The efficiency and feasibility of Rainwater harvesting systems in Aruba: An assessment using a multi-criteria analysis, including the preferences of the Aruban community


Ilse Coelman, Utrecht University

She eventually called us her adopted daughters.

I have learned a great deal, not only about Aruba and academically, but also about myself, making this an unforgettable experience. To be honest, before coming to this island for the Consultancy Project, I was slightly nervous about a few things. Especially the idea of sharing one bedroom with a roommate seemed to be challenging. However, I came here with an open mind, eager to learn to live together with others, to be open to new experiences and being more comfortable in a group. Thanks to that and the amazing group, everything turned out to be wonderful! I got along so well with my roommate, as our personalities naturally clicked. We shared thoughts about our personalities and the dynamics of our group, mutually respecting each other's need for personal space and time. This bond was a significant relief for me.

Through this experience, I've undoubtedly become more spontaneous and inclined to live in the moment. One of the highlights of my time on Aruba was my trip to Bogota, Colombia, with people I had only known for 1.5 weeks at the time, whom I now consider good friends. This adventure was not only extremely fun and spontaneous, but it also opened my eyes to the beauty and vibrancy of Latin America. Additionally, I have climbed the Hooiberg at least 6 times during my stay. And not to mention all the sunsets at the beach, the snorkelling, the dinners, and all of the other activities we did together with the group.

Of course, we had to do our consultancy project as well. This was a very nice experience, particularly due to our interactions with the people of Santa Rosa. As local group, we had to do a large amount of visits to farms and households. During these visits we were accompanied by a person of Santa Rosa, always being Facundo. Initially reserved and shy, Facundo gradually opened up to our group, a heartwarming transformation to witness. It feels like we have made very valuable relationship with him. Afterwards, Nathalie told us she had never seen him so invested in this project and so happy. Nathalie herself was incredibly kind and caring, as she for example helped us with getting a car and reminded us to put on sunscreen and enjoy ourselves during carnival. She eventually called us her adopted daughters, which was really touching.

Lastly I don't want to forget to mention the perspective I gained on teaching. Eric's teaching approach is truly remarkable, as it was always interesting and containing knowledge that will stay in my memory forever - which cannot be said of a lot of other courses. In conclusion, I would like to say that I extremely enjoyed my time here on Aruba and that I will cherish the memories.

The efficiency and feasibility of Rainwater harvesting systems in Aruba: An assessment using a multi-criteria analysis, including the preferences of the Aruban community

Ilse Coelman

Introduction

In investigating the potential of rainwater harvesting (RWH) systems to address water scarcity challenges in Aruba, it is necessary to elaborate the dynamics of implementation and adoption across national and local scale. 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). As calculated by Montoya Rodriguez (2024), the annual amount of rainfall in Aruba is an estimated 7 times the amount of water produced yearly by Water- en Energie Bedrijf Aruba (WEB). This highlights the usefulness of sustainable water management practices. RWH involves the collecting, storage, and utilization of rainwater runoff (Reijtenbagh, 2010). Implementing such a RWH system could provide a new purpose for this water. It can be used for extensive water usage by farmers, as well as the limited application of RWH systems, such as those in households and small businesses. According to Rahman et al. (2014), rainwater harvesting is the most sustainable method for water supply. It is crucial to implement sustainable solutions to reduce the impacts of global climate change, and secure a safe future for the inhabitants of Aruba, especially in small island states (Curren & Metzger, 2017).

Understanding how RWH systems can be integrated with existing water infrastructure in Aruba, while also considering the semi-arid climate of the country, requires further exploration. There is limited availability of long-term 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 new RWH systems.

The results aim to assess the feasibility and efficiency of the existing and future potential implementation of RWH systems in Aruba, focusing on the preferences of the Aruban community. By examining factors such as economic viability, volume, life span, accessibility, and ease of both implementation and maintenance, this research strives to inform about potential implementation of RWH systems on a small and large scale. Small businesses and individual households have limited application of RWH systems, whereas farmers use RWH systems for extensive water usage according to the estimated data given by Santa Rosa, the department of Agriculture, Livestock, and Fisheries. Aruba classifies businesses with less than 10 full year equivalent employees as small enterprises (DEACI, 2018).

2. Methods

Because of the lack of previous academic knowledge on RWH systems in Aruba, the overarching approach for the methodology is based on the Grounded Theory (Bryman, 2012), meaning that the process of data collection and analysis occurred simultaneously, as clarified below.

A systematic literature review was conducted to gain a comprehensive understanding of already existing RWH systems in regions with a semi-arid climate, such as Aruba. Since there was limited academic literature about Aruba, this literature review also included gray literature, such as theses and government reports, and some unpublished data from Santa Rosa. The articles and gray literature found were categorized per sub-question. Following that, interviews were chosen as the optimal qualitative method to explore opinions on RWH system implementation among farmers and households. The interviews targeted farmers, small businesses, and households potentially benefiting from RWH systems. A small sample was drawn from existing contacts, notably in Santa Rosa, employing a snowball approach (Naderifar et al., 2017). The semi-structured interviews followed predefined guidelines but allowed interviewers the flexibility to elicit opinions and perspectives on water systems (Bryman, 2012). Analysis of the interviews included the transcription, coding and analysis of the collected data; see Negrini (2024) for more information. For this research, these interviews have been used as an initial assessment of current RWH systems present on the island and which RWH innovations are feasible, given the current situation. In line with the grounded theory approach, the interviews provided specific systems that were subjected to a multi-criteria analysis (MCA). An MCA was chosen as the optimal approach for assessing the feasibility and adaptability of potential innovations on RWH systems within the Aruban community, as only partial data is available, and the criteria that are relevant for assessment are difficult to quantify.

3. Multi-Criteria Analysis

After the interviews and systematic literature review, the following RWH systems were identified as objects for the MCA:

- Regenbak[1]
- Rain gutters made from aluminum
- Rain gutters from PVC pipes
- 3000 L – 8000 L dark tank
- Totes; discarded Intermediate bulk containers (IBCs)
- Bioswale
- Check dams
- Agroforestry
- Water pit/reservoir

3.1 Objectives, Criteria and Weights

The MCA entailed establishing a framework for integrating various assessment criteria within quantitative analysis without assigning a monetary value to every factor. The RWH systems were evaluated based on different aspects, appearing in Table 1. These aspects were defined during the literature review and correspond to codes identified in Negrini (2024). To assess the feasibility of implementation in the community, weights were given to the criteria based on the importance of each within the Aruban community, hereby reflecting the preferences of the decision makers (Sijtsma, 2006). Rankings for both equal weights and for weights based on the Aruban community were established. Then a score from 1 to 10 was decided on for every system (Taherdoost & Madanchian, 2023). A reasoned narrative for the MCA framework, the scoring and the options had to be provided (Infrastructure Australia, 2021). Then, radar diagrams were created to visualize the results. The goal of this structured approach was to identify the best solutions

[1] A regenbak is a reinforced concrete tank (The Caribbean Environmental Health Institute, 2009), this was a traditional rainwater harvesting system that was implemented in traditional houses before the 70's (Klomp, 1981).

in terms of efficiency and feasibility that align with the socio-economic conditions of the Aruban community.

Table 1; Objectives and Criteria MCA

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

The objectives and criteria were obtained during the initial literature review. Criteria used appear in Table 1. 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 interview participant 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 participants 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 weighted 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 lifespan 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 interview participants 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"

4. Results

Table 2 shows all the ratings given to the RWH systems for the various criteria. In this section the most important explanations concerning the scores will be highlighted. In figure 2, a link to the MCA table with further elaboration on the decision making can be found.

The regenbak has an extremely low score for initial costs and ease of implementation, due to space requirements and construction expenses, estimated at a price of US$0.74 per gallon, corresponding to 0.35AWG per liter. (The Caribbean Environmental Health Institute, 2009). From observations on the island, the volume of a regenbak ranges from 6 cubes to 30 cubes, or 6000 L to 30000 L, with outliers of 200 cubes (Beaujon & Stuivenberg, 1948). Constructing a 6000L regenbak costs 2100 AWG, excluding coating expenses, which are recommended for protection against acids and corrosion. This also leads to a reduction in water losses from cracks (Austin, 2017). Moreover, concrete production emits greenhouse gasses and involves environmental impacts from mining, transportation and processing operations. The mining for limestone and clay as raw materials and coal as fuel leads to deforestation and top-soil loss at the mining site (Mehta, 2001).

PVC and aluminum rain gutters scored a 9 for both maintenance costs and ease of maintenance, as only regular visual inspection of the pipes is needed (Caribbean Environmental Health Institute, 2009). However, their initial costs are relatively high as mentioned by R. Bareno (21 March 2024). Similarly to the regenbak, these systems are not environmentally friendly. Fossil fuel depletion and coal-based energy use for production are the most significant environmental impacts of aluminum production. The total CO_2 emissions of plastic piping systems are lower compared to pipe systems made out of competing materials. Generally, the production and transport of raw materials have the largest environmental impacts (P. Sejersen, 2016).

Table 2: Ratings given to RWH systems

	Regenbak	Rain gutters made from aluminum	Rain gutters from PVC pipes	Big tank	Totes (IBCs)	Bioswale	Check dams	Agroforestry	Water pit/reservoir
Maintenance costs (8)	4	9	9	7	6	4	5	4	6
Initial costs (9)	1	3	4	3	6	6	8	7	7
Efficient use of rainfall (6)	0	7	6	0	0	7	6	9	0
Volume (6)	8	0	0	8	6	0	0	0	7
Life Span (6)	8	6	6	7	7	7	5	8	9
Environmental savings (3)	3	4	5	5	5	8	8	10	7
Accessibility of material (7)	3	5	7	5	6	6	7	6	7
Accessibility of knowledge (6)	9	6	6	7	8	3	5	7	3
Ease of implementation (6)	2	8	4	6	8	5	6	6	5
Ease of maintenance (6)	9	9	9	9	8	7	7	4	8

In the case of Aruba, transport either by plane or ship of the final products, both the PVC and aluminum, has large CO2 emissions as well. Aluminum rain gutters scored higher for accessibility and ease of implementation, as there is a company present on the island that produces these and has the option of installment included (R. Bareno, personal communication, 21 March, 2024).

The tanks, both the bigger PVC and the totes, have similar maintenance costs and ease of maintenance. Initial costs differ, due to bigger sized tanks having more volume, thus being more expensive (Santa Rosa, 2024). Additional expenses for totes are required, as it is advised to paint the outside of the tote in darker colors for algae prevention (IBC Totes Authority, 2023 and Kooyman, 2024). The environmental impacts of the larger tanks are similar to the impacts mentioned for the PVC gutters, while totes are considered relatively sustainable, as they are second-hand discarded IBCs used for chemicals by for example Balashi and WEB (E. Mijts, personal communication, March 29, 2024). Implementation of any tank requires a potentially costly construction of a solid foundation, but the costs are dependent on weight. (The Caribbean Environmental Health Institute, 2009). The accessibility of knowledge and material is good for both types of tanks. According to personal communication with Santa Rosa (2024) and E. Mijts (29 March 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.

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). However, limited literature (Ekka et al., 2021) and lack of familiarity among interviewees pose challenges. (Interviews for consultancy report, 2024). Check dams have proven to improve groundwater recharge in semi-arid/arid countries, such as India. Additionally, they irrigate the land simultaneously (Agoramoorthy et al., 2016) Water that remains in the catchment area of the check dams can be harvested for further irrigation. For both bioswales and check dams, maintenance is needed after high velocity flows, as they can get damaged (Hassanli & Beecham, 2013).

Incorporating agroforestry improves the soil system. It enhances infiltration and water retention due to more extensive root systems. This leads to increased nutrient use efficiency of the system. It has a carbon sequestration potential, which is higher than any other RWH system. Additionally, the integration of various crops and trees into this system improves biodiversity, soil fertility, and water quality (Jose, S., 2009). Agroforestry is an upcoming topic in Aruba under the name "Syntropic Farming". Living Soil Aruba is an agro consultancy company that gives free presentations and workshops on this practice (Living Soil Aruba - Agro Consultancy, n.d.). An agroforestry site can be implemented in any garden; maintenance includes watering, weed control, and harvesting (Godsey, L. D., 2010).

Based on personal observations, the costs, volume, environmental impacts, and ease of implementation and maintenance of water pit/reservoir systems vary greatly depending on size, resources, and space availability. Water in this kind of system tends to evaporate quickly or infiltrate into the ground (E. Kelkboom, personal communication, March 4, 2024).

From these scores, two rankings emerge. A ranking based on equal weights for every criterion, and a ranking based on weights based on the preferences of the Aruban community. These rankings provide a clear indication of which alternative performs best overall according to the criteria considered.

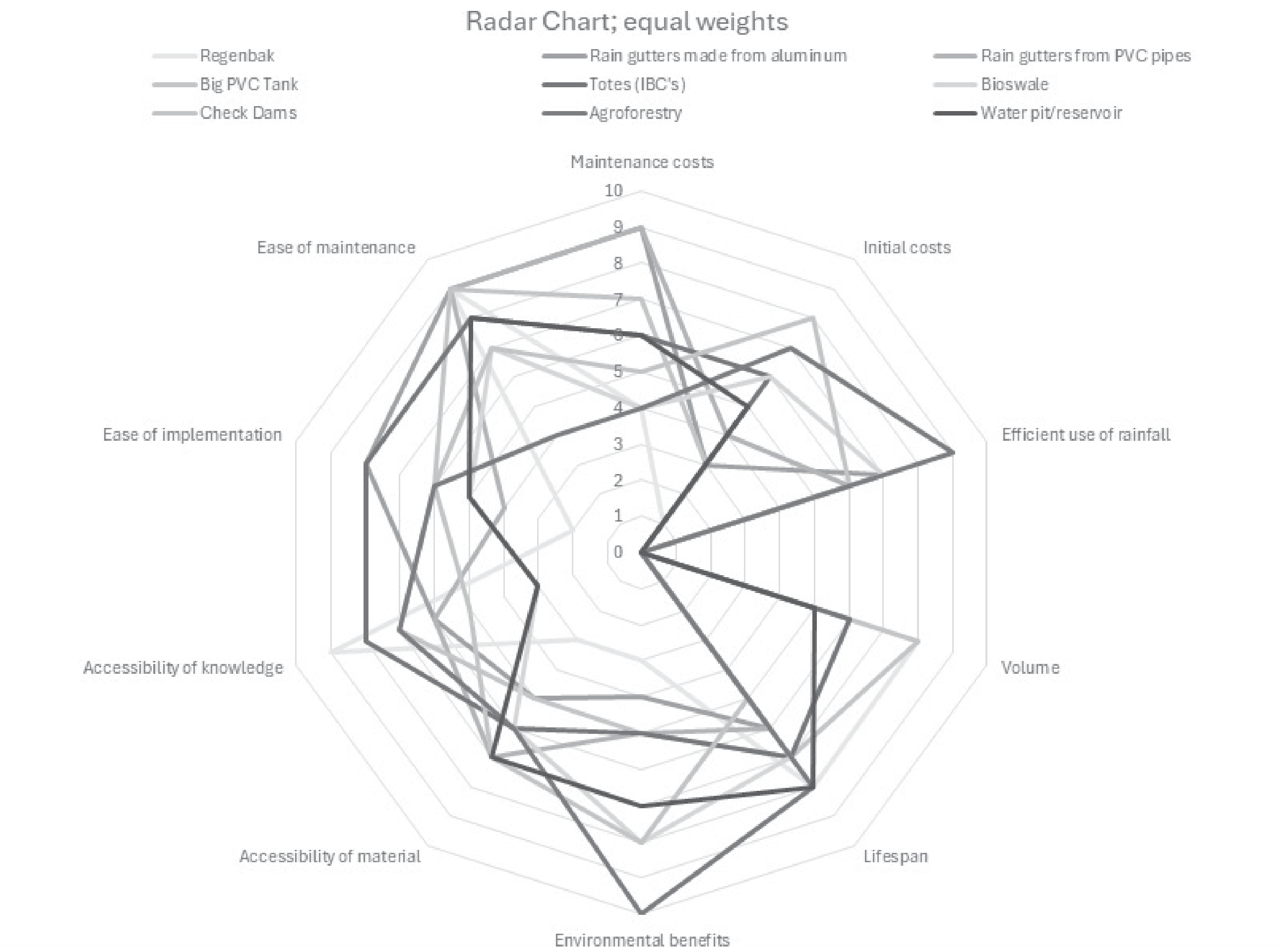
Table 3: Table with results of the MCA analysis. Two rankings are shown; one with scores based on equal weights and another based on weights including the preferences of the Aruban community.

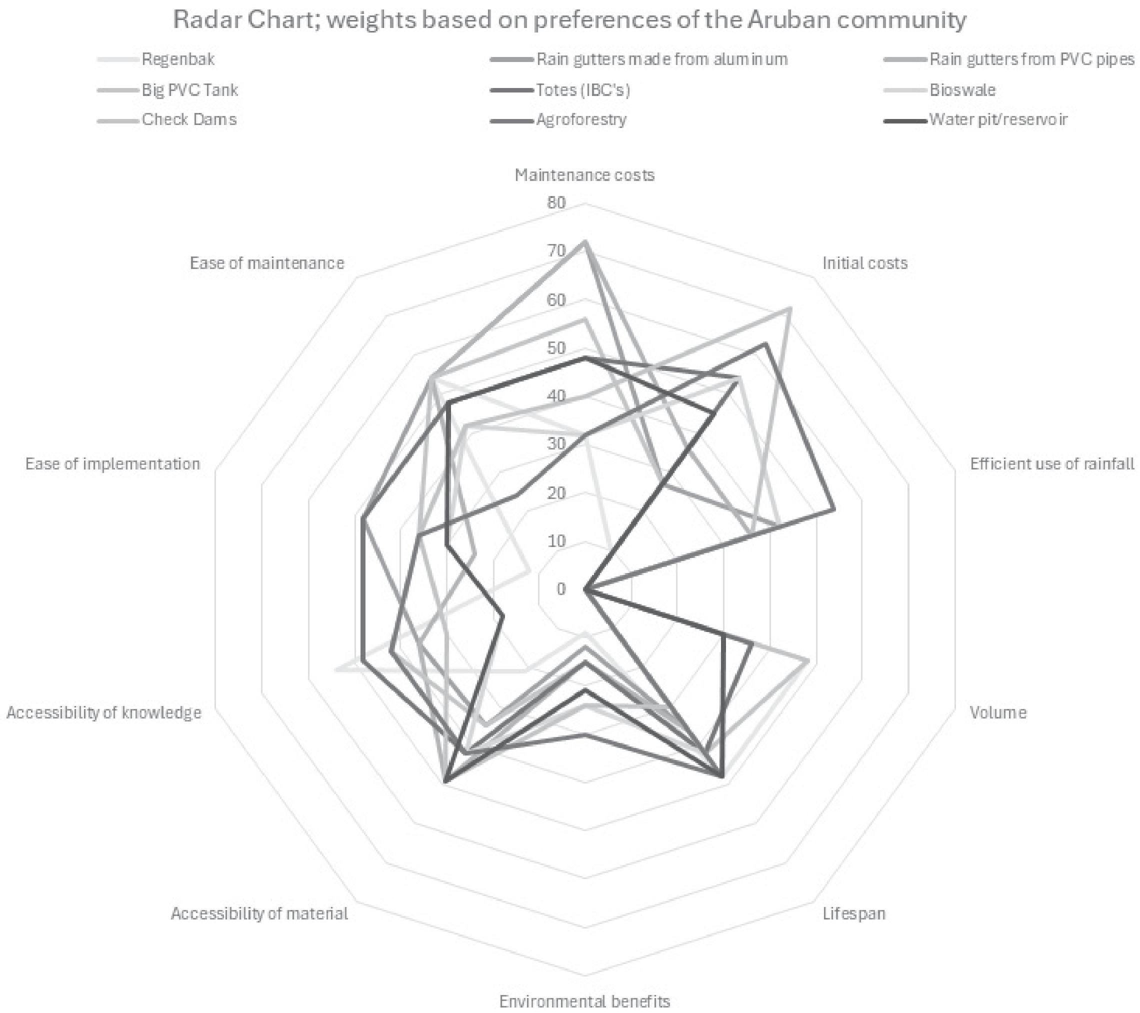
Rank	Score	Based on equal weights	Rank	Score	Based on weights including the preferences of the Aruban community
1	61	Agroforestry	**1**	381	Totes (IBCs)
2	60	Totes (IBCs)	**2**	371	Agroforestry
3	57	Rain gutters made from aluminum, 3000-8000L PVC tank, and Check dams	**3**	362	Rain gutters made from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

As evident, in the weight-based ranking, the totes achieve the highest score, followed by agroforestry. Conversely, 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 scenarios, 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. The community-based weights assign it a lower rank compared to the equal weights. 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 exhibit 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 2; QR code directing to a Google Spreadsheet with the MCA table and the radar diagrams of results MCA

Figure 1; Radar diagrams of results MCA




Radar Chart; weights based on preferences of the Aruban community
Regenbak
Rain gutters made from aluminum
Rain gutters from PVC pipes
Big PVC Tank
Totes (IBC's)
Bioswale
Check Dams
Agroforestry
Water pit/reservoir
Maintenance costs
Initial costs
Efficient use of rainfall
Volume
Lifespan
Environmental benefits
Accessibility of material
Accessibility of knowledge
Ease of implementation
Ease of maintenance
80
70
60
50
40
30
20
10
0

In figure 1, two radar diagrams with the MCA results are displayed. Figure 2 is a QR code, which is also attached in Figure 2, containing the full MCA Table and the radar diagrams in color. The criteria are placed on the outside of the diagram. The inside axis displays the values of the scores that the RWH systems received. For the chart with the equal weights, it is until 10, and for the weights based on the preferences of the Aruban community it is 80. The lines in different colors correspond with the analyzed RWH systems.

The chart with equal weights 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. The chart with the weights based on preferences of the Aruban community reveals outliers in the scores for initial costs of check dams and maintenance costs of rain gutters made from PVC and aluminum. In this chart the 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.

4. Discussion & Conclusion

Firstly, it is important to note that both totes and large PVC tanks, serving as primary water storage systems, yield optimal efficiency when complemented with RWH systems, typically rain gutters. Aluminum rain gutters are preferred, ranking third in the MCA for both the weighing methods. In contrast, PVC rain gutters scored lower, largely due to their susceptibility to leakages at connection points. Aluminum gutters are produced in full length and therefore don't need connection points (R. Bareno, personal communication, March 21, 2024). Material for connecting the separate PVC gutters has to be purchased and implementation is more difficult.

Secondly, while MCA results based on Aruban community preferences offer valuable insights, it's essential to recognize potential divergence between community preferences and the optimal path for Aruba's sustainable development, potentially being the result of knowledge on these systems and most likely also on their efficiency is scarce on the island. Preferences of the community assigned the lowest weight to environmental impacts, despite this being a very important aspect for the future, highlighting a gap in awareness.

There are challenges in using an MCA that you should be aware of. The outcomes, criteria, and weights that make up the MCA framework are defined by the researcher. This configuration may be subject to unconscious or advocacy bias. Additionally, the scoring of criteria across options is likely to involve some subjectivity and this may be reflected in the scores. This was tried to mitigate by providing sufficient academic literature for the choices of objectives, criteria and weights (Infrastructure Australia, 2021).

Future research directions should be on the integration of RWH systems with the existing infrastructure of Aruba, while considering the semi-arid climate. Further research could be done on the monetary benefits of the implementation of RWH systems.

In arid regions like Aruba, such as Aruba, where water scarcity is a pressing issue (Van Sambeek et al., 2000), rainwater harvesting emerges as a potential solution. Despite perceptions of limited rainfall, calculations indicate that precipitation exceeds the yearly water production of WEB by seven times (Montoya Rodriguez, 2024). With the Earth's carrying capacity already being exceeded in six planetary boundaries (Richardson, K. et al, 2023), sustainable water management becomes critical. RWH systems not only preserve ecosystems and biodiversity but also safeguard human health by mitigating air and water pollution and limiting greenhouse gas emissions linked to climate change. The research question focuses on assessing the feasibility and efficiency of both existing and future potential implementations of RWH systems in Aruba.

The results of the MCA indicate varying degrees of feasibility and effectiveness among different RWH systems. Notably, the combination of totes with preferably aluminum rain gutters emerges as the most viable option for future implementation in Aruba. A combination of these systems is required, as a harvesting system (the gutters) is of no use without a storage system (the totes). The MCA, conducted for this consultancy report, highlights the totes superiority. They ranked first based on equal weights for the criteria and second with the weights based on the preferences of the Aruban community. The aluminum rain gutters ranked third for both the weighing methods, surpassing PVC gutters in both scenarios. The accessibility of a system is crucial for implementation, and both the totes and the aluminum gutters scored high on this criterion.

Furthermore, this study highlights the efficiency of agroforestry in rainwater utilization. This RWH system is practical and applicable to a household practice, as every interested person with a backyard could possibly implement it. The economic feasibility of this implementation is really convenient. This system merges two important aspects of rainwater harvesting systems, a durable system and efficient water collector.

Implementing RWH systems in Aruba is feasible, with certain systems proving more efficient than others considering various criteria. However, scaling up implementation requires engagement from additional stakeholders, including the government and the community. Community participation is crucial for the implementation of these systems. Creating awareness involves promoting every aspect of sustainability, showing benefits and ensuring financial profitability. Ideally, alternative norms and values have to be established, achieved by a paradigm shift towards environmentally conscious decisions and practices. Building community engaged awareness is fundamental for effectively promoting and convincing people to adopt scientifically based decisions. Thus, a combination of further research on potential future implementation of RWH systems and creating community awareness would be beneficial on the feasibility of the implementation of RWH systems in Aruba.

5. 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
- 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 promotes 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
- 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
- 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
- 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
- Bryman, A. (2012). Social research methods. Fourth edition. Oxford University press.
- Curren, R., & Metzger, E. (2017). Living well now and in the future: Why sustainability matters. *MIT Press.*
- Department of Economic Affairs, Commerce and Industry of Aruba. (2018). Entrepreneurs Development Policy for Aruba. In https://www.deaci.aw/wp-content/uploads/2019/09/Entrepreneurs-Policy-2018-2021.pdf. Aruba Government. https://www.deaci.aw/wpcontent/uploads/2019/09/Entrepreneurs-Policy-2018-2021.pdf
- 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
- 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

- Infrastructure Australia. (2021). Guide to Multi-Criteria Analysis: Technical guide of the Assessment Framework. ISBN: 978-1-925352-54-2
- 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
- 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
- Living Soil Aruba - Agro Consultancy. (n.d.). *Living Soil Aruba.* https://www.livingsoilaruba.com/home
- 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
- Mehta, K. P. (2001). Reducing the environmental impact of concrete. *Concrete international, 23*(10), 61-66. http://ecosmartconcrete.com/docs/trmehta01.pdf
- Montoya Rodriguez, Y. (2024) The value of rainwater: The economic viability of rainwater harvesting systems in Aruba, in *Mijts & Ballantyne UAUCU Student Research Exchange Collected Papers 2024*
- Naderifar, M., Goli, H., & Ghaljaie, F. (2017). Snowball sampling: a purposeful method of sampling in qualitative research.,14(3). https://doi.org/10.5812/sdme.67670
- Negrini, G. (2024) Farming community and government interaction: a case study of the community perspective on the role of the Aruban government, in *Mijts & Ballantyne UAUCU Student Research Exchange Collected Papers 2024*
- 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
- 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
- Patrick, S. (2005). *Practical guide to polyvinyl chloride.* iSmithers Rapra Publishing. (p. 3)
- 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. T*he Scientific World Journal, 2014.* 10.1155/2014/721357
- 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
- Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S.E., Donges, J.F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., Petri, S., Porkka,

M., Rahmstorf, S., Schaphoff, S., Thonicke, K., Tobian, A., Virkki, V., Weber, L. & Rockström, J. 2023. Earth beyond six of nine planetary boundaries. *Science Advances 9,* 37.

- 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
- 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
- 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
- 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
- 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
- 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