

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Assessing the impacts of land use patterns on river water quality at
catchment level: *A Case Study of Fuluasou River Catchment in Samoa*

Seumaloisalafai Afelē Faiilagi

A thesis presented in partial fulfillment of the
requirements for the degree

of

Master of Environmental Management

at

the Institute of Agriculture and Environment



Palmerston North, New Zealand

December, 2015

DEDICATION

To my parents

Tuimalatū Tovale Foemua Faiilagi Tuimalatū Vili Sali

& Leāmanaia Tuimalatu T. Faiilagi Sali

Abstract

A sound understanding of the impacts of land use on river water quality and their relationships is fundamental in addressing issues of water pollution at the catchment level. However, while the impacts of land use on water quality, at different scales of operation and management, are well researched in temperate climate region, there is limited information on the impacts of land use on water quality in most developing countries in tropical regions, including the Pacific islands. This study contributes to determining this information gap and qualifying these gaps through scientific evidence, as well as assessing the impacts of land use on river water in the Fuluasou River Catchment (FRC), Samoa. The FRC is one of the sub-catchments (and the largest of four) that drain Samoa's largest watershed basin known as the Apia Catchment Basin (ACB) on the island of Upolu. It covers an area of 45.57 km² dominated by forests on the higher elevation of the upland catchment, by agriculture (through mixed cropping e.g. taro and banana plantations with vegetable gardens) and tree crops plantations in the mid-catchment, and by home gardens with patches of small-scale plantations (taro & banana) around households in the lower catchment. This study investigated the impacts of land use on river water quality response at ten sites across the upper, medium and the lower catchment. The study examined the relationships between various physicochemical (pH, temperature (Temp), turbidity (TUR), conductivity (COND), total dissolved solids (TDS), dissolved oxygen (DO), Nitrate (NO₃⁻), total nitrogen (Total N), and total phosphorus (Total P), and microbiological (E. Coli & Total Coliform) water quality parameters, and four major land use types: agriculture (AG), grassland (GR) (ie. livestock), built-up areas (BUA) and forest (FO) cover in the catchment. A change in land use was estimated by comparing the land use maps created from the years 1999 and 2013. The water quality was sampled and measured every 2 weeks at ten sites over the three months of the dry season from August to October, 2013. The findings showed the mean (\pm sd) concentrations levels of Temp (27 ± 3.521), pH (8.4 ± 0.48), COND (124.2 ± 25.73), TDS (62.1 ± 12.88), DO (8.96 ± 0.558), TUR (1.3 ± 0.557), Total P (0.01 ± 0.0026), Total N (0.24 ± 0.0159), NO₃⁻ (0.01 ± 0.0032), T coli (9923 ± 1782), and E. coli (7431 ± 1347) respectively. The measured parameters were analyzed and compared with the WHO, SNDWS and DWSNZ/ANZECC drinking and aesthetic standards. All parameters were found to have had their total mean concentrations below the permissible standards, with the exception of Total coli and E.coli. Out of 53 water quality parameters that were tested and analyzed, all samples for Total coli and E. coli were significantly higher, and therefore failed to comply with the drinking

(SNDWS: 0/100 mL; WHO & DWSNZ/ANZECC: <1/100 mL) and aesthetic regulatory standards (DWSNZ/ANZECC: <260/100 mL) thus indicating a 100% of non-compliances.

The findings are indicative of high levels of microbiological contamination all across the catchment, which indicated very poor microbial water quality of the Fuluasou River. The Total coli and E. coli were recognized as the two major pollutants in the Fuluasou River. The coefficient of variance (CV) for all the measured parameters have indicated a low variation amongst the measured parameters across the upper, mid and the lower catchment at different sampling stations, except TUR (44.4%), NO_3^- (38.9%) and TSS (37%) with a significant degree of variability compared to other parameters.

The land use change analysis from the years 1999 and 2013 informed 12.7% of forest (FO) had been lost since 1999, with AG lands increasing by 10.8%, GR slightly decreased by 0.50%, and with BUA increasing by 2.40%. The findings demonstrate that FRC is under threat from increasing land clearance for agriculture activities such as mixed cropping (eg. taro and banana plantations), tree crops plantation (eg. coconut), and increasing in BUA to allow expansion for new developments (e.g. settlements) especially on the eastern-upper & mid to lower catchment. The study found a strong positive relationship between the four main land use types and water quality parameters. In the upper catchment where high proportion (%) of FO exists and this was found to be strongly associated with decreasing concentration levels of Temp, pH, COND, TDS, Total N and NO_3^- . This is unlikely the mid-catchment where AG is the dominant land use type and it positively influences pH, Temp, COND, NO_3^- , TDS, Total N, Total P, which are indicative of high intensity in mixed-cropping plantations and possible waste input from increasing agricultural activities and settlements going downstream. This spatial relationship is similar to GR areas used for livestock grazing and cattle farming in the upper and the mid-catchment which is strongly reflected in increase in pH, COD, TDS, NO_3^- , E.coli, Temp, Total N, Total coli, and E.coli. Despite having water quality parameters that are strongly influenced by land use across the catchment, individual effects for each land use type could not be determined due to a multicollinearity issue, as a result of the net effects of land use proportions (%) of sub-catchments delineated upstream. This can be further examined in future studies. Future improvements to the assessment of land use impact, can include water quality monitoring covering the wet seasons (Nov-Apr), as more runoff could possibly discharge higher concentration levels of pollution, instead of only having samples from the dry period.

Acknowledgements

This study could not have been made possible without the support of the many people who have contributed to this research. Firstly, I would like to thank my supervisors, Dr. Ranvir Singh and Mr Mike Tuhoy for their guidance and advice that has made this research possible. To my main supervisor, Dr. Ranvir Singh, I am highly indebted to you for your continuous support through your technical advice and the wealth of knowledge you have shared with me, in order to guide me through the different aspects of the research process and writing. 'Faafetai tele lava'.

I would also like to note my appreciation of Sylvia Hooker and the Massey ISSO team for their continuous support through facilitating a number of administrative and financial requests, to ensure the successful completion of my study, and in particular my field work in Samoa. To my fellow Filipino colleagues, Patrick, Jules, Brian and Alain, this journey at Massey has engraved everlasting, and your brotherhood to stay true and united in our commitment has paid off. 'Maraming salamat po'. Thank you so much for all that we have shared whilst encouraging each other to do our best.

Acknowledgement is also made to the Government of New Zealand, through the Commonwealth Scholarship which has made this Masters study program a reality. To the Government of Samoa, through its National Water and Sanitation Sector: the field work would not have been possible without your financial support. Also, I would like to acknowledge the Scientific Research Organization of Samoa (SROS) for allowing me to access their laboratory for chemical and biological analyses, and the technical expertise and support shared by their staff.

To my parents, I could not have done this without your immense support, your endless prayers and your help in countless ways. Thank you so much for instilling in me a faith, a love and a willingness to continue to believe in learning, and your advice stands out in the cloud that paves the path to where I am today. Last, but not least, to my wife Pafuti Miller, my three year old son Iese Caleb and 9 months old Maua Archie. Your moral support, countless prayers and understanding while I was away for study will forever be remembered and etched in my heart. I believe this is a new beginning that will open doors to new opportunities. God bless you all!

Table of Contents

Abstract	ii
Acknowledgements	iv
Table of Contents	v
List of Figures	viii
List of Tables	x
Abbreviations	xi
1. CHAPTER 1. INTRODUCTION	1
1.1 The research context	1
1.2 Aim	3
1.3 Objectives	4
1.4 Water resources challenge and development in Samoa	5
1.5 Thesis Outline	8
2. CHAPTER 2. LITERATURE REVIEW	10
2.1 Introduction	10
2.2 Water issues and challenges in Fuluasou River Catchment	10
2.2.1 Land use developments	10
2.2.2 Water quality challenges	11
2.2.3 Lack of water quality monitoring data	12
2.3 Sources of water pollution	13
2.3.1 Point source pollution	13
2.3.2 Non-point source pollution	14
2.4 Land use relationship with water quality	16
2.5 Approach to land use and water quality relationship	18
2.5.1 Catchment vs sub-catchment approach	19
2.5.2 Statistical Analysis and modelling	20
2.5.3 Geographical Information System (GIS) & Remote sensing	23
3. CHAPTER 3. THE STUDY AREA	25
3.1 Climate Conditions	28
3.2 Geology	29

3.3	Land capability and use.....	31
3.4	Land tenure system	33
3.5	Water resources and the Fuluasou water supply system	35
3.6	Human settlement and administration	36
4.	CHAPTER 4. MATERIALS AND METHODS	39
4.1	Introduction	39
4.2	Selection of field water sampling sites	39
4.2.1	Description of sampling locations	44
4.3	Water quality sampling and analysis	52
4.3.1	Water sample collection	52
4.3.2	Physicochemical water quality analysis (pH, TEMP, COND, TDS, DO)	53
4.3.3	E. coli and Total coliform	53
4.4	Chemical analysis	55
4.4.1	Total Phosphorus (Total P)	55
4.4.2	Total Nitrogen (Total N)	56
4.4.3	Nitrate (NO ₃ ⁻)	57
4.5	River Flow discharge	58
4.6	Land use analysis	59
4.6.1	Land use characterisation & Land use change	59
4.6.2	Delineation of sub-catchment	60
4.7	Statistical Analysis	61
5.	CHAPTER 5. RESULTS AND DISCUSSION	63
5.1	Introduction	63
5.2	Land use characteristics and Land use changes	63
5.3	Catchment delineation and land use distribution	69
5.4	Flow Discharge	72
5.5	Status of river water quality of FRC and its tributaries	75
5.5.1	Concentrations of water quality parameters relative to their benchmark values	75
5.5.2	Spatial variation of water quality parameters among sampling stations	80
5.5.2.1	pH	85
5.5.2.2	Temperature	85

5.5.2.3	Conductivity	86
5.5.2.4	Total dissolved solids	87
5.5.2.5	Dissolved oxygen (DO)	89
5.5.2.6	Turbidity	90
5.5.2.7	Total phosphorous	91
5.5.2.8	Total Nitrogen	92
5.5.2.9	Nitrate	93
5.5.2.10	Total coliform	94
5.5.2.11	Escherichia coli	95
5.6	Statistical analysis	101
5.6.1	Pearson's r correlation among water quality parameters	101
5.6.2	Relationship between land use and water quality	104
5.6.2.1	Forest (%) vs water quality parameters.....	105
5.6.2.2	Agriculture (%) vs water quality parameters	108
5.6.2.3	Grassland (%) vs water quality parameters	111
5.6.2.4	Built-up area (%) vs water quality parameters	114
5.6.2.5	Pearson's correlation among the four main land use type	115
5.6.2.6	Linear mixed effect model (LMEM)	116
6.	CHAPTER 6. Conclusion and recommendation	121
6.1	Limitation of the Study	126
6.2	Recommendations	129
7.	References	132
	Appendix	145

List of Figures

Figure 1.	Location map of FRC indicating locations of water sampling sites	27
Figure 2.	Samoa mean annual rainfall - four years of data.....	29
Figure 3.	Geology map of Fuluasou River catchment	30
Figure 4.	Land capability map of Fuluasou River catchment	32
Figure 5.	Samoa’s total population size since 1902	36
Figure 6.	Population of 20 villages within the boundary of FRC	38
Figure 7.	Clinometer hand-held device	40
Figure 8.	GPS Trimble Juno SB.....	40
Figure 9.	Logs and debris identified in the river channel obstructing river flow	41
Figure 10.	View downstream with example of floating logs in the river path.....	41
Figure 11.	Major land use map of FRC showing locations of the sampling stations	43
Figure 12.	Part of an existing banana plantation right on the slope just above Chinese 1 intake	44
Figure 13.	View upstream from STN2 showing part of a taro plantation adjacent to the stream bank	45
Figure 14.	View downstream from STN3 (measuring section)	45
Figure 15.	View upstream from STN4	46
Figure 16.	SWA water intake downstream from STN4	46
Figure 17.	Low water level at STN5 measuring section (view upstream)	47
Figure 18.	STN6 measuring section (view upstream)	48
Figure 19.	70° steep slope of an abandoned agricultural land on the western side of STN6	48
	(a) & (b). Road track crossing the Fuluasou River in the mid-catchment	48
	just downstream from STN5 & STN	48
Figure 20 (a).	Road track crossing Fuluasou River	49
Figure 20 (b).	Old EPC Hydro dam	49
Figure 21.	View downstream from STN7	49
Figure 22.	View upstream from STN8	50
Figure 23.	View of a family house as an example of how close residential areas are to the edge of the river bank	51
Figure 24.	View upstream from the ford to the location of STN9	51
Figure 25.	View upstream from STN10 with river dried up	52
Figure 26.	Preparation bench with standard equipment used for Total coliform & E. coli determination	54
Figure 27.	Prepared petri dishes ready for incubation	54

Figure 28. Prepared PD incubating at 35°C ± 0.5°C for 22 to 24hours	54
Figure 29. Land use map of FRC showing dominant land use classes, 2013	66
Figure 30. Major land use classification of FRC, 1999	67
Figure 31. Major land use classification of FRC, 2013	68
Figure 32. Map of 10 sub-catchments delineated at each sampling station	69
Figure 33. Proportion (%) of different main land use types within each sub-catchment	70
Figure 34. Monthly average flow for Fuluasou River during sampling period	73
Figure 35. Chinese 1 water intake overlooking upstream	78
Figure 36. Chinese 1 water supply entry point	78
Figure 37. Chinese 2 water intake view from upstream	78
Figure 38. Chinese 2 where river water flows into the intake	78
Figure 39 (i-xi). (i) pH, (ii) Temperature, (iii) Conductivity, (iv) Total Dissolved solids, (v) Dissolved oxygen (vi) Turbidity, (vii) Total Nitrogen, (viii) Total Phosphorus, (ix) Nitrate, (x) Total coli, (xi) E.coli	82
Figure 40. Road drainage as pathway of stormwater from the main road of Tuana'imato into the river	91
Figure 41. One of the families 'Watercress' farm (yellow arrow) for commercial purpose upstream STN2	97
Figure 42. View upstream from Chinese intake No. 2 where STN2 was located	98
Figure 43. A road form & eastern view to the newly built road accessing the SWA water intakes	98
Figure 44. Newly built road to Chinese 1 & Chinese 2 SWA water intakes upstream	99
Figure 45. View of mixed cropping banana and taro plantation in the background uphill from STNs 1 & 2	99
Figure 46. Horse sighted tied by river and owned by the locals and used for transportation	100
Figure 47. Forest (%) against water quality parameters (i-xii)	105
Figure 48. Agriculture (%) against water quality parameters (i-ix)	109
Figure 49. Grassland (%) against water quality parameters (i-xi)	111

List of Tables

Table 1.	Description of land use capability class	31
Table 2.	Population by village and gender for FRC.....	37
Table 3.	Names of water quality sampling sites and river gauging monitoring stations with coordinates	42
Table 4.	Parameters settings for Auto Kjeldahl Unit prior to distillation process	57
Table 5.	Reclassification of dominant landuse types into four main land use	60
Table 6.	Dominant land use in Fuluasou river catchment (FRC), 2013	64
Table 7.	Proportion of land use change in the four main land use types from 1999 to 2013	64
Table 8.	Flow discharge of Fuluasou River across different STNs over three months, 2013	73
Table 9.	Descriptive statistics of total mean concentration of 12 water quality with standard measures	79
Table 10.	Mean concentrations of water quality parameter for every sampling station and flow	81
Table 11.	Standard deviation (Std) of water quality parameter across sampling station	81
Table 12.	Pearson correlation matrix with 'r' and 'p values' of water quality correlation analysis.....	102
Table 13.	Pearson's correlation matrix among the major land use types	114
Table 14.	The summary of output results from the 'linear mixed effects model'	117
Table 15.	Comparison of correlation coefficient of land use consideration in (ha) and (%)	118

Abbreviations

ACB	Apia Catchment Basin
ADB	Asian Development Bank
ANZECC	Australian and New Zealand Guidelines for Fresh and Marine Water Quality
COD	Conductivity
CV	Coefficient of variation
DO	Dissolved Oxygen
DWSNZ	Drinking Water Standard for New Zealand
EPC	Electric Power Corporation
EU	European Union
FAO	Food Agricultural Organisation
FRC	Fulusou River Catchment
FWMP	Fulusou Watershed Management Plan
GPS	Global Positioning System
ISSO	International Student Services Office, Massey University
JR	Name of Water Treatment Plant
LMEM	Linear Mixed-Effect Model
MNRE	Ministry of Natural Resources and Environment
MoH	Ministry of Health
PoAs	Plan of Actions
SNDWS	Samoa National Drinking Water Standards
SOP	Standard Operation Procedures
SPREP	South Pacific Environment Programme
SROS	Scientific Research Organisation of Samoa
STEC	Samoa Trust Estates
SWA	Samoa Water Authority
TDS	Total Dissolved Solids

TUR	Turbidity
TEMP	Temperature
UNDP	United Nation Development Programme
WRD	Water Resource Division, MNRE
WTP	Water Treatment Plant
WHO	World Health Organisation