

# Microbial contamination survey of environmental Fresh and Saltwater resources of Upolu Island, Samoa

Michael A. Ochsenkühn<sup>1\*</sup>, Cong Fei<sup>1</sup>, Odmaa Bayaara<sup>1</sup>, Emarosa Romeo<sup>2</sup>, Patila M. Amosa<sup>3</sup>, Youssef Idaghdour<sup>1</sup>, Gary Goldstein<sup>4</sup>, Timothy G. Bromage<sup>5</sup> and Shady A. Amin<sup>1</sup>

<sup>1</sup> Program in Biology, Division of Science and Mathematics, New York University Abu Dhabi, PO Box 11 129188, Abu Dhabi, United Arab Emirates (in order: [MAO13@nyu.edu](mailto:MAO13@nyu.edu), [cf2290@nyu.edu](mailto:cf2290@nyu.edu), [ob733@nyu.edu](mailto:ob733@nyu.edu), [yi3@nyu.edu](mailto:yi3@nyu.edu), [samin@nyu.edu](mailto:samin@nyu.edu))

<sup>2</sup> Hydrology Division, Ministry of Natural Resources and Environment, Level 3, Tui Atua Tupua Tamasese 13 Efi Building (TATTE), Sogi., P.O. Private Bag, Apia, Samoa ([emarosa.romeo@mnre.gov.ws](mailto:emarosa.romeo@mnre.gov.ws))

<sup>3</sup> Faculty of Science, National University of Samoa, PO Box 1622, Apia, Samoa ([p.amosa@nus.edu.ws](mailto:p.amosa@nus.edu.ws))

<sup>4</sup> Department of Prosthodontics, New York University College of Dentistry, 345 East 24th Street, New York, 16 NY 10010, USA ([gary.goldstein@nyu.edu](mailto:gary.goldstein@nyu.edu))

<sup>5</sup> Department of Biomaterials, New York University College of Dentistry, 345 East 24th Street, New York, NY 18 10010, USA ([tim.bromage@nyu.edu](mailto:tim.bromage@nyu.edu))

\* Correspondence: [MAO13@nyu.edu](mailto:MAO13@nyu.edu)

**Citation:** Lastname, F.; Lastname, F.; Lastname, F. Title. *Environments* **2021**, *8*, 112.  
<https://doi.org/10.3390/environments8110112>

Academic Editor: Firstname Lastname

Received: date

Accepted: date

Published: 26 October 2021

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Table S1: Sampling sites and physicochemical parameters of Freshwater (FW) samples

Area	Site	Latitude	Longitude	DO <sup>#</sup> in		ORP <sup>&amp;</sup>	Nitrate in mg/L	Chloride in mg/L
				mg/L	pH			
Afulilo	A-Upstream	-13.9664	-171.561	8.06	8.32	79	0.26	28.7
Atua	A-Upstream	-13.9664	-171.561	6.94	7.2	141.6	0.1	6.2
Eva	A-Upstream	-13.8668	-171.63	8.27	7.43	154.8	0.02	4.5
Eva	B-Midstream	-13.9434	-171.54	8.74	7.33	161.4	0.04	4.2
Falefa	A-Upstream	-13.9187	-171.587	7.31	7.23	162.3	0.11	9.5
Falefa	B-Midstream	-13.8956	-171.59	7.54	7.42	142.8	0.03	7.2
Falefa	C- Estuary	-13.8973	-171.586	8.25	7.52	152.3	0.02	3.3
Faleseela	B-Midstream	-13.9295	-171.964	4.41	7.3	191.1	0.17	13.4
Faleseela	A-Upstream	-13.9121	-171.961	3.73	7.51	157.5	0.06	6.1
Faleseela	C-Estuary	-13.9395	-171.975	7.68	7.7	172.2	0.06	6.81
Fatuosofia	C- Estuary	-13.8678	-172.056	7.7	8.04	77.9	0.65	11.3
Gase	C- Estuary	-13.835	-171.778	7.48	6.86	179.1	3.85	830
Gase	B-Midstream	-13.8637	-171.788	6.91	7.41	153.91	0.46	82.05
Gasegase	C- Estuary	-13.835	-171.778	2.11	7.03	165.5	0.05	3.92
Lake Lonoanca	C- Estuary	-13.9076	-171.841	5.67	6.78	179.4	1.01	196.5
Laulii	A-Upstream	-13.8718	-171.714	6.44	7.34	156.56	0.47	84.64
Laulii	A-Upstream	-13.8702	-171.712	7.55	6.91	187.8	0.06	5.7
Lepa	C- Estuary	-14.0406	-171.525	8.64	7.48	160.7	0.06	3.9
Lepa	B-Midstream	-14.0292	-171.527	8.44	7.62	149.3	0.02	5.7
Letogo	A-Upstream	-13.8693	-171.733	8.44	7.66	150.3	0.02	6.7
Letogo	C- Estuary	-13.8523	-171.722	7.92	7.14	163.7	0.02	4.2
Letogo	B-Midstream	-13.8686	-171.719	8.53	7.61	161.5	0.07	3.45
Leu	B-Midstream	-13.8668	-171.687	8.4	7.68	137.1	0.09	12.7
Leu	A-Upstream	-13.8674	-171.687	8.16	7.1	145.8	0.17	3.5
Leu	C- Estuary	-13.8655	-171.686	7.98	7.52	136.8	0.12	28.7
Loa	C- Estuary	-13.8343	-171.768	8.46	8.28	116.3	0.06	24.6
Lona	C- Estuary	-13.9416	-171.541	8.01	7.37	146.1	0.06	4.8
Lona	B-Midstream	-13.9434	-171.54	8.66	7.75	131.4	0.03	3.8
Lona	C- Estuary	-13.9416	-171.541	8.99	7.76	168.4	0.12	11.3
Lona	B-Midstream	-13.9434	-171.54	10.78	7.8	162	0.13	15.7
Lotofaga	B-Midstream	-13.9771	-171.855	7.85	7.59	144.6	0.03	6.1
Lotofaga	C-Estuary	-13.9832	-171.856	8.27	8.04	134.6	0.01	2.18
Lotofaga	A-Upstream	-13.9691	-171.849	8.15	8.22	76.5	0.15	27.6
Lotofaga	C- Estuary	-13.9771	-171.855	8.55	7.6	144.9	0.04	3.1
Muliau	B-Midstream	-13.8615	-171.697	8.59	7.5	185.6	20.8	8500
Namo	B-Midstream	-13.8741	-171.654	6.38	7.36	187.9	0.13	7.6
Nuusuatia	A-Upstream	-13.9616	-171.831	8.06	7.5	162.9	0.03	6.4
Piu	B-Midstream	-14.0078	-171.629	8.41	7.63	141.5	0.02	14.4
Salemoa	C-Estuary	-13.8033	-171.519	8.17	7.19	162.4	0.47	237.8

Solo	B-Midstream	-13.8756	-171.638	7.92	7.03	185.1	0.06	6
Solo	A-Upstream	-13.8833	-171.626	7.06	7.87	168.5	0.1	10.9
Solo	C-Estuary	-13.8745	-171.637	8.38	7.99	114.8	0.18	20.6
Taelefaga	B-Midstream	-13.9516	-171.597	6.08	7.2	148.5	0.11	4.8
Taelefaga	C-Estuary	-13.9426	-171.57	8.14	7.34	149.1	0.04	5
Taelefaga	A-Upstream	-13.9707	-171.562	8.59	7.5	185.6	20.8	8500
Tafitoala	C- Estuary	-13.9426	-171.57	8.47	7.33	126.5	0.11	8.4
Tafitoala	A-Upstream	-13.9334	-171.777	8.46	8.28	116.3	0.06	24.6
Tafitoala	B-Midstream	-13.9786	-171.802	7.47	7.46	135.8	0.11	25.3
Tiavea	B-Midstream	-13.9897	-171.462	8.15	8.22	76.5	0.15	27.6
Tiavea	C-Estuary	-13.9885	-171.472	8.15	8.22	96.5	0.25	127.6
Tiavea	A-Upstream	-13.987	-171.508	8.58	7.57	168.1	0.27	17.45
Togitogiga	B-Midstream	-14.0138	-171.717	8.27	8.04	134.6	0.01	2.18
Tuaefu	C-Estuary	-13.8528	-171.804	8.21	7.69	148.8	0.02	4.5
Vai	C-Estuary	-13.8322	-171.764	7.76	7.55	149.4	1.02	372.32

# DO = Dissolved Oxygen, & ORP = Oxidation Reduction potential

Table S2: Sampling sites and physicochemical parameters of Seawater (SW) samples

Area	Site	Latitude	Longitude	DO# in				
				mg/L	SPC <sup>s</sup>	PSU <sup>*</sup>	pH	ORP <sup>&amp;</sup>
Afega	Inside Lagoon	-13.7737	-171.852	6.34	53.5	35.4	7.93	109
Apolima	Outside Lagoon	-13.8451	-172.089	6.29	53.3	35.25	7.93	135.5
Eva	Inside Lagoon	-13.8702	-171.630	7.71	53.3	35.3	7.93	134.2
Fagalii	Inside Lagoon	-13.8393	-171.739	7.39	53.3	35.2	7.95	108.4
Faleasela	Outside Lagoon	-13.9428	-171.972	6.16	53.9	35.7	7.96	135.3
Faleasiu	Outside Lagoon	-13.7882	-171.935	6.23	53.4	35.3	7.77	176.3
Faleasiu	Inside Lagoon	-13.8022	-171.834	6.29	51.1	33.5	7.9	104.4
Falefa	Inside Lagoon	-13.8877	-171.583	6.96	54.1	35.8	7.95	131.1
Falelatai	Outside Lagoon	-13.9256	-171.014	6.31	52.4	34.6	8	127
Faleolo	Inside Lagoon	-13.8264	-171.032	6.49	53.1	45.1	8	88.2
Fasitootai	Inside Lagoon	-13.8127	-171.980	6.4	53.2	35.2	7.93	160.4
Fuailoloo	Inside Lagoon	-13.8330	-172.041	5.98	53.2	35.4	7.89	138
Lalomanu	Outside Lagoon	-14.0547	-171.455	6.48	51.9	34.3	7.94	132.5
Leauvaa	Outside Lagoon	-13.7680	-171.886	6.48	53.7	35.6	8.01	91
Luatuanuu	Inside Lagoon	-13.8606	-171.690	7.65	52.4	34.7	7.93	111.3
Maninoa	Inside Lagoon	-14.0218	-171.780	6.22	51.9	34.2	7.93	131.1
Manono - Uta	Outside Lagoon	-13.8981	-172.089	6.12	54.3	35.8	7.93	135.7
Matatufu	Outside Lagoon	-14.0500	-171.587	6.75	53.1	35.1	7.96	129.3
Moataa	Outside Lagoon	-13.7706	-171.745	6.49	54	35.6	8.03	92
Moataa Off-shore Reef	Outside Lagoon	-13.7638	-171.724	6.36	52.7	34.8	7.9	107.9
Nuusuatia	Outside Lagoon	-13.9953	-171.861	5.66	53.6	35.6	7.85	138.6
Sa'anapu Tai	Outside Lagoon	-14.0092	-171.901	6.19	53.5	35.4	7.85	136.5

Saleapaga	Inside Lagoon	-14.0439	-171.503	7.15	53.9	35.6	8	109.1
Salimu	Inside Lagoon	-13.9364	-171.560	6.96	53.3	35.3	7.96	132.7
Samatau	Outside Lagoon	-13.9099	-172.069	5.9	53.4	35.5	7.85	150.1
Saoluafata	Inside Lagoon	-13.8771	-171.622	8.05	59.7	40	7.84	133.9
Satitoa	Outside Lagoon	-14.0622	-171.408	6.73	53.2	35.3	7.9	141.8
Sauano	Inside Lagoon	-13.9086	-171.560	7.25	53.3	35.3	7.98	128.9
Sauniatu	Inside Lagoon	-13.9237	-171.621	6.77	53.5	35.9	7.93	124.0
Solosolo	Inside Lagoon	-13.8606	-171.642	7.91	53.5	35.4	7.97	108.4
Tafitoala	Inside Lagoon	-14.0124	-171.812	6.22	52.3	34.6	7.88	136.2
Tamaligi	Inside Lagoon	-13.8271	-171.765	6.6	53.4	35.7	7.9	127.9
Tamaligi	Outside Lagoon	-13.7914	-171.760	6.27	54.2	35.9	7.95	164.3
Vavau	Outside Lagoon	-14.0500	-171.554	6.54	52.6	35.1	7.97	139

# DO = Dissolved Oxygen; \$ SPC = Specific Conductivity; \* PSU = Practical Salinity Unit; & ORP = Oxidation Reduction potential

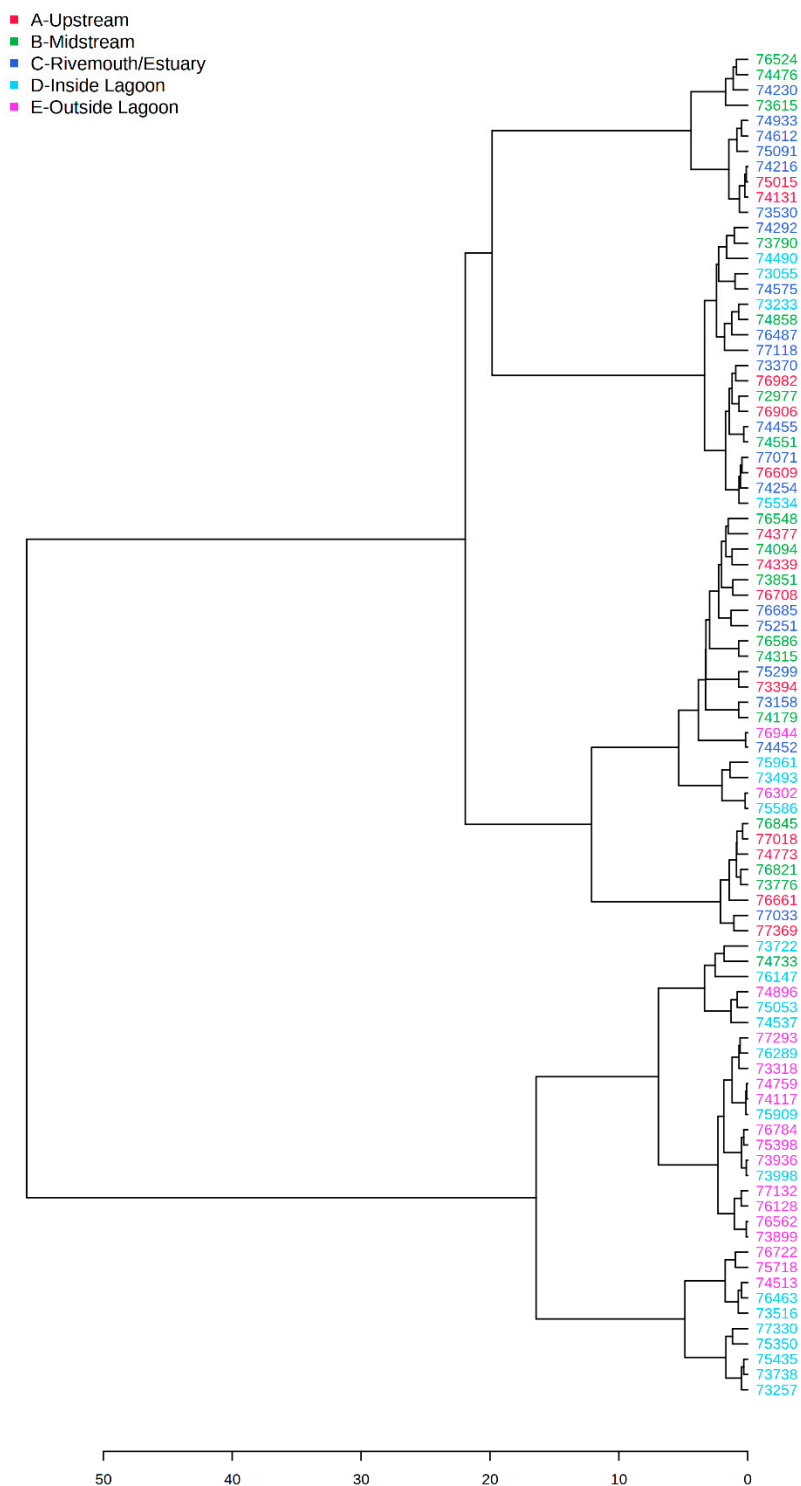


Figure S1: Correlation clustering of samples colored by sampling site (A-Upstream = red, B-Midstream = green, C-Rivemouth = Blue, D-Inside lagoon = cyan, E-Outside lagoon = magenta) using Pearson correlation and Ward clustering algorithm.

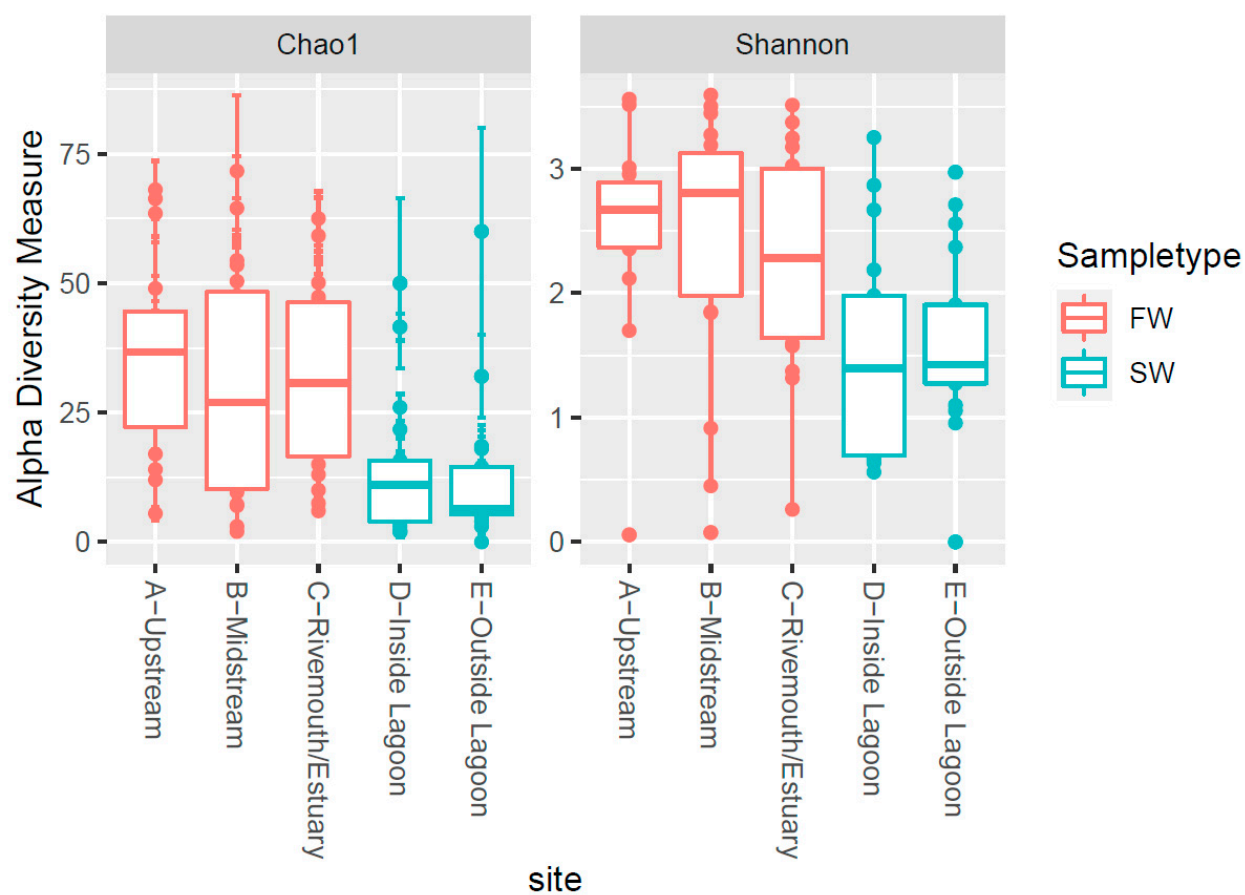


Figure S2: Chao1 and Shannon diversity plots comparing the different sample sites after reducing the bacterial community to harmful bacteria only. Sites are denoted on the x-axis, Sampletypes FW and SW are shown in red and green, respectively. Student's T-test p-values comparing FW to SW samples were  $p_{\text{Chao1}} = 0.009$  and  $p_{\text{Shannon}} = 0.003$ .

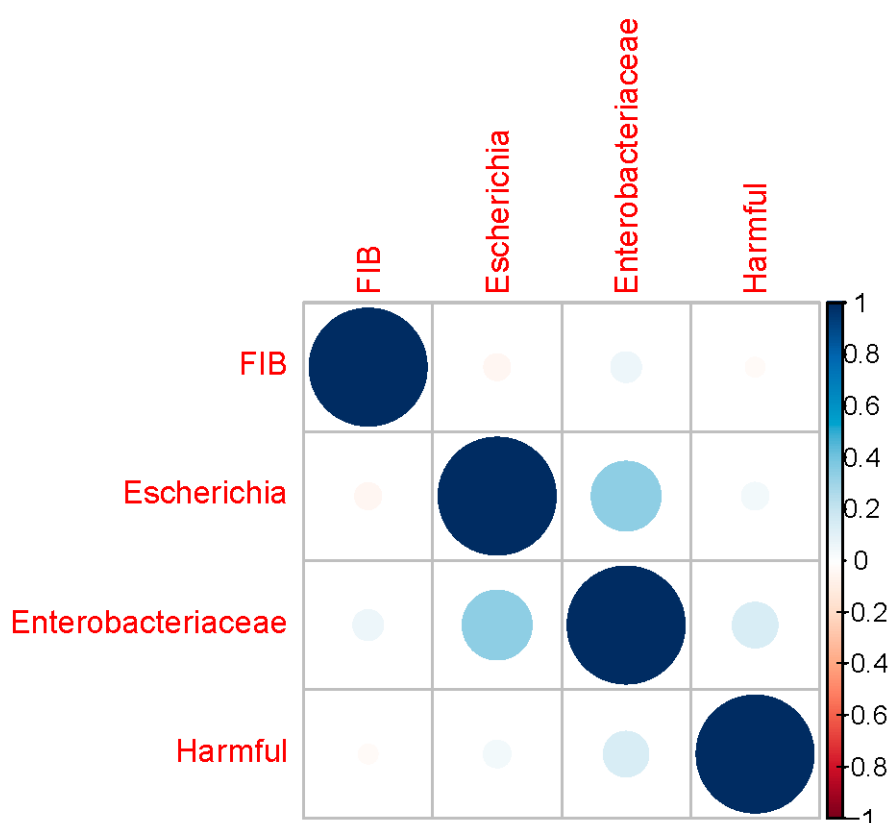
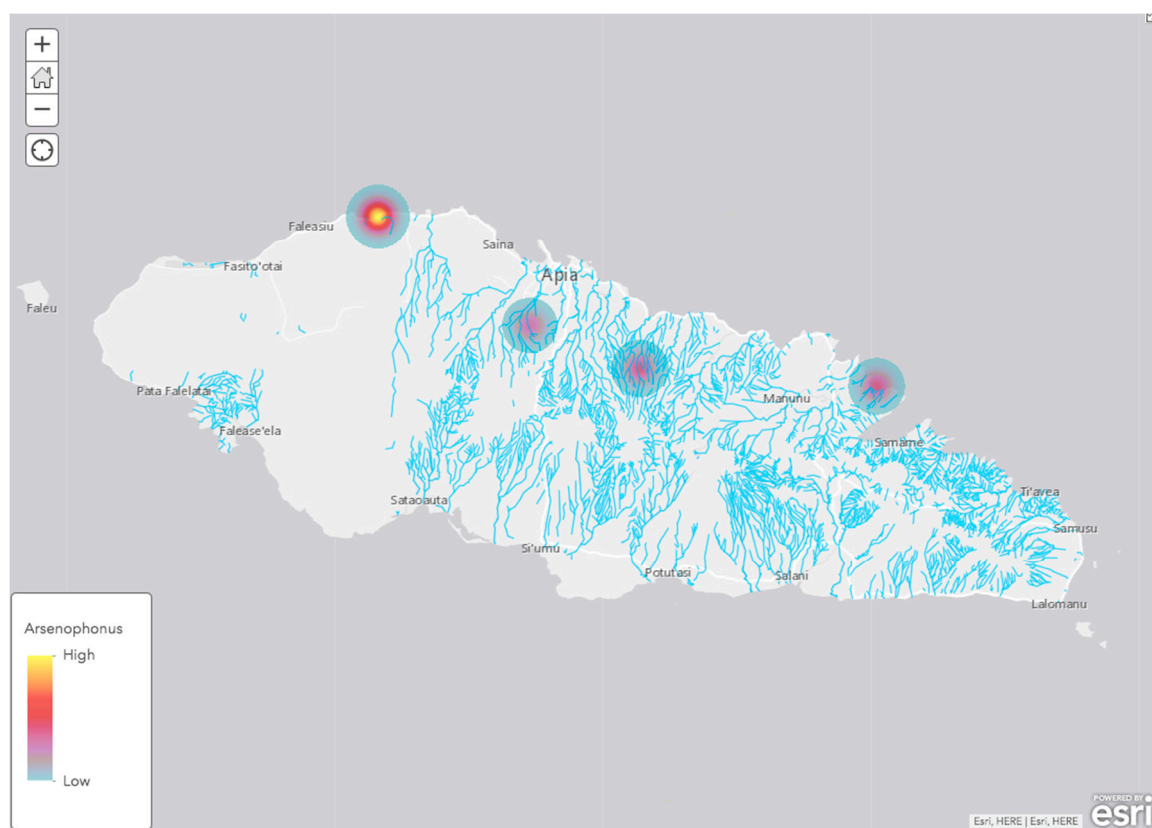
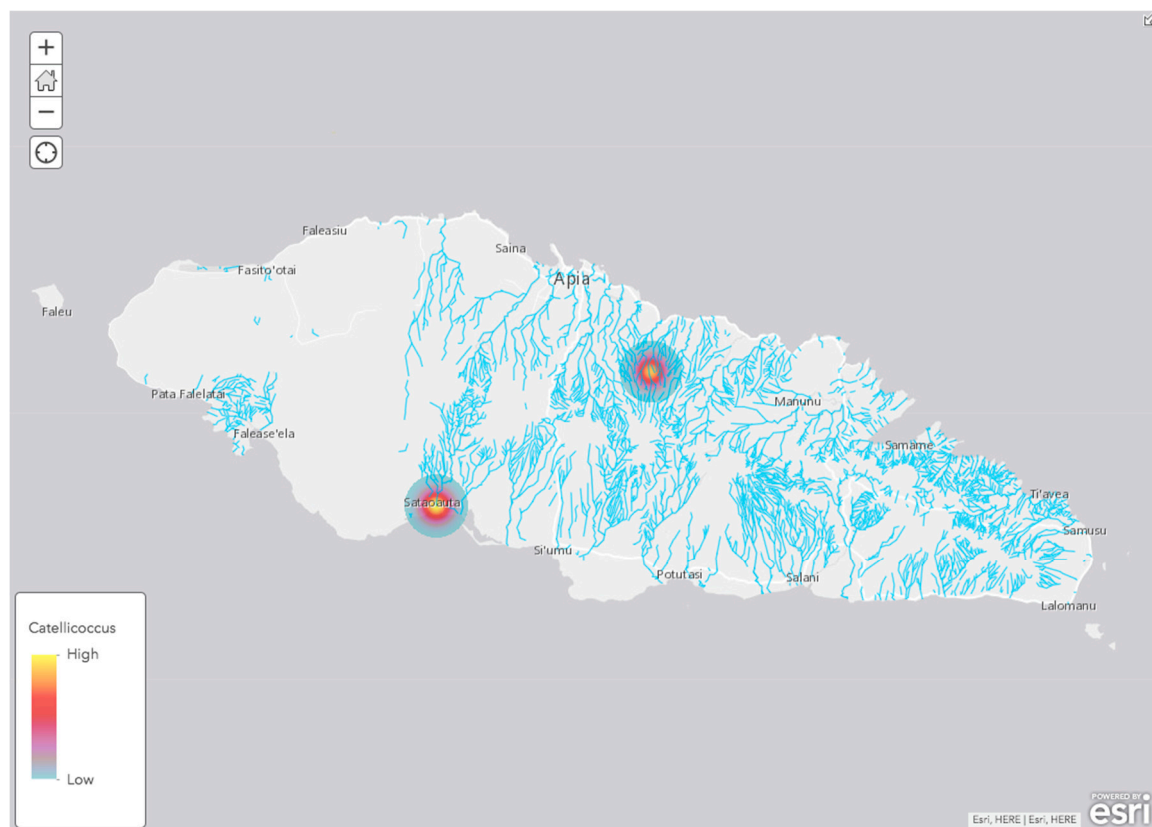


Figure S3: Pearson correlation matrix comparing presence of FIB, *Escherichia spp.*, Enterobacteriaceae family and harmful bacteria at sampling sites. Significant correlation ( $P=0.011$ ) was found between *Escherichia spp.* and Enterobacteriaceae.

A)

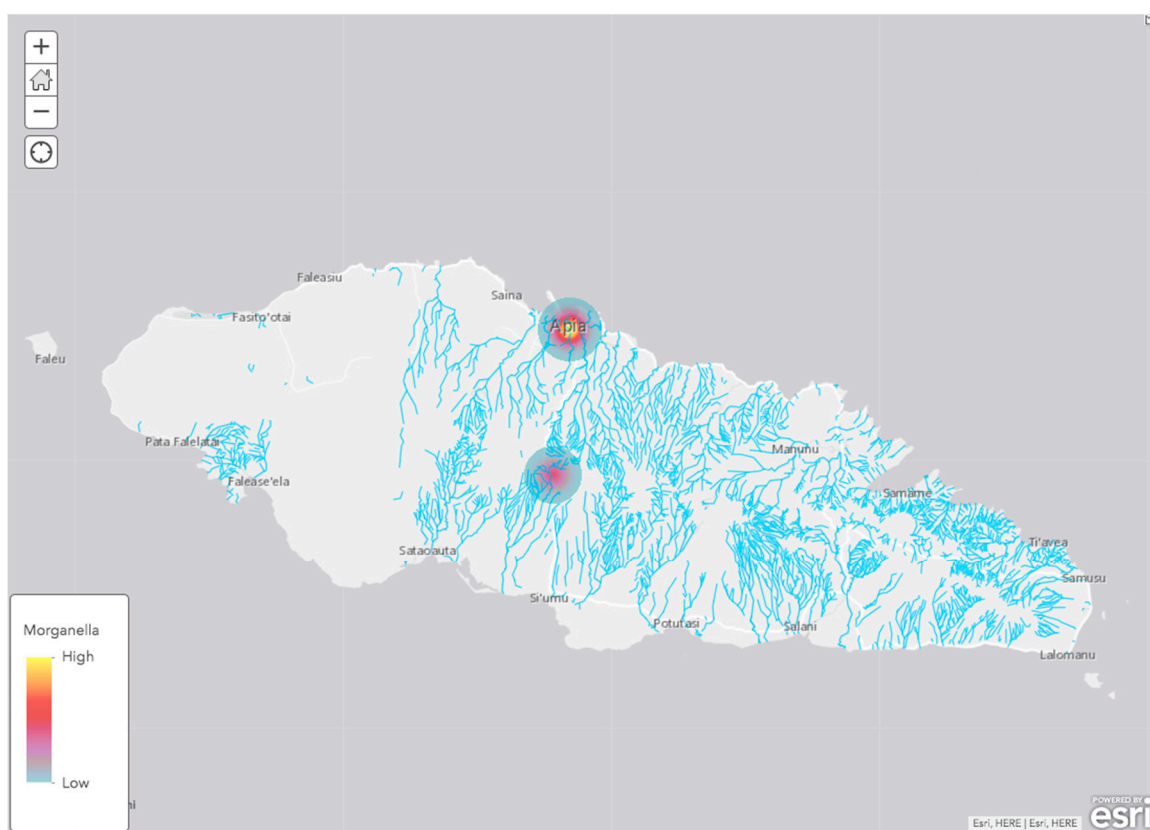


B)

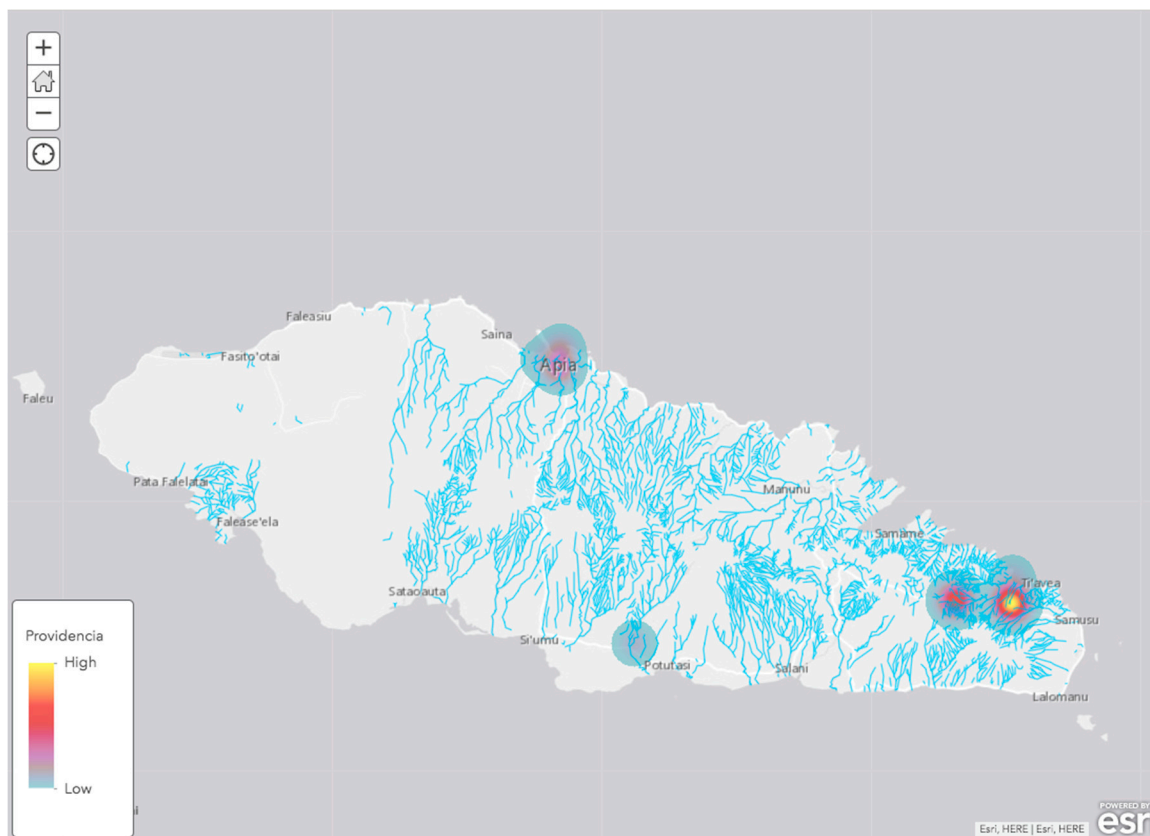


C)

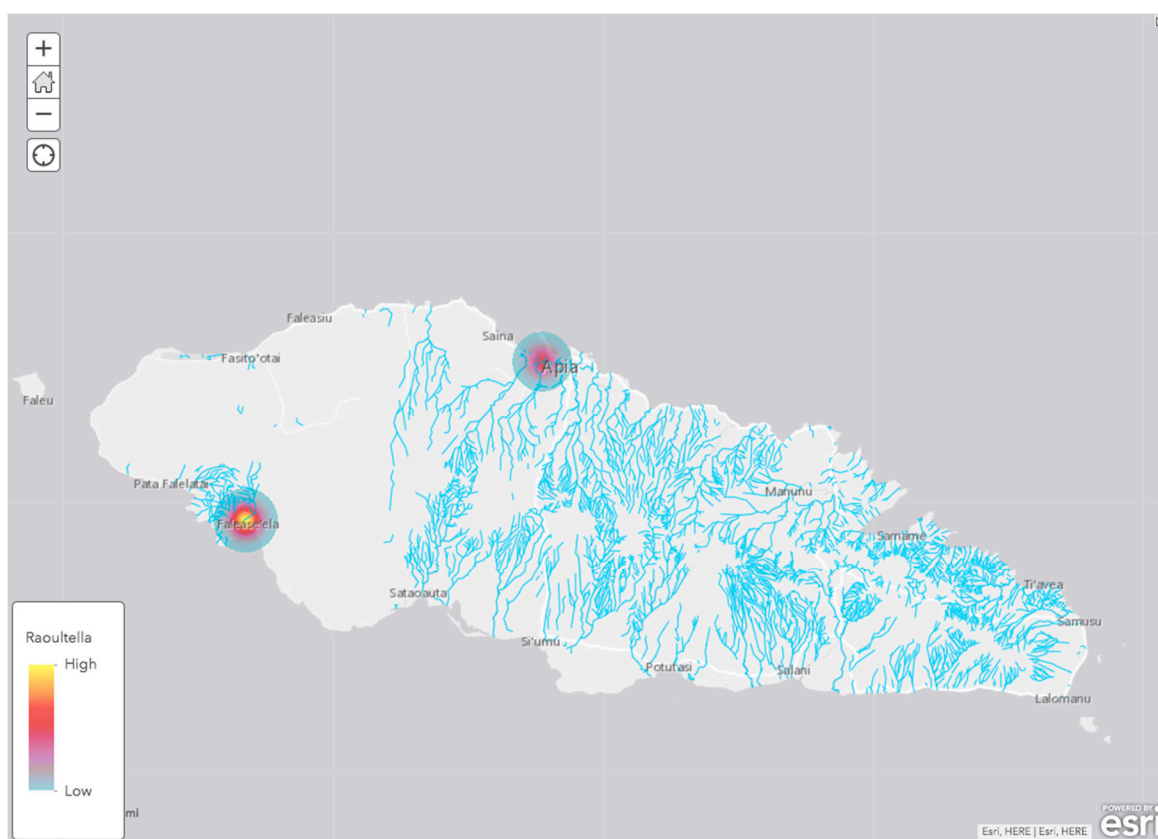




D)



E)



F)

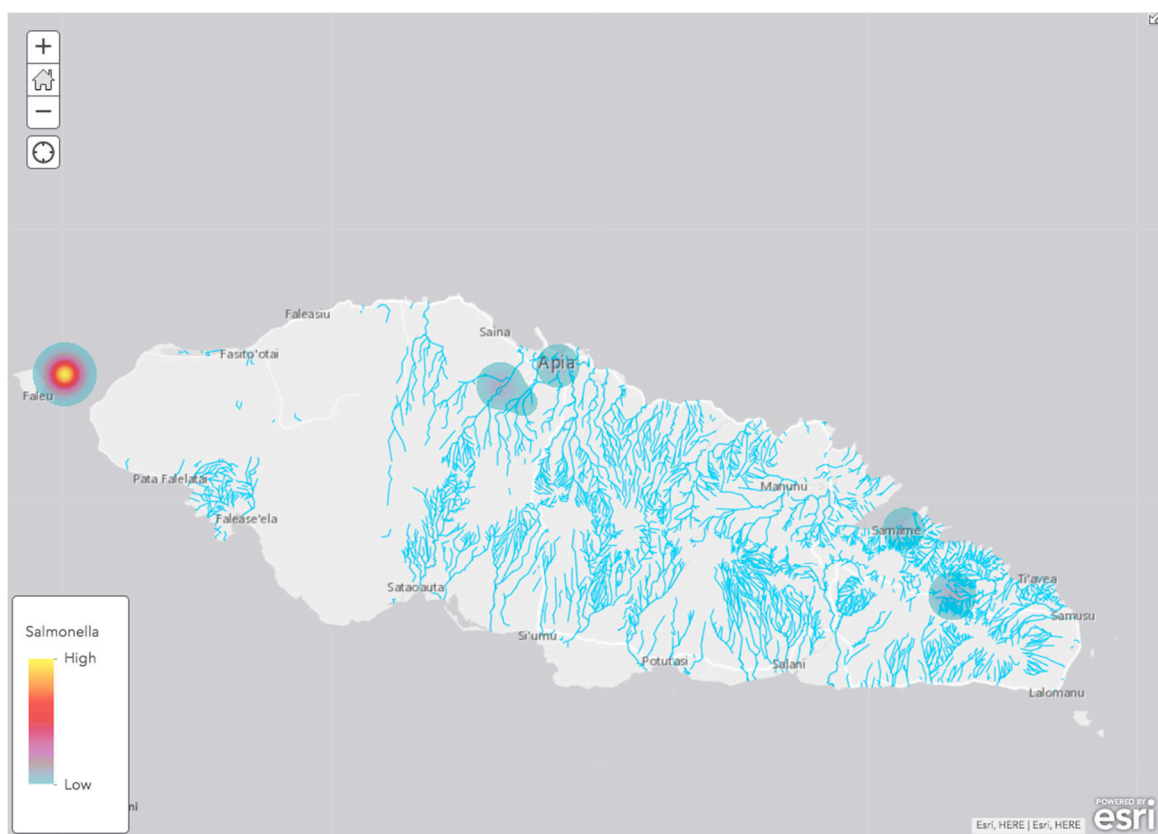


Figure S3: ArcGIS distribution maps with 16S rDNA read abundance in dot size and heat color (blue = low; yellow = high) for human pathogenic genera *Arsenophonus* sp. (A), *Catellibacter* sp. (B), *Morganella* sp. (C), and *Providencia* sp. (D), *Raoultella* sp. (E) and *Salmonella* sp. (F).