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Geographical inequalities in drinking water in the Solomon Islands

Carmen Anthonj[1*], J. Wren Tracy[1], Lisa Fleming[1], Katherine F. Shields[1,4], Waqairapoa M. Tikoisuva[2], Emma Kelly[1], Mamita Bora Thakkar[3], Ryan Cronk[1], Marc Overmars[2], Jamie Bartram[1]

[1] The Water Institute, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, United States

[2] UNICEF Pacific, Fiji Development Bank Building, 360 Victoria Parade, Suva, Fiji

[3] UNICEF Solomon Islands, ANZ Haus, Kukum Highway, Ranadi, P.O Box 1786, Honiara, Solomon Islands

[4] Department of Geography, University of Oregon, Eugene, Oregon, USA

***Corresponding author**: **Carmen Anthonj**

The Water Institute at UNC, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599-7431, NC, USA

Email: carmen.anthonj@unc.edu

Highlights

- First nationally representative baseline on drinking water in the Solomon Islands
- Rural-urban, provincial, and centrality-periphery inequalities in drinking water
- Central provinces use piped water and remote provinces use rain- and surface water
- Inter-national inequalities: the Solomon Islands lag behind other Pacific Island Countries
- Need to incorporate geographical inequalities in monitoring, policy and programming

Abstract

Sustainable Development Goal 6.1 seeks to "by 2030, achieve universal and equitable access to safe and affordable drinking water", which is challenging particularly in Small Island Developing States (SIDS) and Pacific Island Countries (PIC). We report drinking water sources and services in the Solomon Islands and examine geographical inequalities.

Based on two quantitative baseline datasets of n=1,598 rural and n=1,068 urban households, we analyzed different drinking water variables (source type, collection time, amount, use, perceived quality, storage, treatment) and a composite index, drinking water service level. We stratified data by urban and rural areas and by province, mapped, and contextualized them.

There are substantive rural-urban drinking water inequalities in the Solomon Islands. Overall, urban households are more likely to: use improved drinking water sources, need less time to collect water, collect more water, store their water more safely, treat water prior to consumption, perceive their water quality as better and have an at least basic drinking water service than rural households. There are also provincial and center-periphery inequalities in drinking water access, with more centrally located provinces using piped water supplies and more distant and remote provinces using rainwater and surface water as their primary source. There are also inter-national inequalities. Out of all PICs, the Solomon Islands have among the lowest access to basic drinking water services: 92% of urban and 55% of rural households. Of all SIDS, PICs are least serviced.

This study shows that drinking water inequality is a critical issue, and highlights that all identified dimensions of inequality - rural-urban, provincial, center-periphery and inter-national - need to be explicitly recognized and addressed and included in pro-equity monitoring, policy and programming efforts by the Solomon Islands Government and stakeholders to reduce inequalities as per the Agenda 2030.

MAIN TEXT

1 Introduction

In the Solomon Islands, a Pacific Island Country (PIC), that comprises hundreds of small islands and is located remotely in the Pacific Ocean, that is environmentally and economically vulnerable and that is subject to rapid urban growth, the provision of safe domestic drinking water is challenging (Hadwen et al., 2015; MacDonald et al., 2017, Moglia et al. 2008, White et al. 2008). The low coverage of sanitation and sewerage services (Fleming et al. 2019, SOPAC 2007, WHO and UNICEF 2019) poses a contamination threat to the surface water resources (Merson et al. 1977, Mosley et al. 2004, White et al. 2008). This impairs the ability of the different available types of water sources (Carrard et al. 2019, White and Falkland 2009), supply and distribution systems (Foster et al. 2019) to provide safe water (Bain, Cronk et al. 2014, Foster and Willetts 2019, WHO and UNICEF 2018).

Drinking water service provision differs between urban, peri-urban and rural areas (Bain, Wright et al. 2014, Schrecongost and Wong 2015, Schrecongost et al. 2015, Smith 2008, WHO and UNICEF 2019). According to the WHO and UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP), 68% of Solomon Islanders (61% in rural and 91% in urban areas) have an at least basic drinking water service, defined as drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing (WHO and UNICEF 2019, Table 1). These official numbers are based on information from Demography and Health Surveys (DHS), Multiple Indicator Cluster Surveys (MICs) and censuses that lack detail on the drinking water situation across the country. Interpolation and derivations of multiple data points from different surveys and across multiple years, however, do not allow for a detailed assessment of the drinking water situation in the country.

As the Solomon Island Government National WaSH Policy has the declared vision that "*all Solomon Islanders will have easy access to sufficient quantity and quality of water, appropriate sanitation and will be living in a safe and hygienic environment by 2024*" (MHMS 2014), and aimed for *"examining the need to upgrade and extend [the] coverage of water supply [as well as sanitation and hygiene (WaSH)] in urban and rural areas"* (MHMS 2016, SIG 2016), such a detailed assessment is vital.

To support planning for the implementation of national strategies and policies, and to create a baseline / benchmark for reporting on Sustainable Development Goal (SDG) 6.1 ("*by 2030, achieve universal and equitable access to safe and affordable drinking water for all*") (UN General Assembly 2015), two surveys of rural and urban households were conducted by UNICEF Pacific (Anthonj et al. 2018, Shields et al. 2017). Based on these two datasets, here we

i. present an assessment of the drinking water situation in the Solomon Islands;
ii. identify rural-urban, center-periphery, and provincial inequalities; and
iii. present inter-national inequalities in drinking water services by comparing the Solomon Island data to estimates for other PICs and small island developing states (SIDS).

This is the first paper to assess the drinking water situation and examine different geographical dimensions of drinking water inequalities in a SIDS or PICs in detail. The identified dimensions of inequality help to uncover service gaps and pro-equity potential for improvement, informing national WaSH policy, strategic planning and programming in the Solomon Islands to reduce said inequalities as per the 2030 Agenda for Sustainable Development (UN General Assembly 2015).

2 Country context: The Solomon Islands

The Solomon Islands, an archipelagic state in the south-west Pacific Ocean, comprise six major islands and nearly 1,000 smaller islands, of which approximately 350 are inhabited. The country covers an area of 28,000 km^2 and has a coast line of about 5,300 km. The central islands are

mostly of volcanic origin, rugged and mountainous, and outer islands are coral atolls and raised coral reef. The country's lowest point is the Pacific Ocean at 0 m a.s.l., the highest point is Mount Makarakomburu at 2,500 m a.s.l. (SOPAC 2007).

The tropical equatorial climate is characterized by constant high temperatures (~27 °C), high humidity (80%), and abundant rainfall in most areas throughout the year (3,000 to 5,000 mm per annum). Rainfall patterns vary between locations, according to topographical gradients and the season (MECDM 2012, MECDM 2018). The rainy season, within which on average almost 70% of the yearly total rain falls, lasts from November to April. The dry season (~600 mm) lasts from May to October. The far east of the country receives more precipitation (280 to 420 mm per month) (MECDM 2012).

The main islands cover different hydrological regions. Water resources availability ranges from sizeable rivers to small streams, from high mountainous and dense rainforest islands to rainwater harvesting and thin freshwater lens of underground aquifers of the small low-lying atolls and islets (SOPAC 2007). The country has nine provinces and approximately 600,000 inhabitants. The capital, Honiara, is located on Guadalcanal, the largest island (Figure 1) (MECDM 2018, SOPAC 2007). As one of the Pacific's poorest countries, the Solomon Islands mainly rely on subsistence farming and struggle with poor infrastructure, limited labor skills, high utility costs, land tenure issues, inadequate public administration and financial management capacity (DFAT 2018). These factors compromise the provision of public services to the small and geographically dispersed population.

While the largest share of the population (75%) lives in rural areas (UN Habitat 2012), urbanization is rapid, with people migrating to cities seeking employment and business opportunities (SIG 2009). By 2050, the population living in urban areas is expected to increase to about 40% (Figure 2, Schwarz et al. 2011). Rapid growth of urban populations challenges water service delivery (ADB 2012, Anthonj et al. 2014, Cocklin and Keen 2000, Haberkorn 2008,

Hommes and Boelens 2017, Schrecongost and Wong 2015, Schrecongost et al. 2015, SIG 2009, UN-Habitat 2012).

Households in the major urban centres Honiara, Auki, Noro, Tulagi and Gizo are usually connected to water supply systems. Groundwater sources account for 40% of urban water supplies, and spring water sources for 60%. Gravity and pumping systems are used to distribute water from the main reservoir tanks in the mountains to the supply systems in the cities. Rural households supply their water mainly from gravity-fed systems, rainwater harvesting systems and hand dug wells. Water systems are typically fed by rivers, streams and springs. Water quality and water quality monitoring remain challenging in the Solomon Islands despite the Water Act (Government of the Solomon Islands 1992) that calls for the adequate protection of water sources and supplies. Water pollution comes from many different sources, including untreated sewage, industrial discharges, leakage from oil storage tanks, drainage from the residues of agricultural fertilizers and pesticides (SOPAC 2007).

The region faces significant challenges from changing climate and is vulnerable to extreme weather events such as heavy rainfall, flooding, drought, tropical storms and longer-term sea level rise (IPCC 2014, WHO 2015). In 2014, for example, heavy rains from a tropical depression, which later became a cyclone, caused severe flooding that affected over 50,000 people, displaced over 10,000 people. The flooding severely damaged and destroyed buildings and infrastructure, including water supply systems, particularly in the capital Honiara (Howard and Bartram 2016, Reliefweb 2014).

3 Methods

3.1 Survey instrument design and testing

Structured surveys were programmed into the Akvo FLOW mobile data collection tool to allow for data collection using smart phones. The surveys covered information on household characteristics, drinking water source, time spent to collect water, amount of water used, water

use activities, perceived water quality, household water treatment and storage, water point functionality (Supplementary Table 1) and management (Supplementary Table 2), sanitation, hygiene and environmental health. The survey design and survey questions were grounded and categorized in accordance with WHO & UNICEF JMP definitions (see Table 1, WHO and UNICEF 2018, WHO and UNICEF 2019). The questionnaires were developed within the Rural WaSH program within the Solomon Islands Ministry of Health and Medical Services (MHMS) Environmental Health Division (EHD). The broader WaSH sector, the National Statistics Office, WaterAid and UNICEF reviewed the questionnaires.

Two-week trainings of enumerators were conducted by MHMS, WaterAid (for the rural baseline only) and UNICEF. The trainings included planning of data collection, familiarization with the use of the data collection tool, familiarization with the survey, pre-test of the tool, training in the sampling methodology, reporting, supervision and information management (described in detail in Shields et al. 2017, Anthonj et al. 2018)

3.2 Sampling

The sample designs for the urban and rural baseline surveys were developed in collaboration with the Solomon Islands National Statistics Office. The samples were designed to be nationally representative. Enumeration areas (EAs) were the foundation of sampling. EAs correspond to the national population and housing census (SIG 2009) which, for field operational purposes, divides the whole country into 1344 EAs, defined within the ward boundaries.

In rural areas, 79 EAs out of the total 1,061 rural EAs were sampled using the probability proportional to size method in each stratum (province). The selection was done using a fixed interval with a random start point. Within each EA, twenty households were randomly selected and surveyed, resulting in a total sample of 1,597 households. No rural households were sampled in Honiara, because it is an urban area.

In urban areas, 108 EAs of the total 283 urban EAs were sampled; 54 EAs in the Greater Honiara area and 54 EAs in other urban areas. Within each EA, ten households were randomly selected

and surveyed, resulting in a total sample of 1,062 households. The capital Honiara, although located in Guadalcanal, was sampled separately from the rest of Guadalcanal to ensure representation of other urban EAs within the island. No urban households were sampled in the province of Rennell & Bellona, because it has no enumeration areas designated as urban (Table 2) (Fleming et al. 2019).

3.3 Data collection

Data collection was carried out by teams consisting of MHMS WaSH staff, UNICEF Solomon Islands WaSH Officer, volunteers, and DHS enumerators, and conducted in English and Pidgin. The data collection in the rural EAs was conducted from November 2015 to January 2016. In urban EAs, data were collected from August to September 2017. Ethical clearance was obtained from the University of North Carolina at Chapel Hill (studies #16-0842 and #17-3194), and from the Solomon Islands Health Research and Ethics Review Board at the Solomon Islands Ministry of Health and Medical Services (study #HREO33/17) (Fleming et al. 2019).

3.4 Data analysis

We calculated descriptive statistics to describe the magnitude of the disparity between urban and rural areas. Frequencies for ordinal and categorical variables as well as the mean, median, and max for continuous variables were computed for all variables of interest. Observations were separated based on classification as an urban or rural household. The significance of differences between urban and rural areas were calculated for all variables of interest using either the Pearson's chi-squared test (ordinal and categorical variables) or the two samples t-test (continuous variables). The significance level was set at p-value ≤ 0.05. STATA 14.2 was used to format and analyze the data (Version 14.2, StataCorp, College Station, Texas).

Drinking water service levels were generated following guidance from the WHO/UNICEF JMP (for definition of service levels, see Table 1 and WHO and UNICEF 2019). The main drinking water source for each household was categorized as either improved or unimproved based on JMP standard classifications and it was further determined which households had a main water

source on-premise or a round trip collection time within 30 minutes (Table 1). Water quality testing was not part of this study. Therefore, the highest drinking water service – safely managed (Table 1) – was not determined.

4 Results

4.1 Drinking water source and service

The predominant source of drinking water used by urban and rural households in the Solomon Islands was piped water (40%) (Figure 3, Table 3, Table 1 for definitions). Many urban households also used rainwater (43%), while many rural households supplemented piped water with unimproved sources (41%) including surface water (20%). Urban households were significantly more likely to use an improved source (Table 1) than rural households ($p < 0.001$).

The average reported time to go to the source, collect water, and return home was higher in rural (17 minutes) than in urban areas (4 minutes) (Table 4). Overall, 90% of households reported a round trip collection time less than 30 minutes. Households in rural areas were significantly more likely to take more than 30 minutes to collect water (14%) compared to households in urban areas (3%) ($p < 0.001$).

Overall, 70% of households had at an least basic water service as defined by the WHO/UNICEF JMP (Figure 4, Table 1). Households in urban areas were significantly more likely to have access to at least basic water service (92%) compared to households in rural areas (55%) ($p < 0.001$). These data correspond with data released by the WHO/UNICEF JMP (2019) (Table 6).

Self-perception of water quality revealed that the majority of households perceived water quality as good (54%). Significantly more urban (59%) than rural households (51%) perceived water quality as good ($p < 0.001$). Few households perceived the quality of water as poor (9%). Those households perceiving water quality as poor felt the water was polluted, cloudy, or muddy and this was significantly more likely in rural (85%) than in urban households (42%) ($p < 0.001$) (Table 3).

4.2 Water collection, use, storage, and treatment

More water per household per day was used in urban (69 litres) than in rural (29 litres) areas ($p < 0.0001$) (Table 4). More water per capita per day was used in urban (12 litres) than in rural (6 litres) households ($p < 0.0001$).

Water from the main drinking water source was used mainly for drinking (98% of households), cooking (89% of households) and bathing (72% of households) (Table 5). More rural (100%) than urban households (94%) used water from the main source for drinking, and more rural (7%) than urban (3%) households used water from the main source for watering livestock ($p < 0.0001$). Water uses varied by province (Supplementary Table 3).Water was reported to be stored in small, narrow-mouthed containers in urban (79%) and rural (83%) households. Urban-rural differences in household water storage were significant ($p < 0.001$). The majority of storage containers were sealed or had a lid (93%).

Significantly more rural (91%) than urban (77%) households reported that they did not treat their drinking water prior to consumption ($p < 0.001$). Among households that treated their drinking water, boiling was the most common treatment method reported, and was practiced by more urban (76%) than rural (53%) households ($p < 0.001$) (Table 3).

4.3 Provincial differences in drinking water access

The use of piped water as main drinking water source in urban households was highest in Guadalcanal/Honiara (63%), Isabel (62%) and Malaita (59%) provinces and lowest in Temotu and Choiseul (0%). More households in Honiara City (68%) than in the Greater Honiara area (35%) used piped water.

Rainwater in urban households was mainly used in Western (93%) and Temotu (75%) provinces and all households in Choiseul reported rainwater as their primary source (100%). Surface water was the main water source in 15% of urban households in Temotu (Figure 5). The use of piped water as main drinking water source in rural areas was highest in Makira (63%)

and Central (58%) provinces, and lowest in Rennel and Bellona (0%). Rainwater was the primary source in all rural households surveyed in Rennel and Bellona (100%). Surface water was the main water source in 31% of rural households in Western, 29% of rural households in Makira, and 24% of rural households in Guadalcanal and Choiseul (Figure 6).

Urban-rural drinking water service levels differed by province (Figure 7). In urban households, access to an at least basic water service was highest in Isabel (100%) and Western (97%), and lowest in Malaita (85%) and Temotu (74%). In rural households, access to an at least basic water service was highest in Isabel (90%) and Makira (66%) and lowest in Guadalcanal/Honiara (44%) and Temotu (43%). Urban-rural drinking water service level differences were significant in all provinces but Isabel. A comparison of Honiara City and Greater Honiara area revealed that more households in Honiara City (93%) had an at least basic drinking water service than in the Greater Honiara area (85%).

4.4 Comparing our drinking water data to other Pacific Island Countries and Small Island Developing States

According to our survey, most households in the Solomon Islands (92% of urban and 55% of rural households) had an at least basic drinking water service. Of all PICs, households in the Solomon Islands have among the lowest levels of basic drinking water service. According to previous JMP estimates, only Papua New Guinean and Kiribatian households have a lower drinking water status. Of all SIDS, PICs have among the lowest coverage of basic drinking water services (WHO and UNICEF 2019, assembled in Table 6).

5 Discussion

5.1 Rural-urban inequalities

All aspects related to drinking water in the Solomon Islands significantly differed between urban and rural households. Urban households had a better water situation, with more households using improved water sources, needing less time to collect water, perceiving their

276 water quality as better, using more water and treating their drinking water prior to
277 consumption than rural households. Our results are in line with previous evidence on
278 rural/urban drinking water disparities (Bain, Wright et al. 2014).

279 Besides water source, supply and distribution systems that may account for urban-rural
280 differences in the household water situation in the Solomon Islands, differences in inner-
281 household water-related behaviours and decisions may also be related to gender of the
282 household head (81% of rural households versus 66% of urban households headed by men in
283 the Solomon Islands), differences in household size (7 members in urban households versus 6
284 members in rural households on average) (Fleming et al. 2019) and different water needs for
285 different activities in urban versus rural households (Table 5).

286 Despite rapid urban growth and the expansion of informal settlements (SIG 2009, UN-Habitat
287 2012), the nationally established enumeration areas do not consider peri-urban or informal
288 settlements as a separate category. Peri-urban areas and informal settlements are distinct and
289 often undersupplied in terms of water, sanitation and sewerage infrastructure, while a higher
290 population density may increase the likelihood of water contamination and disease exposure
291 (Sinharoy et al. 2019).

292 As these (urban OR rural) enumeration areas are the ones we used in our study, we were only
293 able to distinguish urban from rural household, but not identify peri-urban households.
294 Designing this study to distinguish urban EAs into Honiara and Greater Honiara however did
295 part of this: Honiara is within the official boundary and Greater Honiara is outside this
296 boundary – based on which we could argue that Greater Honiara is peri-urban. Following this
297 classification, our results of more households in Honiara City (93%) having at least basic
298 drinking water service than in the Greater Honiara area (85%), and more households in Honiara
299 City (68%) than in the Greater Honiara area (35%) having piped water as their main drinking
300 water source suggests that peri-urban areas are less well supplied with drinking water than
301 urban areas.Furthermore, Yu et al. (2014) discuss that rapidly growing peri-urban areas are in

different countries often placed in the "rural" category for monitoring purposes, thereby leading to an over-estimate of urban coverage in WaSH provision and a possible corresponding underestimate in rural areas.

The fact that the water supply situation in rural Guadalcanal is worse than in other central rural provinces may point to such misclassification of peri-urban households in the rural category in our study.

Inequalities and WaSH-related undersupply in expanding urban and peri-urban populations have previously been reported in small island developing states in the Pacific (Poustie and Deletic 2014), and globally (Bain, Wright et al. 2014). The rapid urban growth puts an increasing strain on the water services of the Solomon Islands, as city populations grow faster than the ability of the governments' ability to plan for, build and manage these changes (Schrecongost and Wong 2015, Schrecongost et al. 2015, SIG 2009, UN-Habitat 2012). Adverse implications of "rapid, unplanned urban expansion" for the population and the environment are acknowledged in the Solomon Islands National Development Strategy 2016 to 2035 (SIG 2016). However, without disaggregation in the prevalent classification, peri-urban areas, characterized by informal settlement, are not targeted in national water policies. Water utilities are restricted to providing services to households with legal land tenure (Schrecongost and Wong 2015, UN-Habitat 2012), which many households in peri-urban and informal settlements in the Solomon Islands do not have (Saunders et al. 2016, Sinharoy et al. 2019). At the same time, they are unable and/or do not have an incentive to invest in household drinking water infrastructure. These are often the poorest people – and having to provide their own water adds a double burden to them.

Unplanned and unimproved water service delivery in densely populated peri-urban and informal settlements is particularly problematic when considering the impact of extreme weather events such as heavy rains, flooding and drought on drinking water and sanitation infrastructure and resulting exposure to infectious diseases in the Solomon Islands (Fleming et

al. 2019, Grasham et al. 2019, Howard et al. 2010, Howard et al. 2016, Jenkins and Jupiter 2015, McDonald et al. 2011, MID 2014, Tucci 2008, WHO 2015).

5.2 Geographic location and centrality and provincial inequalities

Beyond rural-urban inequalities that occur across islands, there are substantive inter-provincial inequalities in drinking water sources and service levels in the Solomon Islands. These appear to be related to centrality and location. Urban households in the provinces Guadalcanal (including Honiara), Isabel, Malaita and Makira mainly used piped water supplies; the islands constituting these provinces are also the ones located in the center of the country. In the urban areas of Honiara (Guadalcanal), Auki (Malaita), Noro (Western), Tulagi (Central), drinking water supply is managed by Solomon Water, a state owned enterprise (Solomon Water 2019). Piped water supplies were more common for households in urban areas serviced by Solomon Water (54%) than for households in urban areas that were not serviced by Solomon Water (16%). Rural households in the provinces Makira and Central also mainly used piped water supplies, which may speak for rural households in provinces located in the center of the Solomon Islands being covered by functioning supply systems almost as well as their urban counterparts. The proximity to the capital Honiara, where water-related decisions are made and where water-related policies are drafted, may be one reason for the piped supply of central provinces.

Urban households in the north western provinces Choiseul and Western almost exclusively used rainwater as their main drinking water sourc. Urban households in Temotu, located in the far east of the country, used mainly rainwater or surface water. These provinces are all outer and remote island groups. Rural households in the north western provinces Choiseul, Western and Isabel used rainwater or surface water as their main drinking water source and rural households in the far east of the country (Temotu) used mainly unimproved sources. The central provinces and islands are easier to be reached by Solomon Water than the outer and remote provinces which are located more than 200km from the capital. This may explain the

353 dependence on rainwater and surface water sources, as piped supply systems, if available, may
354 be less well maintained and functioning.

355 Rainwater was mainly used in the north western provinces Western and Choiseul, in the eastern
356 province Temotu, and in the southern province Rennel and Bellona. Precipitation patterns vary
357 across the Solomon Islands and are dependent on topography, latitude, and are affected by the
358 movement of the South Pacific Convergence Zone, the Intertropical Convergence Zone, El Niño,
359 and the West Pacific Monsoon (Solomon Islands Meteorological Service 2011). Western,
360 Choiseul, and Temotu have most rainy days per year in the country (Figure 8) and this may
361 explain the use of rainwater as main drinking water source. Households using rainwater as their
362 main water source were on average further away from the nearest river than households using
363 any other main water source type. Overall, and regardless of whether households were located
364 in urban or in rural areas, the drinking water situation was better in the central than in the
365 outer provinces.

366 This points to another possible explanation for the inequalities in drinking water supply at
367 provincial level: according to the most recent Household Income and Expenditure Survey (HIES)
368 (Solomon Islands National Statistics Office 2015), the incomes in the central provinces
369 Guadalcanal with Honiara (144,969 SBD per household, 22,453 SBD per capita), as well as
370 Central (67,445 SBD per household, 12,566 SBD per capita), are the highest in the country,
371 while the incomes in the remote outer provinces Choiseul (58,903 SBD per household, 10,455
372 SBD per capita), Western (44,227 SBD per household, 7,916 SBD per capita), Rennell and
373 Bellona (44,851 SBD per household, 12,566 SBD per capita), Temotu (47,312 SBD per
374 household, 8,455 SBD per capita), and Makira (34,738 SBD per household, 5,546 SBD per
375 capita), are the lowest.

376 In the Solomon Islands, the infrastructure for utility piped systems is usually subsidized by the
377 government, while areas with self-supply – especially in the more remote areas – often have to
378 provide infrastructure themselves. The SDGs aim to achieve universal and equitable access to

safe and affordable drinking water for all. The direction of government actions in the Solomon Islands – piped water infrastructure subsidy – however, points to increasing inequalities rather than reducing them (Fuente and Bartram 2018).

Inter-provincial and center-periphery inequalities in drinking water sources and services illustrate that besides urban and rural setting, populations in different geographical zones (e.g. center and periphery) within the country are potentially at different 'risk' when it comes to water (under)supply (Adams and Smiley 2018, Afifah et al. 2018, Pullan et al. 2014, Smith 2008, Yu et al. 2014).

5.3 Inter-national inequalities

According to our survey, most households, (92% of urban and 55% of rural households) had an at least basic drinking water service in the Solomon Islands. Our data correspond with data released by the WHO/UNICEF JMP (2019) (Table 5). PICs, including the Solomon Islands, lag behind international trends in drinking water development. The levels of at least basic drinking water service, as well as the rates of improvement in WaSH are low (WHO and UNICEF 2019). Of all PICs, the Solomon Islands have among the lowest levels of access to basic drinking water services, and among SIDS, PICs are the country group that have the lowest access to basic drinking water services.

Globally, PICs are being located on the periphery in the Pacific Ocean. Following our previous argument of center-periphery in the Solomon Islands which explained higher coverage of at least basic drinking water service provision in more central provinces and island groups in the countries as compared to less well serviced outer and remote islands, the location of PICs as compared to other SIDS may reflect a similar center-periphery disparity at a larger geographical scale. This may explain the lower service coverage in PICs compared to SIDS in Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS), the Caribbean, and Non-UN Members/Associate Members of Regional Commissions countries (Table 5).

5.4 Limitations

The cross-sectional design of the surveys was useful for providing a snapshot of the drinking water situation. However, it could not shed light on temporal or topographical differences of water source use, perceived water quality, service provision or water-related behaviours. The exclusive focus on the main drinking water source, the dominant paradigm in drinking water monitoring (Anthonj and Brocklehurst 2019), is limitation of our study, as the use of multiple drinking water sources is widespread in the Solomon Islands. The choice of household drinking water source is closely related to seasonality, amongst other factors. Unpredictable and changing precipitation patterns make rainwater – one of the main drinking water sources in the Solomon Islands - an unreliable source, inducing seasonal shifts in domestic water source use and storage during periods of reduced rainfall and drought (Elliott et al. 2017, Foster and Willetts 2018, Grasham et al. 2019, Hadwen et al. 2015, MacDonald et al. 2016, Mosley et al. 2004, Smith 2008). Inclusion of data on seasonality and multiple source use could have allowed for deeper and more contextualized insights, and for an increased understanding of how a "portfolio" of sources can reveal resiliency to water insecurity (Elliott et al. 2017, Anthonj and Brocklehurst 2019).

Water quality testing was not part of this study. Therefore, the highest drinking water service – safely managed (Table 1) – was not determined. Valuable insights on water quality issues associated with different types of water sources were published in a systematic review by Bain, Cronk et al. (2014) and Foster and Willetts (2019).

Our two surveys were planned based on different sampling, and data were collected at different times (Fleming et al. 2019, MacDonald et al. 2017, Tuhaika 2007). The rural survey was conducted during the holiday season, when many people who normally live in Honiara visit their home villages. It is possible that some respondents surveyed were not full-time residents of rural areas, thus lacking some information on and/or misperceiving the water situation while also skewing household size and derived inferences. While the fact that the two surveys were

not conducted in tandem may limit the validity of joint analyses, given the relative lack of data on WaSH services in SIDS and particularly Pacific Island Countries, we felt it important to publicize the results despite these limitations.

Due to logistical and political challenges, the urban survey did not consider differences between formal and informal settlements, or urban and peri-urban areas. However, an approximation based on differences between Honiara City and the Greater Honiara area allowed for insights into the drinking water situation in peri-urban areas. As comparisons of urban and rural areas are sensitive to definitions of urban extent, future research should include the differentiation of peri-urban populations as an integral part of their study design (Christenson et al. 2014).

6 Conclusions

This is the first study to examine rural-urban, inter-provincial and center-periphery inequalities in drinking water source use and services in the Solomon Islands.

Our analyses of drinking water inequalities show that urban households are more likely to use improved drinking water sources, need less time to collect water, collect more water per day, store their water more safely, treat their drinking water prior to consumption, perceive their water quality as better and are more likely to have an at least basic drinking water service than rural households. Beyond rural-urban inequalities, there are provincial and center-periphery inequalities in drinking water access, with more centrally located provinces using piped water supplies and more distant and remote provinces using rainwater and surface water as their primary source. Inter-national inequalities are substantive: PICs lag behind international trends in drinking water development (WHO and UNICEF 2019) and among PICs, the Solomon Islands have among the lowest access to basic drinking water services (92% of urban and 55% of rural households having at least basic drinking water service).

Drinking water inequality is a critical issue, and *tracking inequalities in access to drinking water, sanitation and hygiene is essential for achieving universal access and ensuring progressive realization of the human rights to water and sanitation* (WHO and UNICEF 2019).

Our findings highlight that all dimensions of inequality identified in the Solomon Islands – rural-urban, provincial, center-periphery and inter-national - should be recognized and addressed (Bain, Wright et al. 2014, White et al. 2008). Furthermore, all dimensions of geographical inequality need to be included in pro-equity SDG 6 monitoring, policy and programming efforts by the Solomon Islands Government and stakeholders to reduce said inequalities as per the 2030 Agenda for Sustainable Development (UN General Assembly 2015).

Recommendations:

- Strengthening the roles and responsibilities of drinking water service providers at the provincial level, and deploying more staff to do this work (Shields et al. 2017).
- Prioritizing low-access provinces and vulnerable populations following a 'pro-equity' approach (WHO and UNICEF 2019).
- Creating targeted drinking water policies and strategic plans at the provincial level that consider rural, *peri-urban*, and urban areas in the Solomon Islands, rather than relying on a specifically rural policy and strategic plan for the whole country.
- Revising classification of enumeration areas to include rural, urban *and* peri-urban.

Monitoring and evaluation:

- Monitoring WaSH service levels at provincial levels to track progress towards universal equality in drinking water coverage.
- Aligning WaSH monitoring with the proposed JMP core and expanded survey questions (GLAAS) for the SDGs to allow comparing performance to other countries.
- Reporting water quality monitoring (free from faecal and priority chemical contamination) for the highest level of drinking water service –safely managed.

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Conflict of interest

The authors declare that they have no conflict of interest.

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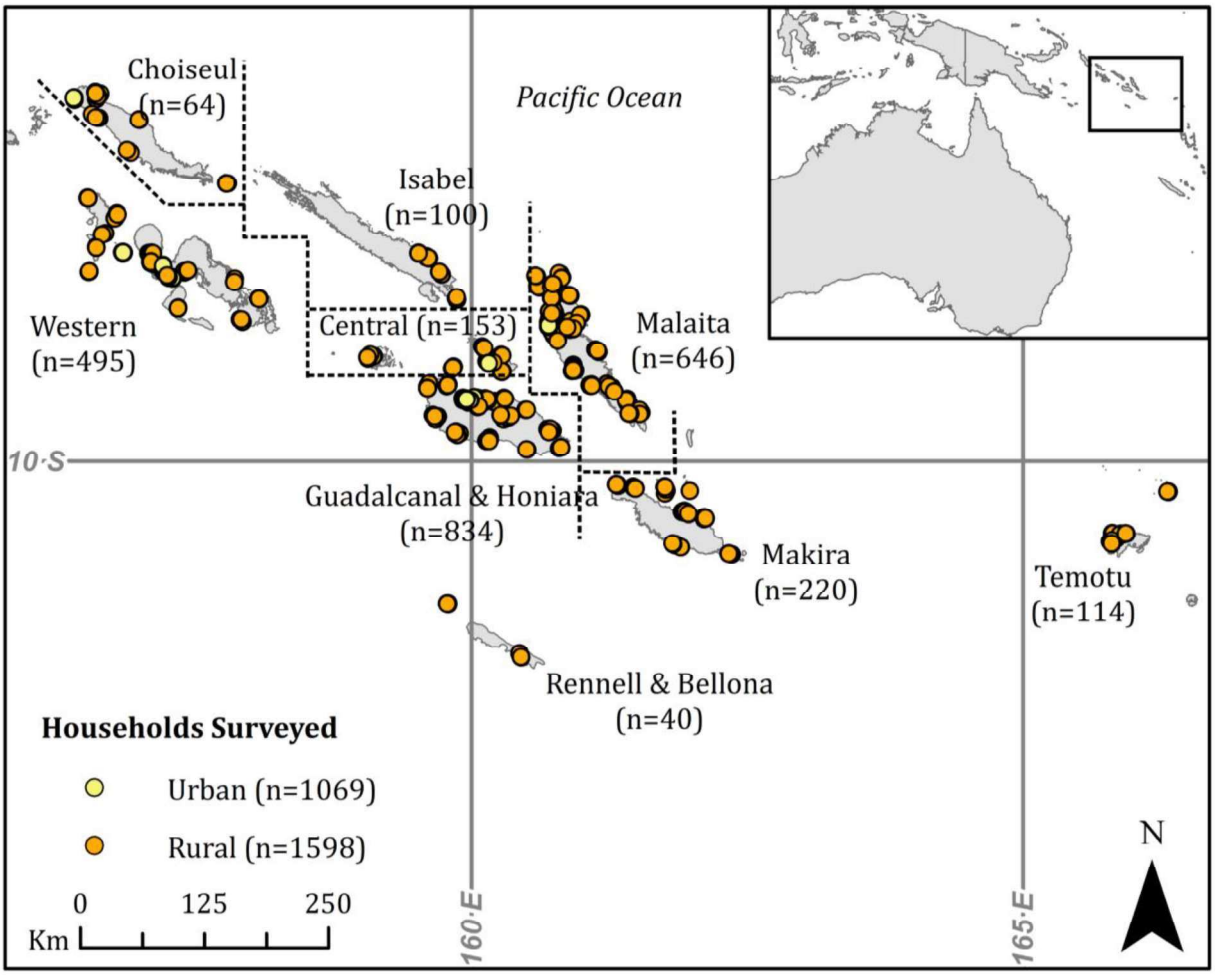

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680 **Figure 1: Rural and Urban Households in the Solomon Islands included in this Study**

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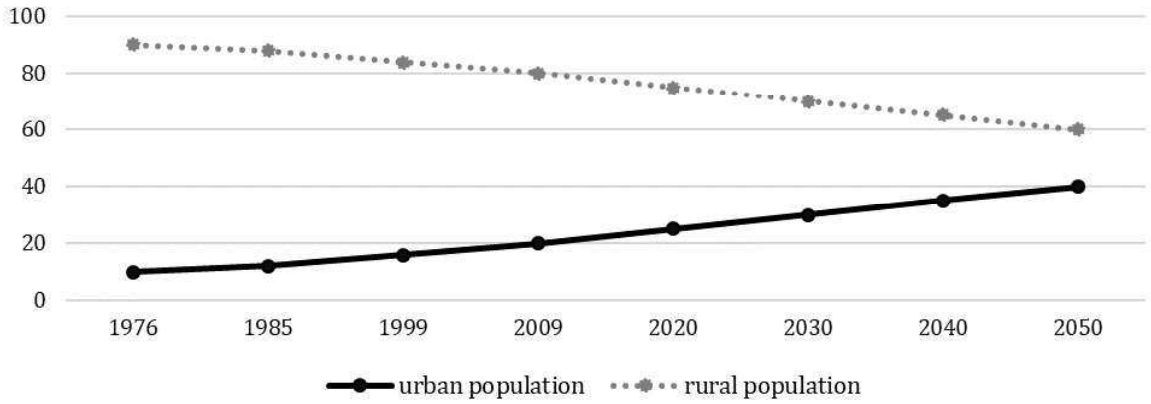

Figure 2: Urban and rural population in the Solomon Islands (share in %) (UN-Habitat 2012)

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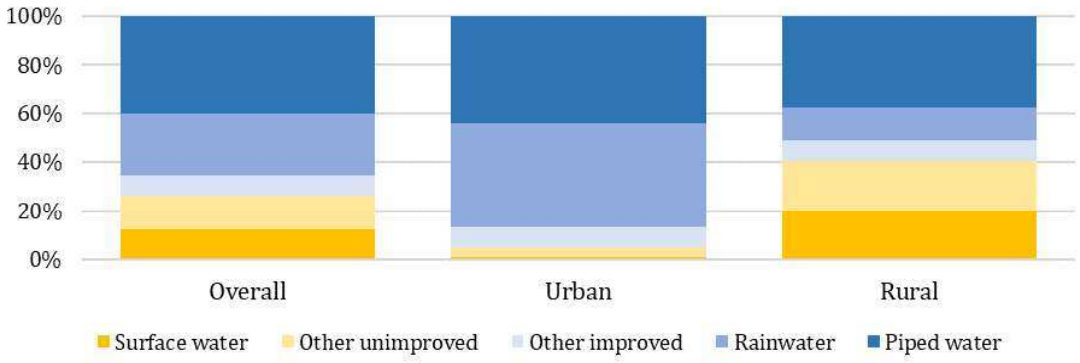

Blue bars indicate improved drinking water sources. Improved drinking water sources are those that have the potential to deliver safe water by nature of their design and construction, and include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water. Protected sources are covered by stonework, concrete or other materials that prevent the entry of physical, chemical and biological contaminants. Orange and yellow bars indicate unimproved drinking water sources. Unimproved sources include surface water, unprotected wells and springs, as well as unknown sources (Source: WHO/UNICEF 2019).

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689 **Figure 3: Main drinking water source in urban and rural households in the Solomon Islands**

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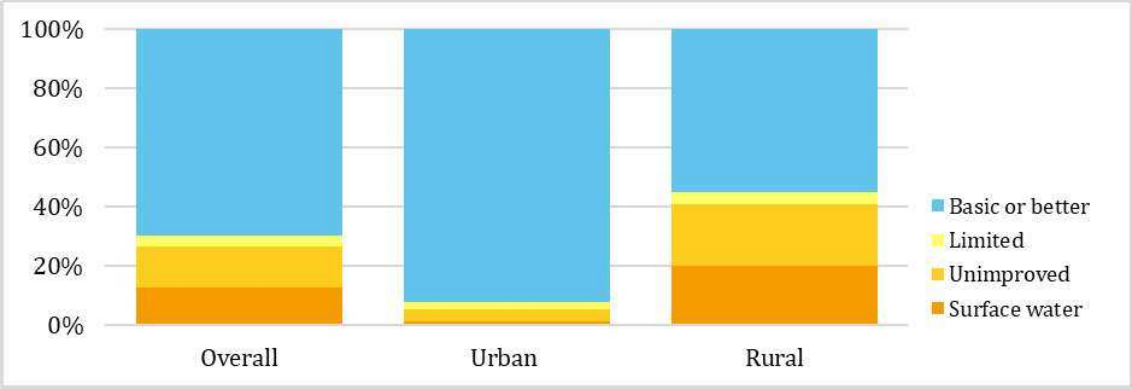

Basic service: Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing. Better than basic service is a safely managed service: Drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination. Limited service: Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing. Unimproved service: Drinking water from an unprotected dug well or unprotected spring. Unprotected sources are not covered by stonework, concrete or other materials that prevent the entry of physical, chemical and biological contaminants. Surface water: Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal (Source: WHO/UNICEF 2019).

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694 **Figure 4: Drinking water service levels in urban and rural households in the Solomon Islands [%]**

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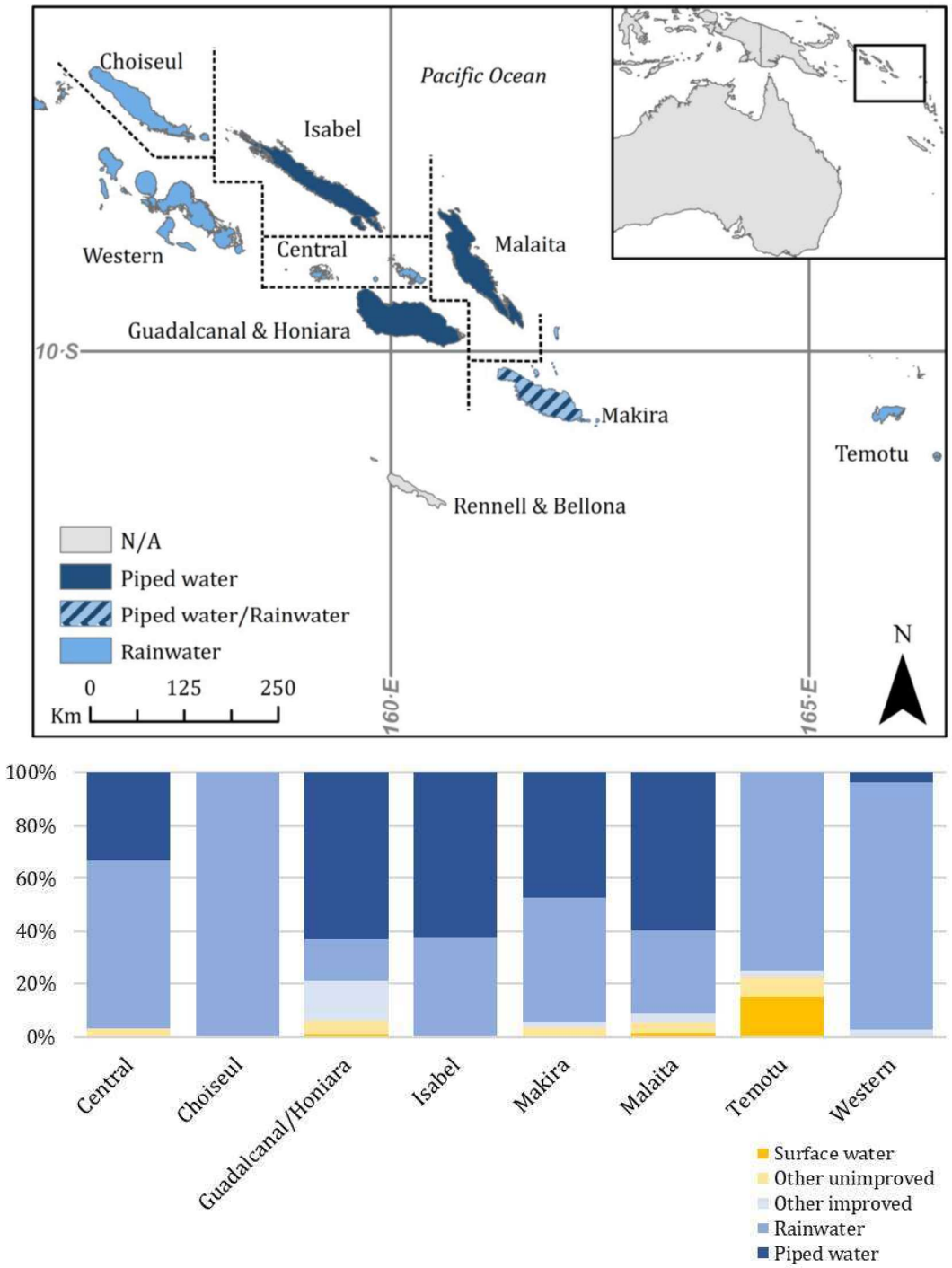


Figure 5: Main drinking water source in urban households in the Solomon Islands by province [%]

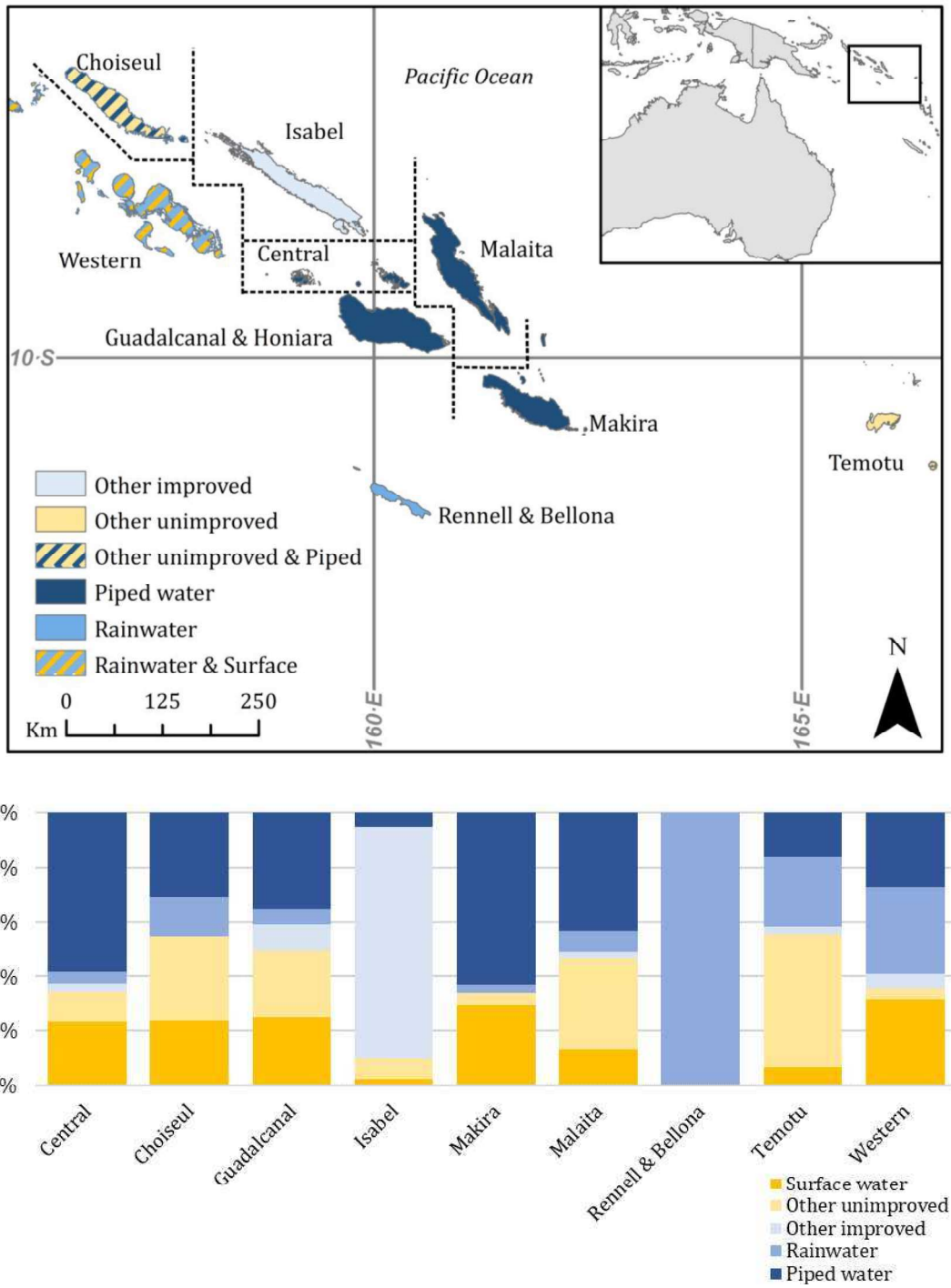


Figure 6: Main drinking water source in rural households in the Solomon Islands by province [%]

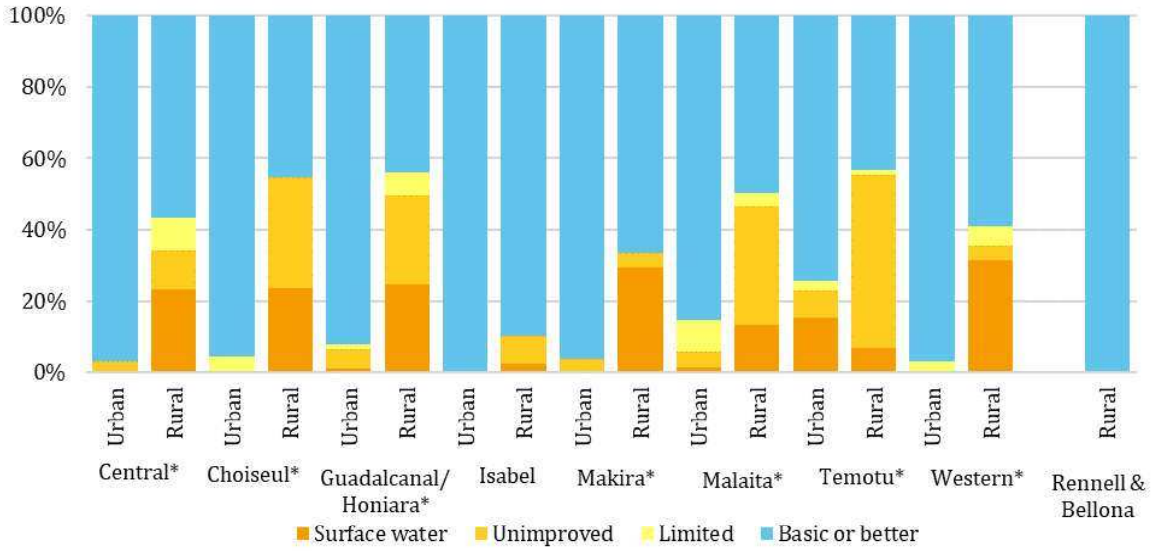
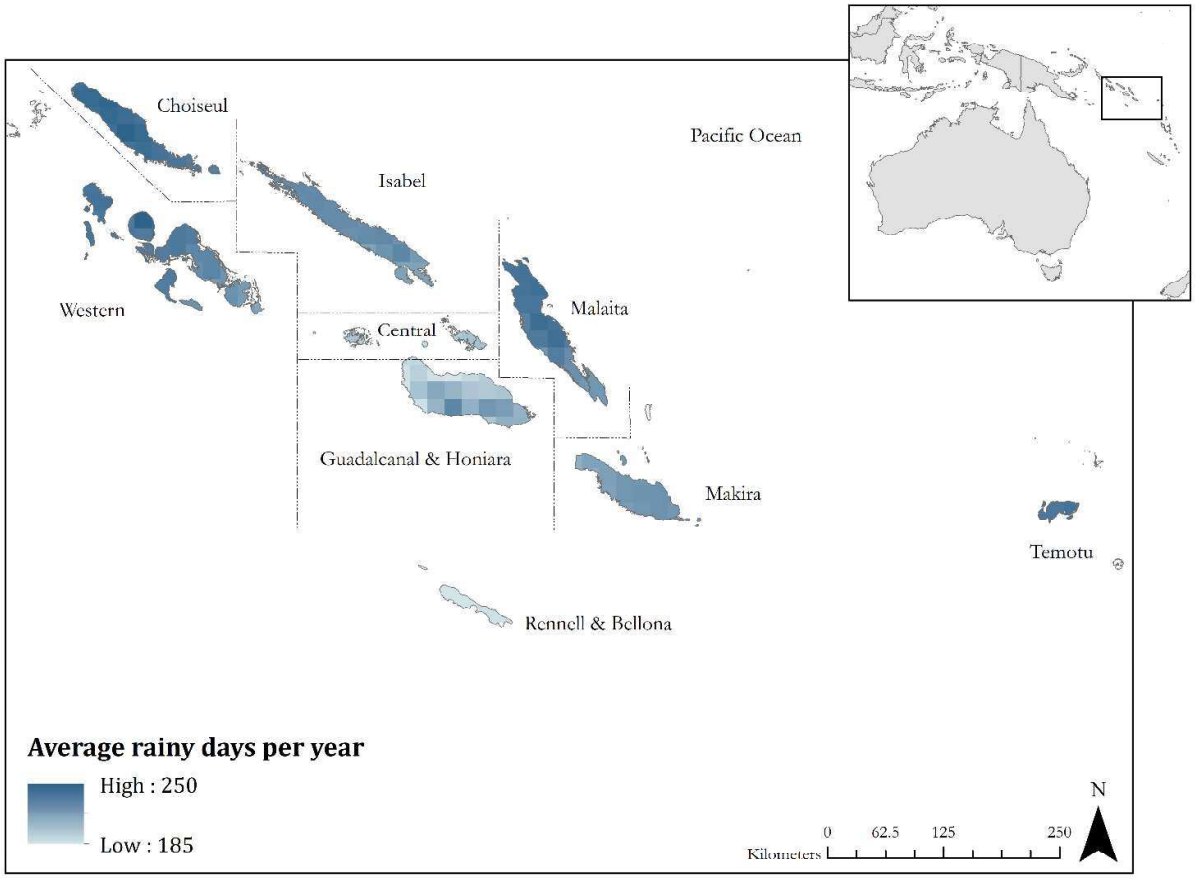


Figure 7: Drinking water service levels in urban and rural households in the Solomon Islands by province [%]



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709 **Figure 8: Average rainy days per year in the Solomon Islands by province (data from UN FAO**
710 **GLOBWAT)**

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712 **Table 1: Definitions of drinking water terms used**

	Drinking water characteristic	Definition
Drinking water sources	**Improved drinking water sources**	Drinking water sources that have the potential to deliver safe water by nature of their design and construction, and include: piped water, boreholes or tubwells, protected dug wells, protected springs, rainwater, and packaged or delivered water.
	Borehole or tubewell	A deep hole that has been driven, bored or drilled, in order to reach groundwater. Boreholes/tubewells are constructed with casing, or pipes, which prevent the small diameter hole from caving in and protect the water source from infiltration by run-off water. Water is delivered through a pump which may be powered by human, animal, wind, electric, diesel or solar means.
	Bottled water	Sold by commercial providers in small or large bottles or refillable containers. This does not include water from other sources stored in plastic bottles.
	Cart with small tank/drum	Refers to water sold or distributed by a provider who transports a tank or drum with small quantities of water into a community using donkey carts, small motorized vehicles and other means.
	Protected spring	A natural spring protected by a "spring box", made of brick, masonry, or concrete, that is built around the spring so that water flows directly out of the box into a pipe or cistern, without being exposed to runoff or other sources of contamination.
	Protected well	A dug well that is protected from runoff water by a well lining or casing that is raised above ground level to form a headwall and an apron that diverts spilled water away from the well. A protected well is also covered so that contaminated materials (including bird droppings and small animals) cannot enter the well. Water is delivered through a pump or manual lifting device.
	Public tap or standpipe	Also known as a public fountain, is a public water point from which people can collect water.
	Piped into dwelling/house	Also called a 'household connection', is a piped water supply connected with in-house plumbing to one or more taps (for example in the kitchen or bathroom).
	Piped into compound, yard or plot	Also called a 'yard tap', is a piped water supply connected to a tap in the compound, yard or plot outside the house
	Rainwater collection	Refers to a system whereby rain is collected or harvested from large surfaces (by roof or ground catchment) and stored in a container, tank or cistern until used.
	Tanker-truck	Refers to water sold or distributed by a provider who transports large quantities of water into a community using a motorized truck with a tank. •
	Unimproved drinking water sources	Drinking water sources include surface water, unprotected wells and springs, as well as unknown sources
	Surface water	Refers to open water sources located above ground including rivers, reservoirs, lakes, ponds, streams, canals, and irrigation channels.
	Unprotected well	A dug well that lacks any of the following: a lining or casing that is raised above ground level to form a headwall; an apron that diverts spilled water away from the well; a cover which prevents contaminated materials (including bird droppings and small animals) from entering the well; or a pump or manual lifting device.
	Unprotected spring	A natural spring that lacks a "spring box" to protect against run off and other sources of contamination (including bird droppings and animals).
JMP drinking water ladder	**Drinking water services**	Drinking water services refer to the accessibility, availability and quality of the main source used by households for drinking, cooking, personal hygiene and other domestic uses.
	Basic service	Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing.
	Safely managed service	Drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination.
	Limited service	Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing.

	Unimproved service	Drinking water from an unprotected dug well or unprotected spring.
	Surface water	Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal.

(Sources of definitions: WHO and UNICEF 2019, WHO & UNICEF 2018)

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716 **Table 2: Surveyed EAs and households by province in rural areas of the Solomon Islands**

	Urban areas				Rural areas			
	EAs		Households		EAs		Households	
Province	n	%	n	%	n	%	n	%
Honiara	54	50.0	519	48.6	0	0.0	0	0.0
Central	3	2.8	33	3.1	6	7.6	120	7.5
Choiseul	2	1.9	22	2.1	4	5.1	42	2.6
Guadalcanal	0	0.0	0	0.0	16	20.3	315	19.7
Isabel	2	1.9	21	2.0	3	3.8	79	5.0
Makira	5	4.6	53	5.0	8	10.1	167	10.5
Malaita	13	12.0	143	13.4	23	29.1	503	31.5
Rennell & Bellona	0	0.0	0	0.0	2	2.5	40	2.5
Temotu	5	4.6	40	3.8	4	5.1	74	4.6
Western	24	22.2	237	22.2	13	16.5	258	16.2
Total	108		1,062		79		1,597	

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Table 3: Drinking water characteristics in urban and rural Solomon Islands households

Drinking water characteristics		Overall		Urban		Rural		*p*-value for difference urban/rural
		N	%	N	%	N	%	
Water Service Levels (WHO and UNICEF 2019, per Table 1)	Basic	1,832	69.68%	953	92.17%	879	55.11%	<0.001
	Limited	93	3.54%	27	2.61%	66	4.14%	
	Unimproved	372	14.15%	41	3.97%	331	20.75%	
	Surface Water	332	12.64%	13	1.26%	319	20.00%	
What is the main source of drinking water for members of the household?	Rainwater collection	667	25.02%	455	42.60%	212	13.27%	<0.001
	Public tap or standpipe	460	17.25%	74	6.93%	386	24.16%	
	Piped to yard/plot outside house	397	14.89%	195	18.26%	202	12.64%	
	Surface water (river, stream, dam, lake, pond, canal)	332	12.45%	13	1.22%	319	19.96%	
	Unprotected spring	232	8.70%	32	3.00%	200	12.52%	
	Piped water into house (kitchen, bathroom, wash tub)	217	8.14%	200	18.73%	17	1.06%	
	Unprotected well	138	5.18%	7	0.66%	131	8.20%	
	Protected spring (spring box)	106	3.98%	16	1.50%	90	5.63%	
	Borehole	48	1.80%	38	3.56%	10	0.63%	
	Protected dug well	26	0.98%	9	0.84%	17	1.06%	
	Bottled water	23	0.86%	22	2.06%	1	0.06%	
	Water from another Island/mainland	10	0.38%	0	0.00%	10	0.63%	
	Tanker-truck	8	0.30%	6	0.56%	2	0.13%	
	Cart with small tank/drum	1	0.04%	0	0.00%	1	0.06%	
	Decline to state	1	0.04%	1	0.09%	0	0.00%	
In your opinion, does water collection take a quick or long time?	It is very quick to collect water	824	41.57%	185	48.18%	639	39.99%	<0.001
	It doesn't take long to collect water	501	25.28%	109	28.39%	392	24.53%	
	It takes a long time	352	17.76%	56	14.58%	296	18.52%	
	Too much time is taken to collect water	304	15.34%	33	8.59%	271	16.96%	
	Decline to state	1	0.05%	1	0.26%	0	0.00%	
Water collected by	Adult female (above 15 years)	2,315	86.80%	808	75.58%	1,507	94.31%	<0.001
	Adult male (above 15 years)	1,925	72.18%	628	58.75%	1,297	81.16%	<0.001
	Children girls (under 15 years)	757	28.38%	187	17.49%	570	35.67%	<0.001
	Children boys (under 15 years)	567	21.26%	140	13.10%	427	26.72%	<0.001
What do you think of the quality of your drinking water source?	Good	1,449	54.35%	627	58.71%	822	51.44%	<0.001
	Acceptable	966	36.23%	369	34.55%	597	37.36%	
	Poor	251	9.41%	72	6.74%	179	11.20%	
Water quality is poor because	Quality - polluted, cloudy/muddy	184	73.02%	31	42.47%	153	85.47%	<0.001
	Aesthetic - smell, taste	89	35.32%	33	45.21%	56	31.28%	0.036
	Seasonal variation - flooding, dries up, gets stagnant	49	19.44%	17	23.29%	32	17.88%	0.325
	Salt water intrusion	6	2.38%	1	1.37%	5	2.79%	0.501
Do you treat the water in any way to make it safer	No	2,279	85.48%	819	76.69%	1,460	91.36%	<0.001
	Yes	366	13.73%	235	22.00%	131	8.20%	

to drink?	Don't know	21	0.79%	14	1.31%	7	0.44%	
Household water treatment method	Boil	248	67.76%	178	75.74%	70	53.44%	<0.001
	Let it stand and settle	74	20.22%	23	9.79%	51	38.93%	<0.001
	Add bleach/chlorine	48	13.11%	43	18.30%	5	3.82%	<0.001
	Strain it through a cloth	17	4.64%	6	2.55%	11	8.40%	0.011
	Use a water filter	14	3.83%	12	5.11%	2	1.53%	0.087
	Clean Water Point	14	3.83%	9	3.83%	5	3.82%	0.995
How is water being stored in the household? (reported)	Stored in narrow-mouthed container	2,177	81.66%	845	79.12%	1,332	83.35%	<0.001
	Stored in wide-mouthed container	372	13.95%	106	9.93%	266	16.65%	
	Stored in large tank	107	4.01%	107	10.02%	0	0.00%	
	Household does not store water	10	0.38%	10	0.94%	0	0.00%	
Is storage sealed or does it have a lid? (reported)	No	184	6.93%	79	7.47%	105	6.57%	0.373
	Yes	2,472	93.07%	979	92.53%	1,493	93.43%	

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	Overall			Urban			Rural		
	Mean (CI)	Median	Max	Mean (CI)	Median	Max	Mean (CI)	Median	Max
Time to collect water (in minutes)	11.94 (10.90-12.98)	3	601	4.22 (3.34-5.11)	0	120	16.86* (15.30-18.42)	5	601
Quantity used per household per day (in liters)	42.81 (39.62-46.01)	20	1250	69.12* (60.77-77.47)	30	1250	29.12 (27.27-30.97)	20	607
Per capita household water quantity per day (in liters/person)	7.94 (7.31-8.56)	3.89	350	12.08* (10.45-13.71)	5	350	5.78 (5.38 - 6.18)	3.33	151.75

* Denotes a significant difference ($p < 0.0001$) between urban and rural (Two Samples T-test). CI stands for confidence interval.

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Table 5: Purposes of water use from main water source in urban and rural Solomon Islands households

	Overall		Urban		Rural		*p*-value for difference urban/rural
	N	%	N	%	N	%	
Drinking	2,601	97.53%	1,010	94.48%	1,591	99.56%	<0.001
Cooking	2,367	88.75%	936	87.56%	1,431	89.55%	0.111
Bathing	1,918	71.92%	762	71.28%	1,156	72.34%	0.551
Laundry	1,576	59.09%	668	62.49%	908	56.82%	0.004
Watering crops	233	8.74%	89	8.33%	144	9.01%	0.539
Watering livestock	148	5.55%	29	2.71%	119	7.45%	<0.001

Table 6: At least basic drinking water service in rural and urban areas of countries Small Island Developing States, including Pacific and the Solomon Islands

	At least basic drinking water service [%]		
	rural	urban	national
Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS)			
Bahrain	NA	NA	>99
Cabo Verde	76	93	87
Comoros	77	88	80
Guinea-Bissau	53	84	67
Maldives	>99	98	>99
Mauritius	>99	>99	>99
Sao Tomé and Principe	77	87	84
Seychelles	NA	NA	96
Singapore	NA	>99	>99
Caribbean			
Antigua and Barbuda	NA	NA	97
Bahamas	NA	NA	99
Barbados	NA	NA	98
Belize	NA	NA	NA
Cuba	90	97	95
Dominica	NA	NA	NA
Dominican Republic	90	98	97
Grenada	NA	NA	96
Guyana	94	>99	96
Haiti	43	85	65
Jamaica	85	96	91
Saint Kitts and Nevis	NA	NA	NA
Saint Lucia	98	98	98
Saint Vincent and the Grenadines	NA	NA	95
Suriname	90	98	95
Trinidad and Tobago	NA	NA	98
Pacific			
Federated States of Micronesia	NA	NA	79
Fiji	89	98	94
Kiribati	NA	NA	72
Marshall Islands	94	87	88
Nauru	NA	>99	>99
Palau	>99	>99	>99
Papua New Guinea	35	86	41
Samoa	97	>99	97
Solomon Islands: our survey	***55***	***92***	
Solomon Islands	61	91	68
Tokelau	>99	NA	>99
Tonga	>99	>99	>99
Tuvalu	99	>99	>99
Vanuatu	88	>99	91
Wallis & Futuna Islands	>99	NA	>99
Non-UN Members/Associate Members of Regional Commissions			
American Samoa	NA	NA	>99
Anguilla	NA	97	97
Aruba	NA	NA	NA

Bermuda	NA	>99	>99
British Virgin Islands	NA	NA	>99
Cayman Islands	NA	NA	NA
Commonwealth of Northern Marianas	NA	NA	>99
Cook Islands	NA	NA	>99
Curacao	NA	NA	>99
French Polynesia	NA	NA	>99
Guadeloupe	NA	NA	>99
Guam	NA	NA	>99
Martinique	NA	NA	>99
Montserrat	NA	NA	NA
New Caledonia	NA	NA	>99
Niue	NA	NA	98
Puerto Rico	NA	NA	97
Sint Maarten	NA	NA	95
Turks and Caicos Islands	NA	NA	94
United States Virgin Islands	NA	NA	99

Classification of Small Island Developing States from UNDESA (2019) at https://sustainabledevelopment.un.org/topics/sids/list.
Data extracted from WHO & UNICEF JMP (2019) at https://washdata.org/data.
NA stands for not available.

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