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Meeting SDG6 in the Kingdom of Tonga: The Mismatch between National and Local Sustainable Development Planning for Water Supply

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Abstract: UN 2030 Sustainable Development Goal 6 presents difficulties for small island developing states such as the Kingdom of Tonga, which relies on rainwater and groundwater lenses for freshwater supply. Planning and managing water resources to supply demands in dispersed small islands under variable climate and frequent extreme events is challenging. Tensions between water planning using top-down versus bottom-up processes have long been recognized. Tonga's overarching national planning instrument is the Tonga Strategic Development Framework, 2015-2025 (TSDFII). This identifies desired national outcomes and is used to direct and resource Ministries and address international and regional commitments. Water supply was a low priority in the three-month consultations that led to TSDFII. Community Development Plans (CDPs), developed by rural villages throughout Tonga's five Island Divisions over nine years, involved participation from 80% of each village population who ranked local priorities. Analysis of priorities in 117 available village CDPs reveals improvements to village water supply was the highest overall priority in all five Island Divisions and ranked within the top three priorities by 76% of all villages, with women, youth and men returning figures of 83%, 66% and 80% respectively. The mismatch between top-down and bottom-up priorities appears to result from an urban/rural divide.

Keywords: groundwater; rainwater harvesting; climate variability; small island developing states; water planning; community participation.

1. Introduction

The United Nations (UN) 2030 Sustainable Development Goal (2030) for water and sanitation, "Ensure availability and sustainable management of water and sanitation for all" (SDG 6 [1]) presents significant challenges for small island development states (SIDS). Limited resources and institutions, dispersed island communities, increasing demands, scarce fresh groundwater sources vulnerable to salinization and pollution, variable and changing climates driven by large-scale ocean-atmosphere interactions and frequent, devastating, extreme events such as tropical cyclones, droughts and floods compound the difficulties of ensuring that communities have access to adequate and safe freshwater supplies [2,3], fundamental for sustainable development.

National strategic development strategies (NSDS) for SIDS have been promoted as a key mechanism for fulfilling government commitments to local, regional and international agendas on sustainable development [4], particularly the 2005 Mauritius Strategy for the Further Implementation of the Programme of Action for the Sustainable Development of SIDS [5] and the 2014 SIDS Accelerated Modalities of Action (SAMOA) Pathway resolution [6]. They are also used predominately by governments to identify national priorities, to allocate resources to government

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agencies and to monitor outcomes. Initially, creating an NSDS involved a two-phase approach with national assessments in phase one followed by selected interventions in phase two [4]. Inexperience, limited resources and institutions in some SIDS meant that donor and funding agency-supported external consultants played central roles in driving early NSDS processes assisted by senior national bureaucrats. These externally originated processes tend to be top-down prescriptions with the planning priorities and expected outcomes predominantly economically focused [7]. While NSDS have evolved through several iterations and are now more locally driven, they still tend to favor externally motivated processes.

One of the key characteristics of SIDS, and particularly those with dispersed island communities, is their well-developed local institutions particularly suited to bottom-up priority-setting processes [8]. A draw-back of bottom-up processes is the time involved to reach agreement or consensus [9]. The South Pacific Kingdom of Tonga, reliant predominantly on fresh groundwater lenses and rainwater harvesting for water supply, presents a unique opportunity to compare priorities in water supply identified by both top-down and bottom up planning processes.

Tonga government with support from the Asian Development Bank developed the Tonga Strategic Development Framework 2015-2015 (TSDFII) through a high-level consultation process over three months in 2014 [10]. TSDFII incorporated lessons learnt in the preceding Tonga Strategic Development Framework 2011-2014. TSDF II identifies 29 highest priority issues as key planned organizational outcomes (OOs) for Ministries, Departments and agencies while 153 more specific objectives are listed as strategic concepts (SCs) under the OOs.

From 2007 to 2016, a very extensive, nation-wide Community Development Plan (CDP) process involved most rural villages throughout Tonga's five Island Divisions. Communities identified and ranked priority development issues in their village and then built and endorsed their CDP. The plans prioritized the most urgent issues in each village in terms of women's, youth's and men's perspectives with 136 CPDs out of 151 rural villages were presented in 2016 [11].

In this work we give an overview of the demographics, water sources, water use, groundwater and rainfall characteristics of the Kingdom of Tonga, to provide background to the planning processes. We then examine the priority given to water supply in the OOs and the SCs of TSDFII. The first analysis of water supply priorities in the 117 available CDPs is then presented. These are analyzed in terms of women's, youth's and men's priorities as well as Island Division priorities. Island Division priorities are related to predominant water sources, groundwater salinity, annual rainfall and its variability. The bottom-up CDP priorities in water supply are contrasted with the OOs and SCs of the top-down TSDFII. The large discrepancy between national and local priorities in water are discussed and suggestions for linking processes are made.

2. Materials and Methods

2.1. Study Location

The population of the Kingdom of Tonga is dispersed over 169 islands in five Island Divisions covering a land area of about 750 km^2 scattered across 700,000 km^2 of the southwestern Pacific Ocean (Figure 1). The Kingdom adjoins the seismically very-active Tonga trench. Tonga's western islands are of volcanic origin while the eastern islands are uplifted coral limestone and sand islands. Many of the eastern islands, such as Tongatapu, the largest island which contains the capital Nuku'alofa, have a mantle of fertile volcanic soil from past volcanic eruptions of the western islands. Volcanic eruptions, earthquakes and subsequent tsunamis, tropical cyclones (TCs), storm surges and El Niño Southern Oscillation- (ENSO) and Pacific Decadal Oscillation-related droughts and floods are frequent natural hazards faced by the Kingdom's island communities.

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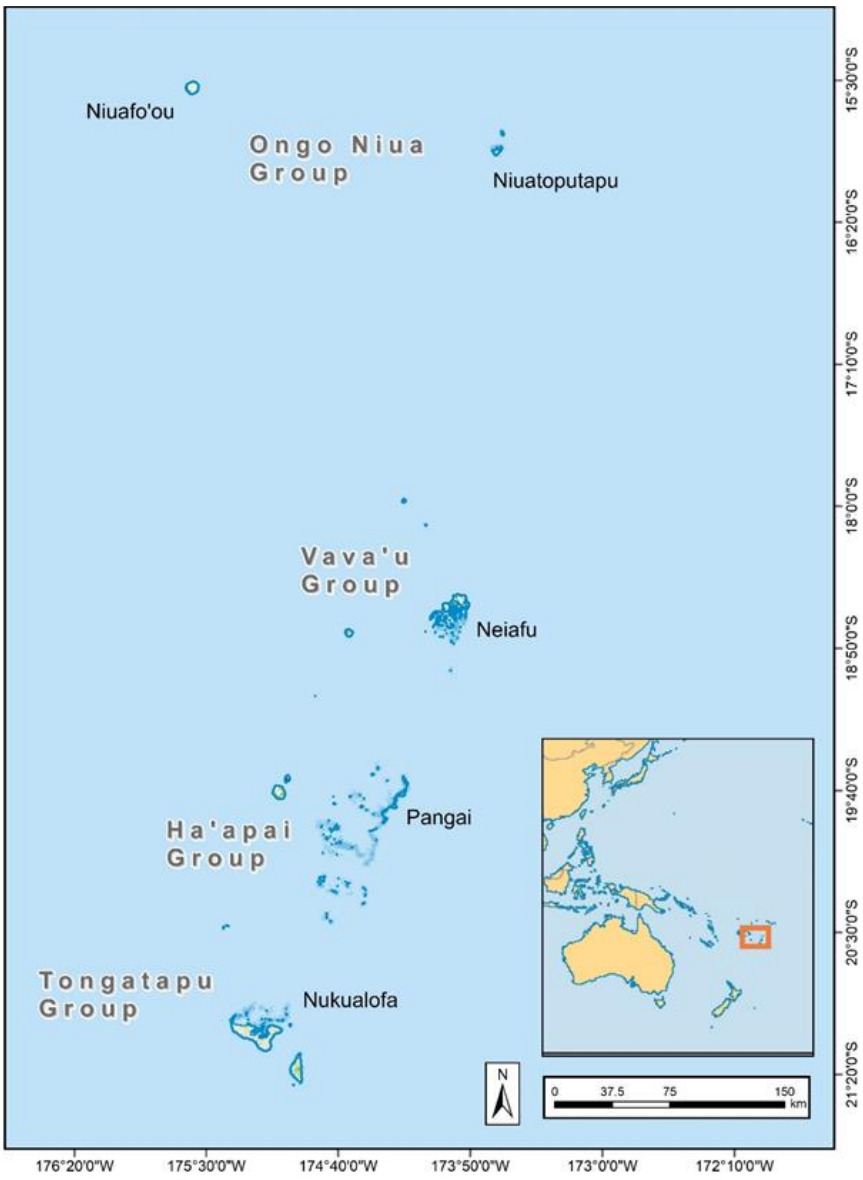

Figure 1. Map of the South Pacific Kingdom of Tonga, main Island Divisions and population centers [13].

2.2. Demographics, Water Sources, Water Use and Water Demand

We use the results of the latest Census in 2016 [12] to examine the urban/rural composition and the distribution of population and their trends across Tonga's five Island Divisions (Figure 1). Census results are also used to compare water sources used by households for different water uses, again between urban and rural communities and across Island Divisions. Outside urban areas, there is comparatively little information on water demand and unaccounted for water in Tonga. Here we make use of recent estimates for urban areas [13] and limited estimates for selected villages in outer islands [14-16]

2.3. Climate, Rainfall, Variability and Rainwater Harvesting Failures

A recent draft report on national water resources in Tonga [13] is used to extract data on average annual and seasonal rainfall and their variability and trends across Tonga's Island Divisions. Trends are examined using linear regression and the statistical significance of the trends is tested. Trends are compared with climate model projections of the impact of climate change on rainfall in Tonga [17].

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The frequency of failure of rainwater harvesting systems over six month wet (Novemeber to April) and dry (May to October) seasons is estimated from the percentile of 360 mm of rainfall over the full seasonal record for that location. That rainfall amount is equivalent to supplying the average household size in Tonga with 20 L/person/day, the World Health Organization recommended minimum quantity of water required to satisfy essential health and hygiene needs in emergency situations [18],, from a typical roof area of 100m^2 with a capture efficiency of 55% [14-16].

2.4. Groundwater

A summary of the limited information on groundwater resources is provided from [13] and the few available island integrated water management plans [14-16]. Other information is sourced from reports and publications [19-25]. Estimates of per capita groundwater use in population centers are based on data provided by the Tonga Water Board [26].

2.4. Tonga Strategic Development Framework 2025-2015

The TSDF II is: "the overarching framework of the planning system in Tonga. It provides an integrated vision of the direction that Tonga seeks to pursue. … It is a ten-year framework within which government, and other organizations in the Kingdom, can plan in a more consistent and integrated manner." [10]. The TSDFII notes that: "Inclusion and equality as well as sustainability have for a long time been matters of importance to Tonga…"[10].

The Ministry of Finance and National Planning (MFNP) led the creation of TSDF II, which was based on a wide, but fairly rapid consultative process. In the period October 2014 to December 2014, consultation meetings were held throughout Tongatapu and the Island Divisions of 'Eua, Ha'apai and Vava'u. Ongo Niua Division was not covered.

The TDSFII was scanned for references to water, freshwater, rainwater, groundwater and water supply and the planned National Outcomes, OOs and SCs were examined for their relevance to water supply.

2.4. Community Development Plans, 2016

Work on CDPs began in 2007, under the Local Government Division of the Ministry of Internal Affairs. The CPDs were a response to the then National Vision "a Progressive Tonga Supporting Higher Life for All." Consultations throughout rural villages in Tonga's five Island Divisions were implemented by Mainstreaming of Rural Development Innovation Trust Tonga (MORDI TT). The CDP process was supported by the International Fund for Agricultural Development (IFAD), UNDP, AusAID and the Tonga Government. One of the requirements of the project was participation of 80% of the population of each rural village in the development, ranking of priorities and endorsement of the village CDP. This was a lengthy process which culminated in District Officers and Town Officers of 136 village communities presenting their CDPs to the then Prime Minister, the late Hon. 'Akilisi Pohiva on 4 October 2016 [11].

During the planning process the Department for Local Government was transferred from the Prime Minister's Office to the Ministry of Training, Employment, Youth, and Sports, and then to the Ministry of Internal Affairs. Action on the Community Development Plans appears to have been deferred by these moves. We have been unable to find any analysis of the valuable information contained in these CDPs.

Of the 136 CDPs presented 117 are available on-line [27]. These represent 77.5% of all rural villages in Tonga. CDPs were downloaded and the priority rankings of each village that mentioned water or water supply were examined and their ranking recorded. Particular note was made when water or water supply ranked in the top three priorities for women, men and youth. Village level results were aggregated to Island Division and the percentage of villages in each Island Divison that ranked water both highest priority and within the top three priorities was recorded. Also recorded was the percentage of villages within each Island Division that did not rank water or water supply as a priority.

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3. Results

3.1. Demographics

The distribution of Tonga's population across its Island Divisions in 2016 is given in Table 1 [12]. Also shown are the total rural, urban and the population of the capital greater Nuku'alofa, as well as the annual growth rate between 2011 and 2016, the population density and the average household size.

Table 1. Summary of 2016 population statistics in Tonga, by Island Division, and total urban, rural and greater Nuku'alofa populations [12]

Item	Tonga	'Eua	Tongatapu	Vava'u	Ha'apai	Ongo Niua[1]	Urban[2]	Rural[3]	Greater[4] Nuku'alofa
Total Population	100,651	4,945	74,611	13,738	6,125	1,232	23,221	77,430	35,184
Male	50,255	2,486	37,135	6,866	3,118	650	11,529	38,726	17,490
Female	50,396	2,459	37,476	6,872	3,007	582	11,692	38,704	17,694
Population change 2011-2016 (%)	-2.5	-1.4	-1.1	-7.9	-7.4	-3.9	-4.2	-2	-2.4
Av. Annual Growth (%)	-0.5	-0.3	-0.2	-1.7	-1.5	-0.8	-0.9	-0.4	-0.5
Population Density (pers/km²)	155	57	286	114	56	17	2,035	121	1,010
Number of Households	18,198	889	13,096	2,745	1,193	275	4,175	14,023	6,240
Average Household Size (pers)	5.5	5.6	5.7	5	5.2	4.5	5.6	5.5	5.6
Number of Villages	165	15	67	44	27	12	3	162	14

[1] Niuafo'ou and Niuatoputapu combined.
[2] Urban area comprises the villages of Kolofo'ou, Kolomotu'a and Ma'ufanga in Tongatapu.
[3] Rural area consists of all villages in Tonga except Kolofo'ou, Kolomotu'a and Ma'ufanga in Tongatapu.
[4] Greater Nuku'alofa is made up of the districts of Kolofo'ou and Kolomotu'a in Tongatapu.

The demographic data in Table 1 show a concentration of population in the main island Tongatapu with 35% of the population of just over 100,000 living in the capital, Greater Nuku'alofa, and a further 40% of the population living in 53 rural villages across the Tongatapu Island Division. Just over 35% of all rural villages are in Tongatapu. The remaining 26% of Tonga's population are scattered over 98 villages in Tonga's other four Island Divisions.

Between 2011 and 2016 the population of Tonga shrank by an annual rate of -0.5% and urban populations decreased at over twice the annual rate of that of rural populations. The rate of loss of population was highest in Vava'u and Ha'apai Island Divisions and lowest in Tongatapu. Table 3 suggests an inward migration from outer islands to rural villages in Tongatapu at an annual rate of about +0.9%.

Population density was over 16 times higher in urban areas that in rural areas. In Tongatapu, the population density was nearly 17 times higher than that of the far northern Ongo Niua division. Average household size in urban areas, however, was very close to that in rural areas, with Tongatapu having the highest average household size (5.7 persons) and Ongo Niua the lowest (4.5 persons).

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3.2. Water Sources

Table 2 lists the percentage of households using water from different sources for drinking and for all other uses for Tonga as a whole and for each of the island Divisions from the 2016 Census [12].

Table 2. Percentages of households in each island Division using water from different sources for (a) drinking water and (b) all other water uses at the 2016 Census [12]

Water Source	TONGA	'Eua	Tongatapu	Vava'u	Ha'apai	Ongo Niua	Urban	Rural	Greater Nuku'alofa
(a) Drinking Water (%)									
Piped Supply	10.0	2.5	11.3	10.3	3.0	1.1	12.2	9.3	11.7
Rain Tank	60.5	73.1	54.8	69.2	86.2	92.3	53.5	62.5	53.8
Neighbour / Community[1]	19.6	23.4	20.7	18.8	10.0	6.6	14.3	21.2	15.8
Bottled water	9.5	0.9	12.8	1.4	0.6	0.0	19.3	6.6	18.1
Boiled Well Water	0.2	0.1	0.2	0.1	0.1	0.0	0.4	0.1	0.3
Other	0.2	0.0	0.2	0.2	0.2	0.0	0.3	0.1	0.2
(b) All Other Water Uses (%)									
Piped Supply	88.3	95.6	93.3	80.7	52.0	59.0	92.3	87.1	92.0
Rain Tank	10.9	4.0	6.0	18.9	44.6	40.3	7.1	12.0	7.1
Own Well	0.6	0.0	0.5	0.0	3.1	0.4	0.4	0.6	0.6
Other	0.3	0.5	0.3	0.3	0.3	0.4	0.2	0.3	0.3
Total Number Households	18,005	885	12,953	2,715	1,179	273	4,089	13,916	6,139

[1] Probably neighbour or community rain tanks.

Table 2 reveals the variety of water sources used for different purposes in the island Divisions. It is apparent that households throughout Tonga prefer rainwater (over 60%) for drinking over piped supply (10%). Most piped water supply is sourced from groundwater. Nationally, nearly 20% of drinking water is sourced from neighbors' or community rainwater tanks.

Urban households in Table 2(a) have a 31% higher use of piped water for drinking than rural users who access rainwater for drinking 17% more than urban users. Bottled water is increasingly being used for drinking, with urban use of bottled water 2.9 times that of rural households. Boiled groundwater from household wells has very low use for drinking, 0.2% nationally. Ha'apai and Ongo Niua stand out in the island Districts, with much less drinking water supplied from piped water than the other Island Divisions and correspondingly much more from rainwater harvesting.

When all other uses of water are considered, Table 2(b) shows that nationally 88% of household water is sourced from piped groundwater systems, with rainwater tanks supplying only 11% of other uses since it is reserved for drinking. Only 0.6% access water from private wells. Rural households access piped water 5.7% less than urban households for non-drinking water uses so that rural households rely on rain tanks nearly 1.7 times more than those in urban districts. Again, Ha'apai and Ongo Niua are quite distinct from the other Island Divisions with less than 60% of other household water use coming from the piped system and more than 40% of supply coming from rainwater harvesting. Figure 2 shows the ratio of the use of rainwater to that of piped water supply for other uses in each Island Division and Tonga as a whole. There is a large difference in the ratio between, Ha'apai, Ongo Niua, Vava'u and Tongatapu and 'Eua. Piped water systems are less available in the Ha'apai and Ongo Niua Divisions than in the other Island Divisions [13].

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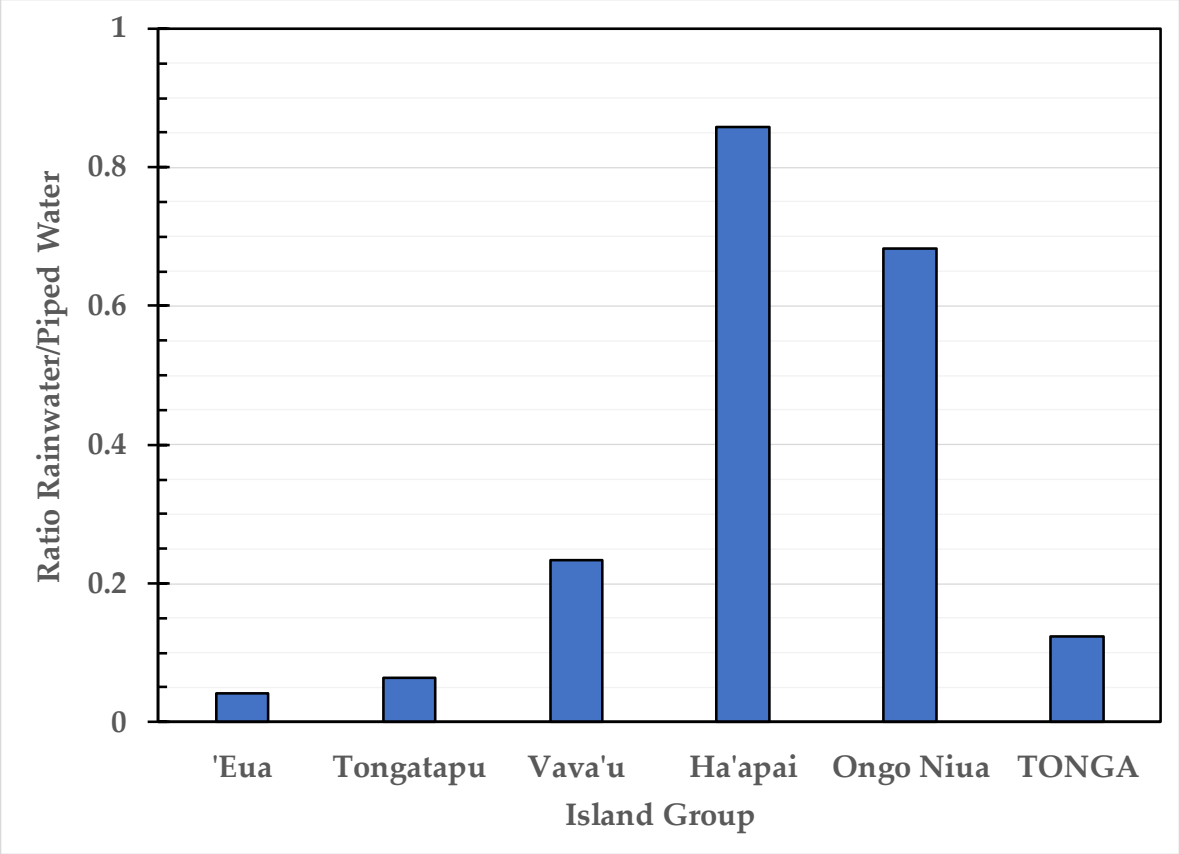

Figure 2. Ratio of the use of rainwater to piped water supply for other uses [Table 2(b)] in households across Tonga's Island Divisions. Also shown are the average results for Tonga.

3.3. Fresh Groundwater

Fresh groundwater in Tonga's islands mostly consists of freshwater lenses overlying seawater in carbonate (limestone and sand) islands [13, 19-22]. The salinity gradient increases with depth through the lens going from low salinity water at the groundwater surface through a diffuse saline transition zone to underlying seawater [21]. Groundwater may also exist in fractured rock aquifers in the volcanic islands, but these are yet to be assessed [13]. There are also a number of springs emanating from fresh perched groundwater on 'Eua, an island with mixed volcanic and carbonate geology, and small freshwater lakes on Niuafo'ou [13].

There is a significant amount of information about the freshwater lens in Tongatapu, used to supply the capital Nuku'alofa from an isolated wellfield location at Mataki'eua-Tongamai, and less about village pumping from local wells and boreholes throughout Tongatapu [19-22, 24, 25, 28]. Local wells and boreholes are vulnerable to contamination from septic tanks and pit latrines.

The mean maximum height of the surface of the freshwater lens in Tongatapu has been estimated to be about 0.6 m above mean sea level and the lens thins toward the coastal margins. Its elevation varies slightly with the oceanic tide. In the period 1997 to 2018, maximum thickness of the freshwater lens was around 16m. Maximum thickness varied with rainfall between 9.5 and 16 m. During the same period, the salinity of water, as measured by the electrical conductivity (EC) of the water supplied to Nuku'alofa, varied between almost 1600 µS/cm, following the dry period in 1998, to about 800 µS/cm following the wet period in 1999 [13].

There is no evidence of any increasing trend in groundwater salinity in Tongatapu over the period 1997 to 2018 [13]. Increases in EC of individual bores due to progressive increases in wellfield pumping rates over time have been observed at Makahi'eua-Tongamai since 1971 (Figure 3 [24]). The current rate of fresh groundwater extraction across all Tongatapu has been estimated to be about 24,000 m^3/day.

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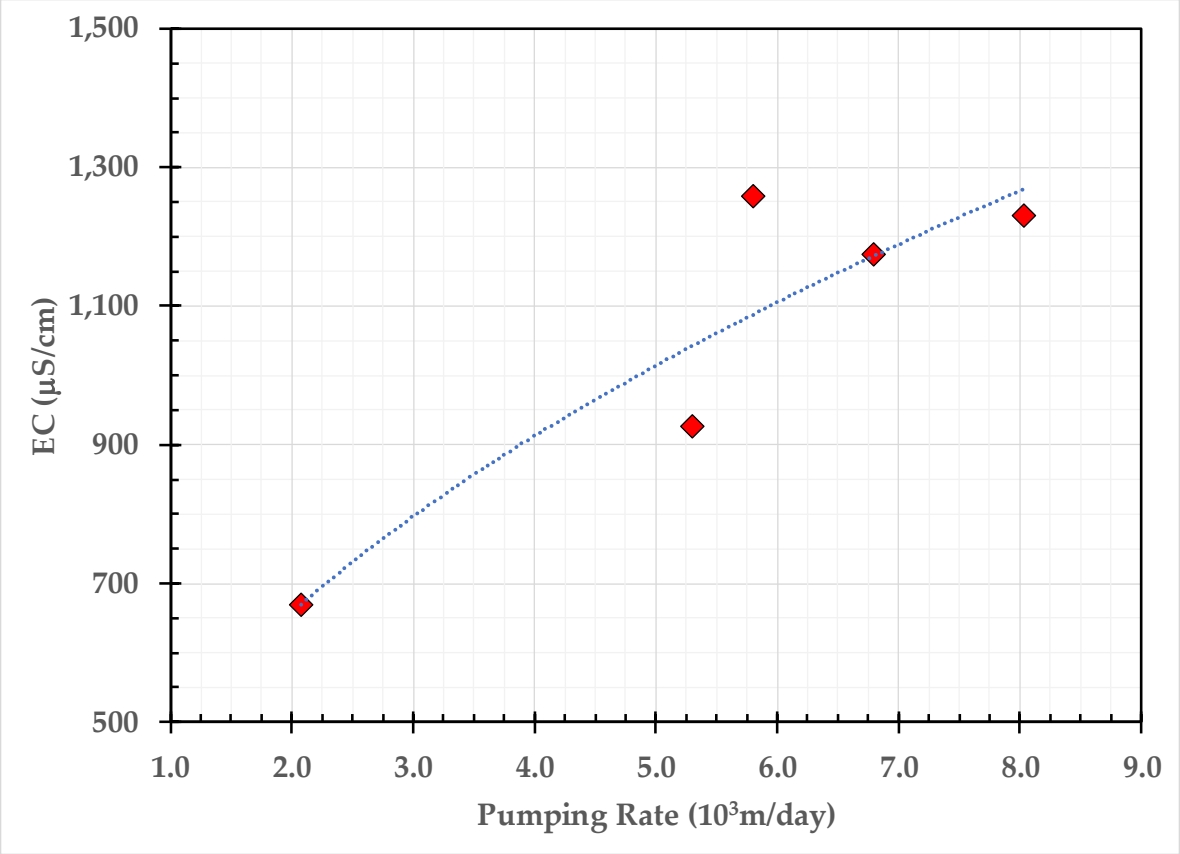

Figure 3. Impact of pumping rate from the Mataki'eua-Tongamai wellfield on the EC of water pumping from an individual well (PS106) between 1971 and 2007 [24].

There is very limited information about groundwater used to supply population centers in Ha'apai or Vava'u. On Lifuka Island in the Ha'apai Division, the spatially limited fresh groundwater lens is much thinner than in Tongatapu, with maximum thickness ranging from 2m in 1998 to 4m at the end of 2011. Because of the thin freshwater lens, the salinity in the water supply system is higher than in Nuku'alofa, varying from a brackish EC of about 10,000 µS/cm to a low of around 1,000 µS/cm. The salinity of the water there depends on the method of extraction with groundwater pumped from vertical wells having a higher salinity, due to upconing of the underlying seawater, than that pumped from horizontal infiltration galleries or skimming wells. The approximate groundwater extraction rate for water supply in Lifuka is a about 500 m^3/day.

The population center of Vava'u, Neiafu, in the main island Vava'u 'Utu, a raised limestone island, is supplied water from a fresh groundwater lens with maximum thickness between 5 to 8.5 m over the period 1999 to 2018. Thickness of the lens varies across the island with some village wells only producing brackish groundwater. The salinity of water supply to Neiafu in this period has varied from an EC of about 500 µS/cm in September 2000 to a brackish 4,500 µS/cm in January 2016. The approximate rate of groundwater extraction to supply Neiafu is about 1,000m^3/day [13].

In 'Eua, water is supplied from groundwater springs and wells. Salinity of the supply water in 'Eua is low, typically less than 500 µS/cm and the water supply is about 1,100 m^3/day [21, 26].

3.4. Water Demand

With the diversity of water sources used (Table 2) and the differences in use between rural and urban and Island Divisions there is little information on the ranges of water demand throughout Tonga. For Greater Nuku'alofa about 12.6 ML/day are pumped from the groundwater Mataki'eua-Tongamai wellfield [13]. Unaccounted for water amounts to between 30 to 40%. It has been estimated that about 11 ML/day of groundwater is extracted to supply the rural villages throughout Tongatapu [28]. Information is also available on groundwater extraction for the urban centers in Vava'u and

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Ha'apai [26]. There is limited information on unaccounted for water in these or in Tongatapu's village water supply systems. Inspections of village groundwater supply systems suggest that 40 to 50% losses are conservative. With this estimate and the population numbers in the 2016 Census [12], the estimated average groundwater demand in Greater Nuku'alofa, in rural villages in Tongatapu and in the urban centers in Vava'u and Ha'apai, as well as spring and groundwater demand in 'Eua are given in Table 3.

Table 3. Estimated average per capita water demand in population centers and rural villages in Tonga's Island Divisions supplied by spring water (SW), groundwater(GW) and rainwater (RW) [13-16, 26, 28].

Island Division	Location	Water Source	Water Supply Rate ($10^3 m^3$/day)	Unaccounted for Water (%)	Average Demand (L/pers/day)
'Eua		SW,GW	1.1	40-50	110-130
Tongatapu	Greater Nuku'alofa	GW	12.6	30-40	230-270
	Rural[1] Villages	GW	11	40-50	130-160
Vava'u	Neiafu	GW	1.0	40-50	140-160
	Koloa	RW	-	-	18
Ha'apai	Lifuka	GW	0.5	40-50	125-150
	Nomuka	RW	-	-	22
Ongo Niua	Niuafo'ou	RW	-	-	14

[1]All villages not within Greater Nuku'alofa.

Rainwater is also used extensively throughout Tonga (Table 2). There is very little information on water demand from rainwater harvesting systems. Measurements at villages on three outer islands, Koloa, Nomuka and Niuafo'ou, in the Vava'u, Ha'apai and Ongo Niua Divisions provide details on the average per capita rainwater and are listed in Table 3 [14-16]. In Koloa the thin groundwater lens is saline and is only used for toilet flushing, cleaning and bathing [14]. In Nomuka, the village piped water supply, which was sourced from beneath a shallow ephemeral freshwater lake is no longer operational, so that household and community rainwater tanks are the only sources of freshwater [15].

Niuafo'ou island is a basalt shield volcano surmounted by an andesitic cone. Communities there rely on rainwater harvesting. It is not known if there is any viable fresh groundwater in Niuafo'ou [16]. The World Health Organization recommends that the minimum quantity of water required to satisfy essential health and hygiene needs in emergency situations is 20L/person/day [18], a value similar to the average rainwater use for all most purposes in these three outer islands.

3.5. Rainfall

Tonga's climate is tropical with a warm period from December to April, when temperatures can reach 32°C, and a cooler season from May to November, with temperatures infrequently rising above 27°C [29]. Tonga's reliance of water sourced from rainfall harvesting and from groundwater (Table 2) means that rainfall and subsequent groundwater recharge are key determinants of water availability [19, 21, 24, 25]. Table 4 summarizes rainfall characteristics at the six long-term meteorological stations throughout Tonga.

Average annual rainfall varies from about 1,750 mm in the south to about 2,500 mm in the northern islands closer to the Equator. Tonga has a wetter season from November to April and a drier season from May to October. Its rainfall is influenced by the position and strength of the South Pacific Convergence Zone (SPCZ) which is influenced both by season, ENSO events [17, 30] and by the Pacific Decadal Oscillation (PDO)[24]. Tonga is periodically impacted by TCs whose intensity appears to be increasing [31] in line with climate change projections [17, 32].

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Table 4. Annual, wet (November to April) and dry season (May to October) rainfall characteristics at meteorology stations in Tonga [13]

Met Station	Island Division	Daily Average Temperature Range (⁰C)[1]	Average Annual Rainfall (mm)	CV of Annual Rainfall	Mean Nov-Apr Rainfall (mm)	Mean May-Oct Rainfall (mm)	Period
Niuafo'ou	Ongo Niua	25.9-27.9	2,534	0.22	886	1,648	1971 - 2019
Niuatoputapu		25.7-27.5	2,315	0.21	803	1,512	1947 - 2019
Lupepau'u	Vava'u	22.9-26.9	2,290	0.22	793	1,497	1947 - 2019
Ha'apai	Ha'apai	23.1-27.4	1,754	0.24	599	1,155	1947 - 2019
Fua'amotu	Tongatapu	21.4-26.6	1,765	0.25	664	1,101	1980 - 2019
Nuku'alofa		21.8-27.2	1,863	0.26	735	1,128	1945 - 2019

[1] Temperatures shown for the period 1980 to 2017.

During the wet season, the SPCZ lies between Samoa and Tonga while during the dry season the SPCZ is positioned normally to the north-east of Samoa, where it is often weak, inactive and sometimes non-existent [29]. In the northern islands, about 35% of annual rainfall occurs in the November to April period while in the south the percentage is slightly higher, 38-39%.

Estimates of average annual potential evaporation in Tonga range from about 1,460mm in Tongatapu to about 1,670mm in Niuatoputapu [29]. These high annual potential evaporation rates mean that open water storages lose large volumes of water. The losses from groundwater systems due to evaporation are much lower so that groundwater storages have an advantage over surface storages.

3.6. Variability of Rainfall

The coefficient of variability (CV) of annual rainfall in Table 4 is moderate at around 0.21 to 0.26 and is less in the wetter, northern islands than in the south. ENSO and the Pacific Decadal Oscillation (PDO) are key drivers of this variability. Two indicators of ENSO, the Niño Index (sea surface temperature anomaly in the Niño 3.4 region) and the Southern Oscillation Index (based on sea level pressure difference between Darwin and Tahiti) are strongly negatively and positively correlated, respectively, to wet season but not dry season rainfall. The PDO index is also strongly negatively correlated to wet season rainfall. In La Niña phases of ENSO (negative Niño Index), the SPCZ tends to move further south and Tonga gets more rain in the wet season, while in El Niño phases (positive Niño Index) it moves further north and causes lower wet season rainfall [17]. Droughts tend to occur during El Niño events. During severe El Niños, the SPCZ can spread azonally along the equator [32] leading to wide-spread impacts across the Pacific. In negative phases of the longer-period PDO, the south-western Pacific is warmer that in positive phases leading to higher rainfalls.

3.6. Changing climate and rainfall trends

Projections for future climate in the 21st century based on the Coupled Model Intercomparison Project Phase 5 using global climate models have been made for Tonga under various Representative Concentration Pathways estimating possible future trends in greenhouse gas emissions [17]. These projections suggest that there will be more extreme rainfall events, continuing sea level rise, increasing ocean acidification, higher risk of coral bleaching and El Niño and La Niña events will continue (all very high confidence). It is projected that the frequency of tropical cyclones will decrease by the end of the 21st century (medium confidence) but their maximum intensity may increase [31]. There is no consensus on whether average annual rainfall will increase or decrease [17].

CSIRO and the Australian Bureau of Meteorology [17] provided no projections of trends in potential evaporation or actual evapotranspiration. Earlier projections based on increasing temperatures [30] are erroneous. The available climate records for Tonga show average atmospheric temperatures increasing by about 1⁰C per century [13], similar to increases in sea surface

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temperatures in the surrounding ocean. Table 5 lists the historic linear regression trends in annual and seasonal rainfall at the meteorological stations in Table 1.

Table 5. Historic trends in annual and seasonal rainfalls with standard errors and significance level for the meteorological stations in Table 4. Long- and short-term records are compared over the same periods, 1947-2019 and 1980 to 2019 respectively.

Met Station	Trend Annual Rainfall (mm/decade)	Signif	Trend Nov-Apr Rainfall (mm/decade)	Signif	Trend May-Oct Rainfall (mm/decade)	Signif	Period
Niuafo'ou	**204±71**[1]	**p<0.05**	**82±36**	**p<0.05**	**141±68**[1]	**p<0.05**	1980 - 2019
Niuatoputapu	-3±30	NS	-9±23	NS	6±19	NS	1947 - 2019
Lupepau'u	34±28	NS	2±24	NS	**34±14**	**p<0.05**	1947 - 2019
Ha'apai	14±25	NS	3±22	NS	14±12	NS	1947 - 2019
Fua'amotu	**212±57**	**p<0.001**	**162±58**	**p<0.01**	60±35	NS	1980 - 2019
Nuku'alofa	0±24	NS	-7±21	NS	9±12	NS	1947 - 2019

[1]Period 1981-2019, data missing for 1980.

There are no significant trends in Table 5 in annual or wet season rainfall over the period 1947 to 2019. Out of the four stations with long-term rainfall records, only Lupepau'u in Vava'u has a significant increasing trend in dry season rainfall. In contrast, the two stations with shorter rainfall records, 1980 to 2019, in the northern and southern Island Divisions, have identical, within error, significant increasing trends in annual rainfall and significant increasing trends in wet season rainfall. While it is tempting to identify these more recent increasing trends over 39-year periods with climate change, they are very strongly negatively correlated with trends over 31 years in the PDO, unrelated to changing climate (Figure 4).

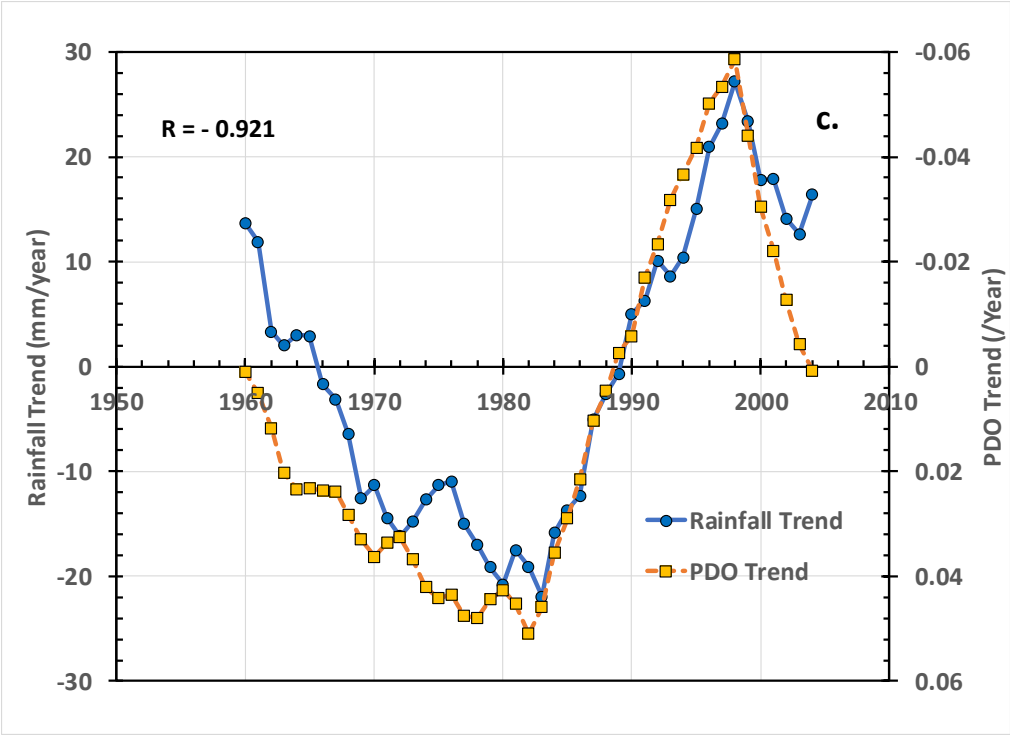

Figure 4. Comparison between the trends in rainfall at Nuku'alofa over 31 year running periods and the running trends in the PDO over the same period. The correlation, -0.921, is highly significant. The year shown is the mid-year of the 31-year period.

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3.7. Droughts

Because of the nation-wide reliance on rainwater harvesting or relatively shallow groundwater, droughts are particularly important in Tonga. They are projected to slightly decrease in frequency under climate change (low confidence) [17]. Projections, however, [34-37] suggest that the frequency of extreme ENSO events will increase from one in 20 years to one in 10 years within the 21st century and the PDO will become less predictable [38]. This impliess that severe droughts in Tonga may increase in frequency. Resident household sizes and their water demands mean that rain tanks supplying households often fail during protracted dry seasons or droughts. Table 6 lists the historic frequency of severe dry periods, defined as 6-month periods in which the average rainfall per month is less than or equal to 60 mm and when household rainwater tanks are expected to run dry.

Table 6. Frequency of severe dry periods in both wet and dry season at meteorological stations in Tonga.

Met Station	Frequency Severe Dry Periods		Period
	Nov-Apr	May-Oct	
Niuafo'ou	-	1/46	1980 - 2019
Niuatoputapu	-	1/43	1947 - 2019
Lupepau'u	-	1/28	1947 - 2019
Ha'apai	-	1/9	1947 - 2019
Fua'amotu	1/40	1/26	1980 - 2019
Nuku'alofa	1/39	1/28	1947 - 2019

In terms of dry season rainwater shortages in the Island Divisions, the frequency in Table 6 increases in the order of Ongo Niua<Vava'u = Tongatapu<Ha'apai. The frequency of extreme dry periods in Ha'apai is three times that in Tongatapu/Vava'u and five times that in Ongo Niua. The frequency of severe dry seasons in the period 1980 to 2019 and in the period 1947 to 2019 are very close at both Ongo Niua (Niuafo'ou and Niuatoputapu) and Tongatapu (Fua'amotu and Nuku'alofa). Surprisingly, Table 6 also indicates that, unlike other Island Divisions, the wet season in Tongatapu will also fail to supply adequate rainfall about once in forty years. Failure of the wet season is a serious concern. These results suggest that both Hapai and Tongatapu have higher risks of rainwater harvesting supply failures than the other Island Divisions.

The larger water storages in most groundwater systems mean that they are more robust supply sources during droughts, provided groundwater extraction is carefully monitored and managed.

3.8. The Tonga Strategic Development Framework 2015-2025

The TSDF II is arranged in a hierarchy where 29 Organizational Outcomes (OO), with 153 accompanying Strategic Concepts (SCs), grouped under three institutional pillars and two input pillars, feed into seven desired National Outcomes which feed into the single planned National Impact of the TSDF II: "A more progressive Tonga supporting a higher quality of life for all" which supports the Motto of TSDF II, given by reformer monarch Tupou I: "God and Tonga are my inheritance." The planned National Outcomes (NOs) are listed in Table 7.

The five institutional and input pillars, together with their accompanying OO the number of associated SCs are listed in Appendix A. Not one of the 29 OO mentions water or water supply. The OO under the Infrastructure and Technology Inputs Pillar, associated with National Outcome E in Table 7, emphasize more reliable, safe and affordable energy, transport and information and communications technology (ICT) services, but they do not include water services.

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Table 7. The seven planned National Outcomes of TSDFII [10]

Code	National Outcome
A.	a more inclusive, sustainable and dynamic knowledge-based economy
B.	a more inclusive, sustainable and balanced urban and rural development across island groups
C.	a more inclusive, sustainable and empowering human development with gender equality
D.	a more inclusive, sustainable and responsive good-governance with law and order
E.	a more inclusive, sustainable and successful provision and maintenance of infrastructure and technology
F.	a more inclusive, sustainable and effective land administration, environment management, and resilience to climate and risk
G.	a more inclusive, sustainable and consistent advancement of our external interests, security and sovereignty

The SCs numbered in Appendix A are considered : "…the priority issues identified for each Pillar during the consultation process with stakeholders. …they are useful inputs to the implementation process. … They are aids to sector, district and Ministry, Department and Agency planning and budgeting." [10]. Scanning the 153 SCs reveals that water appears only once, the second SC under 00 5.2: "b) improve the management and delivery of safe water supply for business and households". While under the Health component of the Social Institutions Pillar, "Percentage of population with safe water supply" is listed as a key performance indicator (KPI). There is no water supply KPI associated with SC 5.2 b).

In mapping the planned National Outcomes against the UN SDGs, the TSDFII identifies National Outcomes F, E, and B (above) as contributing to the UN's SDG6, yet the Infrastructure and Technology Inputs Pillar associated with National Outcome E does not mention water supply services nor sanitation.

3.9. Village Community Development Plans, 2016

Table 8 provides details of the number of village CDPs that were available for analysis for each of the Island Divisions and Districts. In total, 117 CDPs were available of the original 136 that were presented in 2016. The available CDPs are 77.5% of the total number of rural villages in Tonga (151). CDPs for the main island Tongatapu, excluded the Districts of Kolofo'ou and Kolomotu'a that comprise the capital Greater Nuku'alofa, and so represent rural areas of Tongatapu. Villages each identified a different number of priority issues to be addressed and the number varied for women, youth and men.

For the whole country, Table 8 shows that the median numbers of priority issues identified in villages by women, youth and men were the same. Ongo Niua Island Division identified the least number of priority issues while Ha'apai Island Division identified the most. Youth in 'Eua identified slightly more priority issues than youth elsewhere. The maximum numbers of priorities identified for women, youth and men were 12, 11 and 12, respectively, while minimum numbers were 4, 3, 3.

Table 9 lists the percentage of villages in each Island Division that identified water supply issues as their number one priority. Over 55% of the available village CDPs throughout Tonga identified water supply as the number one priority. Women in Tonga ranked water supply as a higher priority issue than did youth or men. Over 53% of all villages in all Island Divisions identified water as the highest priority. Only in 'Eua did men view water supply as a higher priority than did women and in 'Eua youth had the highest concern about water supply of any Island Division. Women in Ha'apai had the highest priority concerns about water supply of any gender-age cohort and Island Division.

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Table 8. The number of accessed village community development plans for Districts and Island Divisions in Tonga and the medium number of identified priorities identified by women, youth and men within each Island Division [27]

Island Division	District	No. of Village CDPs	No. CDPs/Island Division	Median Number of Priorities in Island Division		
				Women	Youth	Men
'Eua	'Eua Motu'a	13	13	8	7.5	7.5
Tongatapu	Nukunuku	9	48	6	5	6
	Tatakamatonga	7				
	Vaini	11				
	Lapaha	10				
	Kolovai	11				
Vava'u	Hahake	8	39	7	6	7
	Hihifo	5				
	Leimatu'a	4				
	Pangaimotu	4				
	Motu	9				
	Neiafu	9				
Ha'apai		5	5	9	7	10
Ongo Niua	**Niuatoputapu**	4	12	5	5	5.5
	Niuafo'ou[1]	8				
	Total	117	Country Median	6	6	6

[1]One village in Niauafo'ou gave aggregated priorities rather than separate women's, youth and men's priorities.

Figure 5 shows the distribution of the percentage of villages throughout the Island Divisions where concerns over water supply were ranked within the top three priorities. The average percentage of villages in Tonga (Figure 5) that ranked water supply in the top three priorities was 79% with women a slightly higher percentage (82%) than men (78%) or youth (75%). Concerns over village water supply were highest in Ha'apai (93%), where both 100% women and youth in villages ranked water within the top three priorities compared with 80% for men. Villages in the wetter, northern Ongo Niua Division had the lowest average percentage but still 72% ranked water supply issues within the top three village priorities. Youth in Ongo Niua villages had the lowest percentage (58%) of any who ranked water within the top 3 priorities.

Table 9. The percentage of villages in each Island Division that identified water supply issues as first priority in terms of women's youth and men's perspectives.

Island Division	Percentage of Villages with Water Supply as Highest Priority			
	Women	Youth	Men	Average
'Eua	46%	62%	54%	54%
Tongatapu	67%	42%	54%	54%
Vava'u	67%	49%	62%	59%
Ha'apai	80%	60%	20%	53%
Ongo Niua	50%	58%	50%	53%
Tonga	**62%**	**54%**	**48%**	**55%**

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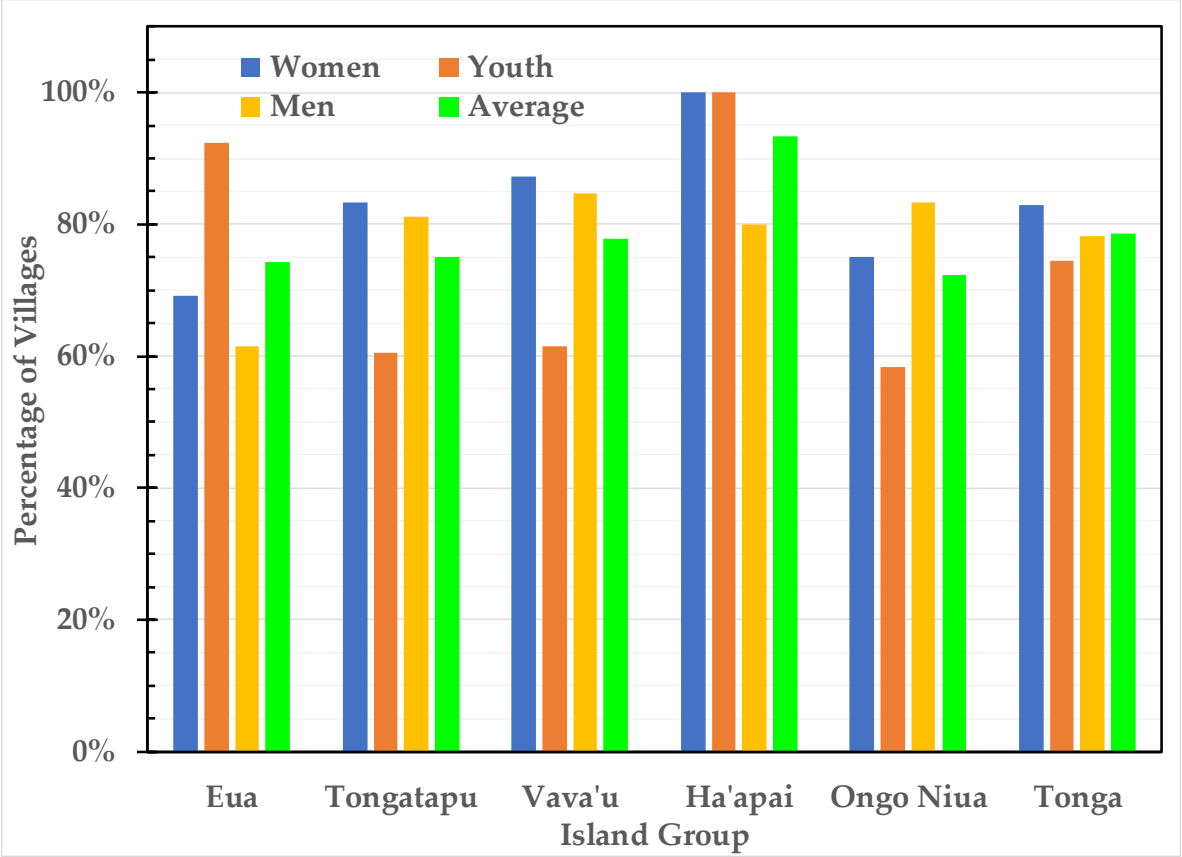

Figure 5. The percentage of villages throughout Tonga's Island Divisions, as well as Tonga collectively, which ranked water supply within the top three priorities in terms of women's, youth and men's perspective and the average of all three.

Table 10 shows the number of villages which did not rank water supply as a concern. Overall, the least concerns over water supply were in the main island of Tongatapu, where youth were the group least concerned about water supply. The most concerns were in Ha'apai, where 100% of women and youth all ranked water supply as a priority, as did youth in 'Eua. Nationally men in villages had slightly more concerns in listing water as a priority than women and both sexes had more concerns than youth.

Table 10. The percentage of villages in each Island Division where water supply was not a priority concern

Island Division	Percentage of Villages where Water Supply was not a Priority			
	Women	Youth	Men	Average
Eua	8%	0%	8%	5%
Tongatapu	10%	31%	10%	17%
Vava'u	5%	21%	8%	11%
Ha'apai	0%	0%	20%	7%
Ongo Niua	17%	8%	8%	11%
Tonga	**8%**	**12%**	**7%**	**9%**

4. Discussion

4.1. Demographics, Water Use, Water Sources and Reliability

The data in Table 1 show the concentration of population of Tonga in both the urban and rural areas of the main Tongatapu Island Division, which includes the capital, Nuku'alofa. About 26% of

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the population is dispersed across villages in the other Island Divisions. The population seems to fall roughly into three main classes: urban Tongatapu, rural Tongatapu and rural outer islands, although there are clear differences in outer islands, especially in terms of population density and household size as well as population centers versus remote islands.

Between 2011 and 2016 there was a net decrease in population in Tonga. There was also an exodus from outer islands, especially the Vava'u and Ha'apai Divisions, mostly to rural villages in Tongatapu.

Table 2 reveals that Tongans switch sources between public piped groundwater supply and private household rainwater harvesting depending on water use with rainwater preferred for drinking. The greater volumetric use of water for non-drinking purposes, such as toilet flushing and washing, means that the piped groundwater supplies are important. Urban areas and population centers have greater access to piped groundwater supply than in rural areas with very limited use of private local groundwater wells.

Ha'apai, Ongo Niua and Vava'u Island Divisions are vulnerable because of their larger reliance on drought-sensitive household rainwater harvesting relative to piped water supply systems (Figure 2). Outer islands in these three Island Divisions that are more reliant on rainwater harvesting, and have very limited average daily per capita water use (Table 3) equivalent to the quantity recommended by the World Health Organization as the minimum quantity of water required to satisfy essential health and hygiene needs in emergency situations [18].

The greatest volumetric use of water in Tonga is sourced from groundwater. In the southern Island Divisions of 'Eua and Tongatapu, water is sourced from springs and well-studied relatively thick freshwater lenses with comparatively low salinity. Increased pumping rates do increase the salinity in individual boreholes in Tongatapu (Figure 3) but salinity of the water supply to Nuku'alofa has shown no trends in salinity over the period 1997 to 2018. In the northern Island Divisions of Vava'u and Ha'apai, fresh groundwater lenses are much thinner, and the salinities of water supplied to population centers are more saline than in Tongatapu and can be even brackish in droughts.

Mean annual rainfall in Tonga is highest in the northern Island Divisions and decreases towards the south (Table 4) due to the position of the SPCZ. The variability of annual rainfall is moderate but increases southward. Large-scale variability is driven predominately by ENSO events and the PDO. Projections on the impact of climate change on annual rainfall are equivocal [17, 31]. The historic record shows no statistically significant long-term trends in annual rainfall over the period 1947 to 2019 (Table 5). There are shorter term trends in rainfall (Table 5) over 31-year periods which are highly significantly negatively correlated with trends in the PDO over the same period (Figure 4) .

Reliance on rainwater harvesting (Table 2) increases the risk of drinking water supply failures during ENSO- and PDO-related droughts, when even well-managed rainwater harvesting systems can fail, especially in large households. The risk of well-managed rainwater harvesting system failure in the dry, May to October season in the Ha'apai Division (Table 6) is three times as frequent as in the Tongatapu or Vava'u Island Divisions and five times as frequent as in the northern Ongo Niua Division, showing that rainwater harvesting is less reliable in Ha'apai. The rainfall data suggests that rainfall harvesting will also fail in the November to April wet season but only Tongatapu (Table 6) with a frequency of one year in 40, which is a significant concern.

Groundwater in other Island Divisions is less well studied than in Tongatapu. Differences in groundwater across Tonga's Island Divisions result from differences in geology and geomorphology. Tongatapu's groundwater occurs as moderately thick, freshwater lens with generally low salinity. Salinity of water is even lower in 'Eua. In Vava'u and Lifuka in Ha'apai the groundwater lens supplying the population center is thinner than in Tongatapu and can become brackish in dry periods. Some small islands in both the Vava'u and Ha'apai do not have reliable fresh groundwater. Groundwater has not been assessed in the northern volcanic islands of Ongo Niua, where rainwater harvesting is the main water supply.

Estimated per capita daily groundwater demands (Table 5) show that population centers in 'Eua, Vava'u, Ha'apai as well as rural villages in Tongatapu have about 48% to 60% of the average per capita daily supply to Nuku'alofa. For villages in the Vava'u, Ha'apai and Ongo Niua Divisions with

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access to only rainwater harvesting, average daily per capita demand is equivalent to recommended minimum emergency requirements for survival.

The demographic, water use, rainfall and groundwater data discussed above reveal the considerable differences in water availability across Tonga, with the capital, Greater Nuku'alofa well served with groundwater while rural Tongatapu and population centers in northern Island Divisions have access to less groundwater and in the north more saline groundwater than in Nuku'alofa. In addition, in Ha'apai and Vava'u the salinity of groundwater can be brackish at times. In the limited number of small outer islands and in Ongo Niua, water supply is predominantly from rainwater harvesting. In Ha'apai, even well-managed rainwater harvesting systems are expected to fail at a much higher frequency than in other Island Divisions, especially Ongo Niua with higher and less variable annual rainfall. It is expected from this data alone that, apart from Greater Nuku'alofa, there may be significant community concerns over water supply in Island Divisions more reliant on rainwater harvesting than on groundwater, particularly in the Ha'apai Division.

4.2. Top-Down versus Bottom-Up Planning Priorities

The largely top-down TSDFII involved discussions with key sectors of the economy including District and Town officers, church leader forums, non-government organizations and all main sectors of private business forums over a three-month period. TDSFII claims that the planned National Outcomes, F, E and B (Table 7) are contributions to the UN's SDG6 on water and sanitation. Water and sanitation do not appear in any of the Organizational Outcomes (Appendix A) or Strategic Concepts associated with NO E or B. Indeed, the infrastructure OOs associated with NO E specifically target more reliable, safe and affordable energy services, transport services, and information and communication technology but do not mention water services. As has been noted [38]: "There is general international consensus that there is a positive correlation between infrastructure and economic outcomes and that investment in infrastructure is a major driver of productivity. Core economic infrastructure, such as transport, electricity, telecommunications, sewerage and water systems, leads to the greatest levels of productivity, particularly when delivered with increased efficiency and reduced service prices."

Water supply appears in only one of the 153 Strategic Concepts listed under the OOs: "improve the management and delivery of safe water supply for business and households." Since the SCs are intended as "aids to sector, district and Ministry, Department and Agency planning and budgeting" it could be construed that the absence of water supply from the OOs and its mention in only one of the associated SCs implies that water supply is a low national priority in Tonga, in contrast to the findings above.

The rural village, bottom-up, Community Development Plans evolved over a 9-year period, partly because each stage of the planning process involved participation of 80% of the population of each village. The available 117 CDPs, analyzed here represents 77.5% of the total number of rural villages in Tonga and 86% of the 136 CDPs presented in 2016. The greatest number of available CDPs come from the main island Tongatapu, followed by the Vava'u Division, reflecting the distribution of rural population (Table 1).

The median number of priority issues identified in the CDPs for Tonga as a whole was 6 with the highest number of priorities identified in the Ha'apai Division and the least number in the wetter, northern Ongo Niua Division (Table 8). Over 55% of all rural villages ranked water supply as their top priority with women ranking water supply as first priority more frequently than youth or men (Table 9). This reflects the fact that in rural villages, household water supply is largely the responsibility of women. In Ha'apai, women in 80% of the villages ranked water supply as first priority, in contrast to men in Ha'apai villages where only 20% ranked it as highest priority.

Around 76% of all villages ranked water supply within the top three priority issues with women having a higher ranking than men followed by youth (Figure 5). The highest rankings were in villages in Ha'apai with women and youth in 100% of villages ranking water supply within the top three priorities. The lowest top three ranking was in the Ongo Niua Division due to low rankings by youth. Even in rural Tongatapu, 75% of villages ranked water supply within the top three priorities. Only

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563 an average of 9% of rural villages in Tonga omitted water supply in their list of local priority issues.
564 Tongatapu villages were the least concerned about water supply, while 'Eua and Ha'apai showed
565 most concern (Table 10).
566 The heavy reliance on rainwater for water supply in Ha'apai (Figure 2), coupled with limited
567 and more saline groundwater resources and more frequent failures of rainwater harvesting systems
568 contribute to the high priority for improved water supply in Ha'apai's CDPs. Even in Tongatapu,
569 where villages overall were the least concerned about water supply, three quarters of villages placed
570 water supply within the top three priorities.
571 The results of the rural village CDPs presents a dramatic contrast to the water supply priorities
572 in TSDFII and confirm expectations from the analysis of demographic, water sources, rainfall and
573 groundwater. The main government ministries, departments and agencies involved in producing
574 TSDFII are all located in the capital Nuku'alofa. Table 3 shows that the average per capita
575 groundwater supply in Nuku'alofa is considerably higher than that in other Island Division
576 population centers and very much higher than the limited number of islands totally reliant on
577 rainwater harvesting where data is available. The minimal water supply priorities identified in
578 TSDFII appear to reflect the priorities of urban Nuku'alofa, while the water supply priorities in the
579 117 village CDPs reflect rural village concerns.

580 **5. Conclusions**

581 National Sustainable Development Strategies, externally considered appropriate for SIDs, are
582 widely used across the Pacific as method for identifying national priorities, allocating government
583 resources and as a way of contributing to international and regional agreements. They are largely
584 top-down processes which are considered more time-efficient than lengthy community consultations
585 involved in bottom-up community priority identifying processes.
586 The Tonga Strategic Development Framework 2015-2025 involved three months of high-level
587 consultations. In contrast the Community Development Plans in rural villages through Tonga's five
588 Island Divisions took 9 years to complete, mainly because they required participation and consensus
589 of 80% of the cohort populations of each village in each phase of the process. The priority issues
590 ranked by the villages provide a valuable insight into the concerns of villages. They have not,
591 apparently, been analyzed previously.
592 Here we concentrated only on water supply priorities. We found an enormous difference
593 between priorities identified in TDSFII, where water supply is barely mentioned and not at all under
594 the Infrastructure Pillar. We have suggested that the low priority given to water supply may reflect
595 the fact that Ministries, Departments and Agencies which contributed substantially to TDSFII are
596 predominately located in the capital Nuku'alofa which has a much higher per capita water supply
597 from groundwater and a lower reliance on rainwater than in northern Island Divisions or in rural
598 Tongatapu.
599 In contrast to the TDSFII, 76% of village CDPs ranked water supply within the top three
600 priorities and 72% or greater of villages in all Island Divisions ranked water supply within the top
601 three priorities. The highest percentage of villages, 93%, being in the Ha'apai Division. Difference in
602 ranking were observed between women, youth and men, with women in villages having the highest
603 priority concerns, reflecting the responsibility of women in villages for household water supply.
604 The large concerns in Ha'apai villages over water supply are predicable from the demographic
605 and water use data in the 2016 Census and from the characteristics of groundwater and rainfall across
606 the Island Divisions. Given that, the failure of TDSFII to identify rural village water supply as a
607 priority throws into question the processes used in its development. This is particularly so as National
608 Outcome B. of the TSDFII is "a more inclusive, sustainable and balanced urban and rural
609 development across island groups".
610 Village CDPs were presented in 2016, about one year after TDSFII was produced. We have only
611 examined water supply priorities ranked in the CDPs. The mismatch between planning processes in
612 this sector is startling. There is an opportunity to revise all identified rural village priorities in the

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613 available CDPs and to revise TSDFII to better reflect identified priorities in CDPs. Without this
614 analysis and recognition, the CDP process was largely ceremonial.
615 The Fale Alea 'o Tonga (National Parliament) has very recently passed the Water Resources Act
616 2020 to conserve, protect and manage the Kingdom's water resources. This requires amongst other
617 objectives "implementation of urban and rural planning regimes that take account of water
618 management". This has the potential to address gaps in knowledge of the Kingdom's water resources
619 and their use, and to focus on improving water supplies in Island Divisions and villages identified in
620 the CDPs.
621 We have been fortunate here of having the opportunity of analyzing water supply priorities in
622 both a national top-down development planning process and a nation-wide rural village, bottom-up
623 priority planning process. Our findings here raise the question as to whether the mismatch found
624 here in water supply priorities also applies to top-down strategic development planning processes
625 and infrastructure investment strategies in other SIDs.

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627 analysis, T.F. and I.W.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft
628 preparation, I.W.; writing—review and editing, I.W., T.F., and T.K.; project administration, T.K.. All authors
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638 **Appendix A.** The Pillars and associated Organizational Outcomes (OO) and number of Strategic
639 Concepts connected with each OO in the Tonga Strategic Development Framework 2015-2025 [10].

Pillars	Organisational Outcomes	No. Strategic Concepts
1. Economic Institutions	1.1 Improved macroeconomic management & stability with deeper financial markets	6
	1.2 Closer private/public partnerships for economic growth	4
	1.3 Strengthened business enabling environment	4
	1.4 Improved public enterprise performance	5
	1.5 Better access to, & improved use of overseas trade and employment, & foreign investment	5
2. Social Institutions	2.1 Improved collaboration with and support to civil society organizations & community groups	7
	2.2 Closer partnerships between government & churches & other stakeholders for community development	4
	2.3 More appropriate social & cultural practices	7
	2.4 Improved education & training providing lifetime learning	11
	2.5 Improved health care & delivery systems (universal healthcare coverage)	5
	2.6 Stronger integrated approaches to address both to address both communicable and non-communicable diseases	4
	2.7 Better care & support for vulnerable people, in particular the disabled	6
	2.8 Improved collaboration with the Tongan diaspora	3

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3. Political Institutions	3.1 More efficient, effective, affordable, honest, transparent & apolitical public service focussed on clear priorities	7
	3.2 Improved Law & order & domestic security appropriately applied	7
	3.3 Appropriate decentralisation of government admin. With better scope for engagement with the public	3
	3.4 Modern & appropriate Constitution with laws & regulations reflecting international standards of democratic processes	4
	3.5 Improved working relations and collaboration between Privy Council, executive, legislative & judiciary	2
	3.6 Improved collaboration with development partners ensuring programs better aligned behind govt. priorities	4
	3.7 Improved political & defence engagement within the Pacific & the rest of the World	4
4. Infrastructure & Technology Inputs	4.1 More reliable, safe & affordable energy services	4
	4.2 More reliable, safe & affordable transport services	7
	4.3 More reliable, safe & affordable information & communication technology (ICT) used in more innovative ways	4
	4.4 More reliable, safe & affordable buildings & other structures	5
	4.5 Improved use of research & development focussing on priority needs based on stronger foresight	3
5. Natural Resources & Environment Inputs	5.1 Improved land use planning, administration & management for private and public use	7
	5.2 Improved use of natural resources for long term flow of benefits	7
	5.3 Cleaner environment with improved waste recycling	5
	5.4 Improved resilience to extreme natural events and climate change	9

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