Multi Country Drought Preparedness and Response Plan Design

Rainwater harvesting, informal settlement, Honiara, Guadalcanal Solomon Islands

Summary of Hot Spot Analysis Based on Historic Rainfall Data, Solomon Islands

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Figure 1 Solomon Islands lying between about 156 to over 168°E and 6.7 to 12.2°S. Red dots indicate the location of seven long-term rainfall stations used in this analysis

Summary

The overall purposes of this activity are to enhance the capacity of the Pacific island countries Solomon Islands, Vanuatu and Fiji and their Water Sanitation and Hygiene (WASH) Cluster partners in drought management, to improve existing preparedness, response and recovery mechanisms and to identify gaps and provide recommendations for appropriate preparedness planning and response arrangements. Key components are rainfall analyses and spatial mapping for the identification of hotspots based on the impact of rainfall deficits on island freshwater resources and existing water supplies. This brief report summarises uses the analyses of existing rainfall monthly data to identify drought hot spots in Solomon Islands (SI).

Rainfall data

Using rainfall data alone to identify droughts impacts is problematic as rainfall deficits are strictly only relevant to meteorological drought. For water supply droughts there are a whole host of other equally important factors, especially demand and losses. Poor management is as big a threat to water security as lack of rain. The best approach to identifying hotspots is to carry out a water balance of the systems of concern. InSI and elsewhere in the Pacific, the information necessary for carrying out a water balance is sparse or non-existent. As an alternative, we use a pseudo water balance approach taking into account only existing rainfall data and estimated evaporation losses.

Rainwater harvesting

This analysis concentrates on rainwater harvesting, since island communities that rely on rainwater as their only source of water are the most vulnerable during drier periods. It is, however, also relevant to water supplies sourced from shallow groundwater systems, small springs and streams and annual crops. The typical household rainwater harvesting system in SI supplying an average-sized household with all their water needs has the risk of failing after only about 10 days without rain. This makes the character of drought for rainwater harvesting systems quite different from slowly developing droughts typical of agricultural drought and impacts on large water storages and major groundwater systems.

Pseudo water balance approach

The pseudo water balance approach estimates that to survive the longest dry spell in SI (about 30 days in Henderson Honiara) and supply 100 L/day/capita (for communities solely reliant on rainwater harvesting) requires rain tank capacity of 3 m^3/capita. The effective roof catchment area needed to supply the tank at a rate equal to the evaporation rate is 30 m^2/capita. With typical tropical rain capture efficiency of around 60% that amounts to a massive catchment area of 50 m^2/capita. With smaller demand rates and conservation strategies, the requirements are reduced.

Probabilities of annual and seasonal water supply deficits

Non-parametric percentile distributions of historic monthly, 3-monthly, seasonal, annual and consecutive 12 month rainfall records throughout SI are used to estimate probabilities of water shortages at any location at any time of the year using estimated evaporation rate as the lower rainfall limit.Only Honiara and Henderson have a 6% (one year in 19) and 11% (one year in 9) chance respectively of annual water deficits.

For the November to April “wet” season, all stations had zero probabilities of water shortages. For May to October “dry season”, Henderson and Honiara have probabilities of water shortages of 48% and 34% respectively (about 1 year in 2 to 1 year in 3). In this season the only other station with nonzeroprobability is Munda with 0.6% chance of shortages (1 year in 160).

For rainfalls over three consecutive months,there is no risk of shortages at any station in the January to March period. Henderson-Honiara have the highest probability of shortages, overall 35 times the probability at the next highest station, Auki. The months May through November have higher overall risk of shortages with July through September having the highest risk. For one month rainfall data, the probabilities increase. Henderson-Honiara have the highest overall probability of shortages, seven times more than the next, Kirakira. Again, May through November months have higher probabilities shortages with June highest. Unfortunately, dry season rainfallsare poorly correlated with preceding ENSO Indices, so that forecasts of rainfall in the dry season from ENSO indices are uncertain. Alternate sources of water

at Henderson-Honiara and the risks associated with them, together with the assumptions made in this analysis, are discussed.

Use of Census RWH data to identify hotspots
The incomplete spatial coverage of long-term rainfall stations means that it is not possible to identify all hot spot regions in SI. Instead, examination of Census data to determine the percentage of households (HH) in a region reliant on either HH or community RWH can be used to identify regions at risk. Based on the 2009 census, these regions are Rennel and Bellona (93% of HH rely on RWH), Western Province (51%), Choiseul (42%) and Temotu (34%). In these regions, alternate sources of water are needed to increase resilience.

Improving spatial coverage of rainfall
Because drought in rainwater harvesting systems occurs over a much shorter period than agriculture drought it is suggested that satellite data be explored for its broad spatial coverage and its daily to weekly time intervals. There is potential to use this remote data to rapidly identify developing hotspots.

Climate change
There is no evidence of a general consistenttrend in rainfall across the Solomon Islands due to climate change and warming sea surface temperatures. The best resilience strategy for the future is to manage demand and use through the current climate variability and to protect water quality.

Recommendations

1. This analyses used only 7 long-term rainfall station records in Solomon Islands and could not identify any orographic effects and could only hint at lee-side location impacts.
   It is recommended that a similar analysis be made of all rainfall records in SI to identify orographic and locational influences on rainfall.
2. The spatial distribution of long-term rainfall stations in SI is limited.
   It is recommended that the use of TRMM and GPM satellite data be explored to provide a better spatial coverage of rainfall across Vanuatu and over periods as short as 10 days when rainfall harvesting systems commence to fail.
3. The complex interaction between ENSO events and rainfall in SI has been revealed in analyses of annual, seasonal and monthly rainfalls.
   It is recommended that further examination of the inter-relations between the intensity of ENSO events and rainfall extremes in SI, particularly in the dry season, be undertaken.
4. Because the analyses here used only monthly rainfall data, it was only possible to crudely estimate the length of record dry periods without rain in SI.
   It is recommended that daily rainfall records be examined to find the maximum number of consecutive rains with zero or very small daily rainfall (<0.3 mm) at each rainfall station in SI.
5. Estimates were made in this work of the actual mean monthly ET losses in SI.
   It is recommended that information on the spatial and temporal variability of actual ET be compiled for SI.
6. This analysis could only use rough estimates of the characteristics of rainwater harvesting systems and the demand and use of rainwater in SI.
   It is recommended that a national survey be carried out of the characteristics of rainwater harvesting systems in SI together with demand and uses.
7. The analysis has concluded that groundwater and surface are possibly the most attractive option as an alternate source of more reliable water in the hot spot region of Henderson-Honiara in SI.
   It is recommended that the sustainable yield of surface and groundwater sources in the Henderson-Honiara region be carried out.
8. The brief examination of alternate water supplies other than rainwater harvesting reveals that surface and groundwater sources are unprotected from overuse, misuse, or contamination.
   It is recommended that policy, plans, legislation regulations be put in place which protect public water sources from overuse, misuse and pollution, especially in the Henderson-Honiara, Eastern Guadalcanal region.
9. Data on the characteristics of rainwater harvesting systems in SI is very limited.
   It is recommended that data be collected on the roof catchment areas, rain tank capacities and guttering, particularly in areas that rely on rainwater harvesting such as Rennel and Bellona, Western Province, Choiseul and Temotu.

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Abbreviations and Acronyms

A	Rainwater catchment area (m^2)
BoM	Australian Bureau of Meteorology
C	Storage capacity (m^3)
C_{Crit}	Critical storage capacity (m^3)
C/n	Storage capacity per person (m^3/capita)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
$\bar{d}$	Daily per capita water demand (L/day/capita)
D_t	Demand (m^3) over time period t
E_t	Evapotranspiration losses over time period t
f	Efficiency of capture of rainwater
$f.A$	Effective rainwater catchment area (m^2)
$f.A/n$	Effective rainwater catchment area/person (m^2/capita)
HH	Household
L	Litre
L_t	Water losses over time period t
m	metre
mm	millimetre
mth	month
m^2	Square metre
m^3	Cubic metre
n	Number of people supplied by rainwater tank
P	Daily rainfall (mm/day)
P_t	Water inputs in time period t
RWH	Rainwater harvesting
SI	Solomon Islands
t	time
t_{Crit}	Time period without rain
t_d	Longest period on record without rain (days)
TC	Tropical cyclone
UN	United Nations
UNICEF	United Nations Children's Fund
ΔS	Daily change in rainwater tank volume (m^3/day)
ΔS_t	Change in water storage over time period t

1. Introduction

Carrying out a "hot spot" analysis of drought using rainfall data aloneis problematic. Firstly, such an analysis depends on what sort of drought is the main concern. Strictly, the analysis of rainfall is only relevant directly to meteorological drought. Other droughts, especially water supply droughts, involve other important issues such as: the storage capacity of the reservoir, or groundwater system, the rate of input of water to storages, stream flows and water levels, evapotranspiration losses, the drawdown of water from storages through demand for water and the losses from the storages and transmission systems and, finally, but importantly, the quality of water in the storages and transmission systems. Poor management of water supply systems, especially rainwater harvesting systems (RWH), is as big a threat to water security as lack of rainfall.

In Solomon Islands (SI), nationally, we have almost none of this extra data.Even with rainfall, the incomplete spatial coverage of long-term stations (Figure 1) means that some key areas may be missed. As well, we have only limited information on the all-important questions of the effect of topography and location on rainfall in high islands. In this "hot spot" analysis the main emphasis is on the most vulnerable island water supply to drought, rainwater harvesting (Falkland, 2011).

2. Water Balance Approach to "Hot Spot" Identification

A more complete analysis of "hot spots" requires a water balance approach:ΔS_t, the change in any storage (positive or negative) over a time period t is simply related to the amount of inputs, P_t,(rainfall, stream flow, groundwater or infiltration etc.), the evapotranspiration losses, E_t, the withdrawals to satisfy demand, D_t, and system losses, L_t n the same time period t:

$$\Delta S_t = P_t - (E_t + D_t + L_t) \quad [1]$$

An emergency situation occurs when the storage capacity, C, of the system falls to a critical level, C_{Crit}, over a time period without rain $t_{crit}$when there is insufficient, safe water to meet reasonable demand, and losses expressed as:

$$C_{Crit} = C - \sum_{t_{Crit}} |\Delta S_t| \quad [2]$$

This applies equally to water supply systems or to crops and forests relying on stored soil water. The art of good drought management is to act before $C_{Crit}$is reached.Unfortunately the information required for a general water balance approach to water supply, such as groundwater recharge rates, aquifer and rain tanks storages, stream flows, evapotranspiration, losses and above all rates of extraction and use of water, is generally lacking in SI.

For perennial and annual crops and pastures and for trees, reliant on soil moisture for survival, the surface water balance simplifies to

$$\Delta S_t = P_t - (E_t + RO_t) \quad [3]$$

Where $RO_t$is the surface runoff. In equation [3], when rainfall in time period t is less than actual evapotranspiration, the soil moisture store will be depleted and crops will start to be stressed. The condition when $P_t \leq E_t$represents the start of water stress for plants.

2.1 What is a critical time period for rainwater harvesting?

Communities relying solely on RWH have been identified as having the most vulnerable water supplies to drought due to limited rainwater tank storage capacity, especially during dry seasons. The water balance approach for RWH can be approximated on a daily basis to:

$$\Delta S = 10^{-3}.\left(f.P.A - n.\bar{d}\right) \quad [4]$$

Where ΔS (m^3/day) is the daily change in rainwater tank volume, f is the efficiency of capture of rainwater which includes all system losses and evaporation (dimensionless), P (mm/day) is daily rainfall, A (m^2) is the roof catchment area, n is the number of people supplied by the rainwater tank,

and $\bar{d}$ (L/day/capita) is the average per capita daily demand. The factor 10^{-3} is to convert units in L and mm.

In equation [4] *f.A* is the effective roof area for RWH. If we assume that the critical storage volume is when the tank is completely empty then the critical time period (days), assuming people continue to use water at the same rate while the tank level is falling, is:

$$t_{Crit} = 1000.C/(n.\bar{d}) \qquad [5]$$

where *C* (m^3) is the capacity of the rain tank. Data on rain tank capacities and daily demand in communities solely reliant on rainwater harvesting is limited.

As a first approximation we will take *C* = 6 m^3, n = 6 persons per household and $\bar{d}$ = 100 L/day/capita. With these estimates, the critical time period is only 10 days without rain if there are no conservation strategies. This demonstrates that the character of drought for communities soley reliant on rainwater harvesting is quite different to that in communities with larger storages such as groundwater or surface water or for agricultural drought. Drought for rainwater does not involve the slow development of water deficits experienced in large island groundwater systems (White *et al.,* 1999), streams and agricultural systems.

2.2 What rain tank storage capacities are required?

The approximation [5] can be inverted to provide estimates of the storage capacity necessary per capita to sustain a community through the longest period without rain on record, t_d(days)

$$C/n = 10^{-3}.\bar{d}.t_d \qquad [6]$$

For the SI, the longest period without rain is about 30 days in the Henderson-Honiara region. Again, using 100 L/day/capita as reasonable demand per person for people solely reliant on rainwater harvesting, equation [6] suggests that a minimum target rainwater storage capacity for people in the Henderson-Honiara Guadalcanal plains area should be about 3 m^3/person. Unfortunately daily rainfall data was not available for other locations in SI but the monthly rainfall record suggests that for other areas, lower per capita rain tank capacities will be required.

It is not possible to estimate *C/n* for other locations in SI because that requires access to daily rainfall data, which is not available to this consultant. However, the impact of the number of consecutive days without rain on *C/n* can be easily estimated from equation [6] for various per capita demand estimates as in Figure 2. This analysis assumes that no conservation measures are taken when the stored volume of rainwater reduces. Conservation means that smaller per capita rain tank capacities can be used.

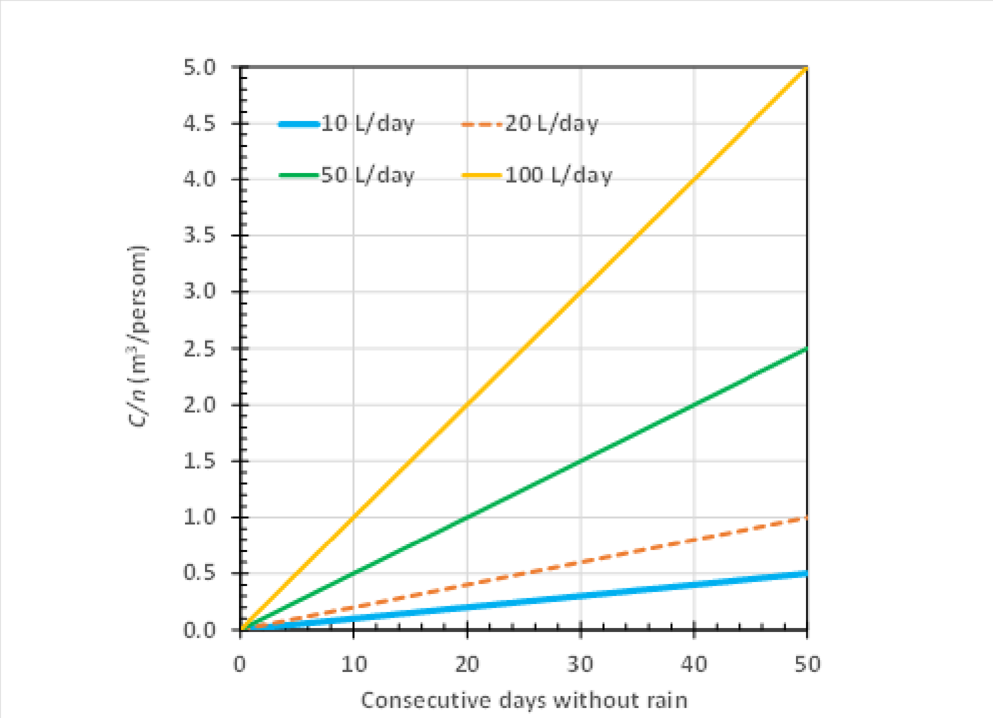

Figure 2 Per capita rain tank capacities required to supply without failure for a range of constant per capita water demands, from 10 to 100 L/cap/day as a function of consecutive days without rain in SI

2.3 What Roof Catchment Areas are Required?

Rain tank capacity is only one part of RWH. Another key consideration is what roof catchment areas are required to supply water to rainwater tanks to prevent rainwater tank failure. One way of estimating this is to ask what combination of roof area and rainfall is required to just meet the daily demand without reducing the daily stored volume of rainwater, that is ΔS = 0 in equation [3] so that:

$$f.P.A/n = \bar{d} \qquad [7]$$

It has been argued in Reports 1, 2 and 3(White, 2016a,b,c)that when rainfall exceeds the actual evaporation rate, excess water should be available. It was estimated from studies in American Samoa and the published Pacific evaporation maps (Nullet, 1987; Izuka *et al.*, 2005) that the mean actual evaporation in SI is around 100 mm/mth, or 3.3 mm/day on average.

In American Samoa (approximately 14°20'S and 189°15'E), at about sea level, monthly potential evaporation varies between about 150 mm/mth September-January to about 110 mm/mth in April-July (Izuka *et al.*, 2005). In terms of estimated actual evapotranspiration, the monthly range is around 80mm/mth in winter to 110 mm/mth in summer. Since information on the annual distribution of monthly evapotranspiration across Vanuatu is not available we will assume an average monthly actual evaporation rate of 100 mm/mth or 3.3 mm/day across all SI and uniform for all months of the year.

If we take this as a target figure, and the average daily demand as 100 L/day/capita, then equation [6] suggests that the effective rainwater catchment area per person, *f.A /n,*is 30 m^2/person, which for SI is a very large area. In many tropical situations only about 60% of the rainwater falling is actually captured (*f* = 0.6). This suggests the actual roof area required to lower the risk of water supply failure is around 50 m^2/person, or 300 m^2 for a household of 6 people. With such large roof areas,however, vast amounts of excess harvested rainwater will be generated in the wet season.

The front piece of this report shows a reasonably typical rainwater harvesting system used in the informal settlements around Honiara. The relatively small roof catchment area, undersized gutters and relatively small capacity tank are evident.

2.4 Limitations of this Approximate Analysis

The above very approximate analysis is based on a number of assumptions. The most critical are that:

- monthly data can be used to estimate rainwater tank performance on a daily basis,
- all losses in rainwater tank capture and storage can be represented by a single rainwater capture efficiency term, f,
- people will continue to use water at a constant rate irrespective of the remaining water volume in the tank,
- a demand of 100 L/day/capita is a reasonable design target for people solely reliant on rainwater harvesting,
- an approximate mean estimate of 100 mm/mth for actual evapotranspiration losses is appropriate across all months and all locations in SI, and
- when monthly rainfalls are less than the above amount storages will start to decline.

What is clearly required is a more detailed daily analysis of RWH relying on actual data on RWH systems in SI.

3. Probability of Water Supply Shortages in SI

3.1 Seasonal and AnnualRainfall

In Reports 1. 2 and 3 (White, 2016 a,b, c) it has been argued that when rainfall drops below actual evapotranspiration, problems in water supply start to occur. Based on this assumption, the rainfall percentile distributions (Gibbs and Maher, 1967; Gibbs, 1975) over seasonal ("wet" November to April and "dry" May to October), annual (calendar year) periods and consecutive 12 month periods at the 7 long-term rainfall stations across SI can be used to estimate the probability of significant dry periods when rainfall equals or is less than actual evaporation across SI over the same time period. Actual evaporation was estimated from Nullet (1987) and Izuka *et al.* (2005) and the assumption that actual evaporation is equilibrium evaporation. The probabilities are shown in Table 1.

In Table 1, based on the current historic rainfall record, a probability of 0 means that there is no probability of deficits occurring, while a probability of 1 means that it is certain to occur. Neighbouring Henderson and Honiara stations have differing probabilities because of their different lengths of rainfall records.

Table 1 Probability of rainfalls over wet and dry seasons and annual periods being less than or equal to estimated actual evaporation losses. Colour coding of probabilities, Pr, is given by:

0	0<Pr≤0.1	0.1<Pr≤0.2	0.2<Pr≤0.3	0.3<Pr≤0.4	0.4<Pr≤0.5	0.5<Pr≤0.6	0.6<Pr≤0.7	0.7<Pr≤0.8	0.8<Pr≤0.9	0.9<Pr≤1.0

Station	Period			
	May to October	November to April	Annual	Consecutive 12 months
Auki	0	0	0	0
Henderson	0.478	0	0.058	0.11
Honiara	0.336	0	0	0.054
Kirakira	0	0	0	0
Lata	0	0	0	0
Munda	0.006	0	0	0
Taro Island	0	0	0	0

On an annual basis, only Henderson would experience a significant annual calendar year deficit but with a probability of less than 6 % (about 1 year in 17). On a consecutive 12 month basis the probabilities increase to around 6% for Honiara (about 1 year in 19) and to 11% for Henderson (about 1 year in 9). All other stations have zero probability of 12 month rainfall not merely being less than actual evapotranspiration but of being less than the estimated potential evaporation of around 1750 mm/12 months. In contrast, in Honiara and Henderson, consecutive 12 month rainfalls have probabilities of being less than the estimated potential evapotranspiration of 42% (about 1 year in 2) and 34% (about 1 year in 3) respectively.

The probabilities for seasonalrainfall being less than seasonal actual evaporation varies dramatically between seasons across SI. Here a fixed November to April "wet" season and a May to October "dry" season have been chosen for comparison purposes. Seasonal water shortages due to inadequate rainfall have zero probability of occurring in the November to April "wet" season at any rainfall stations throughout SI.

The really significantseasonal shortages at Henderson-Honiara occur during the May to October dry season where the probability of seasonal water shortages occurs with probabilities of about 48% and 34% respectively (about 1 year in 2 to 1 year in 3). Of the other stations, only Munda has a very low probability of 0.006 (about 1 year in 161) of water shortages in the dry season.

3.2 Rainfall over Three Consecutive Months

Deficits of rainfall over three consecutive months are of concern for larger community rainwater harvesting systems, small springs, small, low island water lenses (White *et al.*, 2002) and streams and some crops. The analysis for the 3 month period again sets the limit of rainfall below which deficits will start to emerge as equal to the approximate actual evaporation rate of 300 mm/3 months. Table 2 lists the probabilities estimated from the three monthly rainfall distributions at each station.

Table 2 Probabilities, estimated from 3 month rainfall distributions, that rainfall over particular three month periods will be less than actual estimated evaporation losses in SI. Colour coding of probabilities as in Table 1

Months	Station							Average
	Taro	Munda	Auki	Henderson	Honiara	Kirakira	Lata	
Jan-Mar	0	0	0	0	0	0	0	**0**
Feb-Apr	0	0	0	0	0	0	0	**0**
Mar-May	0	0	0	0.10	0.07	0	0	**0.02**
Apr-Jun	0	0	0	0.31	0.27	0	0	**0.08**
May-Jul	0	0	0.01	0.56	0.52	0	0	**0.15**
Jun-Aug	0	0.01	0.02	0.64	0.55	0	0	**0.17**
Jul-Sep	0	0.02	0	0.62	0.60	0	0	**0.18**
Aug-Oct	0.0002	0.01	0	0.55	0.50	0.01	0	**0.15**
Sep-Nov	0.03	0.007	0.007	0.38	0.33	0	0.001	**0.11**
Oct-Dec	0.05	0.008	0.024	0.17	0.17	0.04	0	**0.07**
Nov-Jan	0.02	0	0	0.12	0.05	0.01	0	**0.03**
Dec-Feb	0	0	0	0.04	0.007	0.00	0	**0.007**
Average	**0.008**	**0.005**	**0.005**	**0.29**	**0.26**	**0.005**	**0.0001**	**0.08**

In general, the period May to November has the highest probabilities of water shortages across all SI, while in the period January to April, there is zero probability of water deficits at all rainfall stations in SI. Again, Henderson and Honiara have by far the highest probabilities of deficits, being overall more than 50 times more probable of shortages than Auki, the next highest. Lata has zero probability of rainfall deficits except for a very small probability in the period September to November. There is an interesting progression in the pattern of three month periods where deficits do occur, moving from Taro Island to Henderson-Honiara then back to Lata.

On a three month basis, the frequency of dry periods in Henderson-Honiara between May and October is between one year in two and 5 years in 8. This means that growing annual crops in this region during the dry season will frequently require irrigation.

3.3 MonthlyRainfall

Rainfall over monthly periods is very relevant to domestic RWH systems and smaller community systems. The percentile distributions of individual monthly rainfalls can be used to estimate the probability of monthly water shortages in any particular month at any rainfall station across SI. To do this we need to have an estimate of the lower limit of rainfall below which problems can be expected to arise. This will very much depend on what water sources are used, what the demands and losses are from them and how well they are managed. Such information is,in general,not available. As a first estimate we will assume that when the monthly rainfall drops below the estimated actual evaporation, problems are likely to start to arise. Based on Nullet (1987) and Izuka *et al* (2005), the approximate mean monthly evapotranspiration in SI has been estimated at about 100 mm/month.

As a first approximation then, we assume that when monthly rainfalls are equal to or less than 100 mm, water supply problems may start to arise. While this is so for agriculture, small springs and streams for longer periods such as three months, its applicability to RWH systems for shorter periods is less certain. In order to examine its suitability, let us consider a typical SI household of 6 people with a roof catchment area of 25 m^2. If the efficiency of capture of rainwater is 60% then 100 mm/mth of rain will produce 1,500 L/mth of water, enough to supply on average 8.2 L/day/capita, a very basic survival rate, if the rain tank is depleted at the start of the month and RWH is the only source of water. So the assumption that monthly rainfalls below 100 mm signal the start of water shortages for RWH is a reasonable first estimate. Table 3**Error! Reference source not found.** lists the probabilities that rainfalls at a particular station and particular month will be less than the estimated monthly actual evaporation.

Table 3 Probability in any month that rainfall will be equal to or less than the estimated actual evaporation of 100 mm/mth for all long-term rainfall stations in SI. The probability, Pr, is colour coded:

Month	Station							Average
	Taro	Munda	Auki	Henderson	Honiara	Kirakira	Lata	
Jan	0.12	0	0.02	0.11	0.14	0.01	0	**0.06**
Feb	0.06	0	0.001	0.05	0.07	0.07	0	**0.04**
Mar	0.02	0	0	0.10	0.06	0.02	0	**0.03**
Apr	0	0.01	0.03	0.29	0.12	0.02	0	**0.07**
May	0	0.02	0.06	0.43	0.39	0.02	0	**0.13**
Jun	0.02	0.04	0.10	0.72	0.65	0.09	0.04	**0.24**
Jul	0	0.009	0.07	0.56	0.60	0.08	0.02	**0.19**
Aug	0.001	0.05	0.05	0.65	0.68	0.08	0.04	**0.22**
Sep	0	0.06	0.04	0.64	0.64	0.06	0	**0.21**
Oct	0.02	0.05	0.03	0.49	0.50	0.10	0.05	**0.18**
Nov	0.13	0.08	0.07	0.33	0.35	0.09	0.01	**0.15**
Dec	0.06	0.04	0.02	0.24	0.22	0.12	0.02	**0.10**
Average	**0.04**	**0.03**	**0.04**	**0.38**	**0.37**	**0.06**	**0.01**	**0.13**

For Funafuti Atoll in Tuvalu, an atoll which relies heavily on rainwater harvesting for water supply, Falkland (1999) estimated that domestic water supply deficits start to emerge when monthly rainfall drops below 80 mm/mth. Table 4lists the probabilities of rainfalls falling below 80 mm for all months of the year and all rainfall stations in Vanuatu. In terms of the above estimates, a rainfall of 80 mm/mth could provide only about 6.5 L/pers/day, a very restricted basic survival ration.

Table 3 and *Table 4* provide a method of ranking stations by risk of failure for individual months. It is clear that Henderson-Honiara have much higher probabilities of low rainfalls than other stations as expected from Table 1 and Table 2. The average probability at these two stations is over 6 times that at the next ranked station at Kirakira. In the period June through September the frequency of low rainfalls is about 2 years in 3 at Henderson-Honiara. Overall, the period May to November, covering the “dry” season and start of “wet” season have the highest risks throughout SI. June has the highest overall probability of water shortages about one year in four across all of SI, followed by August and September (about one year in 5). Lata has the lowest risk of water shortages due to the higher rainfalls and lack of seasonality of rainfall there. In Lata in October the risk of shortages is about one year in 20.

Table 4 Probability in any month that rainfall will be equal to or less than 80 mm/mth for all long-term rainfall stations in SI. The probability, Pr, is colour coded as in ***Error! Reference source not found.***

Month	Station							Average
	Taro	Munda	Auki	Henderson	Honiara	Kirakira	Lata	
Jan	0.04	0	0.009	0.06	0.08	0.002	0	**0.03**
Feb	0.04	0	0	0.03	0.01	0.027	0	**0.02**
Mar	0.01	0	0	0.08	0.05	0.004	0	**0.02**
Apr	0	0.004	0.02	0.11	0.06	0.006	0	**0.03**
May	0	0.01	0.02	0.34	0.29	0.003	0	**0.09**
Jun	0.02	0.03	0.06	0.61	0.51	0.04	0.01	**0.18**
Jul	0	0.004	0.04	0.40	0.39	0.07	0.01	**0.13**
Aug	0	0.02	0.02	0.45	0.43	0.07	0	**0.14**
Sep	0	0.02	0.03	0.53	0.55	0	0	**0.16**
Oct	0.02	0.02	0.02	0.42	0.35	0.09	0.04	**0.14**
Nov	0.07	0.008	0.04	0.30	0.24	0.07	0	**0.10**
Dec	0.05	0.02	0.01	0.18	0.13	0.07	0	**0.06**
Average	**0.02**	**0.01**	**0.02**	**0.29**	**0.26**	**0.04**	**0.005**	**0.09**

The analyses in*Table 4* and Table 2 for the probabilities of water supply deficits at all long-term rainfall stations in SI for all months of the year, and for all consecutive three months of the yeardemonstrate that Henderson-Honiara region have between 7 times (monthly rainfall) and 35 times (3 monthly rainfall) the risk of water supply failure than the next ranked stations. The period over which problems are most likely to occur are in the May to November, "dry" season to the early "wet" season. Unfortunately, the correlations for forecasting dry season rainfalls from preceding seasonal ENSO Indices are poor (While, 2016b) so we have limited skill at forecasting the occurrence of drier periods during the May to November period.

3.4 Rainfalls over less than one month

The estimations in Sections 2.1to 2.3 clearly show that for RWH systems in SI, rainfall analyses have to be carried out over periods less than a month. Unfortunately daily data was not available to this consultant. The historic number of consecutive days without rainfall at each of the rainfall stations in SI would be a useful start to estimate probabilities of rain tank failure and rain tank capacities and roof areas required. The installation of automatic weather stations (AWS) by NIWA will provide a way of remotely estimating the length of dry periods at selected sites in SI. There is however the potential that some locations in remote outer islands may still be inadequately covered by the AWS network.

The NOAA TRMM and now GPM satellites provide a method of acquiring rainfall data over daily, weekly or monthly periods across the entire SI. This data could be used to monitor hotspot development for rainwater harvesting over daily or weekly intervals. This would allow the timely recognition of developing water deficits across the entire country.

A note of caution must be added here. Comparison with monthly rainfall derived from TRMM and GPM does not correlate exceptionally wellwith recorded rainfall at rainfall stations. Their use then in determining actual rainfall quantities may be limited. A check therefore needs to be made of their ability to track zero and low intensity rainfalls.

3.5 Hot Spots Based on Provincial Water Sources

It has been pointed out that the limited spatial coverage of the existing long-term rainfall stations means that it is not possible to identify all hot spots within the country from analysis of existing rainfall data. It has also been discussed that communities which rely on rainwater harvesting alone or predominantly are especially vulnerable to water shortages (Falkland, 2011). As an alternate method for identifying hotspots, we can use the Census water source data to identify provinces which are potential hot spots based on the percentage of households which rely on household or community RWH. Data, from the 2009 Census, for the percentage of households that rely on household or community rainwater harvesting are ranked in Table 5.

Table 5 Percentage of households (HH) in Provinces of SI relying on HH or community RWH systems for drinking water . Data from 2009 Census (SIG, 2009)

Province	HH tank	Communal Tank	Total RWH
Renell & Bellona	80%	13%	93%
Western	33%	18%	51%
Choiseul	24%	18%	42%
Central	19%	18%	37%
Temotu	10%	24%	34%
Isabel	10%	11%	21%
Malaita	5%	8%	13%
Guadalcanal	5%	7%	12%
Honiara*	10%	1%	11%
Makira	3%	8%	11%

*Honiara City, Honiara peri-urban area included in Guadalcanal

Rennel and Bellona have a very high dependence on RWH, unfortunately no rainfall data was available for Rennel and Bellona for this consultancy. It is fairly safe to say, however, that the high reliance on RWH means that Rennel and Bellona are especially vulnerable to periods of low rainfall. In Western Province, which also has over 50% reliance on RWH, the data inTable 3 and Table 4indicate that in the April to December there is a maximum risk of about one year in 12 that RWH systems will fail. In Choiseul, with 42% reliance on RWH, rainfall data for Taro suggest that the maximum risk is predominately in the October to March periodwith a maximum risk about one year in 8. In Central and Isabel Province risks cannot be assigned due to lack of local long term records. In Temotu Province the maximum risk of failure of rainwater harvesting systems occurs in the June to December with the relatively low maximum risk of failure of about one year in 20.

This analysis based on the reliance of communities on RWH systems indicates that Rennel and Bellona, Western Province and Choiseul are potential hot spots where alternate sources of water should be considered.

3.6 Water Sources in the Henderson-Honiara Region

The Honiara region is the fastest growing region in SI, with large and growing informal settlements. The identification of the Henderson-Honiara-Guadalcanal plain as a “hot spot” is based on the assumption that water supply is only sourced from rainwater harvesting. Fortunately, Honiara has a public, reticulated water supply sourced from both groundwater and surface water sources. These sources, however are not without difficulties. Groundwater extraction is unregulated and largely unprotected and is increasingly vulnerable to pollution from expanding, unsewered, overlying informal settlements. The surface water sources on the other hand are subject to disruption from

traditional land owners seeking compensation and are also at risk of pollution from settlements and from land use (Figure 3, Figure 4 and Figure 5). These make rainwater harvesting an attractive proposition, particularly in informal settlements.

The Guadalcanal plain south-east of Honiara has large groundwater sources fed from higher elevations where there are no rainfall records and recharge rates are mostly unknown. There are also large numbers of unregulated bores there and the groundwater is not legally protected from over use or surface contamination. So, while other currently copious sources exist in the region, their long-term security and safety is a concern.

Figure 3 Informal settlement along the Matanikau River below the Guadalcanal American Memorial

Figure 4 Rubbish dump in Matanikau River, posts on the floodplain show the force of the April 2014 flood which cleared entire informal houses from the floodplain resulting in an estimated 11 fatalities.

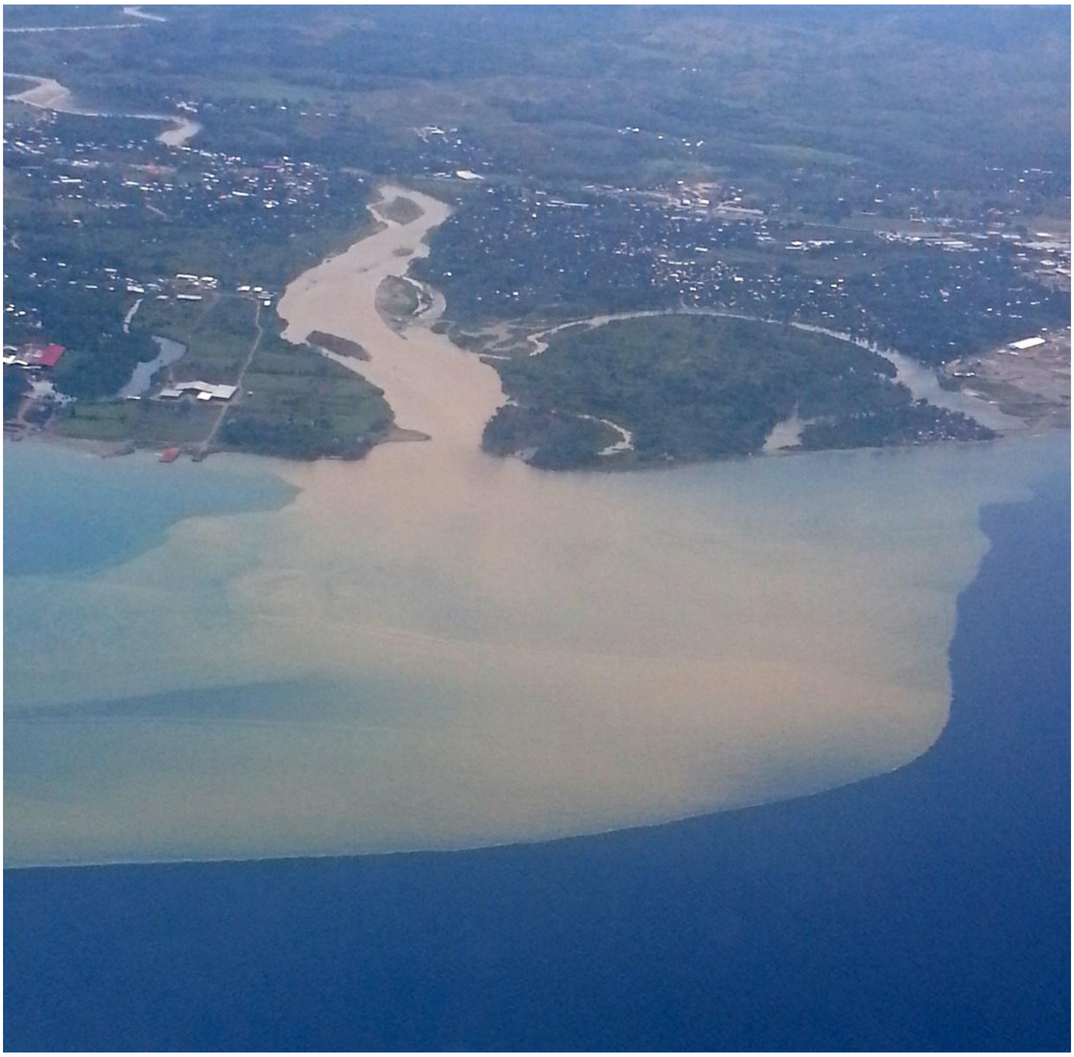

Figure 5 Heavy sediment load generated by land clearing, Lungga River, Guadalcanal

4. Impact of Climate Change

The above probabilities of water shortages and this hotspot analysis have been based on existing, historic rainfall records. A key question is:“what will be the impact of climate change on future rainfalls and droughts”? In their detailed analysis of climate in the Pacific, both at the regional and country level, BoM and CSIRO (2011a, b; 2014) emphasised that current global circulation models (GCMs) do not incorporate realistic descriptions of ENSO events or other major drivers of tropical rainfall in the region. Because of this, projections of future drought frequency and rainfall distributions are uncertain. The general feeling (BoM and CSIRO, 2011a, b; 2014) is that because sea surface temperatures are rising, it is reasonable to expect that rainfalls in island countries in the Pacific should experience increasing rainfalls.

In this analysis, (White, 2016 a, b, c) a detailed examination of trends has been carried out on monthly, three monthly, seasonal and annual data using both linear regression and non-parametric methods (Kendall, 1938; Theil, 1950). The data is noisy, and has, in general, significant gaps, so detecting trends is difficult.Because of this we have set the probability of acceptance of trends as significant at the 90% level for both methods. Only when both methods were significant at this level or higher was the trend accepted.

There were no statistically significant trends found in any monthly rainfalls at Auki, Honiara, Kirakira and Lata. At Henderson, rainfall in October at the end of the dry season has increased at between 23±9 and 26 mm/decade since 1975 and this is significant at the 95% level. An increasing trend in October rainfall in Munda of between 11 and 15±8 mm/decade since 1962 was also found and was significant at the 90% level. Both these trends are consistent with the hypothesis that rising sea surface temperatures will cause increases in rainfall. At Taro Island, however, March rainfalls have decreased by between 32 and 36±15 mm/decade (significant at 95% level) since 1975, perhaps indicating an early withdrawal of the western Pacific monsoon.

For three monthly rainfalls, the only significant trend found in all long-term rainfall stations in SI was at Taro Island for the January to March period where rainfall hasbeen decreasing by between 64±26 mm/decade and 84 mm/decade (both significant at 95% level) since 1975. In report 2 (White, 2016 b) it was found at Taro Island that the rainfall during the whole December to March period had decreased at over 60 and 76±37 mm/decade. There were no significant trends in either “wet” or “dry” season rainfalls or in annual rainfall at any of the long-term rainfall stations in SI.

5. Using the Past to Prepare for the Future

Overall, there is little statistically significant evidence in all the existing long-termmonthly rainfalls records that increasing sea surface temperatures are causing observable, generally increasing rainfalls throughout SI. Because of this the historic rainfall record is the best indicator we have of rainfall variability.Learning to manage through our existing rainfall variability and protecting water quality will surely prepare us to manage better in the future.

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