

# Water Resources Research



## RESEARCH ARTICLE

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### Key Points:

- Two million people in the Pacific depend on rainwater collection for drinking water, but these systems often fail to provide a year-round supply
- This study examined 1,878 rainwater tanks across 19 islands in Vanuatu to assess the comparative performance of private versus communal systems
- Private rainwater tanks were significantly more likely to provide a sufficient year-round supply of water than communal rainwater tanks

### Supporting Information:

Supporting Information may be found in the online version of this article.

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## Contending With Water Shortages in the Pacific: Performance of Private Rainwater Tanks Versus Communal Rainwater Tanks in Rural Vanuatu

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**Abstract** Around 2 million people in the Pacific depend on rainwater collection for their drinking water, however these systems often struggle to provide sufficient quantities of water year round. This study examined the performance of 1,878 rainwater tanks across 19 islands in Vanuatu to assess whether the likelihood of a sufficient year-round supply of drinking water differed between village-level rainwater tanks used communally and private rainwater tanks owned by individual households (i.e., self-supply). More than half of the tanks assessed failed to provide a sufficient supply of water year round. Compared with communal rainwater tanks, private rainwater tanks had significantly higher odds of a sufficient year-round supply of water (adjusted odds ratio 1.61, 95% confidence interval 1.24–2.09,  $p < 0.001$ ). This relationship was evident when adjusting for village-level clustering, year of installation, presence of other improved water sources, tank volume, number of users, and a proxy indicator for rainfall. Private rainwater tanks outperformed communal rainwater tanks irrespective of whether communal tanks were managed by a community-based committee. The findings support the notion that in some circumstances private property rights can help avert resource depletion, and that household self-supply is capable of delivering a more reliable water supply than community-based management. However, the study design was unable to rule out differences in roof catchment area as a factor influencing the results. Further work is needed to confirm and elucidate the mechanisms by which private ownership facilitates a year-round supply and understand the wider advantages and disadvantages of self-supply.

## 1. Introduction

Rainwater collection and storage is critical to water security in Vanuatu and the wider Pacific region. Across all Pacific Islands countries (PICs), more than one in six households—or around 2 million people—rely on rainwater collection as their main drinking water source (Table 1). Rainwater collection systems are especially important in Vanuatu, serving as the main source of drinking water for 36% of households (VNSO, 2017).

Rainwater collection as a source of drinking water presents potential advantages and disadvantages, which in turn have important implications for efforts to achieve the Sustainable Development Goal (SDG) of safe water for all in Vanuatu and the wider Pacific region. The headline indicator linked to SDG target 6.1 requires safely managed water services to be improved source types, accessible on the premises, free of fecal and priority chemical contamination, and available in sufficient quantities when needed. Rainwater at the time of capture is typically of good quality and is defined as an inherently “improved” water source by the WHO/UNICEF Joint Monitoring Programme (WHO/UNICEF, 2018). However, there is clear evidence that rainwater collection systems in Vanuatu are still prone to fecal contamination (Foster & Willetts, 2018), while others have noted concerns in regards to physical and chemical contaminants (Allibone et al., 2012; Kotra et al., 2017). Rainwater collection systems are often owned and managed by private households, and hence are commonly located on the premises of users. This reduces water collection times and minimizes the need for storing water in the household, which otherwise presents a contamination risk (Shields et al., 2015).

Perhaps the most significant weakness of rainwater collection systems is their ability to ensure water is available in sufficient quantities when needed. These systems are highly vulnerable to climatic conditions,

**Table 1**  
*Rural Population Using Rainwater as a Drinking Water Source in the Pacific Region*

Country/territory	Population using rainwater as a drinking water source			Reference
	Urban	Rural	Total	
American Samoa <sup>a</sup>	-	-	5%	USCB (2013a)
Cook Islands	6%	79%	26%	CIG (2018)
Fiji	1%	25%	12%	FBS (2018)
Guam <sup>a</sup>	-	-	0.3%	USCB (2013c)
Kiribati	32%	25%	29%	KNSO (2019)
Marshall Islands	71%	98%	79%	EPPSO-RMI and SPC (2012)
Micronesia, Fed. States	47%	42%	43%	SPC (2021); WHO/ UNICEF (2019b)
Nauru <sup>b</sup>	29%	-	29%	SPC (2012)
Niue	0%	10%	4%	Statistics Niue (2019)
Northern Mariana Islands <sup>a</sup>	-	-	0.8%	USCB (2013b)
Palau	20%	63%	29%	OPS and BBP, 2016
Papua New Guinea	22%	15%	15%	NSO and ICF, 2019
Samoa	3%	8%	7%	SBS (2018)
Solomon Islands	29%	28%	28%	SINSO et al. (2017)
Tokelau <sup>c</sup>	-	100%	100%	TNSO (2017)
Tonga	68%	84%	80%	TSD (2019)
Tuvalu	100%	100%	100%	CSDGT (2013)
Vanuatu	14%	44%	36%	VNSO (2017)
Total <sup>d</sup>	18%	17%	17%	

<sup>a</sup>Census data for these territories did not distinguish between urban and rural areas. <sup>b</sup>Entire population in Nauru is considered urban. <sup>c</sup>Entire population in Tokelau is considered rural. <sup>d</sup>Total estimate is population weighted. Due to lack of data on rainwater collection, table excludes Wallis and Futuna, French Polynesia, New Caledonia, and Northern Mariana.

and are subject to water shortages during prolonged dry spells. In Vanuatu, it is estimated that more than half of all rainwater collection systems fail to provide a sufficient supply of water year round (Foster, Kohlitz, & Rand, 2020). Understanding the degree to which rainwater collection systems meet the “available when needed” criterion—and the opportunities for addressing any shortfalls in this regard—is therefore crucial for accelerating progress toward SDG target 6.1 in Vanuatu and the Pacific more broadly. The importance of this is underscored by the modest headway the Pacific region has made in expanding coverage of safe water services in recent decades: between 2000 and 2017, access to “at least basic water services” in rural areas increased by just three percentage points (40.5%–43.9%) (WHO/UNICEF, 2019a).

The challenge of securing a sufficient year-round supply of water via rainwater collection in Vanuatu is pronounced given the seasonal nature of the country’s rainfall (Figure 1). In most islands, the driest three months of the year (July–September) produce rainfall levels that are 60%–75% lower than that in the wettest three months (January–March). The methods used globally to monitor and assess whether drinking water is “available when needed” vary, but may be ill-equipped to capture seasonal shortages. Benchmarks are commonly based on the number of hours of supply per day or whether water has been unavailable in a standard time period preceding a survey (e.g., previous week, fortnight, or month) (WHO/UNICEF, 2017). The former metric is generally geared toward piped supplies, while the latter will fail to detect seasonal shortages if surveys are conducted in wetter months.

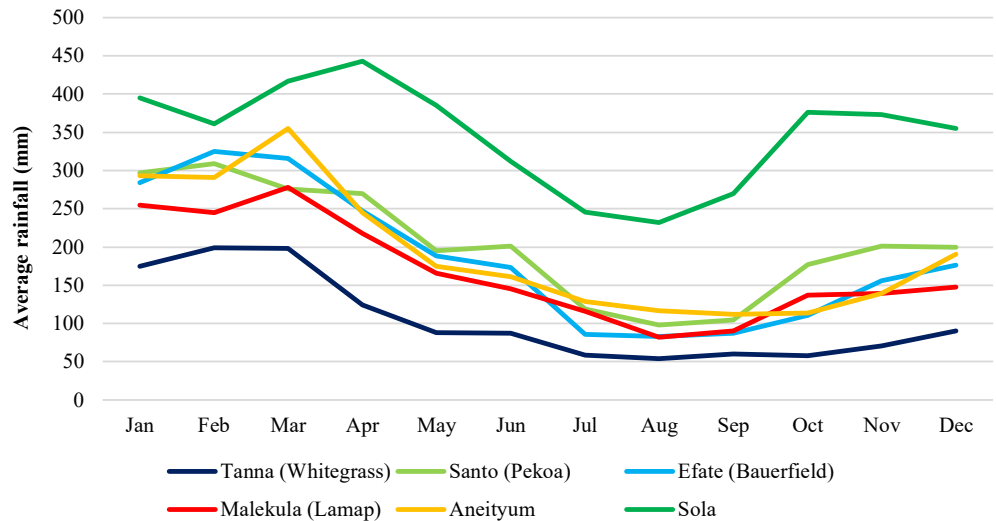


Figure 1. Monthly rainfall averages in Vanuatu (VMGHD, 2019).

### 1.1. Linking Rainwater Tanks, Common-Pool Resource Management, and Property-Rights Regimes

Understanding how different property-rights regimes might influence the performance of rural water supplies has important implications for the rural water sector in low- and middle-income countries. Community management and household-level management (commonly referred to as “self-supply”) are both widespread management models for rural water services, but they embody differing property-rights regimes and emerge for different reasons. Community management has been heavily promoted by governments and development partners over many decades (Harvey & Reed, 2007) and is underpinned by a communal-property regime. Self-supply, on the other hand, involves individual households managing their own water source and reflects a private-property regime. Self-supply is seldom endorsed or promoted by government and it instead tends to be driven by market forces and arises where there is a lack of other formal water services that households can access (Grönwall & Danert, 2020), or where formal water services perform poorly.

Widespread concerns about the sustainability of rural water services in low- and middle-income countries have led to increased attention on management models. These concerns have predominantly stemmed from the mixed performance of community-managed water services, which have been prone to premature failure (Foster et al., 2020; Harvey & Reed, 2007). Sustainable and effective community management assumes ongoing collective action, which requires both the cooperation of community members, and ongoing motivation of committee members who serve on a voluntary basis (Foster & Hope, 2017; Moriarty et al., 2013). Conversely, self-supply involves a reduced collective action burden, as the systems are typically managed and used by an individual household or family. While there is growing recognition of the important role self-supply plays in many regions (Danert & Hutton, 2020; Foster et al., 2021; Grönwall & Danert, 2020; Sutton & Butterworth, 2021), its unregulated nature has meant there is little understanding about its operational performance.

In Vanuatu, there are two main approaches to the management of rainwater tanks: (a) communal tanks, which can be used by anyone in a village and are often managed by a village-based committee, and (b) private tanks, which are owned and managed by an individual household or family. This is also reflected to varying degrees in other PICs (Table 2). Of note is that in all Pacific Island countries with available data, the proportion of rainwater tank users who rely on communal tanks is higher in rural areas than in urban areas. This pattern is also evident in Vanuatu. Of the 44% of households in rural Vanuatu who use rainwater as their primary source of drinking water, there is a 50-50 split between those using private rainwater tanks and shared rainwater tanks (VNSO, 2017). In comparison, this private-to-shared ratio is 67:33 in urban areas. The ratio of private-to-shared rainwater tanks does, however, vary from island to island (Figure 2). As well as having contrasting management arrangements, the private-communal dichotomy has implications

**Table 2**  
*Ratio of Households Using Private Rainwater Tanks Versus Shared or Communal Rainwater Tanks*

Country/territory	Type of tank	Tank type (as a % of all rainwater tank users)		
		Urban	Rural	Total
Fiji (2017)	Own rainwater tank	49	30	31
	Communal tank	51	70	69
Kiribati (2018–2019)	On-premises rainwater	78	40	60
	Off-premises rainwater	22	60	40
Papua New Guinea (2016–2018)	On-premises rainwater	86	70	72
	Off-premises rainwater	14	30	28
Samoa (2016)	Rainwater—own yard/plot	73	71	71
	Rainwater—neighboring household or distant place	27	29	29
Solomon Islands (2009) <sup>a</sup>	Household tank	72	50	54
	Communal tank	28	50	46
Tokelau (2016)	Private household tank	-	95	95
	Tank shared with other households	-	5	5
Tonga (2016)	Own tank	79	75	75
	Neighbor/community tank	21	25	25
Tuvalu (2012)	Tank in dwelling/yard/plot	99.5	98.6	99.0
	Community and neighbor cisterns	0.5	1.4	1.0
Vanuatu (2016)	Private tank	67	50	52
	Shared tank	33	50	48

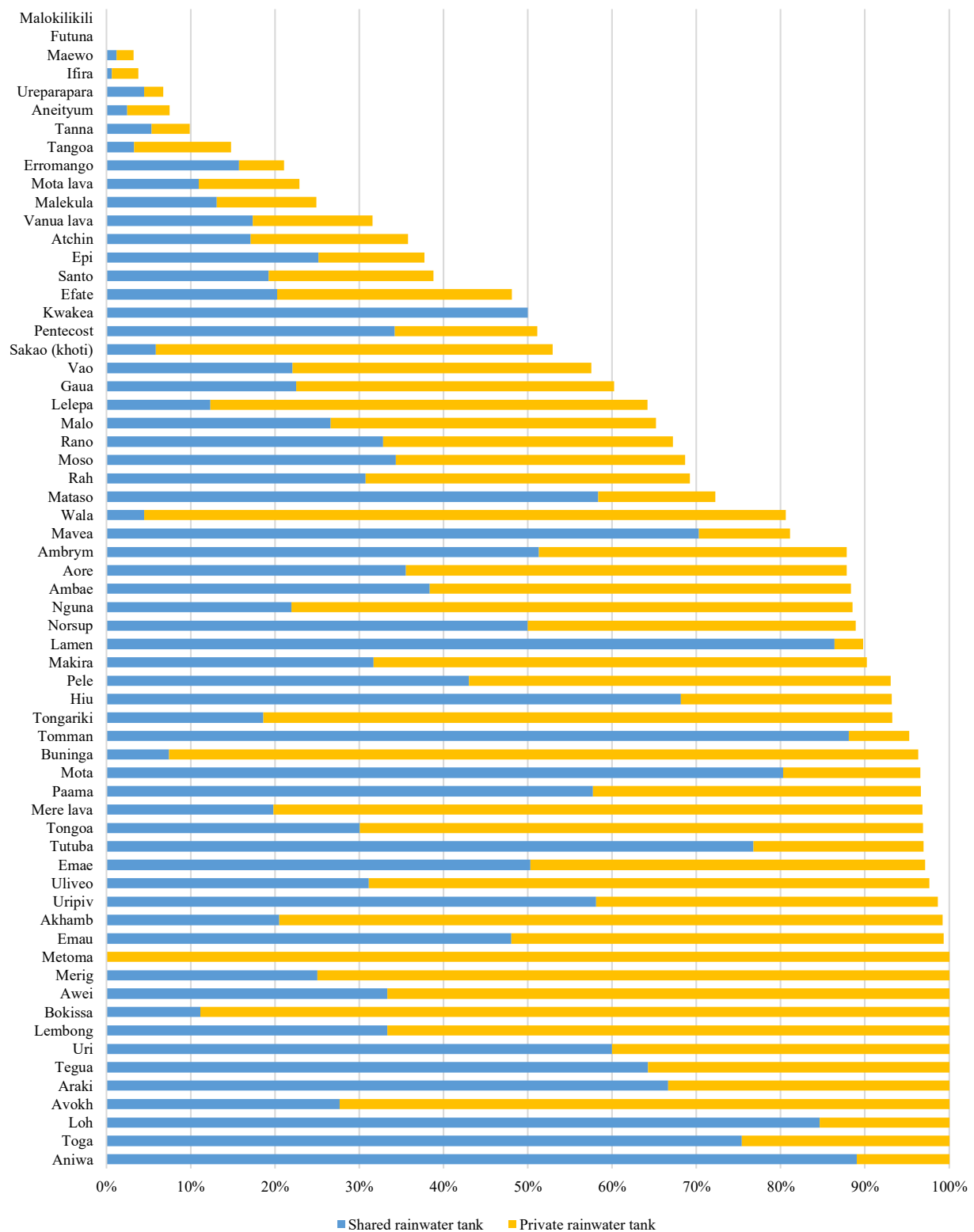
Note. See Table 1 for references for all countries except Solomon Islands.

<sup>a</sup>SINSO (2013).

for the development, oversight and enforcement of access rules, as well as the physical location of rainwater tanks. Private tanks tend to be owned and used by individual households or families and the tanks are typically located on their private premises. In contrast, communal rainwater tanks tend to be owned and used by the wider community and are often located in public areas.

Theoretical frameworks relating to common-pool resources—and other types of goods (private, public, club)—have direct relevance to management models for rural water supply (Foster & Hope, 2017; Koehler et al., 2015). For example, rainwater collection systems possess the key characteristics of a common-pool resource: subtractability and non-excludability. They are subtractable because withdrawal of water by one person reduces the amount available to other users. They are non-excludable because preventing their use by others is not straightforward. Hardin (1968) famously predicted such shared resources would lead to overexploitation and depletion; the so-called “Tragedy of the Commons.” Hardin’s allegory described an overgrazed pasture, which was in effect open access with no regulation of its use. The two possible solutions to this problem, so Hardin’s argument went, were to either convert the resource to private property, or make the resource subject to government regulation (Hardin, 1968). The possibility that community-based institutions might be able to manage common-pool resources sustainably was not explicitly considered.

Common-pool resources can be subject to different property-rights regimes, with the state, communal groups and private individuals all possible holders of these rights (Feeny et al., 1990; Ostrom, 2003). The bundle of property rights considered most relevant to management of common-pool resources include (a) access, (b) withdrawal, (c) management, (d) exclusion, and (e) alienation (Schlager & Ostrom, 1992). In contrast to Hardin’s argument that only private property rights or state regulation could prevent degradation of a shared resource, empirical evidence has since shown that sustainable management of a common-pool resource is also feasible under a communal-property regime (Feeny et al., 1990; Ostrom, 2003). Equally, studies have shown that any of these property-rights regimes are susceptible to failure (Feeny et al., 1990;



**Figure 2.** Proportion of households in rural Vanuatu using a rainwater tank as their main source of drinking water, by island and ownership type (VNSO, 2017).

**Table 3**  
*Number of Rainwater Tanks in Analyzed Data Set by Island*

Province	Island	Communal RWTs	Private RWTs	Total RWTs
Malampa	Ambrym	94	330	424
Malampa	Maskelynes	14	47	61
Malampa	Paama	66	321	387
Penama	Ambae	36	181	217
Penama	Pentecost	80	72	152
Sanma	Espiritu Santo	64	62	126
Sanma	Malo	18	37	55
Sanma	Tutuba	3	2	5
Shefa	Emao	12	56	68
Shefa	Epi	17	39	56
Shefa	Lamen	2	42	44
Shefa	Lelepa	19	44	63
Shefa	Makira	12	18	30
Shefa	Mataso	3	3	6
Shefa	Tongao	3	116	119
Shefa	Tongariki	4	3	8
Tafea	Aniwa	16	8	24
Torba	Hiu	9	3	12
Torba	Loh	14	8	22
Grand total		486	1,392	1,878

Note. RWT, rainwater tank.

Ostrom, 2003). The property-rights regime that leads to optimal outcomes will vary depending on the nature of the resource and other contextual factors (Ostrom, 2003). Ostrom's social-ecological systems (SES) framework lays out many of these factors in recognition that the complexities of sustainable resource management preclude generalizations on preferred institutional arrangements (Ostrom, 2009). Nonetheless, these different property regimes give rise to different incentives and ability to monitor and regulate use; and hence may result in varied outcomes.

This study sought to contribute theoretical and practical insights by examining whether property regime (communal vs. private) affects the degree to which rainwater tanks provide a year-round supply of water in rural Vanuatu. The analysis also sought to distinguish between communal rainwater tanks managed by a community-based committee (which more clearly embody a communal property-rights regime) and communal rainwater tanks without any management committee (which may be more akin to an open access resource devoid of oversight and regulation). In addition to contributing to the body of knowledge on management of common-pool resources, the study aimed to generate important evidence on the comparative performance of community managed water services and private household-level water services (self-supply). Rural Vanuatu provides a conducive context for examining these questions because it has an even balance between the proportion of households using communal rainwater tanks and the proportion using private rainwater tanks.

## 2. Methods

### 2.1. Data

The study was based on data from Vanuatu's Water Resources Inventory (WRI), the details of which are described by Mommen et al. (2017). The WRI database contains information on more than 4,700 rural water supply systems. Data collection for the WRI took place between 2014 and 2016 and spanned 44 islands. The data collection was carried out by trained enumerators under the auspices of Vanuatu's Department of Water Resources. The questionnaire was designed to capture key information relating to technical, operational and institutional aspects of each water supply system, with local water users acting as respondents.

Included in the data collection instrument was a question that formed the basis of this study: "Does the system provide enough water throughout the year?," which elicited a binary response of "Yes" or "No." If a negative answer was provided, a follow-up question sought to distinguish situations where the water was insufficient due to a temporary or seasonal depletion of water (which was the focus of this study) and where there had been a technical failure caused by a lack of maintenance or natural disaster.

Because the aim of this study was to compare the year-round sufficiency of supplies between private and communal tanks, the analysis was limited to islands with both types of tank. Data on private rainwater tanks were not comprehensively collected across all islands, and hence islands were only included in this study where the private rainwater tanks had a total number of users equal to at least 80% of the number of private rainwater tank users counted during Vanuatu's 2016 mini-census. After applying these inclusion criteria, the revised data set used for the analysis comprised 1,878 rainwater tanks distributed across 19 islands (Table 3). Of these, 26% were communal rainwater tanks and 74% were private rainwater tanks. In totality, the rainwater tanks included in the revised data set served ~94,000 people (44% of whom used private tanks, 56% of whom used communal tanks). This equated to around 46% of Vanuatu's rural population.

**Table 4**  
*Variables Included in Analysis*

Variable	Variable type	Definition and categories
Outcome variable		
Year-round sufficiency	Nominal	Sufficient: Enough water year round Insufficient: Not enough water year round (reference category)
Explanatory variables		
Tank ownership	Nominal	Communal: Tank owned by the community (i.e., village) Private: Tank is privately owned by a household or family
Improved source	Nominal	Absent: No other handpump or piped system in village Present: Village also served by a handpump and/or piped system
Year installed	Nominal	Pre-2010: Tank installed before 2010 Post-2010: Tank installed in 2010 or later
Rainfall zone	Nominal	Dry: Located in a dry area of an island, as defined by DoWR (2019) Wet: Located in a wet area of an island, as defined by DoWR (2019)
Tank volume	Ordinal	Volume of rainwater tank based on six categories: (i) 100–650 L, (ii) 650–1,200 L, (iii) 1,200–6,100 L, (iv) 6,100–11,000 L, (v) 11,000–41,000 L, (vi) >41,000 L
Number of users	Continuous	The number of people using the rainwater tank
Latitude	Continuous	The latitude of the rainwater tank based on the GPS coordinates (included as a proxy measure for rainfall)

## 2.2. Analysis

Univariable and multivariable logistic regression analyses in the form of generalized estimating equations (GEEs) were performed in order to examine the association between year-round sufficiency of water (a dichotomous outcome variable) and tank ownership (the explanatory variable of interest). Tank ownership was examined in two ways: first, as a dichotomous variable (i.e., private vs. communal), and second, as a categorical variable that distinguished between communal tanks with and without a committee (i.e., private vs. communal with committee, private vs. communal without committee). The regression analyses were conducted in the form of GEEs in order to adjust for autocorrelation between water sources located within the same village. Two types of analysis were carried out: one that included rainwater tanks from all 585 villages, and another that included rainwater tanks from the 137 villages that had both private and communal rainwater tanks. The latter analysis was conducted to minimize potential bias associated with communities that had no communal tanks or no private tanks, in case the conditions that led to such a situation also independently affected the likelihood of a sufficient year-round supply.

Six explanatory variables were included in the multivariable analysis (Table 4). The key explanatory variable of interest was tank ownership, a dichotomous variable with two categories: (a) private and (b) communal; and also a categorical variable with three categories: (a) private, (b) communal with committee, and (c) communal with no committee. While the definition of “ownership” was not defined in a detailed way, the general concept aligns with the bundle of property rights that accompany “full ownership”: namely access, withdrawal, management, exclusion, and alienation (Schlager & Ostrom, 1992). The analysis also included five other explanatory variables in order to account for potential confounding factors. These other explanatory variables were selected based on their inclusion in the inventory data set alongside their relevance to factors included in Ostrom’s SES framework, with each of the framework’s core sub-systems represented (see Table S1 in Supporting Information S1) (Ostrom, 2009). Because observed rainfall data were not available for 18 of the 19 islands, latitude was used as a crude proxy variable for rainfall due to the correlation between the two variables (Figure S1 in Supporting Information S1). Augmenting this was an additional variable, “rainfall zone,” to account for known drier areas of certain islands as specified by Vanuatu’s Department of Water Resources (DoWR, 2019). Separate analyses were conducted to examine the presence of

**Table 5**  
*Characteristics of Rainwater Tanks Analyzed*

Characteristic	Private RWTs	Communal RWTs	Total
% RWTs providing sufficient supply year round	50	38	47
% RWTs in village with other improved water source(s)	26	24	26
% RWTs installed before 2010	79	60	74
% tanks with volume			
100–650 L	4	3	4
650–1,200 L	14	8	12
1,200–6,100 L	28	27	28
6,100–11,000 L	19	20	20
11,000–41,000 L	28	32	29
>41,000 L	7	10	8
Median number of users per RWT (mean)	8 (30)	50 (108)	11 (50)
Mean latitude	−16.3	−16.0	−16.2
% RWTs used for drinking	94	98	95
% RWTs used for cooking	91	87	90
% RWTs used for washing	69	44	63
% RWTs used for animals or garden	2	1	2

*Note.* RWT, rainwater tank.

a water committee for communal rainwater tanks, and whether this has an effect on year-round sufficiency of water.

### 3. Results

Overall, less than half (47%) of all rainwater tanks provided a sufficient supply of water year round (Table 5). The majority (74%) of rainwater tanks were installed prior to 2010, and just over a quarter (26%) were co-located in the same village as an alternative improved source such as a piped scheme or handpump. The most common tank sizes were 1,200–6,100 L (28%) and 11,000–41,000 L (29%), and the average number of users per tank was 50. Compared with communal rainwater tanks, private rainwater tanks (a) were more likely to provide a year-round supply, (b) were older in age, (c) were marginally smaller in volume, (d) and had fewer users. Among the communal rainwater tanks, 22% had a community-based management committee in place. In terms of water use, private tanks were marginally less likely to be used for drinking than communal tanks, but were more likely to be used for cooking, washing or productive purposes (Table 5).

Results of the univariable GEE logistic regression show that, when adjusting for village-level autocorrelation (but not adjusting for other covariates), the odds of a sufficient year-round supply of water were significantly higher for private rainwater tanks than for communal rainwater tanks (Table 6). However, this

**Table 6**  
*Unadjusted Associations Between Tank Ownership and “Year-Round Sufficiency of Water” (Outcome Variable)*

Explanatory variable	All villages		Villages with ≥1 communal tank and ≥1 private tank	
	Unadj. OR (95% CI)	p-value	Unadj. OR (95% CI)	p-value
Private versus communal	<b>1.37 (1.08–1.73)</b>	<b>0.008</b>	1.18 (0.90–1.55)	0.240
Private versus communal (with committee)	1.39 (0.98–1.96)	0.065	1.29 (0.91–1.83)	0.154
Private versus communal (no committee)	<b>1.36 (1.04–1.79)</b>	<b>0.025</b>	1.14 (0.81–1.60)	0.451
Communal (with vs. without committee)	0.98 (0.65–1.48)	0.937	0.88 (0.57–1.38)	0.590

*Note.* Bold values indicate statistically significant result ( $p < 0.05$ ).



**Table 7**  
Results of Multivariable Generalized Estimating Equation Logistic Regression With “Year-Round Sufficiency of Water” as the Outcome Variable

Explanatory variable	All villages		Villages with $\geq 1$ communal tank and $\geq 1$ private tank	
	Adj. OR (95% CI)	<i>p</i> -value	Adj. OR (95% CI)	<i>p</i> -value
<b>Tanks ownership</b>				
Communal	Ref.		Ref.	
Private	<b>1.61 (1.24–2.09)</b>	<b>&lt;0.001</b>	<b>1.46 (1.05–2.03)</b>	<b>0.024</b>
<b>Other improved source</b>				
Absent	Ref.		Ref.	
Present	1.10 (0.77–1.59)	0.598	0.91 (0.53–1.54)	0.715
<b>Year installed</b>				
Pre-2010	Ref.		Ref.	
Post-2010	<b>1.39 (1.13–1.72)</b>	<b>0.002</b>	<b>1.46 (1.11–1.93)</b>	<b>0.007</b>
<b>Rainfall zone</b>				
Dry	Ref.		Ref.	
Wet	0.85 (0.49–1.48)	0.563	0.80 (0.38–1.73)	0.577
<b>Tank volume</b>				
100–650 L	Ref.		Ref.	
650–1,200 L	<b>3.24 (1.72–6.10)</b>	<b>&lt;0.001</b>	<b>2.05 (1.12–3.76)</b>	<b>0.020</b>
1,200–6,100 L	<b>3.16 (1.69–5.92)</b>	<b>&lt;0.001</b>	<b>2.08 (1.17–3.71)</b>	<b>0.012</b>
6,100–11,000 L	<b>3.26 (1.75–6.07)</b>	<b>&lt;0.001</b>	<b>2.13 (1.18–3.85)</b>	<b>0.012</b>
11,000–41,000 L	<b>3.41 (1.79–6.51)</b>	<b>&lt;0.001</b>	<b>2.27 (1.22–4.22)</b>	<b>0.009</b>
>41,000 L	<b>3.18 (1.59–6.37)</b>	<b>0.001</b>	1.84 (0.88–3.85)	0.107
Number of users <sup>a</sup>	1.00 (0.99–1.01)	0.910	1.01 (1.00–1.02)	0.068
Latitude	0.97 (0.81–1.17)	0.767	1.12 (0.86–1.47)	0.385

Note. Bold values indicate statistically significant result ( $p < 0.05$ ).

<sup>a</sup>To aid interpretation of adjusted odds ratios, a unit change in number of users is equivalent to 10 additional users.

association was only significant when analyzing all villages and was not significant when limiting analysis to those villages that had both communal and private rainwater tanks. When analyzing all villages, the odds of a sufficient year-round supply were significantly higher for private rainwater tanks than for communal tanks lacking a management committee. The odds of a sufficient year-round supply did not significantly differ between communal tanks with a management committee and communal tanks without a management committee.

Results of the multivariable GEE logistic regression show that, when adjusting for village-level autocorrelation and holding other covariates constant, private rainwater tanks had significantly higher odds of a sufficient year-round supply of water, as compared to communal rainwater tanks (Table 7). This association was significant when analyzing all villages and when limiting analysis to only those villages that had both communal and private rainwater tanks. Private rainwater tanks significantly outperformed communal tanks even if the communal tanks were accompanied by a community-based management committee (Table 8). Again, the likelihood of a sufficient year-round supply did not significantly differ between communal tanks with a management committee and communal tanks without a management committee.

**Table 8**

*Multivariable-Adjusted Associations Between Tank Ownership and “Year-Round Sufficiency of Water” (Outcome Variable)*

Explanatory variable	All villages		Villages with $\geq 1$ communal tank and $\geq 1$ private tank	
	Adj. OR (95% CI)	<i>p</i> -value	Adj. OR (95% CI)	<i>p</i> -value
Private versus communal (with committee)	<b>1.87 (1.20–2.91)</b>	<b>0.006</b>	<b>1.81 (1.14–2.89)</b>	<b>0.013</b>
Private versus communal (no committee)	<b>1.55 (1.17–2.07)</b>	<b>0.003</b>	1.36 (0.94–1.98)	0.104
Communal (with vs. without committee)	0.83 (0.52–1.33)	0.441	0.75 (0.45–1.26)	0.281

*Note.* Bold values indicate statistically significant result ( $p < 0.05$ ). Analysis adjusts for presence of other improved water source, year of installation, rainfall zone, tank volume, number of users, and latitude.

#### 4. Discussion

The results suggest private rainwater tanks are more likely to provide a sufficient year-round supply of water than communal rainwater tanks in rural Vanuatu. In this specific context, the results support the notion that, all else held constant, a private property regime is more effective than a communal property regime in averting depletion of a common pool resource. This aligns with evidence from Cambodia that property rights vested in an individual household can lead to more reliable water services than when property rights are held by the wider community (Foster et al., 2018). Importantly, the advantage held by private rainwater tanks in terms of year-round sufficiency in Vanuatu does not seem to come at the expense of households being able to use water for a range of domestic purposes, such as cooking and washing.

Private rainwater tanks held an advantage over communal rainwater tanks both with and without a community-based management committee, with the latter being arguably akin to the kind of open access scenario depicted in Hardin's allegory (Hardin, 1968). It is unclear whether the absence of community-based management committees occurs because they were never established at the outset or because at some point they became inactive and were disbanded. In any event, the existence of a committee at the time of data collection showed no significant association with a sufficient year-round water supply.

Further research is needed to identify how and why private ownership might promote better management of rainwater collection and storage in Vanuatu. Because the analysis adjusted for the number of users, the observed effect cannot be attributed to the tendency of private rainwater tanks to serve smaller user groups than communal tanks. Instead, the results may point to other advantages that indicate a household or family is a more effective unit of management than the village or “community.” For example, household-level ownership and management—particularly when the rainwater tank is located on the premises—could lead to stronger oversight and monitoring, more deep-seated social norms among a family user group, and increased ability to enforce usage rules (and hence enable successful exclusion to those who are non-compliant). Further exploration of these collective action issues are needed, and such investigations would do well to consider the recent history of villages in Vanuatu and the influence of missionization, colonialism and other local agencies (Love, 2021; Rodman, 1992). Delving beyond a simplistic private-communal dichotomy to explore scales of collective action that sit somewhere between the household and village is also worthy of examination. Another important consideration for future research is roof catchment area, which the current analysis was unable to adjust for but could otherwise contribute to the observed relationship between private tanks and year-round sufficiency.

It is important to emphasize that these results are context specific and do not mean private property-rights are a universal remedy. Many have cautioned against promotion of panaceas when it comes to governance of natural resources (Basurto & Ostrom, 2009; Meinzen-Dick, 2007). Pursuant to these warnings, there are several caveats that warrant mention in relation to this study. First, although the sufficiency of supply from private rainwater tanks appears more favorable than communal rainwater tanks, their performance is far from optimal, with half of all private rainwater tanks still failing to provide a sufficient year-round supply. Conversely, more than a third of communal rainwater tanks do successfully provide a sufficient supply of water throughout the year. In other words, there are many examples of successes and failures for both communal tanks and private tanks. Second, rainwater tanks represent a particular SES that differs greatly to others that have been studied (e.g., fisheries, wildlife, forests, etc.) in terms of size, dynamics, and other key

factors. In particular, excluding potential beneficiaries from rainwater tanks is likely easier than many other common-pool resource types. This would suggest rainwater tanks are located further along the excludability spectrum and closer toward the position occupied by private goods, for which the benefits of private ownership are well established (Ostrom, 2003). Another key point of differentiation is that private rainwater tanks are discrete systems or resource pools, where withdrawal of water from one does not directly affect availability of water in another private rainwater tank. This contrasts with a group of private wells drawing on the same aquifer, where withdrawal of water at one source can affect availability at another.

The results support the concept of self-supply and demonstrate that it can be a viable approach for securing more reliable water services in situations where communal systems are underperforming. In that sense, this study addresses the dearth of empirical evidence on the operational performance of self-supply, particularly in direct comparison to community managed water systems within a given context. The scarcity of studies on the reliability of self-supply lies in contrast to the plethora of studies examining community managed water supplies, and testifies to the invisible and informal nature of self-supply. The favourable findings in relation to self-supply have broader relevance to the Pacific region given widespread dependence on rainwater collection systems. Solomon Islands and Kiribati are two examples with a similarly even split of private and communal rainwater tanks (KNSO, 2019; SINSO, 2013). Strengthening the year-round reliability of water supply systems will be critical not only for achieving SDG 6 in the Pacific, but also for withstanding increasingly variable and uncertain rainfall patterns associated with climate change.

In addition to improved reliability, self-supply may present other advantages. First, self-supply means households are investing in their own infrastructure, creating additional sources of funding for an otherwise financially constrained sector (Danert & Hutton, 2020). The benefit of such an investment is not necessarily restricted to a single household. With an average of 30 users per private tank (median of 8 users), the data from this study suggest user groups are often broader than just a single household, with extended family or neighbours also benefitting. Second, self-supply also reduces the time spent collecting water from communal sources. In Vanuatu, for example, around 1-in-5 households served by a communal rainwater tank spend more than 10 min per round trip to collect water (VNSO, 2007). Obviating the need to collect water from outside the premises also reduces contamination risks that might otherwise occur when carrying water (Shields et al., 2015).

Self-supply in Vanuatu also comes with a number of potential disadvantages. First, private rainwater tanks may present greater contamination risks due to poorer construction standards. According to census data, private rainwater tanks in Vanuatu are less likely to be protected than communal rainwater tanks (VNSO, 2017). Construction standards for rainwater collection systems may also impact upon vulnerability to extreme events, such as tropical cyclones, which are common in Vanuatu. Second, self-supply may exacerbate inequities, with poorer households less able to afford their own water source or less able to ensure it attains acceptable construction standards. Data from Vanuatu validates this concern, with a rural household in the wealthiest quintile being almost twice as likely to source water from a private tank than the poorest quintile (VNSO & UNDP, 2012). If self-supply is to be more explicitly supported by policy and practice, efforts to safeguard water quality and ensure equitable outcomes would also be needed. Pursuing these objectives is not without precedent, with household water treatment, improved construction quality and microloans all well-rehearsed strategies for supporting safe drinking water in rural areas (Hunter, 2009; Ikeda & Arney, 2015; Morgan & Chimbunde, 1991). Financial support mechanisms could also enable households to opt for increased tank sizes, which the results show has a significant influence on the likelihood of supplying a sufficient quantity of water year round.

Future efforts to improve understanding of self-supply service levels should seek to address some of the limitations of this study. First, a binary indicator for year-round sufficiency was used in this study, but a more sophisticated measure would ideally unpack reliability based on duration and timing of non-availability, which are both important for understanding the impact of water shortages on households. This would ideally be assessed longitudinally to capture the impact of intra-annual and inter-annual rainfall variability. Second, the robustness of explanatory variables could be improved. For example, analysis would be strengthened with observed rainfall data and more precise rainwater tank volumes (point values rather than ranges). Third, a more comprehensive suite of explanatory variables—particularly socio-economic and cultural factors—could reduce the likelihood omitted variable bias, and also enable analysis to reveal the

nature of relationships in different sub-contexts. Fourth, while the results presented highlight and quantify key relationships, they do not explain the mechanisms and dynamics that underlie those relationships. A richer understanding of how different property-rights regimes translate into collective action require more in-depth qualitative methods. Finally, this study focused on just one indicator of performance (year-round sufficiency). A more comprehensive comparative assessment of self-supply versus community managed systems would need to consider other aspects such as water quality and equity.

## 5. Conclusions

This study has shed new light on the year-round sufficiency of water supplied by rainwater tanks in Vanuatu, and comparatively evaluated the performance of private rainwater tanks versus communal rainwater tanks across 19 islands. The results show that private rainwater tanks were more likely than communal rainwater tanks to provide a sufficient supply of water year round, and found that the presence or absence of a community-based committee had little influence on the strength of this association. The finding suggest self-supply may provide a viable pathway for improving the reliability of rainwater collection systems in rural Vanuatu. This has relevance to other Pacific Island countries where rainwater harvesting is common. However, policies in support of self-supply also need to consider other implications of self-supply, such as water quality and equity. Further work is needed to understand the broader advantages and disadvantages of self-supply versus community managed systems; elucidate the mechanisms by which private ownership facilitates a year-round supply; and identify wider strategies for improving the reliability, safety and inclusiveness of rainwater tanks in Vanuatu and other Pacific Island countries.

## Data Availability Statement

Data for this research can be found in Supporting Information.

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## References

- Allibone, R., Cronin, S. J., Charley, D. T., Neall, V. E., Stewart, R. B., & Oppenheimer, C. (2012). Dental fluorosis linked to degassing of Ambrym volcano, Vanuatu: A novel exposure pathway. *Environmental Geochemistry and Health*. <https://doi.org/10.1007/s10653-010-9338-2>
- Basurto, X., & Ostrom, E. (2009). The core challenges of moving beyond Garrett Hardin. *Journal of Natural Resources Policy Research*, 1(3), 255–259. <https://doi.org/10.1080/19390450903040447>
- CIG. (2018). *Cook Islands population census 2016*. Rarotonga: Cook Islands Government.
- CSDGT. (2013). *Tuvalu 2012: Population and housing census: Volume 1: Analytical report*. Funafuti: Central Statistics Division of the Government of Tuvalu.
- Danert, K., & Hutton, G. (2020). Shining the spotlight on household investments for water, sanitation and hygiene (WASH): Let us talk about HI and the three 'T's. *Journal of Water, Sanitation and Hygiene for Development*, 10(1), 1–4. <https://doi.org/10.2166/washdev.2020.139>
- DoWR. (2019). *Design and construction standards for rural water supply in Vanuatu*. Port Vila: Department of Water Resources.
- EPPSO-RMI, & SPC. (2012). *Republic of the Marshall Islands 2011 census report*. Noumea: Economic Policy, Planning and Statistics Office (Republic of the Marshall Islands) and the SPC Statistics for Development Programme.
- FBS. (2018). *Fiji population and housing census 2017: Administrative report and general tables*. Suva: Fiji Bureau of Statistics.
- Feeny, D., Berkes, F., McCay, B. J., & Acheson, J. M. (1990). The tragedy of the commons: Twenty-two years later. *Human Ecology*, 18(1), 1–19. <https://doi.org/10.1007/BF00889070>
- Foster, T., Furey, S., Banks, B., & Willetts, J. (2020). Functionality of handpump water supplies: A review of data from sub-Saharan Africa and the Asia-Pacific region. *International Journal of Water Resources Development*, 36(5), 855–869. <https://doi.org/10.1080/07900627.2018.1543117>
- Foster, T., & Hope, R. (2017). Evaluating waterpoint sustainability and access implications of revenue collection approaches in rural Kenya. *Water Resources Research*, 53(2), 1473–1490. <https://doi.org/10.1002/2016WR019634>
- Foster, T., Kohlitz, J., & Rand, E. (2020). *Rural water supply services in Vanuatu in need of significant improvements* (WASH Technical Paper TP/13/2020). Port Vila: UNICEF.
- Foster, T., Priadi, C., Kotra, K. K., Odagiri, M., Rand, E. C., & Willetts, J. (2021). Self-supplied drinking water in low-and middle-income countries in the Asia-Pacific. *npj Clean Water*, 4(1), 1–10. <https://doi.org/10.1038/s41545-021-00121-6>
- Foster, T., Shantz, A., Lala, S., & Willetts, J. (2018). Factors associated with operational sustainability of rural water supplies in Cambodia. *Environmental Science: Water Research & Technology*, 4(10), 1577–1588. <https://doi.org/10.1039/c8ew00087e>
- Foster, T., & Willetts, J. (2018). Multiple water source use in rural Vanuatu: Are households choosing the safest option for drinking? *International Journal of Environmental Health Research*, 28(6), 579–589. <https://doi.org/10.1080/09603123.2018.1491953>
- Grönwall, J., & Danert, K. (2020). Regarding groundwater and drinking water access through a human rights lens: Self-supply as a norm. *Water*, 12(2), 419. <https://doi.org/10.3390/w12020419>
- Hardin, G. (1968). The tragedy of the commons. *Science*, 162(3859), 1243–1248. <https://doi.org/10.1126/science.162.3859.1243>
- Harvey, P., & Reed, R. (2007). Community-managed water supplies in Africa: Sustainable or dispensable? *Community Development Journal*, 42(3), 365–378. <https://doi.org/10.1093/cdj/bsl001>
- Hunter, P. (2009). Household water treatment in developing countries: Comparing different intervention types using meta-regression. *Environmental Science & Technology*, 43(23), 8991–8997. <https://doi.org/10.1021/es9028217>

- Ikeda, J., & Arney, H. (2015). *Financing water and sanitation for the poor* (Water and Sanitation Program Learning Note). World Bank.
- KNSO. (2019). *Kiribati social development indicator survey 2018-19, survey findings report*. South Tarawa: Kiribati National Statistics Office.
- Koehler, J., Thomson, P., & Hope, R. (2015). Pump-priming payments for sustainable water services in rural Africa. *World Development*, 74, 397–411. <https://doi.org/10.1016/j.worlddev.2015.05.020>
- Kotra, K. K., Samanta, S., & Prasad, S. (2017). Rainwater harvesting for drinking: A physiochemical assessment in Port Vila, Vanuatu. *The South Pacific Journal of Natural and Applied Sciences*, 35(2), 33. <https://doi.org/10.1071/sp17004>
- Love, M. (2021). Tabu, MPA and community: Nomenclature and the political ecology of marine conservation in Vanuatu. *Journal of Political Ecology*, 28(1), 91–110. <https://doi.org/10.2458/jpe.2301>
- Meinzen-Dick, R. (2007). Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences*, 104(39), 15200–15205. <https://doi.org/10.1073/pnas.0702296104>
- Mommen, B., Humphries-Waa, K., & Gwavuya, S. (2017). Does women's participation in water committees affect management and water system performance in rural Vanuatu? *Waterlines*, 36(3), 216–232. <https://doi.org/10.3362/1756-3488.16-00026>
- Morgan, P., & Chimbunde, E. (1991). Upgrading family wells in Zimbabwe. *Waterlines*, 9(3), 10–12. <https://doi.org/10.3362/0262-8104.1991.003>
- Moriarty, P., Smits, S., Butterworth, J., & Franceys, R. (2013). Trends in rural water supply: Towards a service delivery approach. *Water Alternatives*, 6(3), 329–349.
- NSO, & ICF. (2019). *Papua New Guinea demographic and health survey 2016-18*. Port Moresby: Papua New Guinea National Statistical Office and ICF.
- OPS, & BBP. (2016). *2015 census of population housing and agriculture for the Republic of Palau: Volume 1: Basic tables*. Koror.
- Ostrom, E. (2003). How types of goods and property rights jointly affect collective action. *Journal of Theoretical Politics*, 15(3), 239–270. <https://doi.org/10.1177/0951692803015003002>
- Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, 325(5939), 419–422. <https://doi.org/10.1126/science.1172133>
- Rodman, M. (1992). Empowering place: Multilocality and multivocality. *American Anthropologist*, 94(3), 640–656. <https://doi.org/10.1525/aa.1992.94.3.02a00060>
- SBS. (2018). *2016 census brief No. 4: Housing/dwelling details & household amenities and capital goods*. Samoa Bureau of Statistics.
- Schlager, E., & Ostrom, E. (1992). Property-rights regimes and natural resources: A conceptual analysis. *Land Economics*, 68(3), 249–262. <https://doi.org/10.2307/3146375>
- Shields, K. F., Bain, R. E. S., Cronk, R., Wright, J. A., & Bartram, J. (2015). Association of supply type with fecal contamination of source water and household stored drinking water in developing countries: A bivariate meta-analysis. *Environmental Health Perspectives*, 123(12), 1222–1231. <https://doi.org/10.1289/ehp.1409002>
- SINSO. (2013). *Solomon Islands 2009 population & housing census national report* (Vol. 2). Honiara: Solomon Islands National Statistics Office.
- SINSO, SIMoHMS, & SPC. (2017). *Solomon Islands demographic and health survey 2015*. Honiara: Solomon Islands National Statistics Office, Solomon Islands Ministry of Health and Medical Services and the Pacific Community.
- SPC. (2012). *Republic of Nauru national report on population and housing: Census 2011*. Noumea: SPC.
- SPC. (2021). *Federated states of Micronesia census 2010*. Retrieved from <https://fsm.pogpis.spc.int/#view=map2&c=indicator>
- Statistics Niue. (2019). *Niue household and population census 2017*. Alofi: Statistics Niue.
- Sutton, S., & Buttworth, J. (2021). *Self-supply: Filling the gaps in public water supply provision*. Practical Action Publishing.
- TNSO. (2017). *2016 Tokelau census of population and dwellings*. Apia: Tokelau National Statistics Office.
- TSD. (2019). *Tonga 2016: Census of population and housing, Volume 2: Analytical report*. Nuku'alofa: Tonga Statistics Department.
- USCB. (2013a). *American Samoa 2010 census—Detailed crosstabulations part 1*. United States Census Bureau.
- USCB. (2013b). *Commonwealth of the Northern Mariana Islands 2010 census—Detailed crosstabulations part 1*. United States Census Bureau.
- USCB. (2013c). *Guam 2010 census—Detailed crosstabulations part 1*. United States Census Bureau.
- VMGHD. (2019). *Vanuatu climate update—August 2019*. Port Vila: Vanuatu Meteorology & Geo-Hazards Department.
- VNSO. (2007). *Vanuatu household income and expenditure survey 2006*. Port Vila: Vanuatu National Statistics Office.
- VNSO. (2017). *2016 post-TC Pam mini census report*. Port Vila: Vanuatu National Statistics Office.
- VNSO & UNDP. (2012). *Vanuatu hardship & poverty report: Analysis of the 2010 household income and expenditure survey*. Suva: Vanuatu National Statistics Office and UNDP Pacific Centre.
- WHO/UNICEF. (2017). *Safely managed drinking water—Thematic report on drinking water 2017*.
- WHO/UNICEF. (2018). *JMP methodology: 2017 update & SDG baselines*.
- WHO/UNICEF. (2019a). *Drinking water | JMP*. Retrieved from <https://washdata.org/monitoring/drinking-water>
- WHO/UNICEF. (2019b). *Estimates on the use of water, sanitation and hygiene in Micronesia (Federated States of)*.