the existing dams, and the need to work around infrastructure. The infrastructure on the island, as introduced in Argument 2.3 of the .2 (national level), has not been designed for RWH, and thus this may pose as a challenge for RWH implementation as you have to take the already existing infrastructure into consideration. A socio-economic threat that has been identified is the lack of awareness on the benefits of RWH. According to the survey, many respondents expressed a barrier for implementing RWH structures as being the lack of knowledge on how it works, and what to use it for. Thus, to implement RWH, awareness has to be considered. Another socio-economic threat was identified as the high costs of implementing RWH structures. In the survey, 50% of the respondents expressed that they cannot afford installing RWH in their household (see Figure 4). Lastly, a political threat for RWH implementation in Aruba has been identified as the lack of political commitment, time, and resources to implement in legislation. Without political commitment, it is increasingly difficult to implement such practices, and thus political will and commitment is key in the implementation process.

Gantt Chart

This Gantt chart represents the process. Important deadlines, such as the impact deliverable, final report, and reflection are displayed in the Gantt chart. An additional sheet, titled “Appointments”, has been included, to provide a brief overview of the appointments scheduled with potential interviewees or contacts who may offer valuable information.

Link to Gantt Chart:

<https://docs.google.com/spreadsheets/d/1TFx0sch77MsCLVYXGceE6GEr0wf1A5b2P3-la3-Fukl/edit?usp=sharing>

6. References

- Abbasi, S., Vaezin, S. M. H., Samani, A. N., & Bozorg-Haddad, O. (2020). *Spatial Assessing of cost-effectiveness of check-dams in controlling sediment load*. University of Tehran. https://www.researchgate.net/publication/340384306_Spatial_Assessing_of_cost-effectiveness_of_check_dams_in_controlling_sediment_load_Case_study_Kond_watershed
- Acevedo, D., Mijts, E., John, N., El Bouzidi, M., & van Der Bruggen, B. (2023). Perspective in resource recovery from reverse osmosis brines: the case for sustainable seawater refineries for small islands. *Journal of Chemical Technology & Biotechnology*, 98(10), 2359-2364.
- Agarski, B., Vukelić, D., Mićunović, M. I., & Budak, I. (2019). Evaluation of the environmental impact of plastic cap production, packaging, and disposal. *Journal of Environmental Management*, 245, 55–65. <https://doi.org/10.1016/j.jenvman.2019.05.078>
- Agoramoorthy, G., Chaudhary, S., Chinnasamy, P., & Hsu, M. J. (2016). Harvesting river water through small dams promote positive environmental impact. *Environmental Monitoring and Assessment*, 188(11). <https://doi.org/10.1007/s10661-016-5640-5>
- Ahmed, S. A., Jesson, M., & Sharifi, S. (2023). Selection Frameworks for Potential Rainwater Harvesting Sites in Arid and Semi-Arid Regions: A Systematic Literature Review. *Water*, 15(15), 2782. <https://doi.org/10.3390/w15152782>
- Amos, C. C., Rahman, A., & Gathenya, J. M. (2018). Economic analysis of rainwater harvesting systems comparing developing and developed countries: A case study of Australia and Kenya. *Journal of Cleaner Production*, 172, 196–207. <https://doi.org/10.1016/j.jclepro.2017.10.114>
- Amos, C. C., Rahman, A., & Gathenya, J. M. (2018). Economic analysis of rainwater harvesting systems comparing developing and developed countries: A case study of Australia and Kenya. *Journal of Cleaner Production*, 172, 196–207. <https://doi.org/10.1016/j.jclepro.2017.10.114>
- Austin, J. (2017). *Tank Coatings and Maintenance* (The SUEZ Canal Company, Ed.) [Slide show; Powerpoint]. <https://www.rusa-or.org/files/4c728ec47/Concrete+%26+Steel+Tank+Maintenance.pdf>
- Batterton, K. A., & Hale, K. N. (2017). The Likert Scale What It Is and How To Use It. *Phalanx*, 50(2), 32–39. <http://www.jstor.org/stable/26296382>
- Beaujon, R. J., & Stuivenberg, P. A. (1948). *De Landswatervoorzieningsdienst*. <https://ia803106.us.archive.org/30/items/BNA-DIG-KOSTBARE-0165-ARUBA-05-LWV/BNA-DIG-KOSTBARE-0165-ARUBA-05-LWV.pdf>
- Benzaghta, M. A., Elwalda, A., Mousa, M. M., Erkan, I., & Rahman, M. (2021). SWOT analysis applications: An integrative literature review. *Journal of Global Business Insights*, 6(1), 54-72. <https://www.doi.org/10.5038/2640-6489.6.1.1148>
- Borst, L., & De Haas, S. A. (2005). Hydrological research Bonaire; a hydrogeological investigation of Bonaire's water system. *Amsterdam: Acacia institute and Vrije Universiteit Amsterdam (VUA)*'.
- Bowling, J., Tattersfield, S., & Darakjian, T. (2011). Triple bottom line assessment of rooftop catchment system. In *UBC Social Ecological Economic Development Studies (SEEDS) Student Report*. University of British Columbia. <https://doi.org/10.14288/1.0108625>

- Boyer, B., Horton, J., Millán, M. F., Grosjean, C. F. R., Arias, R. E., Lopez, E. M., Wrede, P., De Kort, R. E., Ivelisse, J., & Chapman, R. (2020). *Building resilience in Aruba's food security during the COVID-19 pandemic and beyond*. World Bank: Washington D.C
- Bryman, A. (2012). *Social research methods*. Fourth edition. Oxford University press.
- Cook, B.I., Mankin, J.S. & Anchukaitis, K.J. Climate Change and Drought: From Past to Future. *Curr Clim Change Rep* **4**, 164–179 (2018). <https://doi.org/10.1007/s40641-018-0093-2>
- Cortes, F. R. & Mayrhofer, D. K. (2019, October). Cost-Benefit Analysis. The World Bank. GFDRR. https://gps.worldbank.org/sites/gps/files/knowledge_products/2019/CBA%20Technical%20note_IPF.pdf
- Crawford, M. (n.d.). Agroforestry.org - Overstory #242 - What is a forest garden? <https://agroforestry.org/the-overstory/14-overstory-242-what-is-a-forest-garden>
- Curren, R., & Metzger, E. (2017). *Living well now and in the future: Why sustainability matters*. MIT Press.
- Dario. (2022, November 1). *An introduction to Syntropic Agriculture - part 1*. Orto Foresta. <https://www.ortoforesta.it/post/an-introduction-to-syntropic-agriculture>
- De Luca, R., & Faella, O. (2017). Communicating vessels: a non-linear dynamical system. *Revista Brasileira De Ensino De Física*, *39*(3). <https://doi.org/10.1590/1806-9126-rbef-2016-0306>
- Departamento Meteorologico Aruba. (2020). Aruba climatological summary 2020. http://www.meteo.aw/files/Download/aruba_rep_2020.pdf
- Department of Economic Affairs, Commerce and Industry of Aruba. (2018). *Entrepreneurs Development Policy for Aruba*. Aruba Government. <https://www.deaci.aw/wpcontent/uploads/2019/09/Entrepreneurs-Policy-2018-2021.pdf>
- Derix, R. (2016). Landscape series no.6: Inconveniences in the home neighborhood in Aruba. *Spatial and Environmental Statistics - Central Bureau of Statistics (CBS Aruba)*.
- Doten, A. (2020, June 12). *Check Dams: A Simple Method with Compound Results — San Isidro Permaculture*. San Isidro Permaculture. <https://www.sipermaculture.com/blog/check-dams>
- Ekka, S. A., Rujner, H., Leonhardt, G., Blecken, G., Viklander, M., & Hunt, W. F. (2021). Next generation swale design for stormwater runoff treatment: A comprehensive approach. *Journal of Environmental Management*, *279*, 111756. <https://doi.org/10.1016/j.jenvman.2020.111756>
- Everhart, G. J. (2010). *Comparison of Life-Cycle Energy of Water Storage Tanks* [Graduate Thesis, University of Florida]. https://ufdcimages.uflib.ufl.edu/UF/E0/04/25/73/00001/everhart_g.pdf
- Fenner, A. E., Kibert, C. J., Woo, J., Morque, S., Razkenari, M., Hakim, H., & Lu, X. (2018). The carbon footprint of buildings: A review of methodologies and applications. *Renewable and Sustainable Energy Reviews*, *94*, 1142-1152.
- Finneran, N. P. (2017). The materiality of human–water interaction in the Caribbean: an archaeological perspective. *Wiley Interdisciplinary Reviews: Water*, *4*(5), e1235.
- Fletcher, T. D., Andrieu, H., & Hamel, P. (2013). Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. *Advances in Water Resources*, *51*, 261–279. <https://doi.org/10.1016/j.advwatres.2012.09.001>
- Ghimire, S. R., Johnston, J. M., Ingwersen, W. W., & Sojka, S. (2017). Life cycle assessment of a commercial rainwater harvesting system compared with a municipal water supply system. *Journal of Cleaner Production*, *151*, 74–86. <https://doi.org/10.1016/j.jclepro.2017.02.025>

- Godsey, L. D. (2010). Economic budgeting for agroforestry practices. In *AGROFORESTRY IN ACTION*. University of Missouri Center for Agroforestry. <https://centerforagroforestry.org/wp-content/uploads/2021/05/af1006.pdf>
- Hassanli, A. M., & Beecham, S. (2013). *Criteria for optimizing check dam location and maintenance requirements* (Doctoral dissertation, Nova Science). https://www.researchgate.net/profile/Ali-Hassanli/publication/287636490_Criteria_for_optimizing_check_dam_location_and_maintenance_requirements/links/56a6bb6508ae860e0253cf4c/Criteria-for-optimizing-check-dam-location-and-maintenance-requirements.pdf
- Hayes, A. (2024, February 26). *What Is Cost-Benefit Analysis, How Is it Used, What Are its Pros and Cons?* Investopedia. <https://www.investopedia.com/terms/c/cost-benefitanalysis.asp>
- Hofman, C., & Haviser, J. B. (2015). *Managing our past into the future: Archaeological heritage management in the Dutch Caribbean* (p. 356). Sidestone Press.
- Hofman, J. A. M. H., & Paalman, M. (2014). Rainwater harvesting, a sustainable solution for urban climate adaptation? (KfC 142/2014). *KWR Watercycle Research Institute*. <https://edepot.wur.nl/345625>
- Infrastructure Australia. (2021). *Guide to Multi-Criteria Analysis: Technical guide of the Assessment Framework*. ISBN: 978-1-925352-54-2
- Inglese, P., Mondragon, C., Nefzaoui, A., & Sáenz, C. (2017). *CROP ECOLOGY, CULTIVATION AND USES OF CACTUS PEAR*. the Food and Agriculture Organization of the United Nations and the International Center for Agricultural Research in the Dry Area. i7012e.pdf (fao.org)
- Integrated Water Resources Management in the Caribbean: The challenges facing small island developing States. (2014). In GWP Technical Committee. Global Water Partnership. Retrieved April 1, 2024, from https://www.gwp.org/globalassets/global/toolbox/publications/technical-focus-papers/04-caribbean_tfp_2014.pdf
- Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry Systems*, 76(1), 1–10. <https://doi.org/10.1007/s10457-009-9229-7>
- Kenton, W. (2023). *SWOT analysis: How to with table and example*. Investopedia. <https://www.investopedia.com/terms/s/swot.asp>
- Kim, Y., Han, M., Kabubi, J., Sohn, H. G., & Nguyen, D. C. (2016). Community-based rainwater harvesting (CB-RWH) to supply drinking water in developing countries: lessons learned from case studies in Africa and Asia. *Water science and Technology: water supply*, 16(4), 1110-1121.
- Klomp, A. (1981). *Het "oude" Bonairiaanse woonhuis*. Koninklijk Instituut voor Taal, Land- en Volkenkunde. https://www.researchgate.net/publication/47433463_Het_%27oude%27_Bonairiaanse_woonhuis/fulltext/588b714b45851567c93c5846/Het-oude-Bonairiaanse-woonhuis.pdf
- Kooyman. (n.d.). *Eslon Half Round Gutter Type 150 4 m PVC Grey*. https://www.kooymanbv.com/aruba_en/eslon-pvc-half-round-gutter-type-150-4-meter-length-grey100003656.html
- Kravchenko, A.N., Guber, A.K., Razavi, B.S. et al. Microbial spatial footprint as a driver of soil carbon stabilization. *Nat Commun* 10, 3121 (2019). <https://doi.org/10.1038/s41467-019-11057-4>
- Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability (Basel)*, 7(5), 5875–5895. <https://doi.org/10.3390/su7055875>
- Living Soil Aruba - Agro Consultancy. (n.d.). *Living Soil Aruba*. <https://www.livingsoilaruba.com/home>
- Lumivero. (2023). NVivo (Version 14). www.lumivero.com

- Marchena, F. A., & Halman, J. I. (2018). Aruba's desalination's knowledge and experience: Conquering the sea toward desalination's sustainability. *AQUA-LAC*, 10(1), 39–50. <https://doi.org/10.29104/phi-2018-aqualac-v10-n1-04>
- Mark. (2023, October 19). *What is an IBC water tank?* ITP Packaging. <https://itppackaging.com/what-is-an-ibc-water-tank>
- Matos, C., Cabrera, P., Carta, J. A., & Melián-Martel, N. (2024). Wind-Powered Desalination on Islands: A Review of Energy–Water Pathways. *Journal of Marine Science and Engineering*, 12(3), 464. <https://doi.org/10.3390/jmse12030464>
- Mehta, K. P. (2001). Reducing the environmental impact of concrete. *Concrete international*, 23(10), 61–66. <http://ecosmartconcrete.com/docs/trmehta01.pdf>
- Mitchell, C. (2024, February 10). What is an initial investment? Smart Capital Mind. <https://www.smartcapitalmind.com/what-is-an-initial-investment.htm>
- Montoya Rodriguez, Y. (2024) The value of rainwater: The economic viability of rainwater harvesting systems in Aruba, in *Mijts & Ballantyne UAUUCU Student Research Exchange Collected Papers 2024*
- Mukarram, M. M. T., Kafy, A. A., Mukarram, M. M. T., Rukiya, Q. U., Almulhim, A. I., Das, A., ... & Chowdhury, M. A. (2023). *Perception of coastal citizens on the prospect of community-based rainwater harvesting system for sustainable water resource management. Resources, Conservation and Recycling*, 198, 107196.
- Naderifar, M., Goli, H., & Ghaljaie, F. (2017). Snowball sampling: a purposeful method of sampling in qualitative research.,1.(3)4 <https://doi.org/10.5812/sdme.67670>
- National Academies of Sciences, Engineering, and Medicine (U.S.). (2016). Using graywater and stormwater to enhance local water supplies: an assessment of risks, costs, and benefits. *The National Academies Press*. <http://site.ebrary.com/id/11235781>
- Olesen, V. (1994). Feminisms and models of qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), in: *Handbook of qualitative research* (pp. 158–174). Sage Publications, Inc
- Osouli, A., Bloorchian, A. A., Grinter, M., Alborzi, A., Marlow, S. L., Ahiablame, L., & Zhou, J. (2017). Performance and cost perspective in selecting BMPs for linear projects. *Water*, 9(5), 302. <https://doi.org/10.3390/w9050302>
- Oxley, D., & Baete, G. (2012, September). Time is money. *Principal Leadership*, vol. 13, no. 1. National Association of Secondary School Principals. https://go-gale-com.proxy.library.uu.nl/ps/retrieve.do?tabID=T002&resultListType=RESULT_LIST&searchResultsType=SingleTab&retrievalId=c31e2487-8b5e-455e-b8bb-ae2a03808879&hitCount=1&searchType=AdvancedSearchForm¤tPosition=1&docId=GALE%7CA373033296&docType=Article&sort=RELEVANCE&contentSegment=ZONE-MOD1&prodId=AONE&pageNum=1&contentSet=GALE%7CA373033296&searchId=R2&userGroupName=utrecht&inPS=true
- P. Sejersen. (2016). Comparative Life Cycle Assessment of a PVC-U rain gutter system versus a system made from galvanized steel. *Plastic Pipes Conference* (18th ed.). TEPPFA, Berlin.
- Pal, D., Galelli, S., Tang, H., & Ran, Q. (2018). Toward improved design of check dam systems: A case study in the Loess Plateau, China. *Journal of Hydrology*, 559, 762–773. <https://doi.org/10.1016/j.jhydrol.2018.02.051>

- Pal, K. (2023). *BioSwales (SUDS): Solution to Urban Stormwater Management | Meristem Design*. Meristem Design. <https://www.meristemdesign.co.uk/blog/rain-gardens-and-bioswales-suds-solutions>
- Patrick, S. (2005). *Practical guide to polyvinyl chloride*. iSmithers Rapra Publishing. (p. 3)
- Peters, E. J. (2016). Success and success factors of domestic rainwater harvesting projects in the Caribbean. *Journal of Sustainable Development*, 9(5), 55. <https://doi.org/10.5539/jsd.v9n5p55>
- Rahman, S., Khan, M. T. R., Akib, S., Din, N. B. C., Biswas, S. K., & Shirazi, S. M. (2014). Sustainability of rainwater harvesting system in terms of water quality. *The Scientific World Journal*, 2014. 10.1155/2014/721357
- Rainwater Equipment (n.d.) *Poly & Metal water tanks | Rainwater tanks | Water storage tanks | Fire protection water tanks*. Rainwater Equipment. <https://rainwaterequipment.com/water-tanks/>
- Reijtenbagh, R. (2010). Minimum design requirements for domestic rainwater-harvesting systems on small volcanic islands in the Eastern Caribbean to prevent related water quality and quantity issues. <http://resolver.tudelft.nl/uuid:06a2ebaf-78a3-44f2-a3bb-e0d491aa8c5f>
- Robinson, M. (2007). The Politics of Successful Governance Reforms: Lessons of design and implementation. *Commonwealth & Comparative Politics*, 45(4), 521–548. <https://doi.org/10.1080/14662040701659944>
- Salimi, Y., Shahandeh, K., Malekafzali, H., Loori, N., Kheiltash, A., Jamshidi, E., Frouzan, A. S., & Majdzadeh, R. (2012). Is Community-based Participatory Research (CBPR) Useful? A Systematic Review on Papers in a Decade. *International journal of preventive medicine*, 3(6), 386–393. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3389435/>
- Santa Rosa. (n.d.). *Santa Rosa - information*. <http://www.santarosa.aw/en/information>
- Sendanayake, S. (2016). Life cycle analysis of ferro-cement rainwater tanks in Sri Lanka: A comparison with RRC and HDPE tanks. *International Journal of Applied Engineering Research*, 12(2), 1-8.
- Sijtsma, F. J. (2006). *Project evaluation, sustainability and accountability: combining cost-benefit analysis (CBA) and multi-criteria analysis (MCA)*. [Thesis fully internal (DIV), University of Groningen]. Stichting Ruimtelijke Economie Groningen, Rijksuniversiteit Groningen
- Sitzenfrei, R., Zischg, J., Sitzmann, M., Rathnayaka, S., Kodikara, J., & Bach, P. M. (2017). Effects of implementing decentralized water supply systems in existing centralized systems. *World Environmental and Water Resources Congress 2017*. <https://doi.org/10.1061/9780784480625.064>
- Sran, D. S., Kukal, S. S., & Singh, M. J. (2012). Run-off and sediment yield in relation to differential gully-plugging schemes in micro-catchments of Shiwaliks in the lower Himalayas. *Archives of agronomy and soil science*, 58(11), 1317-1327. DOI: <https://doi.org/10.1080/03650340.2011.577422>
- Strand, K. (2003). *Principles of Best Practice for Community-Based Research*. <https://quod.lib.umich.edu/m/mjcs/3239521.0009.301?rgn=main;view=fulltext>
- Taherdoost, H., & Madanchian, M. (2023). Multi-Criteria Decision Making (MCDM) methods and Concepts. *Encyclopedia*, 3(1), 77–87. <https://doi.org/10.3390/encyclopedia3010006>
- The Caribbean Environmental Health Institute. (2009). *Handbook on Rainwater Harvesting for the Caribbean: A practical guideline featuring best practices for rainwater harvesting in small island Caribbean*. United Nations Environment Programme and the Caribbean Environmental Health Institute.

- https://www.pseau.org/outils/ouvrages/cehi_handbook_for_rainwater_harvesting_for_the_caribbean_2009.pdf
- Toosi, A. S., Tousi, E. G., Ghassemi, S. A., Cheshomi, A., & Alaghmand, S. (2020). A multi-criteria decision analysis approach towards efficient rainwater harvesting. *Journal of Hydrology*, 582, 124501. <https://doi.org/10.1016/j.jhydrol.2019.124501>
- Torquebiau, E. F. (2000). A renewed perspective on agroforestry concepts and classification. *Comptes Rendus de l'Academie des Sciences-Series III-Sciences de la Vie*, 323(11), 1009-1017.
- Turner, A. (2009). Bottom-up community development: reality or rhetoric? the example of the Kingsmead Kabin in East London. *Community Development Journal*, 44(2), 230-247. <https://www.jstor.org/stable/44259106>
- United Nations. (n.d.). Goal 2 | Department of Economic and Social Affairs. <https://sdgs.un.org/goals/goal2>
- University of Missouri Center for Agroforestry. (2021). *Training Manual for Applied Agroforestry Practices*. <https://centerforagroforestry.org/wp-content/uploads/2021/09/Chapter-2-Planning-Agroforestry-UMCA-AF-Training-Manual.pdf>
- Van Sambeek, M., Eggenkamp, H., & Vissers, M. (2000). The groundwater quality of Aruba, Bonaire and Curaçao: A hydrogeochemical study. *Netherlands Journal of Geosciences*, 79(4), 459-466. doi:10.1017/S0016774600021958
- Waterproductivity. (2022). *Demi lunes/ half-moons*. Waterproductivity - Agricultural Solutions. <https://www.waterproductivity.org/product/demi-lunes-half-moons/>
- Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. In Proceedings of the 18th *International Conference on Evaluation and Assessment in Software Engineering (EASE '14)*. Association for Computing Machinery, New York, NY, USA, Article 38, 1-10. <https://doi.org/10.1145/2601248.2601268>
- World Agroforestry. (2020). <https://tree.worldagroforestry.org/about>
- Wright, K., Koo, J., & Beldy, A. (2015). *Enhancing Resilience in Boston: A Guide for Large Buildings and Institutions*. A Better City. <https://www.abettercity.org/docs/resiliency%20report%20web%20FINAL.pdf>
- Yannopoulos, S., Giannopoulou, I., & Kaiafa-Saropoulou, M. (2019). Investigation of the current situation and prospects for the development of rainwater harvesting as a tool to confront water scarcity worldwide. *Water*, 11(10), 2168. <https://doi.org/10.3390/w11102168>
- Zhang, Y., Sun, M., Hong, J., Han, X., He, J., Shi, W., & Li, X. (2016). Environmental footprint of aluminum production in China. *Journal of Cleaner Production*, 133, 1242-1251. <https://doi.org/10.1016/j.jclepro.2016.04.137>