International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Microbiological Assessment of River Water Quality in Samoa

Patila Amosa[1], Taema Imo[2], Fa'ainu Latū[3], Varea Vaurasi[4]

[1]National University of Samoa, Science Department, PO Box 1622, Apia, Samoa

[2, 3, 4] National University of Samoa, Science Department, PO Box 1622, Apia, Samoa

Abstract: ***The microbiological quality of two rivers in Samoa was examined over eight months to provide some baseline data on the composition of these water resources. Total coliform (TC) and faecal coliform (FC) were quantified using the membrane filtration technique while pH, dissolved oxygen (DO) and biological oxygen demand (BOD_5) were determined using standard methods. Samples were collected monthly from a total of five sites from Gasegase and Loimata o Apaula (LoA) rivers to also identify seasonal and spatial variations of these parameters. All sites exceeded the threshold for TC and FC as stipulated in the Samoa Drinking Water Standards for open waters. DO ranged from 8.21 – 8.29 and 7.92 – 8.85 mg/L for Gasegase and LoA respectively while BOD ranged from 4.28 – 5.61 mg/L for Gasegase and 4.45 – 5.15 mg/L for LoA. There was no significant difference in the spatial distribution of all parameters across the two rivers and between the sites in each river. Dissolved oxygen concentrations were generally higher during the dry season but for pH and BOD_5, concentrations were higher in the wet season along with the concentration of coliform bacteria. However, the seasonal variation was not significant as supported by statistical testing. Bacteria in water could be linked to faecal wastes, decomposition of organic matter in the rivers, weathering and soil runoff into rivers and leaching of untreated wastewater.***

Keywords: surface waters, indicator organisms**,** faecal coliform, pollution, microbiological water quality

1. Introduction

The recent outbreak of water-borne diseases such as diarrhoea and typhoid fever has prompted the need to seriously address the safety of available water for human consumption and domestic activities in Samoa. Communities may rely solely on river water for these purposes or use it to supplement their reticulated supply, especially in regions where water shortage is frequent during the dry season.

The contamination of rivers poses a health risk to communities and is reliant on uses of water and bacterial concentration from point sources [1]. To detect waterborne pathogens at limited cost, indicator bacteria such as Total coliform (TC) and Faecal coliform (FC) are used as proxies for pathogenic bacteria. An alternative indicator organism that can be used is the *Enterococcus* bacterium. *Enteroccoci* bacteria have the advantage of surviving conditions that faecal coliform bacteria cannot tolerate such as extreme light intensity [2]. However, it shares the same disadvantage of originating from multiple sources apart from human faeces [3], [4]. It is recommended to use these three indicator organisms if clear scientific evidence to firmly support one indicator over the others is missing or to select *Enterococci* if funding to assess water quality is limited [2].

The main source of pathogens in water bodies is the faeces of humans and warm-blooded animals which enter the aquatic environments through the release of wastewater effluents [5], surface runoff and soil leaching. The concentration of these pathogens is susceptible to changes

in hydrology, in-stream bacterial stores [6] and land use activities [7]. This is critical in the tropics where climate change is expected to cause prolonged dry periods as well as intense rain events and flooding which can increase soil runoff, sediment transport [8], [9], washing out of faecal matter from latrines into drinking water supplies and subsequent contamination of groundwater and reservoirs [10]. Changes in land use activities [11], [12], rainfall patterns and the behaviour of wildlife and domestic animals [13] will exacerbate the problem by enhancing sediment and bacterial transport into streams [14] during rain events. Rivers and streams are the main sources of water for domestic activities and agriculture and are also vulnerable to pollution from these activities [15].

Water quality also plays a major role in maintaining a balanced ecosystem whereby living organisms and their environment exist in a mutualistic relationship[16].

1.1 Guidelines for Drinking Water Quality

The guidelines for drinking water quality are established mainly to protect public health and are preferred over international standards due to a risk-benefit and preventive management approach of guidelines from catchment to consumer [17]. Samoa established National Drinking Water Standards (SNDWS) for unpiped water supplies but does not clearly distinguish between the various types of open water sources [18].These waters must have pH within the range of 6.5 – 8.5 and must not detect any TC and FC in 100 mL sample [18]. Little information however, is known about whether rivers and streams in Samoa actually meet these standards. Previous research on freshwater springs [19] identified high contamination from coliform bacteria.

Licensed Under Creative Commons Attribution CC BY

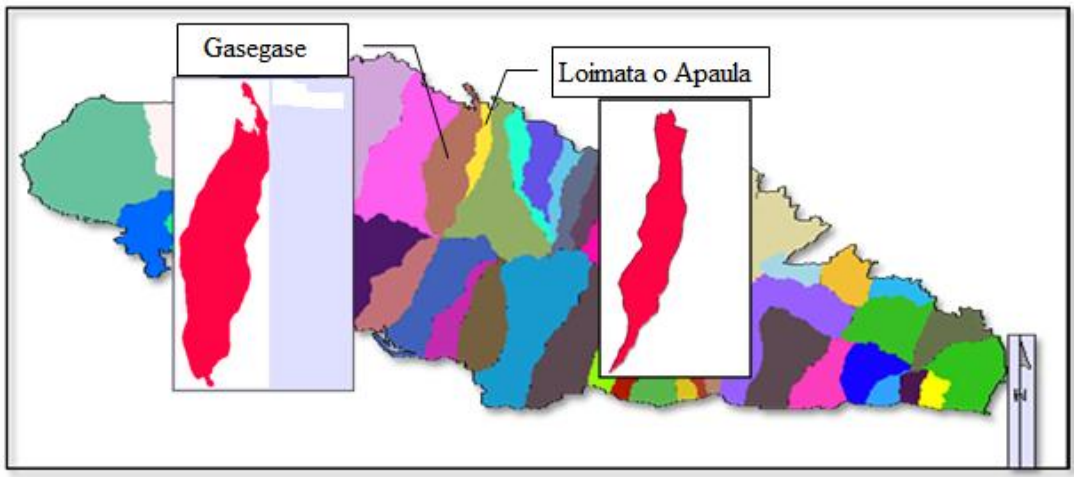

Figure 1: Geographical map of Upolu **Inset:** Mask maps Loimata o Apaula and Gasegase Source: Water Resource Division, Ministry of Natural Resources and Environment (MNRE)

Of particular concern is the fact that the SNDWS does not specify any standards or limits for dissolved oxygen and biochemical oxygen demand in open surface waters. As the guideline values for the SNDWS align closely with the concentration limits published by the World Health Organisation (WHO), the values for these parameters can be compared to the WHO [17] thresholds. The Water Quality Criteria for the South Pacific which also include standards for discharge of sewage effluent [20] stipulate a median FC composition of 35 organisms/100 mL for fresh waters and not more than 6 mg/L for DO.

High biochemical oxygen demand (>50 mg L^{-1}) and low dissolved oxygen (< 4.0 mg L^{-1}) concentrations are indicative of anthropogenic pollution [21]. It is crucial to identify the levels of these indicator chemicals in rivers and streams to assist with the development of conservation and remediation strategies for open surface waters.

The majority of streams in the Tropical Pacific have not been scientifically explored for chemical and microbiological quality compared to streams in the temperate and other tropical regions [22]. Fewer studies conducted in the vicinity of Samoa on the quality of streams [22], [23] have shown only partial compliance to established drinking water standards. For example, of 44 streams analysed in American Samoa [23], only 16% complied with water quality standards for phosphorous. Analysis of freshwater springs commonly used by communities in Samoa showed TC and FC levels way above the recommended national and WHO limits [19].

1.2 Research Objectives

An understanding of the microbiological composition of waterways is crucial, especially in regions which consume untreated tap water and which rely on river water for consumption and various domestic activities. Bacterial contamination can lead to various health impacts and may enter water bodies through surface or soil erosion, waste deposition by animals or as a consequence of increased anthropogenic activities in the vicinity of the rivers. It is imperative to identify and understand the link between human activities, natural process and hydrological functioning and their ultimate impacts on human health as prerequisites for efficient water resources management.

Due to the paucity of research on the quality of streams and rivers in Samoa, this study was conducted to characterise the microbiological properties of Loimata o Apaula (LoA) and Gasegase (G) rivers on Upolu Island, Samoa in terms of the concentration of TC and FC bacteria in water. The research also aimed to identify the potential sources of these parameters and to determine their spatial and temporal distribution in the rivers.

2. Methods

2.1 Study Sites

The study sites are located along LoA and Gasegase rivers on Upolu Island, Samoa (Fig. 1). The LoA watershed runs from an elevation of about 600 m to the coast covering a total area of approximately 630 hectares from ridge to reef [24]. The catchment is bordered by Gasegase Watershed on the west and Vaisigano Watershed on the east. The Gasegase watershed is bordered by Fuluasou Watershed on the east and Loimata o Apaula Watershed on the west, with a total area of approximately 1,200 hectares from ridge to reef [25]. The average annual rainfall for both catchments is 3,000 mm while the average rainfall for the wet and dry seasons is about 3,700 mm and 1,700 mm respectively [24],[25].

Two sampling sites, Malololelei and Moamoa were located along Gasegase river while three sampling sites Vaoala, Vailima and Mulivai were situated along LoA. The lower number of sites for Gasegase river was due to most of the waterway drying up after the second site. The different sites for each river and the time period were selected to determine a monthly, spatial and seasonal distribution of the investigated parameters. Some characteristics of the five sampling sites are summarised in Table 1 below.

Table

1: Characteristics of water sample collection sites

River	*Collection site*	*Coordinates*	*Elevation (m)*	*Site Description*

Licensed Under Creative Commons Attribution CC BY

Gasegase	Malololelei (G1)	S:13.89705 W:171.79311	581	The site was accessed from Cross Island Road and is located approximately 3 km inland from a reserve which was established in partnership with MNRE. The elevation of the reserve with respect to the water source in the valley was approximately 600 m. Access to the water source was by means of a winding hiking trail which is steep (> 45 degrees) in some areas. The area is moderately forested along the track but heavily forested at the base with heavy growth of liana and shrub undergrowth. Water depth is about 15 - 19 cm, fast flowing and with low turbidity.
	Moamoa (G2)	S;13.87052 W:171.78734	91 m	Samples were collected from Moamoa behind Chanel College about 40 meters upstream from access and from where water was flowing through heavily vegetated area with thick bushes. The riverbed consisted mostly of medium and large-sized boulders, fallen decaying trees and with small, slow flowing water. Large amounts of decaying leaves and decaying detritus were present on the riverbed. Water was at times slightly turbid.
Loimata o Apaula	Vaoala (L1)	S:13.88111 W:171.77074	367	Access to the headwaters at L1 was about 1 km from the main road through privately owned land and an 800 - 900 m winding descent through sparse vegetation of mainly vines, small trees (approximately 3 - 3.5 m) and a few tall trees (20+ m). The water source is at the bottom of the descent. The waterway is narrow and slow-flowing through thick undergrowth with water depth of about 12 – 28 cm. The South ridge of the headwater is part of the MNRE Water Resources Division reserve and has higher diversity of tree growth, mainly native species.
	Vailima (L2)	S:13.87573 W:171.77139	260	This water catchment area is about 1.5 km from the main road and about 500 m from an access road to the Live Stock Division of the Ministry of Agriculture. Samples were collected from the water catchment area about 10 meters above the collection basin. The area is heavily forested with thick undergrowth. High content of decaying leaves and tree trunks were seen close to the riverbanks. The stream was fast flowing with low water turbidity. Water depth was usually about 1.8 m at collection point.
	Mulivai (L3)	S:13.83437 W:171.76802	9	Samples were collected from under the crossing into Marist Brother's School at approximately 3 m from the main road. Water depth was about 60 cm, mostly fast-flowing but high turbidity at times. The collection area showed high growth of algae on the riverbed with abundant detritus. Single species of *Tilapia* fish were often present in low numbers. Surrounding vegetation consists of a few Tamaligi (*Falcataria moluccana)* species about 9 m high. The river canal was lined with large boulders presumably to stabalise the river banks.

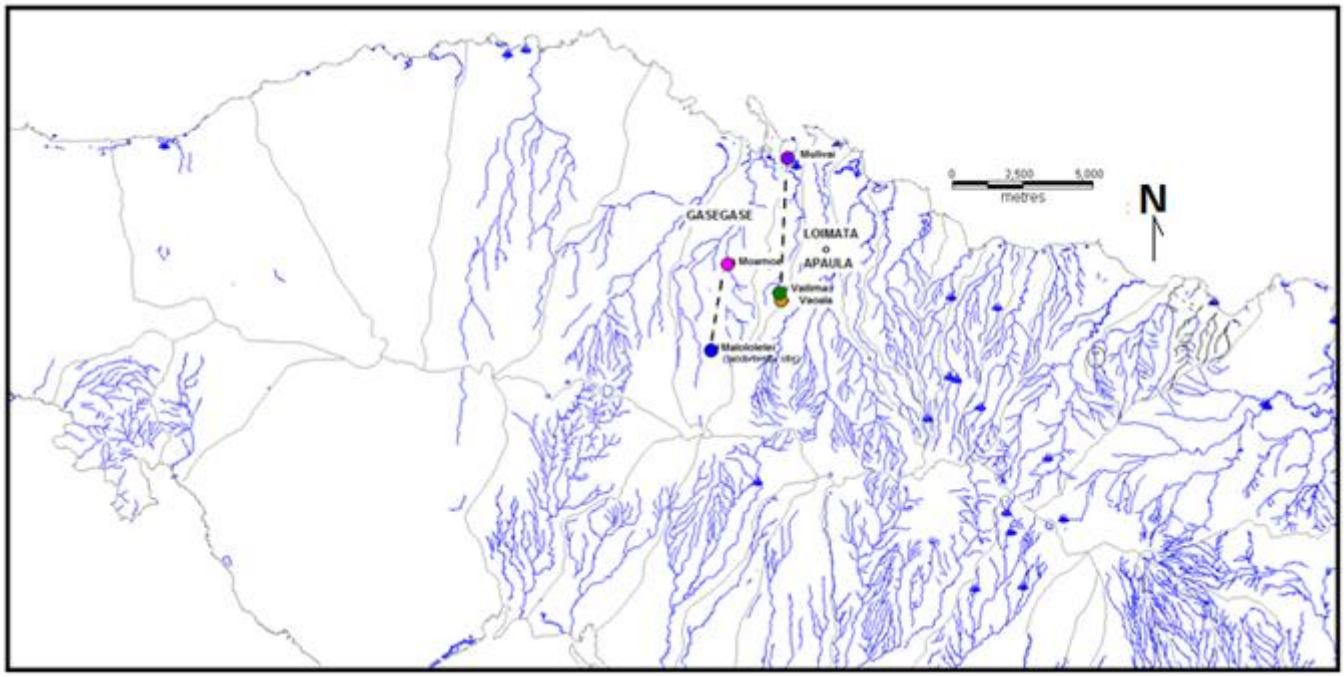

Figure 2: Sample collection sites along Gasegase and Loimata o Apaula rivers Source: Water Resource Division, MNRE

2.2 Sample Collection

Water samples were collected monthly from the five sites from July 2015 to February 2016 (Fig. 2). Six samples were collected at each site in 250 ml and 1 L sterilised Schott bottles at a depth of about 10 cm below the water surface [26]. This sampling strategy was performed to avoid any

Licensed Under Creative Commons Attribution CC BY

contamination from debris and bacteria deposited by wind on the water surface.

2.3 Water Analyses

The pH of water at each site was measured on-site during each sampling event using a hand-held MP-103 pH/ORP/Temperature Meter. The water samples were immediately taken to the National University of Samoa (NUS) laboratory and processed within 5 hours of sampling for DO and BOD concentrations and bacterial composition. The DO and BOD of all water samples were measured using a modified Winkler method [27], [28]. BOD was measured as the difference between the initial DO and 5-day dissolved oxygen content, after incubation of samples in the dark at 20°C and expressed as BOD_5.

The microbiological composition of the water samples was determined using the membrane filtration technique. This procedure shows discrete bacterial colonies that can be visually counted.

Highly contaminated water requires several sample dilutions in order to obtain filter plates with an appropriate range of colonies to validate enumeration [27]. The measurements for July for all sites showed dense bacterial growth of raw samples hence all samples for the subsequent months were serially diluted to 10^{-3} to obtain viable counts of bacterial colonies.

TC and FC bacteria were grown on mEndo LES agar (DIFCO) and mFC agar (DIFCO) respectively [27], [29]. The mFC agar contains selective and differential agents. These include: 1. Rosolic acid, a selective agent added to the agar media during preparation to inhibit bacterial growth except for faecal bacteria; and aniline blue which indicates the ability of FC bacteria to ferment lactose acid, change pH in the growth medium and subsequently produce blue colonies [27]. Both growth media were prepared in accordance with instructions by the manufacturer (DIFCO laboratories), poured into 60 x 14 mm disposable petri dishes then placed in the refrigerator at 4°C [27] until use. All growth media were prepared at least 24 hours before use.

All samples collected over the study period were prepared and processed in an identical manner. For each sample, 100 ml from the 10^{-3} dilution was vacuum filtered through a 0.45 µm nitrocellulose millipore membrane (Millipore). The membrane was then placed on mEndo agar. Another diluted 100 ml sample was also membrane filtered then placed on mFC agar. The mEndo and mFC plates were subsequently incubated at 37°C and 44.5°C respectively for 24 hours [30].

2.4 Data Analyses

The validity of the data and potential relationships between parameters were addressed by conducting statistical analyses on the measured data using the statistics computer software package MINITAB 17. Analysis of variance (ANOVA) was performed to determine whether there was any significant difference in the concentration of chemicals and bacteria between the rivers over the sampling months, between the sites in each river and between the wet and dry seasons. All statistical tests were performed with a confidence level of 95%. Potential source of contaminants were identified via a survey of the immediate surroundings of the rivers and the land use maps of the river locations.

3. Results

3.1 Monthly Variations

All parameters were detected in the water samples. The characteristics of each parameter are detailed in the next sections.

3.1.1 pH

The monthly variations for pH are depicted in Fig. 3 below. The pH for all sites fluctuated below and above neutral pH of 7.0 with generally sharp increases during September and lowest declines during October. The range of pH measured at G1, G2, L1 and L2 was similar around 20% while L3 showed the smallest pH range.

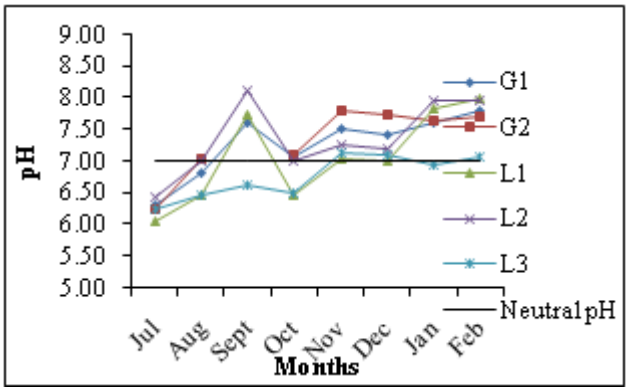

Figure 3: pH of the five study sites over eight months
····· Includes missed data

However, a one-way ANOVA using Tukey's pairwise comparison showed that there was no significant difference between the mean pH of the five sites during 8 months with $p = 0.197$.

3.1.2 Dissolved Oxygen and BOD_5

The levels of DO and BOD of water samples are summarised in Table 2 while the monthly variations are shown in Fig. 4 and 5. No obvious trend was seen in the level of DO over 8 months. The highest DO concentrations were measured in September and November with marked declines in October and December. There was no significant correlation between the sampling months and DO at each site with *p-values* for the correlations being 0.85, 0.74, 0.72, 0.92, 0.77 for G1, G2, L1, L2 and L3 respectively.

The BOD values were generally lower than DO concentrations as expected. In contrast to DO, the highest BOD values were detected in November and the lowest in August. An ANOVA was also performed to determine if the difference in the overall mean DO and BOD for each site was significance. The *p-values* in Table 2 show that the 5 means for each parameter were not significantly different amongst the study sites.

Licensed Under Creative Commons Attribution CC BY

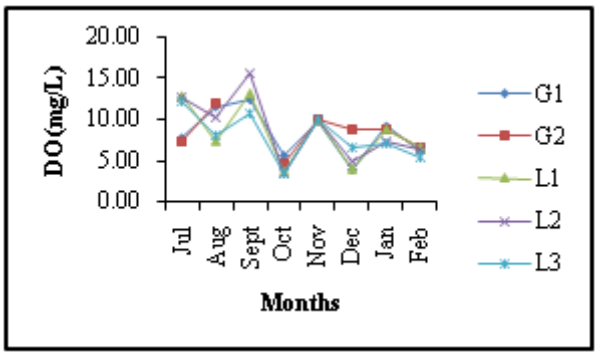

Figure 4: Monthly dissolved oxygen concentration in water

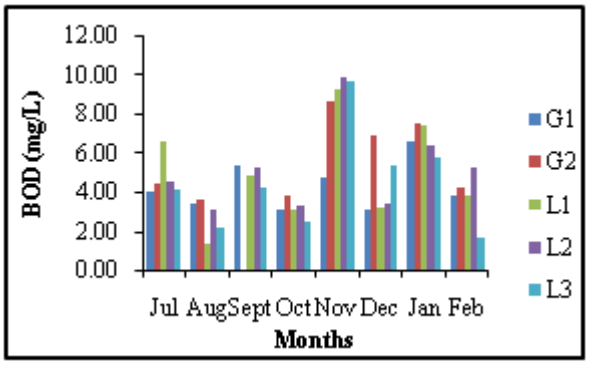

Figure 5: Monthly BOD levels of river water

3.1.3 Total and faecal coliform bacteria

The concentrations of the two bacteria were way above the threshold established in the Samoa National Drinking Water Standards (2008). The mean concentration of total and faecal coliform for the study sites were calculated from counts for

Table 2: DO and BOD of water

Site	n	DO (mg/L)					BOD (mg/L)				
		Mean	Std Dev.	Minimum	Maximum	*p-value*	Mean	Std Dev.	Minimum	Maximum	*p-value*
G1	8	8.29	3.01	3.87	12.47		4.28	1.25	3.10	6.67	
G2	7	8.21	2.41	4.57	11.87		5.61	2.05	3.60	8.67	
L1	8	8.39	3.66	3.67	13.33	*0.97*	4.95	2.62	1.33	9.27	*0.78*
L2	8	8.85	4.04	3.50	15.53		5.15	2.25	3.07	9.90	
L3	8	7.92	2.90	3.40	12.17		4.45	2.62	1.70	9.77	

Table 3: Concentration of Total and Faecal Coliform bacteria in water

Site	n	Total Coliform (x10^3 cfu/100 ml)					Faecal Coliform (x10^3 cfu/100 ml)				
		Mean	Std Dev.	Minimum	Maximum	*p-value*	Mean	Std Dev.	Minimum	Maximum	*p-value*
G1	7	7.52	2.96	1.30	24.00		2.20	8.33	0.04	19.50	
G2	6	66.80	30.06	8.60	201.00		21.40	11.45	10.00	40.00	
L1	7	9.02	1.81	1.87	16.00	*0.14*	4.55	3.20	0.18	9.00	*0.003*
L2	7	39.62	27.07	3.73	201.00		5.67	3.64	1.28	12.00	
L3	7	23.09	7.12	2.30	56.00		22.89	18.56	1.00	50.00	

August - February. The July results could not be enumerated as only raw samples were cultured and growth for all sites were too dense to clearly separate out individual colonies. Hence, all samples from August were serially diluted to 10^{-3} to enable counting of individual colonies. Counts for all sites ranged from a mean concentration of 9.02 – 66.80) x 10^3 cfu/100 ml for total coliform and (2.20 – 22.89) x10^3 cfu/100ml for faecal coliform.

The highest counts of TC were measured for G2 and highest FC counts for G2 and L3. An ANOVA was performed on the data for TC and produced $p = 0.143$ suggesting no significant difference between the mean concentration of the five sites.

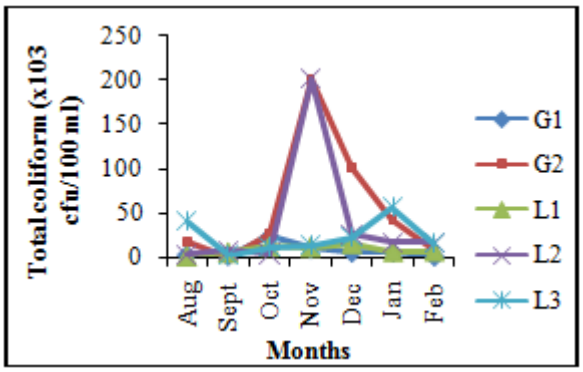

Figure 6: Monthly distribution of Total coliform bacteria

The monthly distribution of TC bacteria showed no consistent pattern except that highest counts were recorded in November with counts in the original samples expected to be well over 20 x 10^4 cfu/100 ml. Similarly, no consistent trend was seen in the monthly distribution of FC

Licensed Under Creative Commons Attribution CC BY

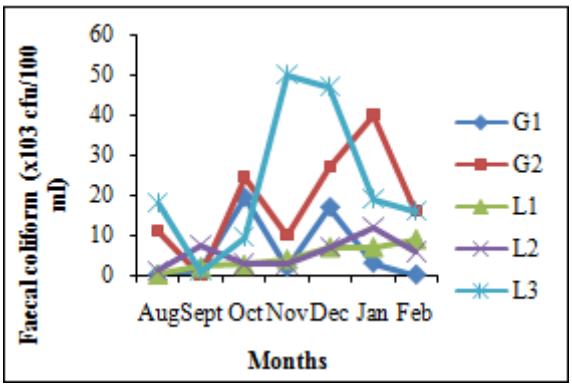

Figure 7: Monthly distribution of Faecal coliform bacteria

Consistent trend was seen in the monthly distribution of FC bacteria. An ANOVA on FC produced $p = 0.001$ showing that at least two of the mean FC concentrations were significantly different. A subsequent Tukey's comparison showed that the mean FC concentration for G2 and L3 were significantly similar but different from the means of G1, L1 and L2 which were similar to each other.

3.2 Seasonal Variations

To identify any seasonal changes in the composition of the two rivers, the study months were categorised into dry and wet seasons with the former season comprising of July – October and the latter one November - February. A correlation test was performed to identify a potential relationship between study site and season. The changes in the mean pH of river water at the five study sites during the wet and dry periods are depicted in Fig. 8.

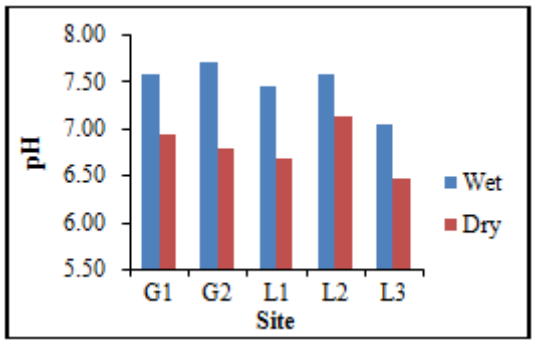

Figure 8: Mean pH of the study sites during the wet and dry seasons

The mean pH at all sites was generally higher during the wet than the dry season. The ANOVA data for individual results for each site to test for any significant variation in the characteristics of river water between the wet and dry seasons is shown in Table 4. A significant difference is evident in pH values between the two seasons for G2 and L3 ($p < 0.05$). The difference between the mean pH for the two seasons was statistically similar for the rest of the sites.

The mean DO concentration (Fig. 9) showed variable trends across the five sites with G1, L1, L2 and L3 having higher levels during the dry season and G2 measuring a slightly higher DO level during the wet season.

Table 4: The *p*-values for an ANOVA test between the wet and dry data for each site. Bold values imply significantly different means between the two seasons.

Sites	pH	DO	BOD	TC	FC
G1	0.064	0.363	0.506	0.559	0.83
G2	**0.011**	0.781	**0.052**	0.353	0.633
L1	0.135	0.495	0.329	0.341	**0.013**
L2	0.313	0.287	0.179	0.314	0.303
L3	**0.001**	0.565	0.213	0.575	0.093

The ANOVA however, shows that the mean DO levels at each site during the wet and dry season was statistically similar (Table 4).

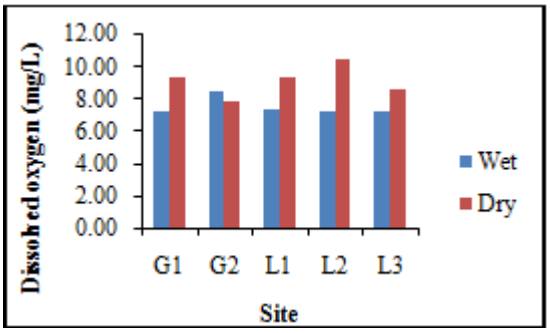

Figure 9: Mean dissolved oxygen concentration in the wet and dry seasons

The mean level of BOD at all sites showed reverse trends to DO with the wet season showing higher concentrations than the dry season (Fig. 10). As indicated in Table 4, the difference between BOD levels in the two seasons was significant only at G2. The wet and dry season concentrations in the rest of the sites were statistically similar ($p > 0.05$).

All water samples were highly contaminated with both TC and FC bacteria having high mean concentrations in the wet season except for G1 where the mean concentration was higher in the dry season. G2 water had the highest mean TC levels in the wet season while L3 had the highest mean FC concentration in the same season (Fig. 11 & 12). Table 4 however shows that the mean concentration of TC and FC for both seasons was statistically similar except for L1 where FC levels were significantly different between the wet and dry seasons ($p < 0.05$).

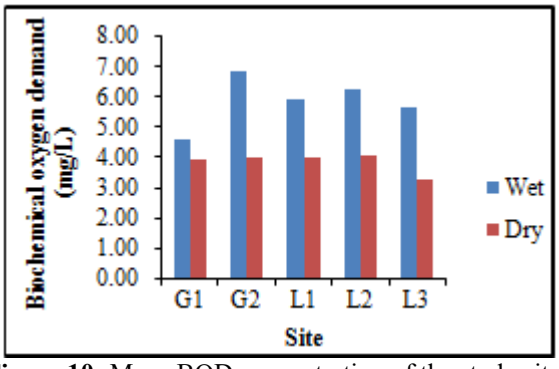

Figure 10: Mean BOD concentration of the study sites during the wet and dry seasons

Licensed Under Creative Commons Attribution CC BY

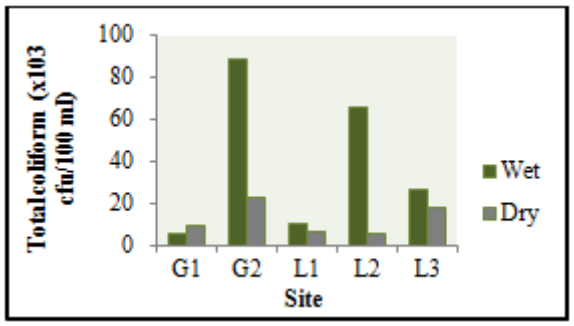

Figure 11: Mean seasonal distribution of Total coliform bacteria in the river sites

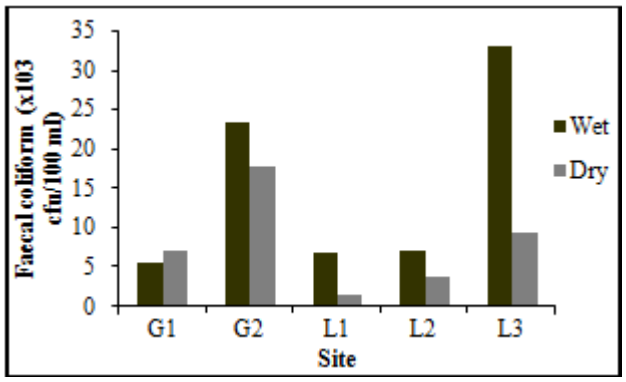

Figure 12: Seasonal distribution of Faecal coliform bacteria in the river sites

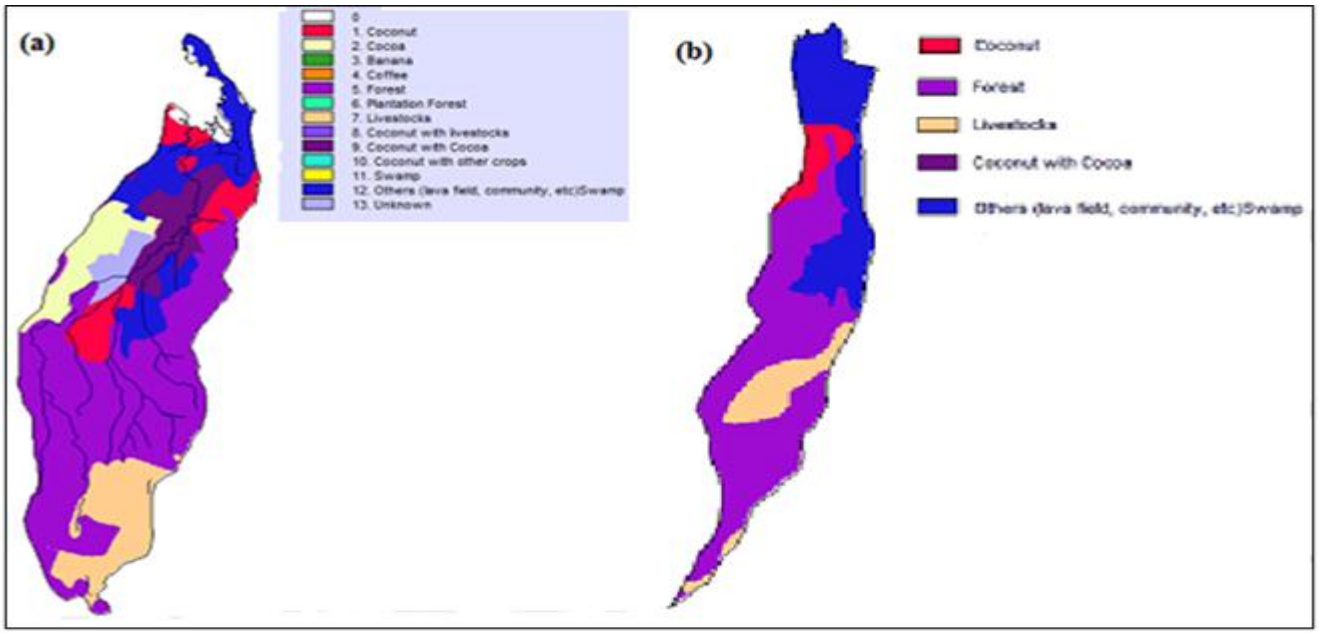

Figure 13: Land use maps of (a) Gasegase and (b) Loimata o Apaula watersheds.
(Source: MNRE Gasegase Water Management Plan 2012 and Loimata o Apaula Water Management Plan 2012)

4. Discussion

4.1 Biological Contamination of Rivers

The detection of total and faecal coliform in the rivers provides strong evidence of pollution in the water from human activities and with faecal contamination originating from humans, ruminants and birds [3]. To identify potential sources of contamination of the study sites, land use maps within the vicinity of the two rivers were collected from the MNRE. The Land use maps of the two watersheds (Fig. 13) show predominantly forested areas and agricultural activities including livestock.

Residential housing located near the sampling sites and leaching of untreated wastewater from latrines into the groundwater system is a potential source of bacterial contamination. The results showed no significant difference in the TC concentration of all sites but a significant difference between the FC levels of Sites G2, L3 and Sites G1, L1, L2. G2 is situated right behind a college with ablutions and a pig sty located near the river banks. Hence, faecal contamination is expected to be higher at this site. L3 is located in the town area and is the recipient of all contaminants and wastes from upstream flow. The level of faecal contamination from residential areas along the river's path and wild life is also expected to accumulate as the waters enter L3 site. G1 was not expected to have any contamination as it is located within a reserve. However, the site is located at the bottom of a cliff and receives upland waters which could be flowing through heavily livestocked areas.

Table 5: Comparison of the study findings to SNDWS and WHO guidelines. (- means a value is not stated)

Water Parameter	unit	SNDWS	SPREP	WHO	This study
pH	no unit	6.5 – 8.5	6.5 – 9.0	6.5 – 8.5	G: 7.08-7.26 L: 6.76-7.37
DO	mg/L	-	6.0	-	G: 8.21 – 8.29 L: 7.92 – 8.85
BOD_5	mg/L	-	-	-	G: 4.28 – 5.61 L: 4.45 – 5.15
Total coliform	cfu/100 ml	0	150/100 mL[1]	0	G:(7.52 –(6.80)x10^3 L:(9.02 – 39.62)x10^3
Faecal coliform	cfu/100 ml	0	35/100 mL[1]	0	G:(2.20–21.40)x10^3 L:(4.55 – 22.89)x10^3

[1]Unit=number of faecal organisms/100 mL

Licensed Under Creative Commons Attribution CC BY

The detection of BOD_5 at concentrations above the maximum permitted by law and DO concentrations at levels below the minimum required by law, intensifies the evidence that there is strong pollution in the river waters coming from domestic and industrial sewage, animal excreta, and fertilizer use without proper treatment [5]. DO is an indicator of bacterial contamination as dissolved oxygen is used in the breakdown of organic matter by bacteria. The trend for faecal contamination matches that for DO with both G2 and L3 having the lowest DO supporting the higher concentration of FC in these two sites. All five sites however, did not have significantly different mean concentrations of DO.

4.2 Temporal distribution of pH, DO, BOD and bacteria

For the microbiological features of river water, TC and FC were generally higher in the wet than dry season. A possible reason for this trend is that increased rainfall intensity dislodges more soil and bacteria as run off compared with water-logged soils [13]. The higher pH measurements in the wet season could be attributed to more rainfall deposition which dilutes the acidity of water raising pH. Increased runoff and transport of organic matter during rainy periods is expected to require more oxygen for decomposition hence the increase in biochemical oxygen demand. The lower DO values during the wet season is to be expected if bacteria concentrations are high as these use up dissolved oxygen for the breakdown of organic materials.

4.3 Drinking Water Standards

To determine the level of safety of the water bodies for drinking and domestic activities, the levels of the various parameters investigated in this study were compared to Samoa's National Drinking Water Standards [18] and WHO guidelines for drinking water when missing from the former document. This comparison also determines the level of compliance to the SNDWS. The comparison is shown in Table 5.

At all sites, the measured pH complied with the desired range in the SNDWS. No guideline values were stated for DO [17] and BOD_5 as these depend on the conditions of a water body and its surrounding during the time of sampling. The bacterial concentrations at all sites were extraordinarily high. L2 is a water catchment for the supply of piped water and urgently needs further monitoring to eliminate the bacterial composition of water.

5. Conclusion and Recommendations

This research investigated the concentration of various chemicals and bacteria in two river systems to determine the level of contamination, if any, from human activities or natural events. The measurements showed that:

1) The concentration of total and faecal coliform bacteria well exceeded the threshold stipulated in the SDWS for open waters.
2) The levels of dissolved oxygen in the two rivers ranged from 8.21 – 8.29 and 7.92 – 8.85 mg/L for Gasegase and Loimata o Apaula respectively while biological oxygen demand ranged from 4.28 – 5.61 mg/L for Gasegase and 4.45 – 5.15 mg/L for LoA.
3) From a survey of the study sites and analysis of Land Use Maps for the two watersheds, the potential sources of bacteria in water include faecal wastes from humans, livestock and birds, decomposition of organic matter in the rivers, weathering and soil runoff into rivers as well as leaching of untreated wastewater.
4) Generally, there was no significant difference in the spatial distribution of microbes across the two rivers and between the sites in each river. Dissolved oxygen concentrations were generally higher during the dry season but for pH and BOD_5, concentrations were higher in the wet season along with the concentration of coliform bacteria. However, the seasonal variation was not significant as supported by statistical testing.

One of the highly bacteria-contaminated sites (L2) is a catchment which feeds a reticulated system. It is crucial that this site continues to be monitored and its condition evaluated to ensure it is safe not only for human consumption but also for recreational activities downstream. Because one of the sites dried up during one of the sample collection periods and water flow was sometimes very slow and shallow, it is proposed that more sampling be conducted during the wet season to confirm the measurements of this study. Based on these observations, the following recommendations are proposed:

1) That site L2 along Loimata o Apaula catchment be vigilantly monitored to ensure that future levels of microbes comply with the SNDWS.
2) Regular monitoring of all sites through chemical and microbiological analyses and when water level is deeper and flow velocity faster.
3) The SNDWS need to provide further details on accepted values or limits to DO and BOD in open surface waters if future assessment and monitoring of water resources include these parameters. Alternatively, National Environmental Water Quality Guidelines can be established for all water bodies and for a wider range of activities including recreation to avoid using guideline values from multiple sources for comparison.
4) Readily available data are required for good decisions regarding resource management and also in determining how to allocate monitoring and research efforts. Results from the current study can contribute to the development of a national framework for activities to be integrated into current coastal waters monitoring programmes.
5) This research sampled only a few locations along the two rivers. More sites need to be studied to fully achieve a complete profile of each river.

6. Acknowledgement

The authors would like to acknowledge the Water Sector Coordination Unit of the Ministry of Natural Resources and Environment, Samoa for financial assistance which funded this research.

References

[1] Ouattara, N.K., Passerat, J. & Servais, P. (2011). Faecal contamination of water and sediment in the rivers of the

Licensed Under Creative Commons Attribution CC BY

Scheldt drainage network. Environ Monit Assess, 2011: p. 15.
[2] Noble, R.T., Moore, D. F., Leecaster, M. K., McGee, C. D. &Weisberg, S. B. (2001). Impacts of variuos types of anthropogenic inputs on coastal waters of Southern California: an integrated approach. in Aquatic Sciences Meeting. Albuquerque: ASLO Press.
[3] Kirs, M., Harwood, V. J., Fidler, A. E., Gillespie, P. A., Fyfe, W. R., Blackwood, A. D. & Cornelisen, C. D. (2011). Source tracking faecal contamination in an urbanised and a rural waterway in the Nelson-Tasman region, New Zealand. New Zealand Journal of Marine and Freshwater Research, 45(1): p. 43-58.
[4] Layton, B.A., Walters, S. P., Lam, L. H. & Boehm, A. B. (2010). Enterococcus species distribution among human and animal hosts using multiplex PCR. Journal of Applied Microbiology, 109(2): p. 539-547.
[5] Dalla Vecchia, A., Rigotto, C., Staggemeier, R., Soliman, M. C., Gil de Souza, F., Henzel, A., Santos, E.L., do Nascimento, C.A., de Quevedo, D.M., Fleck, J.D., Heinzelmann, L.S., de Matos Almeida, S.E. & Spilki, F.R. (2015). Surface water quality in the Sinos River basin, in Southern Brazil: tracking microbiological contamination and correlation with physicochemical parameters. Environmental Science and Pollution Research, 22(13): p. 9899-9911.
[6] Chu, Y., Salles, C., Tournoud, M.-G., Got, P., Troussellier, M., Rodier, C. & Caro, A. (2011). Faecal bacterial loads during flood events in Northwestern Mediterranean coastal rivers. Journal of Hydrology, 405(3–4): p. 501-511.
[7] Liang, Z., He, Z., Zhou, X., Powell, C.A., Yang, Y., He, L.M. & Stoffella, P.J. (2013). Impact of mixed land-use practices on the microbial water quality in a subtropical coastal watershed. Science of The Total Environment, 449: p. 426-433.
[8] Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S.A., Karl, T.R. & Mearns, L.O. (2000). Climate Extremes: Observations, Modeling, and Impacts. Science, 289(5487): p. 2068-2074.
[9] Fauvel, B., Cauchie, H.-M., Gantzer, C. & Ogorzaly, L. (2016). Contribution of hydrological data to the understanding of the spatio-temporal dynamics of F-specific RNA bacteriophages in river water during rainfall-runoff events. Water Research, 94: p. 328-340.
[10] Wirmvem, M.J., Fantong, W.Y., Wotany, E.R., Ohba, T. & Ayonghe, S.N. (2013). Sources of bacteriological contamination of shallow groundwater and health effects in Ndop plain, Northwest Cameroon. Journal of Environmental Science and Water Resources, 2(4): p. 2.
[11] Viau, E.J., Lee, D. & Boehm, A.B. (2011). Swimmer risk of gastrointestinal illness from exposure to tropical coastal waters impacted by terrestrial dry-weather runoff. Environ Sci Technol, 45(17): p. 7158-65.
[12] Uriarte, M., Yackulic, C.B., Lim, Y. & Arce-Nazario, J.A. (2011). Influence of land use on water quality in a tropical landscape: a multi-scale analysis. Landscape Ecology, 26(8): p. 1151-1164.
[13] Strauch, A.M., Mackenzie, R.A., Bruland, G.L., Tingley, R. & Giardina, C.P. (2014). Climate Change and Land Use Drivers of Fecal Bacteria in Tropical Hawaiian Rivers. Journal of Environmental Quality, 43(4): p. 1475-1483.
[14] Dunkell, D.O., Bruland, G.L., Evensen, C.I. & Walker, M.J. (2011). Effects of Feral Pig (Sus scrofa) Exclusion on Enterococci in Runoff from the Forested Headwaters of a Hawaiian Watershed. Water, Air & Soil Pollution, 221(1): p. 313-326.
[15] Carpenter, S.R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N. & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8(3): p. 559-568.
[16] Ntengwe, F.W. (2006). Pollutant loads and water quality in streams of heavily populated and industrialised towns. Physics and Chemistry of the Earth, Parts A/B/C, 31(15–16): p. 832-839.
[17] World Health Organisation. (2011). Guidelines for Drinking Water Standards. Gutenberg: Malta. p. 564.
[18] Ministry of Health, (2008). Samoa National Drinking Water Standards. MOH: Apia.
[19] Latu, F., Amosa, P., Imo, T. & Taufao, V. (2012). The microbiological survey of potential water borne pathogens in fresh water springs of the selected community located in the Upolu Island, Samoa. International Journal of Environmental Science and Development, 3(2): p. 89-93.
[20] SPREP, (1996). Water Quality Protection Criteria for the South Pacific Including Standards for Discharge of Sewage Effluent.
[21] Yildirim, M., Sen, E. & Külköylüoğlu, O. (2009). Research note: modelling of the water quality of Büyüksu stream, Bolu, Turkey. Water Environment Research, 81(3): p. 325-336.
[22] DiDonato, G.T. (2005). Nitrogen and phosphorus concentrations in tropical Pacific insular streams: historical data from Tutuila, American Samoa. Micronesica, 37(2): p. 235-247.
[23] Bardi, E., Fanolua, S., van Houte-Howes, K., Wade, L.M., Vargo, A.M. & Vargo, D.L. (2007). Stream Water Chemical Parameters for Tutuila Island, American Samoa, in ASCCLGP Tech Rpt 46. p. 17.
[24] Ministry of Natural Resources and Environment, (2012). Gasegase Watershed Management Plan. 2012. MNRE: Apia. p. 42.
[25] Ministry of Natural Resources and Environment, (2012). Loimata o Apaula Watershed Managemaent Plan. MNRE: Apia. p. 38.
[26] Gameson, A.L.H., (1978). Applications of coastal pollution research, 2, Sampling coastal waters for bacteriological, in WRC Technical Report 77. p. 2.
[27] American Public Health Association, (1999). Standard Methods for the Examination of Water and Wastewater 1999, APHA: Washington, D.C.
[28] Delzer, G.C. & McKenzie, S.W. (2003). Five-day biochemical oxygen demand: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, section 7.0, November.
[29] Cox, P., Griffith, M., Angles, M., Deere, D. & Ferguson, C. (2005). Concentrations of pathogens and indicators in animal faeces in the Sydney Watershed. Applied and Environmental Microbiology, 71(10): p. 5929-5934.
[30] Berg, J.D. & Fiksdal, L. (1988). Rapid detection of total and fecal coliforms in water by enzymatic hydrolysis of 4-methylumbelliferone-beta-D-galactoside. Applied and Environmental Microbiology, 54(8): p. 2118-2122.

Licensed Under Creative Commons Attribution CC BY

Author Profile

Patila Amosa received a B.Sc. (Biology/Chemistry) from the Flinders University of South Australia in 1989, M.Sc. in Environmental Science and PhD in Chemistry from the University of Otago in 2007 and 2015 respectively. She is now the Dean of the Faculty of Science at the National University of Samoa.

Taema Imo is an Associate Professor in Environmental Science in the Faculty of Science of the National University of Samoa. Her research is geared towards environmental and marine pollution, management and toxicology. She is a lecturer in the Faculty of Science.

Faainuseiamalie Latū is the Head of the Science Department of the Faculty of Science. He has been intensively involved in various environmental projects with the Ministry of Natural Environment in Samoa and also with regional organization such as SPREP and international universities.

Varea Vaurasi is a final year Postgraduate student in the School of Agriculture of the University of the South Pacific.

Licensed Under Creative Commons Attribution CC BY