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

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To my parents

Tuimalatū Tovale Foemua Faiilagi Tuimalatū Vili Saili

& Leāmanaia Tuimalatu T. Faiilagi Saili

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 km^2 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 (NO_3^-), 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 (± 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), NO_3^-(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.

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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	Fuluasou River Catchment
FWMP	Fuluasou 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

CHAPTER 1: INTRODUCTION

"Although we as humans recognize this fact, we disregard it by polluting our rivers, lakes, and oceans. Subsequently, we are slowly but surely harming our planet to the point where organisms are dying at a very alarming rate. In addition to innocent organisms dying off, our drinking water has become greatly affected as is our ability to use water for recreational purposes. In order to ***combat water pollution****, we* ***must understand the problems*** *and* ***become part of the solution****". (Krantz and Kifferstein, 2005)*

1.1 The research context

Concerns over the impacts of land use on river water quality are not only restricted to local and national levels in temperate and tropical regions but they are also found worldwide in both developed and developing countries (European Commission, 2003; Cogueto et al., 2011; Gyawali et al., 2013; Hoegh-Guldberg, 2000; Santhl et al., 2005). These concerns stem from continuous pollution problems relating to sources of water supply for drinking purposes, contact recreation and ecosystem health. Water quality problems are found to be associated mainly with land-based developments in agriculture, the impacts of rapid urbanization encroachment on catchment protection zones and, from other social and economic activities. These adverse effects, as a result of poor land use planning and unsustainable land management practices, tend to adversely impact on catchment areas that protect surface and ground freshwater resources. Degradation to water catchment areas would impair sources of waters supply from streams, rivers and lakes.

Adverse effects of land use on river water quality threatens not only human water uses but their life supporting capacity and the integrity of whole fresh water ecosystems which challenge future management of catchment areas. The adverse effects increasing water pollution have evidently attracted management attention and research interests in both developed and developing countries. This challenge consequently became the focus of research and studies worldwide (Bagalwa et al., 2013; Charles, 2011; Chu et al., 2013; Fisher, 2000; Gyawali et al., 2013; Huang et al., 2013; Kibena et al., 2013; Mattikalli, 1996; Santhl et al., 2005; Seeboonruang, 2012; Shilla et al., 2012; Tong, 2002; Tu, 2011; Zhang et al., 2012).

Krantz and Kifferstein (2005) have argued the importance of understanding water quality problems associated with land use effects, in order that we can be instrumental in helping solve these problems. This reinforces the notion of how critical it is to understand the effects of land-based developments on our rivers and lakes, in order to consider appropriate and sustainable management of these activities. Freshwater quality, however, is significantly affected in both developed and developing countries (European Commission, 2003; Santhl et al., 2005,) including the Small Islands Development States (SIDS) located in the Pacific Region (Hoegh-Guldberg, 2000). The impact of land use on river water quality and the potential relationship that coexists between the two has been studied and well documented, through previous developments in both temperate and cold climate regions. The improved management of water catchment areas and pollution control of rivers, lakes and streams have significantly improved as a result. An example of such improvement in nutrient management has seen a steady decrease in phosphorus in rivers with high level of nutrient in New Zealand Rivers since mid-1990s as a result of improved pasture management in intensively farmed areas (Ministry for the Environment, 2007). However, there is very limited knowledge on land use influence on water quality, from the experience of countries located in tropical climate regions, such as Samoa. Since gaining substantial insight and relative understanding of the negative impacts and detrimental influence of land use activities on water quality, a land use study in Brazil by Cogueto et al. (2011) recommended that this be a priority area of focus for future research and development.

Therefore, this paper affirms that a sound understanding of the impacts of land uses on river water quality, with its associate relationships, is the key component of managing catchment areas for the protection of water resources and ecosystem health in Samoa. This study identifies a lack of baseline research information on the status of river water quality and ecosystem health conditions of rivers in Samoa, and current inconsistencies in the hydrological monitoring datasets that limit our knowledge to understand this critical component for effective management of catchments in Samoa. Unreliable monitoring data is 'only numbers without meaning' that is being applied to a real situation. We cannot continue with 'blind management' not knowing and understanding the cause of the problems. This notion should draw scientific interest for more baseline studies of the current status of river water quality and its nature, in response to the land use composition within catchment areas. Ahearn et al. (2005) have learnt of water quality being linked to the land use of a catchment area. Further research focusing on this linkage could provide better understanding of the nature and potential sources of pollution as a result of the impact of land use on river water quality at the source level.

A change in land use patterns can affect the quality of receiving water bodies. In order to prevent water contamination and pollution at the source level, it is of utmost importance to understand the impacts of land use on water quality and their linkages within the catchment area. The study of water pollution can be best understood at the catchment level (NZ Parliamentary Commissioner for the Environment, 2012). This knowledge can help strengthen catchment management and improve land use planning to manage and mitigate any adverse impacts of freshwater quality and ecosystems health.

1.2 Aim

This study aims to assist in the provision of a platform, as a baseline study to assess the current river water quality conditions of the Fuluasou River Catchment (FRC) in Samoa. The study assesses the river water quality in relation to the spatial land use distribution patterns, and determine how they relate to each other within the catchment. The assessment comprises an analysis of the physicochemical and microbiological river water quality parameters against local and international water quality standards and guidelines; correlation analysis between the selected water quality parameters, including correlation among the major land use types; an assessment of land use change, based on GIS data for years 1999 and 2013; and the catchment's delineation and land use relationship with the river water quality. The assessment intends to generate the essential baseline information needed to develop a better understanding of the existing status of the FRC. In order to be able to achieve the aim of this research, the following research objectives set out to guide the research's operational assessment, in regards to the limitations of the analysis.

1.3 Objectives

The specific objectives of the thesis are to:

i. *determine the current status of the Fuluasou River Catchment through measurement and analysis of the physicochemical and microbiological parameters of the river water, and to compare the results with water quality regulatory standards, in order to identify any major pollutant(s) of concern.*

ii. *determine the spatial variation pattern of water quality responses, relative to the land use distribution pattern across segments of the catchment: the upper, mid and lower parts of the catchment.*

iii. *determine the status of potential correlations amongst physicochemical and microbiological water quality parameters of the Fuluasou River water.*

iv. *determine the potential land use relationship with the river water quality and their degree of association and if possible, to identify any key land use category that may strongly influence water quality in the catchment area.*

v. *determine possible changes in land use development based on the year 1999 and 2013, and construct an updated land use characterisation of the catchment.*

vi. *contribute to knowledge in the field of land use impact and its relationship with river water quality in the catchment.*

1.4 Water resource challenge and development in Samoa

Samoa is a small, tropical island country in the South West Pacific, lying between 13 and 15 degrees south and longitudes 168 and 173 degrees west (GoS, 2013). It has a population of approximately 187,820 people (GoS, 2012) and a total land area of 2,935 km^2. Apart from a closed and indigenous forest, Samoa's predominant land use is agriculture, comprising a common mix of cropping, such as taro and banana and includes coconuts. Present land use distribution patterns and nationwide practices are subsistence farming and commercial plantations, which have been developed using a mixed cropping system of farming. The adverse impacts of some unsustainable agricultural developments on water resources have become increasingly acknowledged.

This situation attracts political attention, due to the importance of the issue, which has currently turned the state's focus onto the development of integrated water resource management and the need for the protection of water catchment areas (Government of Samoa (GoS), 2013). This needed effort is required to ensure the protection of river water quality that supplies potable water to the public or 'the populations' health should not be compromised, and a careful consideration is needed to maintain an environmental flow for the aquatic ecosystem health.

Landuse impacts on water resources became evident in the early 1990s, when traces of chemicals were found in shellfish from Vaiusu, which is a village situated within the boundary of the FRC (GWS, 1993). Moreover, a water quality and biological study report of Apia Sewage Project conducted in 1993, to investigate freshwater contamination, found sewage contamination of natural surface flows reduced freshwater habitats (GWS, 1993). This was viewed as a serious environmental problem with potential high risks and the government at the time therefore considered the urgent need for the protection of these catchment areas. Furthermore, intense deforestation of catchments for taro plantations in the early 90s has caused river water quality decline due to greater runoffs and erosion. As a result, there were reported cases of poor water supply and also frequent shortages of water experienced at the time (GWS, 1993). Thus, the quality of public water supply was a matter of concern for citizens, due to increasing developments over the years that threatened the critical buffer zone of the water catchment areas.

Some of the main water resource challenges during this period were identified as fragmented control and, poor management of the protection of water resources because of poor coordination and limited collaboration amongst the responsible government ministries, where notably portfolios overlapped and subsequent functions were duplicated in relation to control over the usage and protection of water resources. In addition to those water resource challenges, the poor quality of water was identified as one of the emerging key issues.
There was a noted lack of knowledge about the underlying causes of pollution and a limited understanding of water resources problems. A comprehensive understanding and detailed knowledge is necessary to help minimize or mitigate the adverse effects of the degradation of watershed areas, which predominantly occurred due to deforestation and land clearance for agriculture development.

Recognizing the problems that affected Samoa's water resources prompted the government to address the urgent need for improvement using an integrated water resource management approach. These improvements were filtered through government reforms and institutional strengthening initiatives that were undertaken at the time. The protection of water resources and catchment areas was therefore covered as one of the key infrastructural development priorities. Samoa's first National Biodiversity Strategy & Action Plan (NBSAP) was then developed as requirement of Samoa's binding obligations under the Convention on Biological Diversity (CBD), with specific focus on ecosystem management and water resource management. The focus on ecosystem drew specific attention to the need for an extension of watershed protection programmes, to include small community-based catchment areas under village management. This resulted in government focusing on further actions to restore degraded ecosystems, including watershed areas.

The Government of Samoa, in partnership with overseas development programmes, also offered significant assistance towards several projects for water resources management. This assistance included aid from New Zealand, Australia, Germany, Japan, the European Union, the Asia Development Bank (ADB), the Food Agricultural Organisation (FAO), the United Nation Development Programme (UNDP) and the South Pacific Environmental Programme (SPREP) (GWS, 1993). An institutional framework was then introduced for government ministries to manage the water supply and purification of water quality. This resulted in the establishment of the Samoa Water Authority (SWA) in 1993, with the key mandate to manage and ensure a sustained clean water supply for Samoa.

These developments are evidence of a national commitment to the protection and management of water resources from the impact of landuse based activities. This commitment has progressed significantly over the years. However, while management programmes are focusing on addressing water resources related issues, challenges identified over the past years continue to be issues of concern. Official reports throughout the years have prompted remedial actions. A 2011 Benchmarking report for Pacific Water Services (PWS) providers recorded that Samoa only had 35% drinking water quality compliance (PWWA, 2011). This report's recent 2013 publication recorded a slight improvement for Samoa but the country still failed to comply with its 100% water quality requirements (PWWA, 2012). In the category of drinking water quality residual chlorine, Samoa was recorded as still underperforming with 58% despite improvement from the previous year (35%). For microbiology, again Samoa was found to be underperforming with only 70% compliance rate. The Pacific benchmarks for the two categories were 100%. A survey by the Asian Development Bank (ADB) recorded only 50-70% of Samoa residents had access to safe water (Hoegh-Guldberg et al., 2000). A KEW Consult report (2007) stated that the Apia Catchment Basin (of which the Fuluasou Catchment is a major part of) is the largest basin in Samoa known to have been pressured by the rapid rate of economic development and residential encroachment within most watershed critical buffer zone areas. The percentages presented in PWWA (2011) and Hoegh-Guldberg et al. (2000) report have indicated poor water quality of FRC and Samoa is still continuing to face water quality pollution. This was reflected in a recent government publication of the 5th Annual Review Report 2011-2012 which recorded significant non-compliant months for the Samoa Water Authority (SWA) Treatment Plants in the year 2011 to 2012. The report recorded SWA Treatment plants micro compliance with the SNDWS at 33% in September 2011, 7% in October, 27% in November and 0% compliance for the month of December 2011 due to shortage of chlorine for treatment. In January 2012 a slight improvement to 29% was recorded (MNRE,2013).

According to available statistics, it is evident that Samoa has and does continue to experience water contamination and pollution. This is a result of a combination of many negative internal and external factors

Therefore this study, the first of its kind in Samoa expects to generate the essential baseline information required to understand the current conditions of the FRC and their possible sources of pollution within the catchment. By understanding the current conditions, it is hoped that possible solutions will arise from this understanding and be implemented to improve water quality in the country.

1.5 Thesis outline

This thesis is structured into six thematic chapters:

Chapter 1 provides the introduction (research context, aim & objectives) and general background on water resources and development in Samoa.

Chapter 2 subsequently presents a literature review on how landuse impacts on water quality through different scales of operation and management. It reviews existing methodologies, technologies, and approaches used in assessing the impacts of landuse on water quality. The water quality referred to in this thesis is the surface water river source of the FRC.

Chapter 3 provides a detailed description of the study area, with specific reference to the physical, geographical and demographical characteristics of the FRC. This information is crucial, since it provides background information and knowledge on the factors underlying the geological formation of the catchment area, the meteorological conditions, population and current landuse practices within the catchment area.

Chapter 4 describes the methods and procedures undertaken and materials used during the implementation of different stages and components of the research.

Chapter 5 presents and describes the final results of the research analysis, as to the purpose and objectives of the study. This includes land use characteristics and land use changes and mapping, current water quality status and conditions of the river in comparison to specific water quality standards and guidelines, the spatial variation in water quality responses at different sampling sites, and the relationship between land use and water quality parameters.

Chapter 6 draws an overall conclusion in accordance with the aim and objectives set out for this research study to achieve. A number of recommendations for improvement of FRC management and future research developments on land use impact on river water quality in Samoa are also presented.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This review chapter introduces the major issues and challenges facing the current management of the FRC and its river water quality. Central to the review of these challenges are the issues of current land use development in the catchment; the condition of water quality of the Fuluasou River; emerging issues facing proper hydrological data management; and the status of current monitoring activities. Subsequently, there is a review of the main sources of water pollution at the catchment level and how these sources might be responsible for the contamination and pollution of the Fuluasou River. In addition, the review highlights some of the experiences of previous and recent research initiatives around the world that have addressed the main sources of water pollution and how they could be related to the case of the FRC. This is followed by a review of the land use relationship with river water quality and several approach initiatives that have been taken to assess such a relationship. The experiences of using widely adopted technologies in the field of watershed management, such as a geographic information system (GIS) and remote sensing and how they integrate with statistical analysis to improve understanding on water issues, are also reviewed and presented.

2.2 Water issues and challenges in Fuluasou River Catchment

2.2.1 Landuse developments

The current landuse activities of FRC varied from lower to upper catchment based on its landscape capability. Forests dominated most of the upper catchment, agricultural activities such as mixed cropping (eg. Taro, banana, cocoa, coconut) were identified with higher coverage in the mid-catchment while the lower catchment is dominated mainly with urban areas with scattered patches of small-scaled mixed cropping plantation. Field observations of land use practices within the catchment has revealed more areas of mid to upper catchment has been cultivated and there is increased development for agriculture and residential purposes.

The vulnerability of the FRC, as a result of it becoming increasingly developed to allow economic growth and support the subsistence living of the local people, has raised concerns about the current pollution problems facing the FRC. Like other catchments, the FRC has identified multiple issues facing its river water quality, as a result of human and natural hazards.

Increasing land use activities such as agriculture, through mixed cropping and livestock/cattle farming and the establishment of new residential area within the borders of the catchment, threatens the water quality of the Fuluasou River. These developments are currently encroaching on the FRC's critical buffer zones that are important for safeguarding freshwater resources and the river's water quality. The effects of land-based developments in the FRC, by local residents and existing government infrastructures, have both exacerbated the pressures on the FRC: the catchment has often been reported as suffering severe degradation of critical catchment zones, which leads to water quality impairment (KEW Consult, 2000; SOPAC, 2007).

The relative increase in the local population, together with commercial ventures utilising the water supply from the Fuluasou River, has consequently increased water demands. At the same time the decrease of the water level will negatively impact on aquatic plants and animals within the aquatic ecosystem. The adverse impact will increase with unsustainable land use practices in which illegal deforestation of the upper catchment is being observed. This problem is elevated with the establishment of sub-divisions of land along the FRC for new residential area and the extension of agriculture activities, such as cattle grazing and the use of pesticides that further degrade the surface water quality of the FRC (Brown et al., 2011).

2.2.2 Water quality challenges

Poor water quality is one of the main problems facing the FRC, as identified in a recent management plan for the FRC (Fuluasou Watershed Management Plan - FWMP) (MNRE, 2012). Water pollution problems associated with the illegal dumping of solid waste, discharges from cattle effluents, farm wastes and agricultural chemicals from farm lands, have been identified as the major problems among others (MNRE, 2012).

Water quality analysis from the Samoa Water Authority (SWA) untreated water supply intakes (Chinese 1 and 2), which are located in the upper catchment of the Fuluasou River, have indicated concerns over health risks through the presence of pathogens in high level *E. coli* concentrations exceeding the health drinking water standard (i.e. Samoa National Drinking Water Standard 2008 - SNDWS) (MNRE, 2012). Furthermore, an increase in anthropogenic activities, such as agriculture, endangers the natural landscape and the biophysical environment of the catchment, thus causing sedimentation that escalates water quality impairment. For instance, given the steep slopes of the upper catchment topographical characteristics, in the course of heavy rains the landscape is susceptible to serious soil erosion, as a result of forest clearing. This consequently causes water pollution and deterioration of water quality through sedimentation (KEW Consult, 2007).

The Samoa Water Resource Management Act 2008 sets out buffer zone restrictions for cultivation activities to be at least 50 metres away from a river. However, there is no close monitoring by the state, nor has any prosecution case of this nature ever occurred, despite on-going illegal encroachment and rubbish dumping into rivers.

2.2.3 Lack of water quality monitoring data

Cogueto, *et al.* (2011) highlighted the importance of generating scientific base-line information from the experiences of countries in tropical regions. Having these baseline data and information (and what they mean for water quality improvement relative to land use planning and management) would help to better understand how surrounding land use and land use modification can be responsible for degrading water resources. This information can be used to assist with a best management approach and thus improve the operational monitoring of river water quality and the management of catchment areas in Samoa.

Despite current water resource management initiatives for water catchment areas in Samoa, a lack of research-based information and the unreliable nature of collected field data (eg. hydrological and water quality monitoring data) would be a major concern for water quality and river health monitoring and management of catchment areas for Samoa in the future. Inconsistencies of data collection and field monitoring operations have contributed greatly to a lack of knowledge and understanding on the effects of land use and their relationships with water quality. As a result, this situation prevents any firm confirmation of land use impacts on water quality impairment, as previously reported on the catchment area (SOPAC, 2007). To date, a lack of well-coordinated and reliable hydrological and water quality data has limited any advances in water resource analysis, including the status on water quality conditions nationwide. This has subsequently hindered progress towards resolving some of the major issues facing water resources and catchment areas in Samoa (Brown et al., 2011).

2.3 Sources of water pollution

Surface water, such as that in a river, can be contaminated and polluted by a variety of sources. These range from agricultural runoffs as possible sources of nutrients and chemicals; urban areas as a potential source of sewage contamination; mixed pollutants discharge from storm water; and possible chemical discharges from businesses and industries. These potential pollution sources can be classified as point and non-point sources of pollution.

2.3.1 Point source pollution

Point source pollution is referred to as pollution from a known point of discharge, or basically discharges of contaminants that originate from a fixed outlet and can be released into water bodies in man-made pipes or drainage (Gyawali et al., 2013). For instance a mole pipe of known location, which drains waste discharge from cattle farm areas, may be responsible for increasing the nutrients level in a river system that may cause eutrophication river problems. While possible contaminants from a point source can be easily monitored by measuring discharge and pollutant levels (Zhang and Wang, 2012) from an identified discharge point, its impact can be manageable, compared to non-point sources of discharges. The focus over the previous years of research work was to address point source pollution through managing the known point of discharges, such as urban wastewater effluent, as described by Lee et al. (2010) and Perona et al. (1999) which was found to have been successfully under pollution control and management.

There is no existing pollution control and management mechanism from the government in the case of Fuluasou River Catchment to source the origin of discharge into FRC. For example some of the road drainages responsible for draining surface runoffs with possible waste water contamination from around the nearby families and from the major Government sport complex at Tuanaimato, with outlets discharge into Fuluasou River are not treated with any form of pollution control before entering the river system (eg. Road drainages at Tuana'imato and Tuaefu). Household discharge carried by pipes into the Fuluasou River have been identified as being untreated. This should be closely monitored by the State through the Ministry of Natural Resources and Environment. Examples of possible main water pollutants from these point sources such as detergents and fecal contamination which originates from households, animal manure and weedicides for agriculture development are a point of concern. Assessing of Fuluasou River water quality through this study could assist identifying some of these contaminants and their points of origin into the FRC. This will assist greatly in the future identification and management of point source pollution in FRC.

2.3.2 Non-point source pollution

The problems associated with water quality contamination and pollution from a non-point source is that its origin cannot be guaranteed from a singular source, but rather a combination of sources of different natures, which are often difficult to identify at a fixed locality. Generally, they originate from urban and rural runoffs, as a result of urban storm water runoffs from agricultural and anthropogenic activities, which are often described as non-point source discharges. For instance, the nutrients from a nearby cattle farm can be washed into the river by heavy rainfall and they can infiltrate or seep through the layers of soil profile into the underground groundwater aquifers. Furthermore, chemicals, fertilizers and pesticides are potential pollutants from agricultural practices with unknown origin and nature. Some examples of these pollutants include nutrients, sediments, inorganic and organic matters, heavy metals, polycyclic aromatic hydrocarbons, organochlorines and bacteria, which will all eventually enter into waterways and/or water bodies if not treated, thus polluting surface water (Ermens, 2007; Wauchope, 1977). The major concern is that these pollutants, once they enter the river, will continue to flow and accumulate in the river system unless they are otherwise treated. Such treatment is important as non-point source pollution has been demonstrated in many studies as 2001; Li *et. al*., 2009; Zampella *et. al*., 2007).

The early stage of research development focused on the effect of point source of known origin. The management of point source has since been improved and experienced positive results over the years since management of a particular source of pollution (eg. Point source) can be more manageable at its point of discharge. A classic example of such an improvement is the case of New Zealand's nutrients control experience, which saw the improvements in water quality due to effective management that resulted in the subsequent reduction of point-source discharges to its rivers over the past 20 years (MfE, 2004). This improvement further resulted in a considerable reduction of E. coli levels since the 1970s (MfE, 2004).

Nevertheless, the management of non-point sources of pollution became the challenge, since its origin can be diffused from different unknown sources of agricultural practices, which is considered to be an important factor (MfE, 2004) and the major cause of water quality pollution (Gyawali et al., 2013; Ly, 2010). The same problem is experienced in the United States, as stated by Bhuyan *et al*. (2003), where non-point source pollution is an important environmental and water quality management problem. Despite some improvement in management of river water quality over the years, the complex nature of such research, which involves various factors and processes (Santhi, *et al*., 2005), offers this field of study even more challenging consequences at the present time (Arheimer, *et al*., 2004). This challenges further studies of land use relationship with water quality at different scales of operation and management (eg. Catchment scale). The challenge continue as the experiences of a study in a one region would not necessarily be applicable to other regions, since water quality responses vary, due to different environmental conditions and ecosystem characteristics of different geographical representation.

The same challenge is facing the Fuluasou River in Samoa in which non-point source pollution can only be indirectly managed through a water supply system that is sourced from Fuluasou River intakes and treated through a chlorination process in collection tanks prior to supply for public use. Despite treatment to the water supply, this would not provide a long term solution to the source of the problem as the origin of pollution from agriculture and urban development cannot be identified through a single source. Examples of some of the main pollutants of concern include fertilisers, pesticides, runoff of nutrients from cattle farms and agricultural lands and, as well as possible faecal contamination of water source (eg.) bacteria from nearby households. The lack of research-based information to identify possible sources and to understand the nature of landuse impact and its relationship with river water quality has lessened understanding on the control and management options to prevent nonpoint pollution within the FRC. Thus, the case of FRC shall require the strengthening of state law enforcement and appropriate regulatory framework such as bi-laws to enforce at the village community level under the authority of the village council. The combined efforts from the state and key stakeholders including the community would ensure proper future management and control of pollution at non-point sources.

2.4 Land use relationship with water quality

Land use and water quality are somehow inter-related. This inter-relatedness could explain their potential relationship. By definition, land use refers to how land is being used for any form of development (e.g. agricultural, industries, or for the purpose of building in residential areas). Water quality can be defined as water that is suitable (given acceptable conditions) for a given use, for example, human drinking water, stock water and recreational uses (NZ Parliamentary Commissioner for the Environment, 2012). While the definition of water quality is said not to be an objective, depending on the desired use of water, the UNEC (1995) further defined water quality as the physical, chemical and biological characteristics of water that are necessary to sustain water uses. Different water quality parameters are measured and used to assess water quality for different purposes. In order to measure how water can be accepted for different purposes, it must not exceed permissible levels and standards set out by national governments and international organizations such as the WHO. Examples of such standards include E.coli and Total coliform must not be detected in a 100mL of water sample (ie. no/100mL for SNDWS for both drinking and aesthetic standards; <1/100mL for WHO drinking water standards; and <260/100mL for aesthetic standards). Water quality standards and guidelines are set for the sole purpose of protecting water quality for human purposes, contact recreation uses and the ecological health of freshwater ecosystem.

The effects of land use developments affect the water quality of freshwater resources of rivers, lakes and streams. The realisation of the risk involved and the detrimental effects of increasing concentrations of water pollutants, from both known and diffuse sources, marked an early attempt in the 1970s by the European Union to call for action to improve the quality of water resources. Researchers in the United States as part of this water quality improvement initiative were investigating any relationship between non-point sources, land use and the stream nutrients level of watersheds across the United States (Holt, 1771; Omerick, 1976; US EPA, 1974). Their results showed that streams draining from agricultural watersheds obtained higher nutrient concentrations than streams draining from forested watershed areas. Several studies have been conducted, which have considered different factors affecting this relationship. Some of these studies have found that the type and intensity of land use have a strong influence on the receiving water quality (Seeboonruang, 2012; Ribolzi et al., 2011; Tong &Chen, 2002). Different land use types require a different intensity of land development, which could then determine how much it affects and influences the quality of water sources. In the case of agriculture, land use types range from crop cultivation and cattle grazing grasslands, to poultry developments. Several experiences from previous studies have positively concluded on the impact of agriculture, with high deforestation causing soil erosion and contamination to receiving water bodies (Bahar et al., 2008, Tong & Chen, 2002). The study of Ngoye and Machiwa (2004) found that concentrations of nutrients (NO_3-N, NH_4-N, TP) were higher in urban and agricultural areas, as a result of higher inputs of waste into the river system.

Water pollutants and their sources are increasingly being identified and managed, in order to reduce their impact on freshwater quality. Assessing the effects of land use on freshwater quality is found to be quite difficult, due to the complexity in nature of land use effects and their potential relationships with water quality (Landers et al. 2002). Since its early development in 1970s, researchers are continuing to study land use effects and their relationships, to further understand the impacts of land use on water quality in different geographical regions around the world.

Despite agricultural practices appearing to be the main dominant indicator in relation to degraded water quality, the experience is varied amongst the results of studies conducted in different parts of the world. A study by Sliva and Williams (2001) in Canada opposes the theory that agriculture is the main cause of pollution for degrading water quality. The same situation experienced by Wang and Yin (1997) in the United States showed that a negative correlation exists between conductivity and agricultural land use. A similar case with conductivity and total nitrogen in the Han River in South Korea, surprisingly found that agricultural areas have a negative association with these parameters (Chang, 2008). Osborne and Wiley (1988), in their study in the United

States, have found that urbanisation is a major factor controlling soluble reactive phosphorous, compared to agriculture. In regards to urbanisation, the experience of Li et al. (2012), in their study of the Liao River basin in China, recorded high concentrations of TN, NH_4-N, NO_3-N, NO_2-N and TP in urban land, which resulted in high nutrients discharge into the river, thus causing eutrophication problems.

These various experiences show how the effects of landuse practices on water quality can be sometimes misleading, without conducting more research on site-specific locations in different countries and regions around the world. The outcomes and results of a study from a specific country are not necessarily applicable to other countries with their local watershed settings and catchment characteristics with varied climatic conditions. Therefore, the varied results of previous studies may depend on the local topographical characteristics of watershed and catchment areas, soil conditions, types of land use development, and local climatic factors, which could differentiate the experiences of one country and region from others.

Thus, in order to have a clear understanding of such landuse impact and its relationship to water quality, several approaches have been put to test for better management options which hope to eventually assist restoring water quality in affected areas.

2.5 Approaches to assess land use and water quality relationship

The management of land-based pollution involves consideration of the two main sources of pollution: point and non-point sources. The nature underlying these two causes can be very complex with regards to their respective causes. Therefore in order to address such complexities and their nature of pollution, it requires several approaches, rather than having a 'one-fits-all' approach. This has been signaled by Gyawali et al. (2013), who stated that the effects of land use on water quality are complicated, since such assessment involves complex biotic and abiotic interactions, especially in large drainage areas. This section provides a review of several approaches and methods that have been engaged by previous and recent studies, to help understand the underlying factors affecting water quality, by considering the land use composition of water catchment areas and other associated factors. The review would also assist with the identification of an appropriate approach and methodology for this study.

Such approach includes the use of a catchment scale, compared to only a part of the catchment/watershed; statistical analysis and modeling; and the wide use of technologies such as a geographical information system (GIS) and remote sensing (RS), as being well-advanced and useful management tools for water resources and land use management within catchment areas.

2.5.1 Catchment vs sub-catchment approach

Sliva and Williams (2001) studied land use relationship with the river water quality of an Ontario watershed in Canada using two different scales of approach, where one is a 100m buffer zone and the other is a whole catchment approach. The results were compared between the two approaches over three seasons in which catchment landscape characteristics appeared to have a slightly greater influence on water quality than the buffer zone. This can be explained as follows: a large drainage area would have more space for draining more pollutants into water sources, compared to the lesser scale of a 100m buffer zone. However, a recent study in Zimbabwe by Kibena et al. (2013), which focused on the upper catchment/upland area of the Manyame River, found that both rural and urbanized parts of the catchment were responsible for a high degree of pollution (i.e. point and non-point pollution) within the catchment area. Their results indicate that an increase in settlements and agriculture activities had positive impacts on water quality, compared to forested lands. Following these results, a recommendation to consider a combined programme for point and non-point sources has been drawn up, as an outcome of their study. This could be an appropriate approach in the case of the Manyame River, as this catchment area comprises a mix of land use including urbanization and agriculture activities. However, a holistic approach is needed for whole catchment areas, where low land areas could be considered to generate some interesting results, based on how much the lower reaches of the catchment could have impacted on the catchment river quality. This approach would see consideration of a ridge to reef approach that could help to identify problems facing all segments of the catchment, rather than just relying on the impacts on upper catchment areas.

In consideration of water quality linkages to land use composition of a catchment, the variation in water quality response (through measurement of physicochemical characteristics) can provide some insights on the different extents of impact and the nature of association between land use and water quality. The study of Correll et al. (1992) on the Rhode River located in the mid-Atlantic coastal plain of North America examined the effect of land use, by dividing the watershed study area into two sub-watersheds defined by dominant land use. The differences in the results were accounted for in the differences in land use and topography between the two sub-watershed basins. Their results have shown a large seasonal variation was observed on all types of land use, due to differences in evapotranspiration rates. This could be the advantage of considering a more holistic approach, such as a catchment scale or watershed scale, compared to only some portion of the catchment areas, especially in large catchment areas.

More comparisons with different results can be found in a study in the United Kingdom by Muscutt et al. (1993), which considered the use of buffer zones, in search of possible measures to control the pollution of surface waters and to assess the effectiveness of buffer zones application. While the experiences and effects of using buffer zones have been reported as positive, especially when controlling loads of sediment and phosphorus in surface runoff (Muscutt et al., 1993), their study concluded with a recommendation for buffer zone limitation that would require a wider use of buffer zones and additional measures would also be required, in order to maximize its effectiveness on improvement in water quality and pollution control.

2.5.2 Statistical analysis and modelling

The study of the U-Tapao River basin in Thailand by Gyawali et al. (2013), to assess land uses of its riparian zone and how they relate to water quality for sustainable development of the river basin, explored the use of descriptive statistics; analysis of variance (ANOVA) and Pearson's correlation analysis. In addition, stepwise multiple regression analyses and best predictive models were used to further study the relationships among the land use composition within the 100m riparian zone, and to determine the amount of variation between the two variables: land use and water quality. Water quality parameters, such as temperature (TEMP); pH, biological oxygen demand (BOD); dissolved oxygen (DO); electrical conductivity (EC); suspended solid (SS); dissolved solid (DS);

turbidity (TUR); fecal coliform bacteria (FCB); nitrite (NO_2); nitrate (NO_3^-); ammonia (NH_3); and total phosphorous (TP) were selected for the study. For land use indicators, five broad land use categories were classified: agriculture, forest, urban, grass and water body. These were used to link the water quality parameters. With the integration of different statistical methods, the results show that the four land use types have a significant relationship with water quality parameters. The use of regression analysis to predict water quality response to land use modification has been found to be an effective analytical approach. However, despite what seems to be the successful integration of simple but effective statistical methods, other studies excel on using more comprehensive statistical approach, for example, modelling, which has a different perspective on how this relationship should be assessed and determined. This can be viewed as a limitation to the basic statistical approach used by Gyawali et al. (2013).

Considering the use of modelling was one of the effective water quality assessment tools to study land use-water quality relationship. This method dates back to the 1990s, when modelling was first used to predict the impact of land use change on non-regulated streams during extreme events (LeBlanc et al., 1996). Ten years later, the use of modelling is becoming very common and it has improved on many facets of tools operation. The study by Tong and Chen (2002) attempted to use a comprehensive approach to examine the hydrologic effects of land use and their relationship with water quality. Statistical and spatial analyses were employed to help with determining the relationship. As a comprehensive nature type of study, a widely accepted watershed-based water quality assessment tool, known as Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), was adopted to assist the analyses with modelling the plausible effects of land use on water quality (Tong and Chen, 2002). The advantage of using BASINS for modelling in such a study is that it can be easily adapted for use with other watersheds, with little modification. This advantage makes BASINS widely accepted as a watershed-based water quality assessment tool.

The advanced capability of BASINS and its adaptive features can be adopted for the study of Fuluasou River. However, the lack of baseline data as an essential input datasets from previous years of monitoring (eg. Historical data of hydrological monitoring) and the unavailability of a more up to date GIS based-data for Samoa and Fuluasou catchment have prevented its adoption and use for the assessment of impacts of land use patterns on river water quality of Fuluasou River.

With similar models, and the one that could describe a relationship between any two variables where one is a *response,* and the other is the *covariates* (can be measured or observed along with the response) (Pinheiro & Bates, 2000), a 'linear mixed effects model' was reviewed to be more appropriate in this regard. Considering the use of land use as independent variable and water quality parameters measured at every sampling station as dependent see this model fit to adopt. A study by Hurley (2008) to investigate the spatial scale of land use and source water quality relationships adopts the use of linear mixed effects models which revealed different spatial areas of landuse influence drinking source water quality depending on the parameter and season investigated. The findings showed variations of water quality responses at different spatial scale, in which turbidity found exhibited a complex association with land use of local to watershed scale whereas total organic carbon concentrations were found only associated with landuse characterized at the entire watershed scale (Hurley, 2008). This result suggests that the entire watershed approach of management is required to reduce risk of pollution in the source.
While Hurley's (2008) study was looking at the spatial scale of landuse on source water quality, the study of Ahearn et al. (2005) investigates the impact of land use and land cover influence on river water quality in Sierra Nevada, California. The impact of land use through human development on river water quality was assessed using a linear mixed effects model. The findings revealed that land use activities as a result of human development was evident with both agricultural areas and lands with high population density have closely the same effects on TSS loading. Since agriculture and the most populated areas were mostly located in the lowlands, the results indicate that lowlands are the primary source of TSS. The use of linear mixed effects model for the study of land use impacts on river water quality by Ahearn et al. (2005), could be applied to the study of Fuluasou River Catchment given the focus is on the assessment of the land use pattern and how they may have impacted on the water quality of the Fuluasou River.

2.5.3 Geographical Information System (GIS) and Remote Sensing

The application of GIS and remote sensing technologies, within water resource related studies and the management of catchment and watershed areas, are regarded as powerful technologies and they have been used as indispensable tools for hydrology analysis and modelling (Khairy et al., 2000). GIS is a computer-based, geographically referenced information system, which has been designed to work with data referenced by spatial and geographical coordinates (Maantay and Ziegler, 2006). Its great advantage involves a high capability capacity for analyzing, integrating and organizing geo-referenced information into one system, in order to allow effective integration of spatial and non-spatial information (Afeta, 2006). The source of information involved in GIS works can be extracted from satellite data imagery, topographical maps and other data sources representing soils, land use/land cover, weather and topography. Through the capacity of remote sensing to capture up to date satellite information for large ground areas, together with the ability of GIS to store, manipulate and manage data from various sources, this makes the integration of these technologies highly regarded in land use watershed management (Tattao, 2010).

The use of GIS is quite advanced with its powerful capability to analyze land use change, and how this change, over time, affects water quality at different management scales. Several studies from the past and recent times have used GIS to assist spatial data interpretation, when assessing land use-water quality relationships in different management scale (Ahearn et al., 2005; Bahar et al., 2008; Jiake, 2011; Liu, 2009; Omernick, 1976; Ribolzi et al., 2011; Zhang and Wang, 2012). The results of GIS and modelling analysis from some of these studies have confirmed the potential advantage of GIS integration with the use of ecological and water quality modelling. This integration helps to develop and advance decision-making supporting systems, to properly manage land use development and to improve control of non-point sources of pollution at the watershed level (Zhang and Wang, 2012). With land use linkages to water quality, the use of GIS and remote sensing has experienced advances in providing estimations of how land use can be related to water quality, over long-term assessment. This is crucial to understand how water quality responds over time to land use modification.

Given the potential capability of using satellite imagery, Chu et al. (2013) studied the relationships between water quality and land cover changes in Taiwan, using fine resolution satellite imagery that captured land use changes over a time period of ten years. Multiple satellite images were collected and evaluated by using a Normalized Difference Vegetation Index (NDVI), in which the results of land use/water quality relationships were explained by NDVI data, which was found to be quite useful for interpretation and improvement of analysis.

While these different approaches discussed may seem to be essential in addressing land use impacts and associated relationships with water quality, their application is dependent on many factors, including a consideration of their appropriateness based on the purpose of the study. For example in Zhang and Wang's (2012) study, they were only considering land use related variables in their models whereas, in fact, there are other related factors, such as population characteristics, soil types, average precipitation and other physical or biological variables that could be worth considering in relation to water quality levels in a sub-catchment area. These factors are essential as indicative of population density in relation to current land use development, climatic influence on water availability and geology underlying the nature of surface and ground water system. Therefore, the model in their study failed to reflect these variations, which could have elucidated on other associated pollution problems, which in turn could help to develop rigorous linkage models between land use type and water quality.

CHAPTER 3: THE STUDY AREA

The study catchment, the Fuluasou River Catchment (FRC), is one of the sub-catchments (and the largest of four) that drains Samoa's largest watershed basin known as the Apia Catchment Basin (ACB). The FRC is located south-westerly central of Apia Township on the island of Upolu (Fig. 1). It is situated between 13°48' 20.00" and 13°54' 06.92" south latitude, and between 171°46' 59.94" and 171°52' 14.73" west longitude. It covers an area of 4,557 hectares (45.57km^2) and approximately 20,702 inhabitants (Government of Samoa (GoS), 2012). The catchment at its highest elevation is approximately 900 metres above mean sea level. The main Fuluasou River, from the ridge to the ocean, has a length of approximately 12.3 km (Brown, 2011). Being the largest catchment of the ACB basin, the FRC drains the Fuluasou River and its tributaries that supply three water supply intakes and three water treatment plants (WTPs), which are all located within the catchment. This combined water supply system serves approximately 50,000 persons/households living in the catchment area, which extends to the Western Upolu area (Brown, 2011).

The Fuluasou River (FR) appears to originate from within a native and montane intact forest and makes its way from the mountainous craters of Lake Lanoto'o as headwater streams of the Fuluasou main river. The headwater streams, with rainfall falling over the catchment, contribute sources to both surface and groundwater for the FRC (Fig. 1). These headwater streams flow and form the first segment of tributaries which, further downstream, form the three main river branches known locally as the eastern, middle and western river branches of the catchment. Several tributaries flow through the Tapatapao and Leaupuna hills heading north and further downstream they connect with the Fuluasou western branch leading to form the main river stream. This main river channel flows downstream making its way through the middle segment and the low-lying areas of the catchment. However, it has been identified that the western branch is experiencing major flow problems (no environmental flow) and it is now dried up and has remained inactive for quite some time. This has allowed the government and residents to establish infrastructures and other social and economic developments (e.g. Tuana'imato golf course) on the river path covering the lower reaches of the dried up western branch of the river path. Due to this problem, this study focuses on the FR branches that drain from the eastern side, in addition to the middle branch, which is a diverge single stream that comes from tributaries on the upland central montane. All branches meet in the mid-catchment and form the main river branch of the FR. This main river stream eventually, at its lowest stretch on the low-lying area near the coast, empties into the sea (Fig. 1).

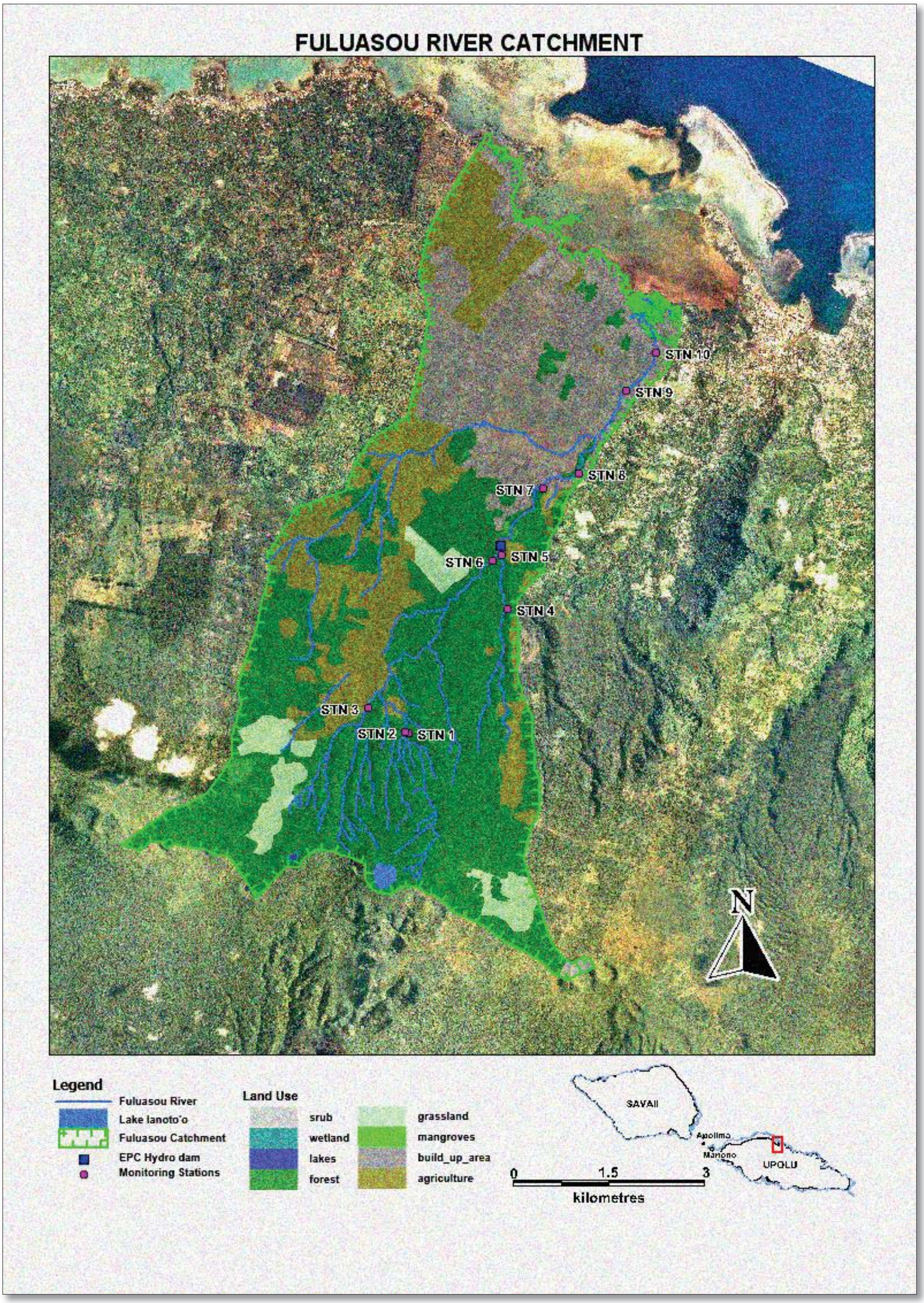


Figure 1. Location map of the FRC (constructed) indicating locations of water quality sampling sites (STNs).

3.1 Climate Conditions

The climate of Samoa is characterised by a mild air temperature (ranges between 22°C and 30°C) all year round, humidity ranges from 64% (mildly humid) to 97% (very humid), persistent easterly or north-easterly trade winds (Kendall & Poti, 2011) and a distinct dry (May-October) and wet (November-April) seasons. The average yearly rainfall is noted to be as high as >3,000 mm (120 inches) (Kendall & Poti, 2011) with about 75% of the precipitation occurring during the wet season. The average annual rainfall can be varied from 2,500 mm/year, mostly on the western part of Upolu island, to approximately 6,000 mm/year in the higher uplands of Savaii Island (MNRE, 2012; GoS, 2012) (Fig. 2).

There is less variation in the climate of the Fuluasou River Catchment given the relatively small land mass of the Samoan Islands with a total land area of 2,830 km^2. Several rain gauges are located, ranging from the lower end of the catchment (Apia observatory), the Alafua and Moamoa areas in the middle of the catchment, and the Afiamalu station located in the higher altitudes at the ridge of the Lake Lanoto'o area (refer to Figure 1 showing these locations). The average annual rainfall for the Fuluasou catchment is approximately 4,277 mm/year. The average rainfall during the wet season (November-April) is about 2,923 mm, with the rest of about 1515 mm received during the dry season (May-October) (GoS, 2013). The annual rainfall at the catchment’s highest peak, the Lake Lanoto'o in the headwaters of the catchment, ranges from 3,000 to 5,000 mm/year (GoS, 2013). The mean annual temperature at the lower reaches of the catchment is 27°C, compared to 22°C at the higher elevation at the Lake Lanoto'o.

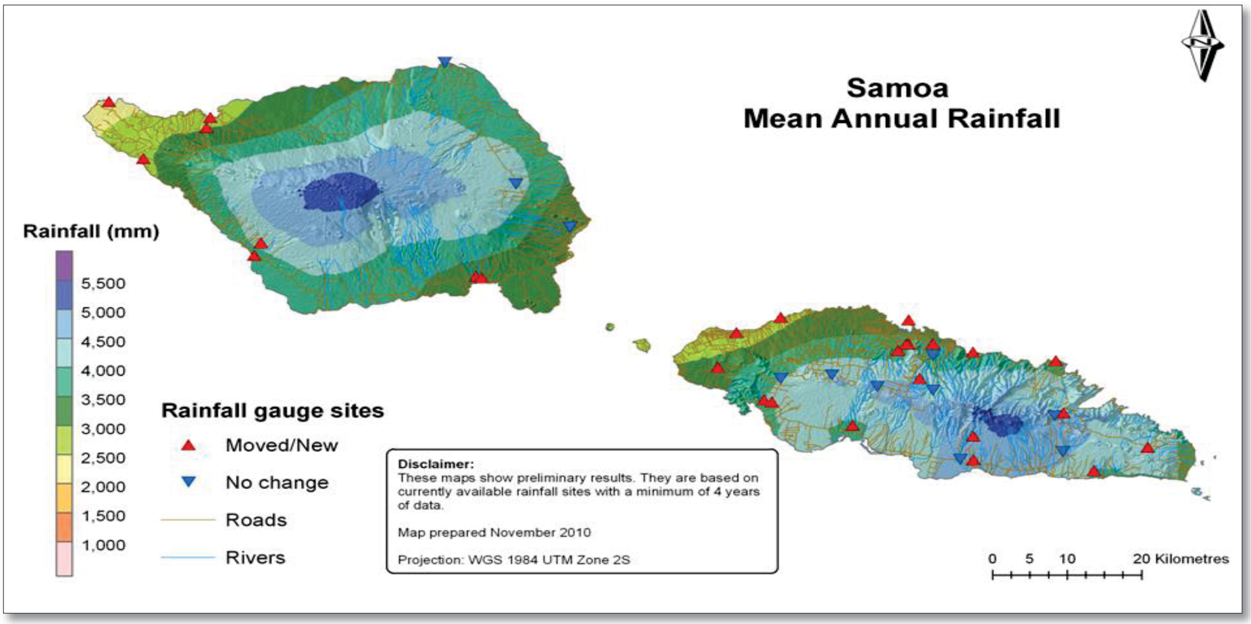


Figure 2. Samoa Mean Annual Rainfall - four years of data (MNRE, 2010)

3.2 Geology

The geology of Samoa was first described by Kear and Wood in 1959, and there has not been another survey undertaken to date. Kear (1959) described the Samoa Islands geology as being composed almost wholly of basic volcanic rocks, which are divided mainly into six formations based on weathering and erosion criteria. The Fuluasou catchment geology is comprised mainly of the Salani and Mulifanua formations (Fig. 3). The upper mountainous segment of the catchment is mainly formed by Salani geology, which was formed some 100,000-200,000 years ago (Atherton, 2013). It consists of greyish black basalt lava that are more permeable in comparison to the less surface drainage of the youngest geology of Mulifanua formation (MNRE, 2012 & Atherton, 2013). Mulifanua forms most of the western part of the catchment. The oldest formation is known as Fagaloa, which is the most weathered rock in Samoa. The Lake Lanotoo on the ridge of the catchment is partly formed by Salani and the older Fagaloa formations (Fig. 3).

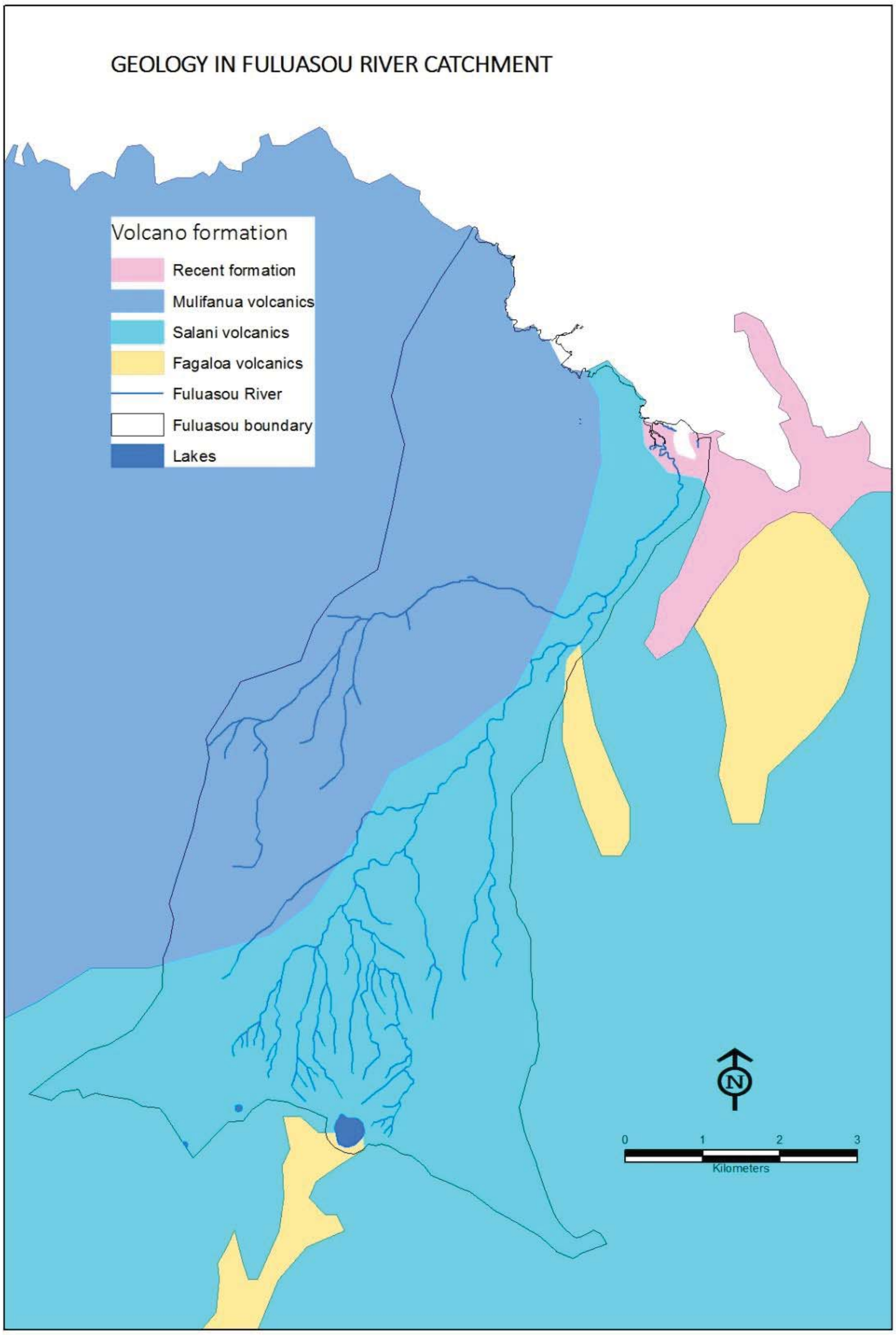


Figure 3. Geology map constructed of Fuluasou River catchment

3.3 Land capability and use

The landscape of the FRC was once blanketed with natural forest and various vegetation types (e.g. forest, closed forest, medium dense forest, open forest, secondary forest and forest plantations), until locals starting to move into the area for residential settlement and to start cultivating the catchment area.

The land use capability classes for the Fuluasou catchment can be explained and is summarised in Table 1 based on the Land Resource Study for Samoa (formerly known as Western Samoa) by the Asian Development Bank (ANZDEC 1990).

Table 1. Description of land use capability class (ANZDEC 1990)

Class	Description
1	Land with **few limitations** on agriculture use
2	Land with **moderate limitations** on agricultural use and **few limitations** on forestry
3	Land with **severe limitations** on agricultural use and **moderate to severe limitations** on forestry
4	Land **unsuitable** for agriculture or forestry

Figure 4 is a map of land use capability constructed specifically for the Fuluasou River Catchment. The map indicates different land capability classes within the catchment from the low-lying to the upper montane areas without overlaying the GIS layers of the river systems. The description of different classes in Table 1 explained the **higher** the land capability number the **lower** the capability of the land for forestry and agricultural uses. This further indicated on Figure 4 where lower northern part of the catchment is comprised of areas in land capability Class 4 (e.g. 4d), which are low suitability or inappropriate for agriculture and forestry but suitable for building residential and business (urbanised) as it is mostly flat areas.

The middle segment of the catchment can be seen as a mixture of Classes 1, 2, and 3, which are suitable for agriculture with moderate to severe limitations. This segment of catchment is where land is most suitable for agriculture uses and farming occurs. Field observations, during field work, confirmed further new agricultural developments was evident in the mid catchment and extends further upland from the western part of the catchment.

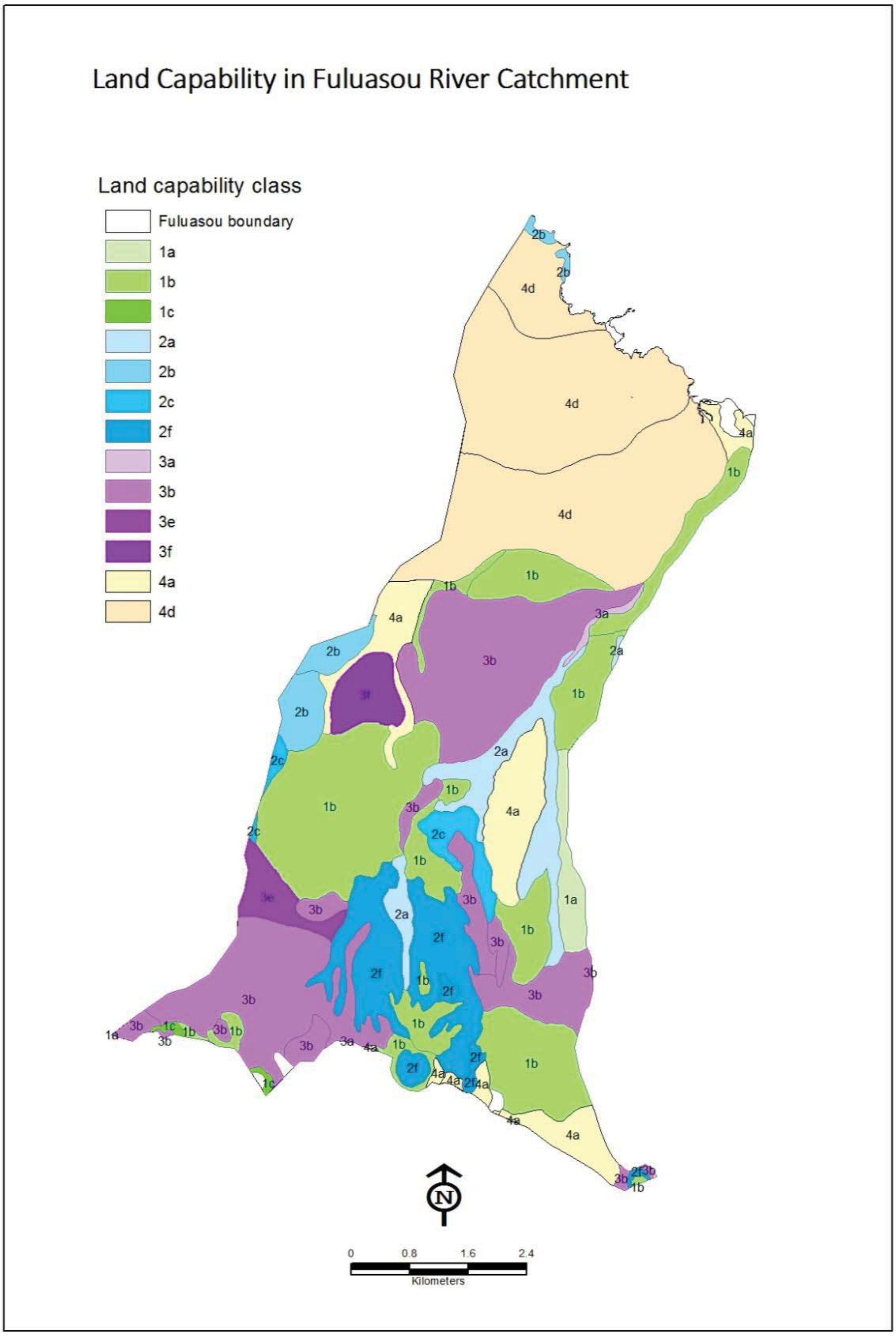


Figure 4: Land use capability map contructed of Fuluasou River catchment

The current landuse activities of the catchment are generally dominated by forests on the higher elevation of the upland catchment. Agriculture, through mixed cropping (e.g. taro and banana plantations with vegetable gardens) and plantations of mostly tree crops dominate the mid-catchment. The majority of agriculture activities have been developed on freehold and customary land under long term lease agreements (e.g. up to 50 years) (MNRE, 2013). The lower catchment land is generally flat and dominated by home gardens (e.g. they support subsistence living and people sell their produce in local markets) and coconut plantations, with patches of small-scale plantations of taro and banana around households. Most of these agricultural lands, especially in the mid to upper catchment have been under fallow periods since the taro blights in the early 1990s that destroyed the taro industry in Samoa. However, these areas have been re-developed with new plantations for new taro cultivars that have been proven by the government's taro breeding programmes: and these cultivars are tolerant to taro blight.

All these land use developments have caused further modification of land cover, resulting in the current land use within the catchment. The land based activities within the FRC are evidence of social and economic growth by the local people, who reside mostly on the mid to upper part of the catchment. These activities represent different land uses/land cover, based on the catchment land use capability potential. Factors as reported by Atherton (2013) such as soil types, drainage, pH, stoniness, slope or climate can determined land use capability potential of FC. More details of the dominant types and uses within the catchment are shown on the land use map (Figure 1).

3.4 Land tenure system

Land is central to the economic and cultural structure of Samoa (GoS, 2008). The sustainability of land use management solely depends on how land is being utilised to ensure and maximise its full capability and potential for appropriate developments. However, the use of land resources in Samoa has experienced numerous changes over the past decade, particularly in the Apia urban area. Moreover, land under intense agricultural development in rural areas is also experiencing modification to current land use (GoS, 2008). These changes can be related to the land tenure system and practice in Samoa. Such system gives more than 80% of land ownership to the head of Samoan families who are the Chiefs and Orators.

The land tenure system in Samoa is classified into three main categories: customary, freehold and government lands (GoS, 2008). The use of land in rural communities is solely under customary ownership (e.g. the Chief and his extended family), which accounts for approximately 81% of total land. The alienation of customary land is protected by law in Samoa. This means that customary land cannot be transferred, nor available as freehold, although lease arrangements are possible within the current system. Other lands include 11% owned by the government, which is used mainly for plantation farming, national reserves, public buildings and infrastructure. Five percent remains under the Samoa Trust Estates (STEC), mainly for commercial plantations. The remaining 3% comes under freehold ownership (GoS, 2008).

The same tenure system controls and administers the land use of the Fuluasou Catchment. Out of 4557 hectares of the FRC total land area, 2200 hectares of land is under customary rights. This accounts for 48.3% of the total land area of the FRC. The other remaining land areas are shared amongst other categories, such as the government, freehold and the Samoa Trust Estates (STEC). Due to a large proportion of land resources being under customary ownership, the utilisation of land in urban and rural areas sees a large proportion of land resources under cultivation for agricultural and family developments. This places a great deal of pressure on water resources, as uncontrolled activities move towards critical buffer zones for water protection areas. This situation remains a challenge, not only for water resource management, but for sustainable development since, in many cases, communal ownership encourages open access regimes that result in depletion of water resources (MNRE, 2013). The sole ownership of customary land is under the authority of the Chiefs (e.g. High Chiefs), who represent extended families. Thus, the customary right to use the land for any purpose is becoming evident, as farmers make their own decisions on how the land is used. This could be seen as a disadvantage, since control of the land relies heavily on how the local people manage their land as they wish. Although the government has a process of development consents in place for any development, its monitoring operations are very limited to urban areas.

The Government of Samoa has realised the vulnerability of such resources and their future sustainability which reflected in its recent committed to purchase 40 hectares of land owned by the Catholic Church (Semisi, 2013). The purpose of this purchase is mainly for conservation and protection of critical buffer zones on the uplands of the FRC basin to protect freshwater water resources. Further negotiations with the Council of Samoa Catholic Church is in progressive for another 485 hectares (≈4.85 km^2) of land on the upper catchment of FRC which have an estimated value of approximately 81 million Samoan Tala (1NZ = 1.8 ST), to come under state watershed protection (Semisi, 2013).

3.5 Water resources and the Fuluasou water supply system

Samoa has abundant water resources in the form of surface and groundwater, water springs, lakes and rainwater harvesting. However, these resources can only be sustained through proper water management at both national, village and household levels. The distribution of water resources across the country is fundamentally controlled by its geology and topography (GoS, 2013). Freshwater resources in the form of rivers and streams have recorded more than forty river systems in the country, which all originate in the uplands and drain into the sea (GoS, 2013).

Previous hydrological surveys and monitoring works for the FRC have confirmed (based on data analysis) abundant water resources, due to its catchment capabilities (MNRE, 2012). However, this could be a different story when prolonged dry spells are experienced over the years. The national drinking water supply in the country is estimated to be 65% sourced from rivers and streams, while 35% is supplied by groundwater (SWA, 2011).

The Fuluasou River is one of fourteen perennial rivers on Upolu island and its average flow rate is recorded at approximately 0.25m^3/s (or 250 L/sec) (SWA, 2011). The majority of these river systems experience flooding during the wet season. Following a prolonged or intensive period of rain, most rivers continue to flow, thus meeting the needs of various social and economic development purposes. Nevertheless, many times over past years, it has been witnessed that the ephemeral rivers and streams begin to dry up, with perennial river systems experiencing low flows. The situation can only worsen when droughts are prolonged for more than three months without any rain.

Three of the Samoa Water Authority's (SWA) treatment plants are currently sourced from the east of the Fuluasou River (e.g. mid-catchment) and the middle branch (e.g. upper catchment). The significance of the Fuluasou water treatment plants is their capacity to supply almost 50% of the island's population, who reside in the most populated area of Apia Township extending its service to the western side of Upolu towards Falelatai, and the most economically viable Vaitele industrial zone.

The capacity of the Fuluasou River to supply water has a metered recorded service demand of 4,525 m^3/day, for both the domestic and commercial zones it serves, which is quite a sufficient capacity compared to its total treated inflow of 15,552 m^3/day (SWA, 2011), which is the total amount of water flowing in from the raw water intake (inflow water) that is treated per day.

3.6 Human settlement and administration

Samoa recorded its first population official count in 1902 with only 32,612 people. Given Samoa's latest population size of 187,820 (an increase of about five times from its first official count), this is an indication of 155,208 additional person within its current total population.

According to the recent Population Census 2011, the total number of people enumerated on 7th November 2011 is 187,820: 96,990 males and 90,830 females. This is an increase of 3.9%, which is equal to 7,079 people from the last Population Census in 2006 that recorded 180,741 people (GoS Bureau of Statistics, 2012).

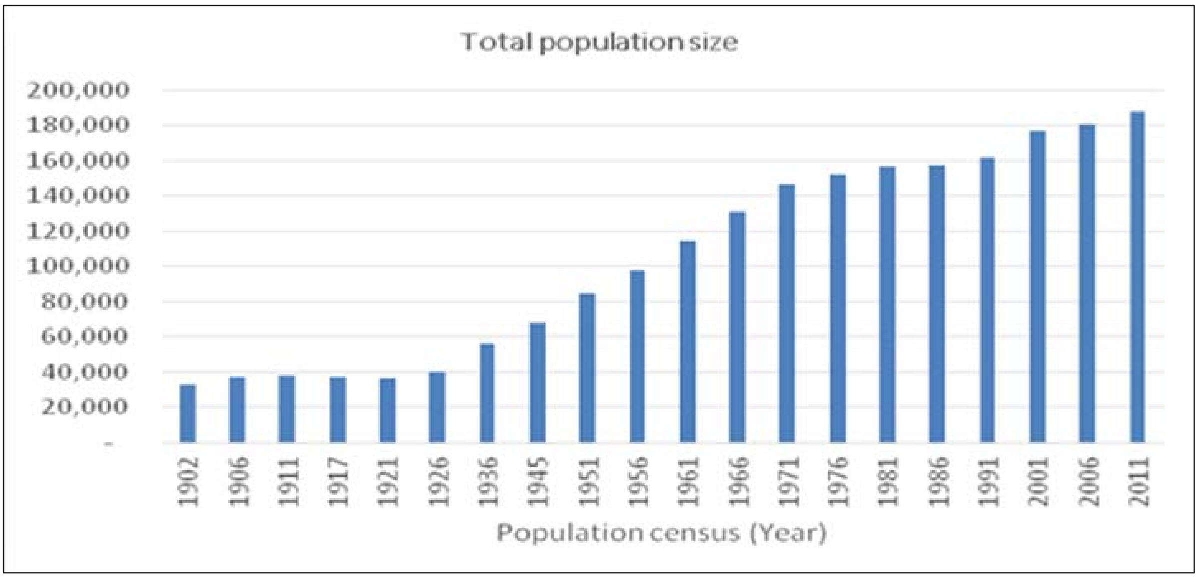


Figure 5. Samoa's total population size since 1902 (GoS, 2012)

The Fuluasou Catchment encompasses the main administrative district of Faleata Sisifo (West) with a total population of 18,895 persons and includes part of Faleata Sasa'e (East) with a population of 12,630 persons. The actual estimated population of Fuluasou catchment can be counted from the 20 villages identified within its actual physical boundary, as it is difficult to match it with the administrative borders, where part of Sagaga le Falefa borders its western boundary, and Faleata East is partly included in its physical boundary on the eastern side. Nevertheless, the population of the twenty villages provides a good estimate of the total population size of 20,251 people (GoS Bureau of Statistics, 2011) residing in the catchment area (Table 2).

Table 2. Population by village and gender for FRC (GoS, 2012)

Village/ Census (Year)	Male		Female		Total population	
	2006	*2011	2006	2011	2006	2011
Elisefou	99	116	98	126	197	242
Falelaniu	45	31	32	23	77	54
Leaupuni	33	36	26	33	59	69
Lepea	372	320	349	334	721	654
Safune	141	142	131	137	272	279
Saina	99	92	85	81	184	173
Siusega	1050	1173	957	1128	2007	2301
Talimatau	480	491	460	436	940	927
Tanumapua	422	564	401	554	823	1118
Tapatapao	77	107	67	71	144	178
Toamua	393	473	365	449	758	922
Tuaefu	108	122	88	102	196	224
Tuana'imato	237	278	233	273	470	551
Tulaele	210	210	204	206	414	416
Ululoloa	85	103	67	104	152	207
Vaigaga	376	400	342	370	718	770
Vailoa	774	744	782	768	1556	1512
Vaitele	3334	3671	3111	3511	6445	7182
Vaitoloa	427	347	388	307	815	654
Vaiusu	1076	1186	1070	1083	2146	2269
TOTAL	11844	10606	11262	10096	21100	20702

* Recent Population and Housing Census, 2011

The table above indicates a relatively marginal distribution of gender: male population 51% (0.512) and female population 49% (0.487). Vaitele village is known as the country's main industrial zone and it has the highest percentage of population distribution of 35% (0.346), compared to other villages. More locals moving into urban areas for employment and schooling have increased the population of Siusega and it is the second most populated village within the catchment, with 11% (0.111) of the total population. Figure 4 illustrates population trends of 20 villages, from 2006 to 2011, which recorded a drop of approximately 2% in the population size of the FRC.

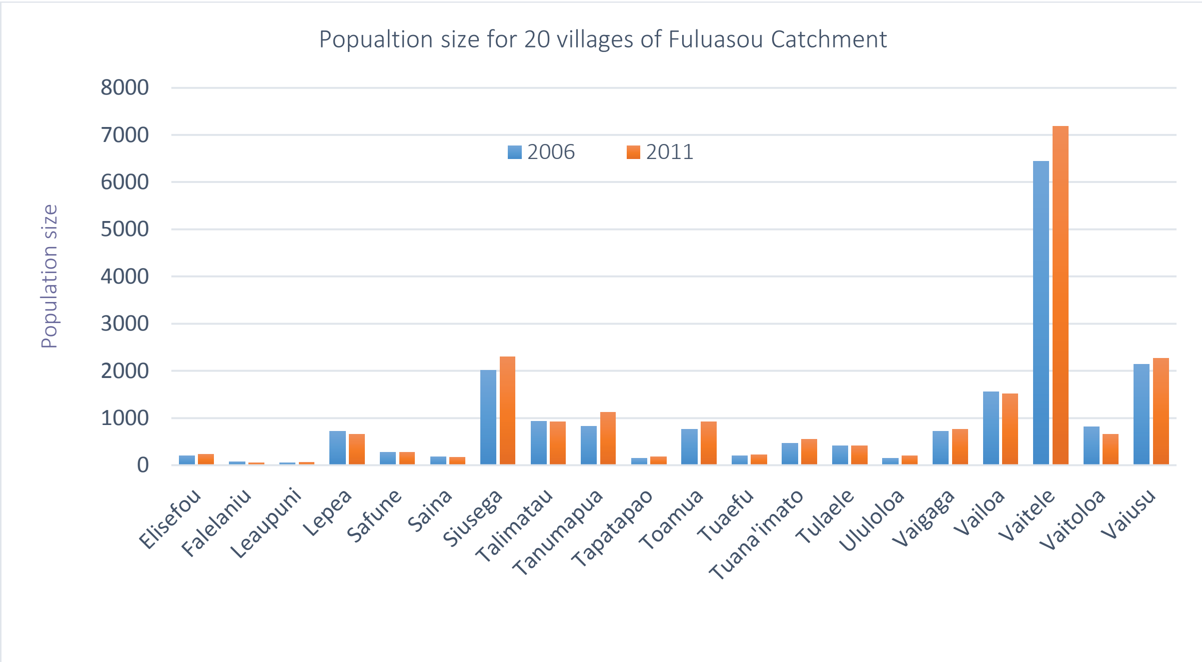


Figure 6. Population of 20 villages within the boundary of FRC (GoS, 2012)

During the process of formulating the Fuluasou Watershed Management Plan (WMP), a pilot project was carried out by the Ministry of Natural Resources and Environment, in order to collect demographics information for the Fuluasou Catchment and this revealed that the population distribution, per village population size, is highly significant, since it reflects the rate of water consumption per village (MNRE, 2012).

CHAPTER 4: MATERIALS AND METHODS

4.1 Introduction

The research required collection and collation of existing land use information, conducting field water sampling and measurements, monitoring of river discharge and the analysis of water quality samples for the selected physicochemical and microbiological parameters. This chapter explains the research methods and procedures and how the research file work was implemented relative to field water sampling and measurements; the data collection and analysis; the GIS analysis for catchment delineation and mapping; and the presentation of statistical analysis.

4.2 Selection of field water sampling sites

The selection of field water sampling sites were made to ensure raw water samples were taken to analyse physicochemical (pH, turbidity, temperature, COND, DO, TDS, Total N, Total P, and NO_3^-) and microbiological (Total coliform & E. coli) water quality parameters. Prior to the actual water quality sampling and monitoring, preparation work was carried out for site appraisal to validate the sampling sites in the field or stations as referred to in this study. Moreover, it was necessary to make an assessment and record observations along the river tributaries and main river channel, in an effort to identify possible sources of pollution into the river. Topography and land use classification maps were sought from the mapping section of the Ministry of Natural Resources and Environment that were used in planning before going out into the field.

A total of ten water quality sampling stations were identified on the land use classification map, based on possible sources of pollution identified from land use within different segments of the catchment. The proposed sampling stations were adjusted and validated in the field, based on a ground-truthing exercise which was a field survey to validate map references of sampling stations with their true 'on-ground GPS coordinates'. Readings from steep slopes of some areas of interest, (eg. steep slopes of the areas near sampling stations STN2 and STN6) were taken, by using a clinometer SILVA ClinoMaster CM-360 (Fig. 7) that will later be explained in the discussion.

Figure 7. Clinometer hand-held device

Figure 8. GPS *Trimble Juno SB*

The ten monitoring stations were also identified on the basis of ensuring representation of a catchment scale, by having them spaced out across different segments of the catchment: *upper catchment; mid-catchment and lower catchment* (Bahar, et al., 2008; Gyawali, et al., 2013; Shilla and Shilla, 2011; Zhang and Wang, 2012). The possibility of the close proximity of some land use developments, from the nearby community, was also considered in the selection of sampling stations, in order to be able to identify any possible effect of pollution (Zeb et al., 2011) from these developments. The use of local knowledge of the area, based on my previous work experiences within the catchment, was very helpful for validating the sites on the ground and for easy accessibility during sampling and monitoring.

The ten sampling stations were also used as monitoring stations (STN) for river discharge measurements, during the course of field work. Therefore, these sampling stations were also selected, based on locations that were free of river boulders and rocks or any obstructions and protruding items, such as large logs carried by the river during high flows and flooding events. These were identified on some sections of the river channels and observed as obstructions to the river path or a disruption to the natural flow regime of the stream (Fig. 9 & 10). The selection criteria/standards and practical controls used for the project's site selection were identified and adopted from the New Zealand National Environmental Monitoring Standards (Willsman, 2013).

Figure 9. Logs and debris identified in the river channel obstructing river flow

Figure 10. View downstream with example of floating logs in the river path

A GPS model, *Trimble Juno SB (*Figure 8), was used as an integrated GPS receiver to plot field coordinates of sampling sites and other field points of interest (e.g. EPC DAM). The names to identify sampling stations (STN) with their corresponding GPS location (coordinates) are shown in Table 3. The coordinates of the actual GPS locations of the water sampling site and monitoring stations for river discharge are shown on Figure 11 with major land use associated with the selection.

Table 3. Names of water quality sampling sites and river gauging monitoring stations with coordinates

Sampling & Monitoring stations	Name of sampling & monitoring stations	GIS Coordinates		Elevation above sea level	River Flow Direction
		South Latitude	West Longitude		
STN1	SWA Intake Chinese 1	13° 53' 23.49" S	171° 49' 27.42" W	400	⇩
STN2	SWA Intake Chinese 2	13° 53' 23.05" S	171° 49' 28.86" W	408	
STN3	MNRE Hydro Station	13° 53' 10.44" S	171° 49' 48.58" W	371	
STN4	SWA Intake (East branch)	13° 52' 19.62" S	171° 48' 35.48" W	204	⇩
STN5	Fuluasou East	13° 51' 52.22" S	171° 48' 38.63" W	138	
STN6	Fuluasou Middle	13° 51' 55.19" S	171° 48' 43.07" W	144	
STN7	Tuaefu (before the bridge)	13° 51' 17.97" S	171° 48' 16.51" W	80	⇩
STN8	Tuana'imato (corner of golf course)	13° 51' 09.95" S	171° 47' 58.30" W	56	
STN9	Vailoa (before the bridge)	13° 50' 27.55" S	171° 47' 33.10" W	30	⇩
STN10	Lepea (before the bridge)	13° 50' 08.15" S	171° 47' 17.48" W	17	

* The old EPC retaining reservoir is currently inactive for hydro and it is a major water and environmental flow barrier for the Fuluasou River (NB: EPC Dam located between STN^-STN7)

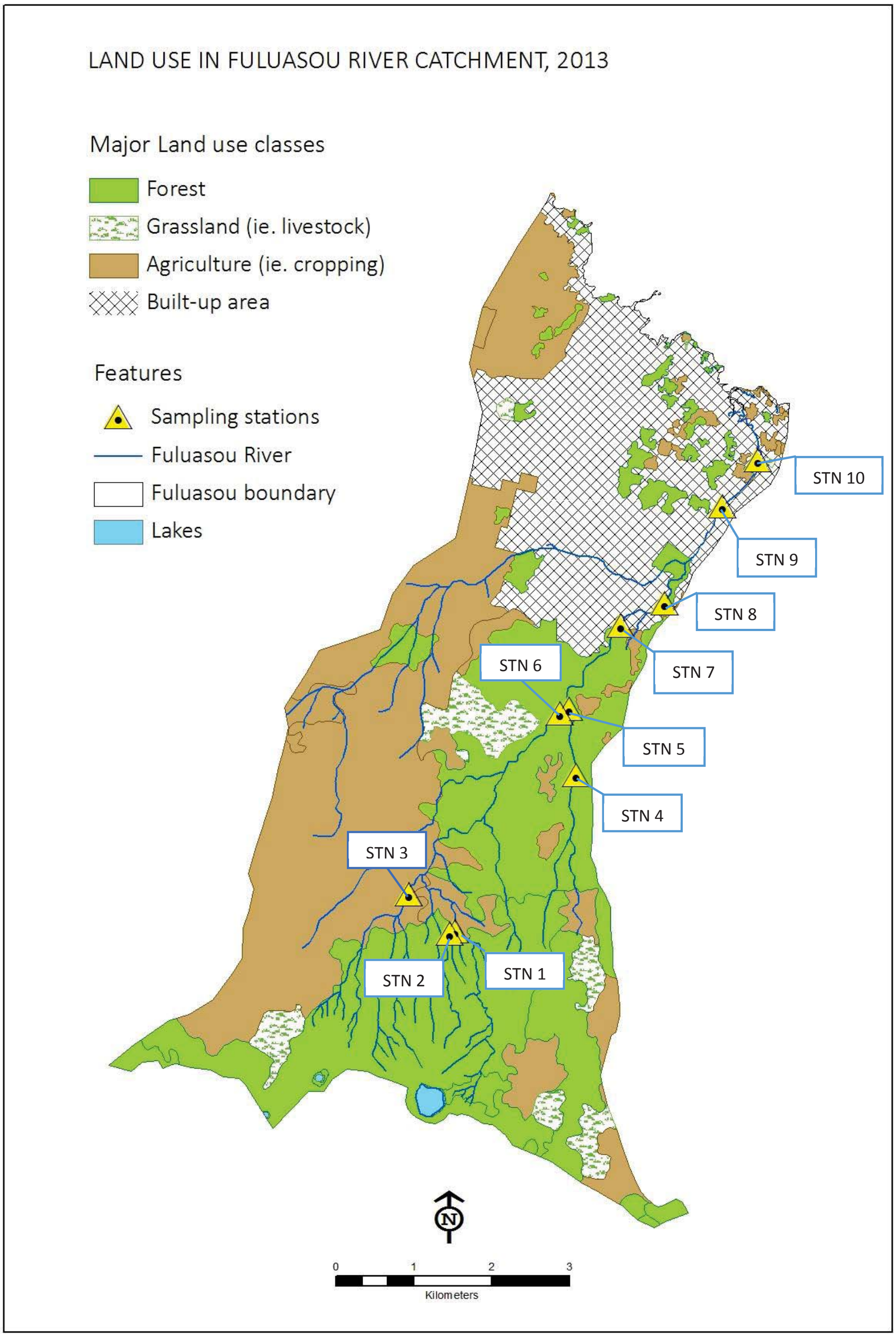


Figure 11. Major land use map of FRC (constructed) showing locations of the sampling stations

4.2.1 Description of sampling locations

STNs 1 and 2 were located on the upper catchment and on separate river tributaries. These tributaries feed the two SWA untreated water intakes known as Chinese 1 and Chinese 2. The sampling stations STN1 and STN2 were located 30-50 metres upstream from these two water intakes. Despite the two stations being located on the upland catchment, patches of agriculture development, such as mixed cropping and vegetable gardens with taro and banana plantations (Fig. 12 & 13), were observed in cultivation around the area. Agriculture plantations and cattle farming were also identified further upstream from the two stations. These developments are part of newly established sub-divisions that are encroaching from the eastern side of the upper catchment of the FRC. During the term of field work, construction works were being carried out by contractors to upgrade the two water supply intakes (Chinese 1 & 2). These works included building a new access road to the area (Fig. 43 & 44); structural construction work for the two intakes; a road ford; and an underground tunnel for pipe laying.

Figure 12. Part of an existing banana plantation right on the slope just above Chinese 1 intake (NB: Arrow pointing to Chinese 1 intake

Figure 13. View upstream from STN2 showing part of a taro plantation adjacent to the stream bank.

STN 3 was also located on the upland catchment about 1km on the western side of STN1 and 2. On the western side of STN3, agriculture activity, such as banana and taro plantations were also observed extending further upland, in addition to some cattle farms paddock further upstream. The STN3 is called the MNRE Hydro station (Fig. 14), as the site is also monitored by the Water Resources Division of MNRE for hydrological data. This is the only existing monitoring station for river discharge that is coordinated by MNRE to represent the flow of the catchment.

Figure 14. View downstream from STN3 (measuring section)

STN 4 was located in the mid-catchment and fed by a separate tributary draining from the eastern part of the catchment (Fig. 15). This river tributary feeds SWA's water intakes (Eastern branch) (Fig. 16) that supplies the SWA Water Treatment Plants (e.g. EU & JR WTP). Due to clearance of land for a new sub-division, to allow building of new settlements on the eastern upper part of the catchment from STN4, this may have some effects on the water, as some of these developments were identified and observed encroaching over the catchment boundary from the eastern side further upstream. Intensive agriculture activities, such as mixed cropping and cattle farming, were also identified on the upper catchment from STN4.

Figure 15. View upstream from STN4

Figure 16. SWA water intake downstream from STN4

STN 5 is located on the same tributary as STN4, but approximately 1km downstream. Agriculture lands were also identified draining into the tributary before the STN5. The section of the river between STN4 and STN5 is often being observed crossed by members of local families using horses as mode of transportation to their farms and plantations. Some of these horses were tied closer to river banks (Fig. 46) and could be possible source of faecal contamination of river water.

Figure 17. Low water level at STN5 measuring section (view upstream)

STN 6 was also located in the mid-catchment but in a separate tributary from STNs 4 and 5. This river tributary (Fig. 18) was referred to as the 'middle river branch' of the FRC. The tributaries that flow from the upper catchment (where STNs 1-3 were located) meet further downstream and formed the main tributary that flows through STN6. The same tributary that further downstream meet with the tributary where STN4 and STN5 were located to form the main branch of the Fuluasou River. STN6 was observed being located about 500 m downstream from a commercial poultry and cattle farm located on the western slope of the river gully.

Figure 18. STN6 measuring section (view upstream)

Figure 19. 70° steep slope of an abandon agricultural land on the western side of STN6

[Note: the open steep slope was once part of a large taro plantation and the land is now left uncultivated]

The eastern and middle branches of the Fuluasou River meet after STNs 5 and 6 to form the main channel of the Fuluasou River that flows mostly through to the lower part of the catchment. The meeting point of the two branches is where the old Electric Power Corporation hydro dam is located (Fig. 20 b). The water flows from the upland fills the dam before slipping over the retaining wall to drain the lower catchment.

20 (a) Road track crossing Fuluasou River 20 (b) Old EPC Hydro Dam

Figure 20 (a) & (b). Road track crossing the Fuluasou River in the mid-catchment just downstream from STN5 & STN6 and into the old EPC Hydro dam [Note: blue arrow points to direction of river flow]

STN7 was located at the lower mid-catchment (Fig. 21) near several residential areas, including Ulululoa and Tuaefu villages along the western side of the river gully. This station was also located downstream from a local 'Samoa Traditional Resort' located on the heights of Ulululoa on the western side of the gully.

Figure 21. View downstream from STN7

STN8 was located (Fig. 21) further down the lower catchment and near populated areas on both sides of the river. Many households/families live on both sides of the river bank going downstream from STNs s 7-10, going downstream. Going further downstream from STN8 on the western side is the golf course. School buildings and a college compound, Faleata College, are located further down on the eastern side of the river channel.

Figure 22. View upstream from STN8. Note some houses in the background at the top right end [Note: yellow arrows pointing to family houses) and a low level of water without any flow]

STN 9 was located further downstream about 1km. The same setting is observed on both sides of the river as STN8 with more developments (eg. Small-scaled mixed cropping & business) and residential areas (Fig. 23) going further downstream to the lower reaches of the catchment. The area around this sampling station is becoming populated along the river channel, with families living on both edges of the river bank. STN9 was observed dried out in the last month of monitoring (Fig. 24).

Figure 23. View of a family house as an example of how close residential areas are to the edge of the river bank. Note: Arrow points to direction river flow

Figure 24. View upstream from the ford to the location of STN9

[Note: No water and river dried up]

STN 10 was located further downstream (Fig. 25) from STN9 closer to the main road at the lower reaches of the catchment. This part of the lower catchment is crowded with family residents and settlements that formed part of the Apia Township where often more people residing all along the river banks (approx. 5-10 m from the river bed).

Figure 25. View upstream from STN10 with river dried up

4.3 Water Quality Sampling and Analysis

4.3.1 Water sample collection

Grab water samples were collected from ten sampling stations along the main river and its tributaries (Fig. 11). These water samples were collected every Wednesday morning through to mid-afternoon on a fortnightly basis during August, September and October, 2013. In total, 6 water quality samples were collected at each site except few samples of 5, 2 and 1 were collected at STN8, STN9 and STN10 due to drying conditions at the lower reach of the catchment. The river was in low flow conditions during the sampling period (August to October) since August to October are the last three months of the dry season in Samoa (from November to April). Grab water samples of 100mL were collected in *Sterile WhirlPak* sampling bags for chemical analysis and the same amount taken using special *Sterile polyethylene* containers (Bahar, 2008) for microbiology analysis. All samples were stored in a cooler box with a pack of ice while out in the field. All samples were later transported, immediately after field sampling, to the Scientific Research Organization of Samoa (SROS) laboratory for microbiological and chemical analysis. The SROS laboratory is an accredited laboratory under the International Accreditation New Zealand (IANZ) Standard.

4.3.2 Physicochemical water quality analysis (pH, TEMP, COND, TDS & DO)

Physical water quality parameters, such as pH, temperature (TEMP) , conductivity (COND), total dissolved solids (TDS) and dissolved oxygen (DO) were measured *in situ* using a special Multi-parameter meter *HACH HQ40d* (DO in mg/L) and a *Mettler Tolledo SevenGo* portable meter (COND, TDS, TEMP & pH). The probes of the two meters were submerged into the centre of the stream and readings were taken about a 5cm depth of the water at each measuring section. All water measuring sections of all sampling stations were observed to be less than 1m depth. Readings for the measured parameters were taken once the numbers appeared stable on the meter.

4.3.3 E.coli and Total coliform

E. coli and Total coliform were measured and determined in accordance with standard methods for the examination of water and wastewater (APHA, 1992) and the test method procedures (C2/8) of the SROS Standard Operation Procedures (SROS Microbiology SOP Manual, 2009). A filtration apparatus (Fig. 26) was assembled which included a vacuum pump, filtration manifold, glass funnels, clamps and 47 mm filter paper (Elbag, 2006). Samples were labelled on petri dishes with sample codes and volume used. All pipette, tips and small tubes were sterilised in an autoclave before use. All samples went through a dilution process, where three dilutions (i.e. 1 ml, 0.1 ml and 0.01 ml) were prepared for each sample.

All dilutions were prepared and poured into fermentation tubes and labelled with sample codes and volume used. Approximately, 100 ml of buffered water was poured through the funnels and vacuum. When all the water had run through, the vacuum was turned off and clamps and funnels were removed. Flamed tweezers were used to transfer a sterile 0.45 µm gridded membrane filter onto the receptacle (with the gridded side up), before carefully replacing the funnels back on and locking it with the clamps.

Prepared dilutions (1 ml, 0.1 ml and 0.01 ml) were poured onto the filter. The vacuum was turned on, to allow the sample to draw completely through the filter. Once the water was filtered through the membrane, the vacuum pump was turned off. Using sterile tweezers, membrane filters were removed and placed carefully (to avoid tears) and placed onto the m-Endo-LES agar in each receiving labeled petri dish. The filter funnels were then washed with buffered water and the filtration steps were repeated. Petri dishes were placed in the receiving tray (Fig. 27) in an inverted position, to allow visible growth of bacteria and these were then taken for incubation at 35 ± 0.5°C for 22 to 24 hours (Fig. 28). Interpretation of results included placing the petri dishes under the colony counter and counting for typical colonies for Total coliform. Coliform colonies were pink to dark red in color with a green metallic surface sheen for ease of identification. Results of Total coliform were calculated as follows: [(No. of colonies)/(volume filtered)] × 100 in cfu/100 mL.

Figure 26. Preparation bench with standard equipment used for Total coliform and E.coli determination

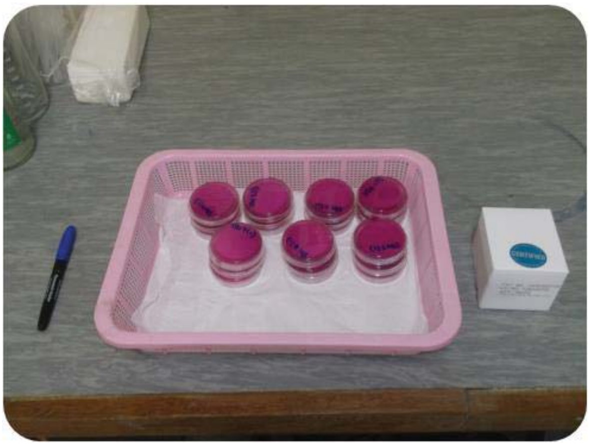


Figure 27. Prepared petri dishes ready for incubation

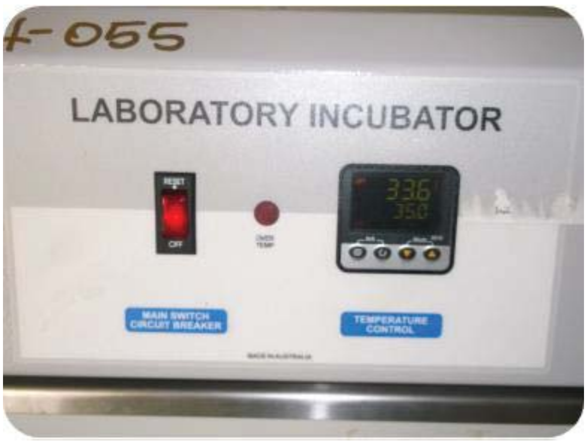


Figure 28. Prepared PD incubating at 35°C ± 0.5°C for 22 to 24hours

For E.coli, the filters with Coliform growth were transferred onto NA-Mug Figures (Nutrient Agar Figures). These Figures were then incubated at 35°C ± 0.5°C for four hours before readings were taken for the presence of E.coli. Once incubation completed, the petri dishes were then placed under a UV Light to view the blue fluorescence colonies for E.coli counts.

4.4 Chemical Analysis

4.4.1 Total Phosphorus (Total P)

The analysis of total phosphorus was carried out using an Ascorbic acid reduction method described in the Standard Methods for the Examination of Water and Waste Water (APHA, 2005) and the SROS Standard Operation Procedures (SROS Chemistry Manual, 2011). In this method, water samples undergo a digestion process to convert combined phosphate to orthophosphate which then reacts with ammonium molybdate and potassium antimonyl tartrate in acid medium to form a heteropolyic acid. This reaction can be reduced by ascorbic acid to form highly coloured molybdenum blue (APHA, 2005; SROS SOP, 2008).

The reagents used for this method include sulfuric acid, (H_2SO_4) 5*N*: dilute 70mL concentration of H_2SO_4 to 500mL with distilled water. Potassium antimonyl tartrate solution: dissolve 1.3715g $K(SbO)C_4H_4O_6 \cdot {}^1/_2H_2O$ in 400mL distilled water in a 500-mL volumetric flask and dilute to volume. Ammonium molybdate solution: dissolve 20g $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in 500 mL distilled water. This was stored in glass-stoppered bottle. Ascorbic acid, 0.1*M*: dissolve 1.76g ascorbic acid in 100 mL distilled water. All the reagents were prepared into a calibrated volumetric flask. Combined reagent: mix the above reagents in the following proportions for 100 mL of the combined reagent in a 100mL volumetric flask: 50mL *5N* H_2SO_4, 5mL potassium antimonyl tartrate solution, 15mL of ammonium molybdate solution, and 30mL of ascorbic acid solution.

Once all reagents were prepared, they were left standing to reach room temperature before the analysis. The digestion of samples was prepared beforehand, according to APHA, 2005; DHV Consultants et al, 2000.

Once the process was completed, samples were cooled at room temperature and ready for the analysis of samples. This involved the following procedures (APHA, 2005): Pipette 50mL sample into a 125mL conical flask. Add 1 drop (0.05mL) phenolphthalein indicator. A discharge red colour appeared and another 5*N* (Normality) of H_2SO_4 was added. Add 8.0mL of combined reagent and mix thoroughly. Sample stood for 10mins for the reaction to occur, but it was necessary to ensure that the standing time did not exceed 30 minutes. The samples were put inside the UV spectrophotometer, which was already set at 880 nm and the absorbance of each sample at 880nm was measured. Blanks were also prepared by adding all reagents, except ascorbic acid and potassium antimonyl tartrate, to the samples. Therefore, blanks were recorded first before the samples. After reading absorbance from the samples, the absorbance of blanks was subtracted from the sample absorbance. Results of phosphorus concentration (mg/L) were recorded by checking the sample's absorbance against the calibration curve.

4.4.2 Total Nitrogen (Total N)

Total nitrogen (TN) was analyzed using the process of digestion, distillation and titration of the Kjeldahl method, in accordance to the method described by Blakemore et al. (1987), and the test method (C2/8) of SROS Standard Operation Procedures (SROS Chemistry Manual, 2011). These procedures basically convert organic nitrogen to ammonia, which then distills the total ammonia into an acid absorbing solution(Boric Acid), determined by titration of 0.25M of H_2SO_4.

The procedure involves pipetting 2mL of raw water samples into dry digestion tubes (500mL calibrated glass test tubes), sorted out in an Aluminum heating block. The blanks and quality control samples were all prepared in triplicate. Two Kjeldahl copper catalyst tablets were then added to each digested tube. When all the samples were prepared (tubes), 20mL of concentrated sulfuric acid (95%) (H_2SO_4) was carefully added into each mixture and gently swirled around.

During preparation of samples, the Digester unit (BUCHI DIGEST AUTOMAT K-438) was turned on and pre-heated at 420°C (~60mins), as it takes some time to heat up the unit to its required temperature. At 420°C, the prepared samples in the rack were placed in the digested block (BUCHI DIGEST AUTOMAT K-438) and run for two hours. The samples' colour turned clear green as an aliquot sample solution, which completed the digestion process after a set time of 120 minutes.

The samples were allowed to cool down to room temperature before they were transferred to the distillation unit (Kjeldahl Unit K-370).

Each digested sample (tube) was placed in the Kjeldahl Distillation Unit (K-370) one at a time, in order to undergo distillation. The Kjeldahl Distillation unit, with its build-in titrator, enables automatic calculation by the unit and readings were taken from the display on the titrator. The average of individual samples (with their triplicates) was taken, in order to determine total nitrogen concentration (mg/L).

Before distillation, the Auto Kjeldahl Unit (K-438) was programmed according to the following parameters.

Table 4. Parameters settings for Auto Kjeldahl Unit prior to distillation process (SROS Chemistry Manual, 2011)

Distillation		Titration	
Water	80 mL	Type	Boric acid
NaOH	90 mL	Titr solvent	H_2SO_4 (0.25M)
Retention time	5s	Vol receiving sol	60 mL
Distillation time	300s	Min. titr time	5s
Steam power	100%	Max. titr vol	40ml
		Titr mode	Standard
Asp.sample	Yes	Titr pH meas. Type	Endpoint
Stirrer speed	5	Stirrer speed	7

4.4.3 Nitrate (NO_3^-)

Nitrate was analysed in accordance to Standard Methods for the Analysis of Water and Wastewater (APHA, 1998) and the test method (C2/8) of SROS Standard Operation Procedures (SROS Chemistry Manual, 2011). In this method, water samples undergo a digestion process where 2mL of raw water sample pipetted into 500mL digested tubes. UV absorption of water samples was measured through a process of UV-screening using a Spectrophotometer set at 220nm to determine NO_3^- under UV absorption. Water samples were gone through a 0.45um sample filtration to remove the effects of turbidity. A 0.2mL of 1M HCL was added into the filtrate and mixed thoroughly. Distilled water was then used to zero the spectrophotometer at 220nm, before taking the reading for the standards and water samples. This process repeated under a 275nm Spectrophotometer screening, followed by taking nitrate concentration readings.

Standards used for this analysis were prepared in accordance with SPACNET recommended methods for soil, plant and water analysis (Daly and Hill, 2014) adopted for SROS use: Nitrate stock, 1000 mg/L NO_3^-: carefully dissolve 7.218 g potassium nitrate (KNO_3^-), dried at 105°C for 1hr in a 1L volumetric flask and make up with distilled water to the mark; Nitrate intermediate standard, 100 mg /L NO_3-N: dilute 10ml of Nitrate standard (1000 mg/L NO_3^-) to 100 ml volumetric flask and make up with distilled water to the mark; Nitrate working solution: 10, 5, 2 ,1, 0.5, 0 mg NO_3^-/L were prepared by diluting 5, 2.5, 1, 0.5 and 0.25 ml of Nitrate intermediate standard (100 mg/L NO_3^-) to 50 ml volumetric flask and make up with distilled water to the mark.

4.5 River flow discharge

The velocity-area method was used to measure river flow discharge at all 10 monitoring sites. At every monitoring station, a flow meter, *Model 801 (Flat) EM VALEPORT,* was used to measure the velocity of river flow at 0.6 m of the water depth from the surface across the river cross-sectional area, over a 30 second interval. The process involved measuring the width of the stream cross-section, using a 30m tape measure, from one side across the other where water mark ends on both sides of the stream. Depending on the width of the cross-section, the stream was further divided into a series of subsections, as different measuring sections were varied in their widths and depths. Each subsection required measurements of width and depth. A flow meter was used to obtain the reading of a mean water velocity at 0.6 m of the water depth from the surface (i.e. at 0.4 m of the mean water depth from the bottom of stream) for each sub-section, over a 30 second interval. The measured stream subsections widths, depths and velocities were used to calculate and sum up to estimate the river flow discharge as explained by Nolan and Shields (2000).

4.6 Land use analysis

4.6.1 Land use characterization & Land use change

The land use characteristics of the FRC were determined by using Arc GIS. All GIS dataset used in this study were obtained from the mapping section of the Technical Division of the MNRE, Samoa. These GIS dataset layers include land use classification for Samoa for the years 1999 and 2013, in addition to topographic information, such as 10m contour GIS layers, the land capability and geology layers of Samoa. All GIS layers provided as MapInfo format were first converted to shapefile by using GIS software *Quantum GIS 1.8 (QGIS) Lisboa,* which is compatible with ArcGIS. The land use characteristics and land use composition of the catchment were determined by using the ArcMap of ArcGIS software (Ahearn et al., 2005).

A geographic coordinate system of GCS_WGS_1984 was first checked and set up as a projection to WGS 1984, using the Spatial Reference Properties' function of ArcMap, before the data was used to create land use composition maps for the two years 1999 and 2013. The shapefiles were then added to the table of contents layers window of ArcGIS. The land use layers of Samoa were first clipped using the 'Clip Analysis' tool of the Geoprocessing drop down menu on the ArcMap toolbar, in order to extract the area of interest defined by the boundary GIS layer of the catchment. The same procedures were undertaken for land capability and geology maps for the FRC. A categories features option, under the 'symbology' function of layer properties, was used to create different features on different maps.

The 2013 existing GIS layers for dominant land use types of Fuluasou catchment was used to create an up to date land use map for the catchment with 12 dominant land use classes. These land use were then re-classified into four main land use types as the major land use focus of the study: agriculture (AG) (eg. mixed cropping and plantations), forest (FO) (eg. Forest plantation, secondary forest etc), grasslands (G) eg. Livestock/cattle farms) and Built-up areas (BUA). Table 5 summarise the original dominant land use types assigned to each of the major four landuse types.

Table 5. Reclassification of dominant land use types into four main land use

Four main land use	Dominant land use
1. Forest	Forest
	Forest Plantation
	Secondary Forest
	Lake
2. Agriculture	Mixed cropping
	Agriculture Plantation
	Scrub (mostly associate with agriculture lands)
3. Grassland	Grassland (eg.) livestock
4. Built-up area	Built-up area
	Infrastructure
	Mangrove

The re-classification of land use types were made by using the 'attribute table' function of the Spatial Analyst tools of ArcMap, where all features are opened in an attribute table. New fields were added for the new reclassification codes: forest, agriculture, grasslands and built-up areas. The 'symbology' function was then used to display the new fields, by ticking on 'all values' option. Each land use composition attributes were viewed using the 'attribute table' of each layer to assess the features of the land use composition, including the area (ha) for each polygon that represents each land use type.

4.6.2 Delineation of sub-catchments

The ten water sampling stations were located across several land use types within the study catchment. The FRC was divided into 10 sub-catchments: each defined by a sampling station, so that the area of each land use type, within each sub-catchment, can be calculated to assess spatial relationship between land use and measured water quality in the catchment.

The FRC topographic data, the 10 metre contour GIS layer, was used to create a Digital Elevation Model (DEM) of the catchment. This included the clipping of 10m contour lines using the 'clip analyses' of the 'Geoprocessing' menu in the toolbar. This process extracted the area of interest defined by the catchment boundary polyline layer. Subsequently, the 'Topo to Raster' interpolation method of the Spatial Analyst Tools was used to create the DEM.

For sub-catchment delineation, the procedures involved the use of ArcHydro>DEM manipulation>reconditioning the DEM>Flow direction>Flow accumulation. Special analyst tools were used for this analysis. Using the ArcView topology of the ArcGIS toolbar, the proportions (%) of each land use type, within every sub-catchment defined by each sampling station, were determined (Bahar, 2008). This was done by dividing the area of each land use type by the area of the sub-catchment, times 100%, in order to obtain the percentage of sub-catchment covered by each land use type.

4.7 Statistical Analysis

The analysis undertook for this study include descriptive statistics, correlation analysis (eg.) Pearson *r* correlation and linear mixed effect models. The descriptive statistics was performed in Minitab 16 statistical software to analyse the mean, min, max, coefficient of variance (CV) and standard deviation (sdev) of physicochemical (pH, TEMP, TURB, DO, TDS, COND, Total P, Total N & NO3) and microbiological (E.coli, Total coliform) parameters of water quality in the FRC (Gyawali et al., 2013; Lee et al., 2009).

For Pearson correlation coefficient values, Minitab 16 was used to produce a correlation matrix with r values for statistical analysis among water quality and land use parameters. Pearson correlation analysis was performed, to determine possible correlations amongst physicochemical and microbiological parameters, and to determine potential land use relationships with water quality parameters (Gyawali et al., 2013; Lee et al., 2009; Li, et al., 2008).

The Pearson correlation coefficient values should be in the range between -1 and 1. The greater the absolute value of a correlation coefficient, the stronger the linear relationship. The strongest linear relationship is indicated by a correlation coefficient of -1 or 1, where -1 shows a strong inverse correlation between any two variables.

Finally, a 'linear mixed effects model' was used for regression analysis, by using *'R'*, a free statistical software (*R* Core Team, 2013). The analysis capability of *R* suits repeated sampling and measurements at the set locations of the sampling stations in the study. This model was used to assess possible land use relationship with the measured river water quality parameters. The nature of this relationship is determined by studying any association (p<0.05) between water quality parameters relative to an individual, or combination of land use types (Ragosta et al, 2010). The model involves parameters that associate with the whole sample population, known in the language of *R* model as 'fixed effects', and with possible association with individual unit of measure as 'random effects'.

The application of this model involved fitting the linear mixed effects model onto each of the water quality parameters, with the 'Landuse' as the 'fixed effects' and the 'Station' as the 'random effect'. This applies as 'Landuse' is a non-random quantity that is intended to investigate and 'Station' is a source of random variation. The *R* code that was used to fit the model is: "lmer (fixed=y ~ LandUse, random=~1|Station, method="ML".

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents the results of the research analysis and discusses the outcomes of these analyses, relative to the aim and objectives of the research. The discussion is presented through an analysis of each topic that the objectives in the study set out to achieve. These comprise land use characteristics with land use change and mapping; current water quality status and conditions of the river in comparison to specific water quality standards and guidelines; the spatial variation in water quality responses at different sampling sites; and the relationship between land use and water quality parameters. The effects of land use distribution are assessed on the basis of different segments of the river catchment defined by sampling stations, such as the upland (e.g. STNs 1, 2, 3, 4), middle (e.g. STNs 5, 6, 7) and lower (STNs 8, 9, 10) catchment parts. Subsequently, the potential status of the relationship between land use and water quality is assessed and discussed.

5.2 Land use characteristics and land use changes

The state of land use in the FRC is graphically presented in maps created from GIS MapInfo layers available for the years 1999 and 2013. Table 6 summarises the extent of different land use in FRC during the year 2013 (Fig. 29). The landuse in FRC is currently dominated by forest lands with 36.6% of total land area under forests and 32.1% of agriculture lands as the second dominant land use type (refer to Table 6 & Figs. 29 and 30). The two major land use maps of 1999 and 2013 (Fig. 29 & 30) were compared to estimate the change in land use over time. This change was calculated in percentage, by dividing the total land use area by the total land use area of the catchment and multiplying by 100%, to give the proportion of total land use area for each main land use type. Table 7 summarises the results of land use characterisation and change analyses.

Table 6. Dominant land use in Fuluasou River Catchment (FRC), 2013

DOMINANT LANDUSE	AREA (ha)	PERCENTAGE OF TOTAL LAND AREA (%)
Built-up area	995.42	21.843
Forest	719.89	15.797
Forest Plantation	22.91	0.503
Secondary Forest	907.76	19.920
Grassland (livestock)	195.86	4.298
Infrastructure	15.89	0.349
Lake	11.58	0.254
Mangrove	16.80	0.369
Mixed cropping	239.06	5.246
Agriculture Plantation	1394.22	30.595
River and creeks	0.40	0.009
Scrub	29.63	0.650
Wetland	7.65	0.168
TOTAL	4557.066 ha	100 %

Table 7. Proportion of land use change in the four main land use types from 1999 to 2013

LANDUSE TYPE	LAND USE AREA (ha)		PERCENTAGE OF TOTAL LANDUSE AREA (%)		LANDUSE CHANGE (%)
	1999	2013	1999	2013	
Forest (FO)	2248.496	1666.35	49.3	36.6	↓ 12.70%
Agriculture (AG)	970.13	1462.91	21.3	32.1	↑ 10.80%
Grassland (GR)	218.4	195.86	4.8	4.3	↓ 0.50%
Built-up area (BUA)	1120.04	1231.946	24.6	27.0	↑ 2.40%
TOTAL	4557.066 ha	4557.066 ha	100%	100%	

The results of the land use change analysis showed in Table 7 revealed FRC is currently dominated by forest which accounts for 36.6% of the total land use area. However, the forest land use area has reduced by 12.70% since 1999, as illustrated by the 'red' arrow that shows the decreasing trend. Unlike forested lands, agriculture has increased by 10.8% since 1999. The common agriculture practice in Samoa is 'shift cultivation' for mixed cropping (e.g. taro, banana and vegetable gardens) and plantations (mainly taro crop and banana). This shifting cultivation can explain the main cause of a decreasing in forest land, as agriculture patches extend into the upland areas. This situation was observed during the initial reconnaissance survey and also during sampling activity from STN1 to STN3, and along the main river system going downstream (e.g.

STN4–STN10). Most of the agriculture developments are for subsistence purposes, as taro and banana are staple foods in Samoa. A few small (eg. 0.2 hectare, 1 acre = 0.405 hectare) to medium scale (eg. 0.4 to 0.81 hectares) farms were also for commercial purposes supplying the local produce market.

The built-up area (BUA), on the other hand, currently accounts for approximately 27% of the total land use area of the catchment. A slight increase of 2.4% is due to some new residential build-up developments around the villages of Siusega and Vaitele, through urban sprawl at the low-lying area of the catchment. These two villages have the highest population out of all 20 villages in the catchment (refer to the Table 2 & Fig. 6). The population of Vaitele is 35% higher than other villages, and Siusega, as the second populated village, records 11% of the total population living in the catchment (GoS Bureau of Statistics, 2011). The extension of infrastructure for Samoa's only sports complex at Tuana'imato, at the lower mid-catchment of the FRC, also adds to the increase of the built-up area since 1999.

Grassland currently accounts for approximately 4.3% of the total land use area in the catchment. There has been a minor reduction in grassland areas of approximately 0.5% since 1999. The small proportion of grassland areas can be explained by agriculture activities extending upland and taking over those lands previously occupied by cattle farms on the far south-western upland of the catchment. This can be seen in a comparison of agriculture land use area and grassland on the western part of the upper catchment (Figure 29 & 30).

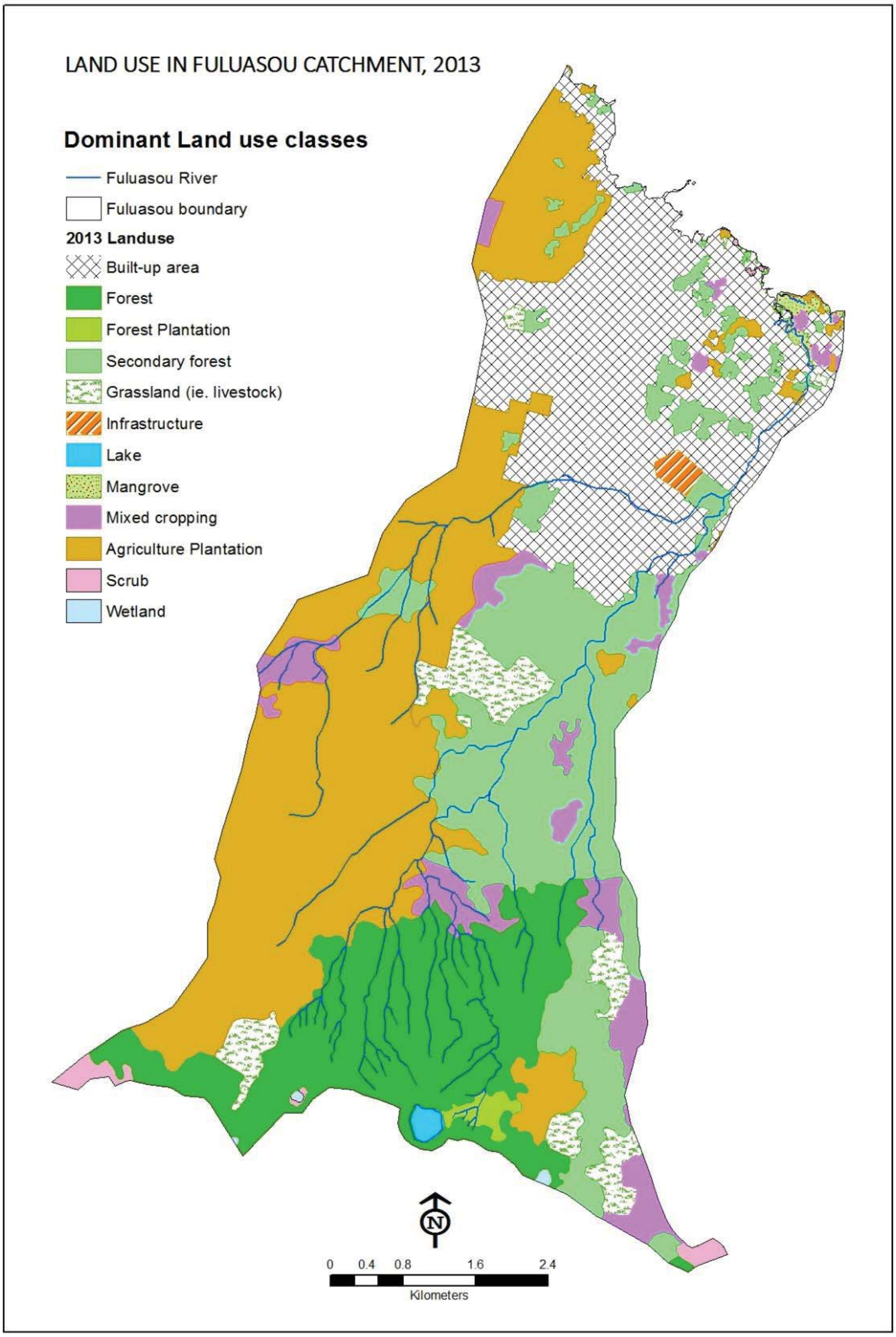


Figure 29. Land use map of FRC (constructed) showing dominant land use classes, 2013.

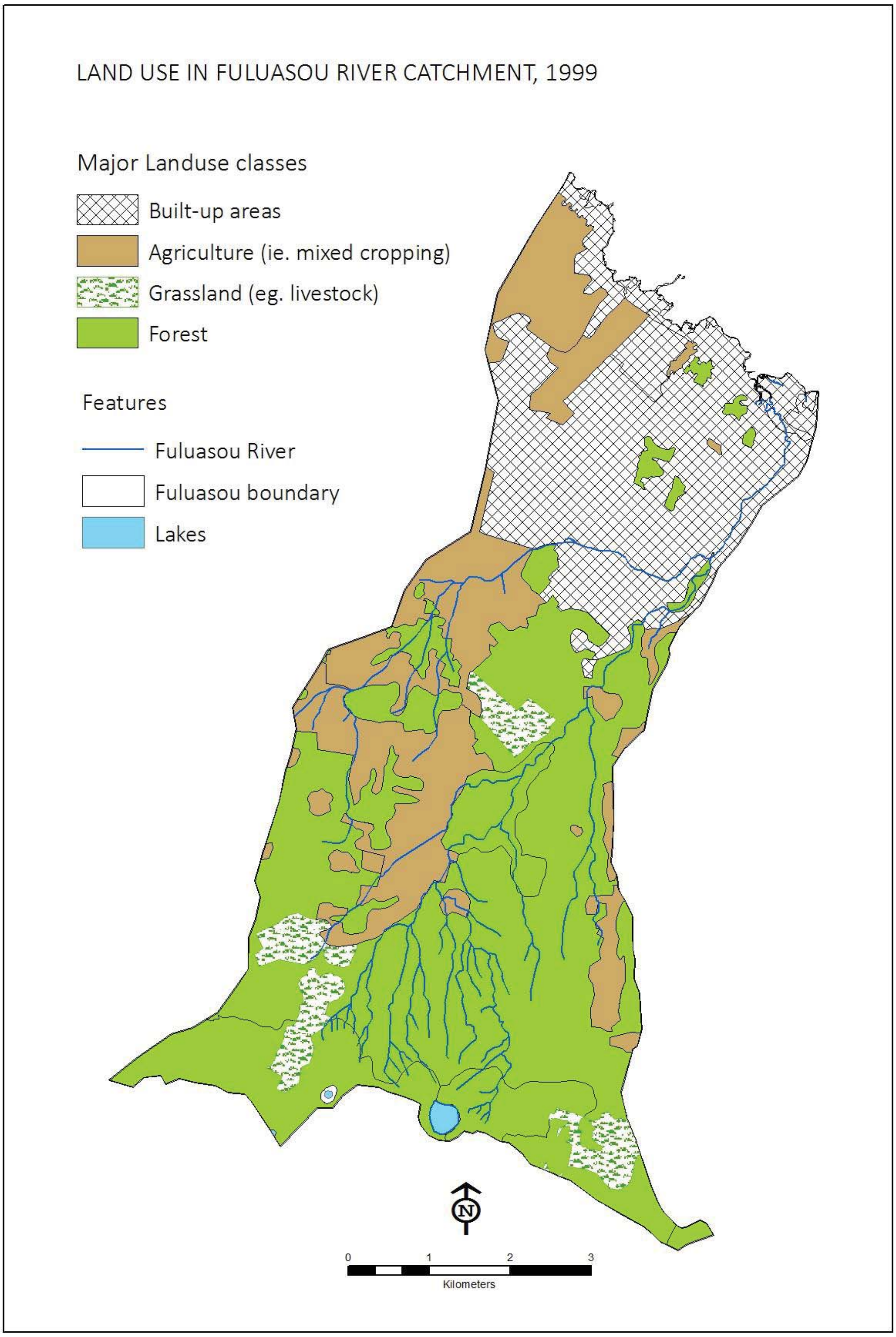


Figure 30. Major land use classification constructed of FRC, 1999

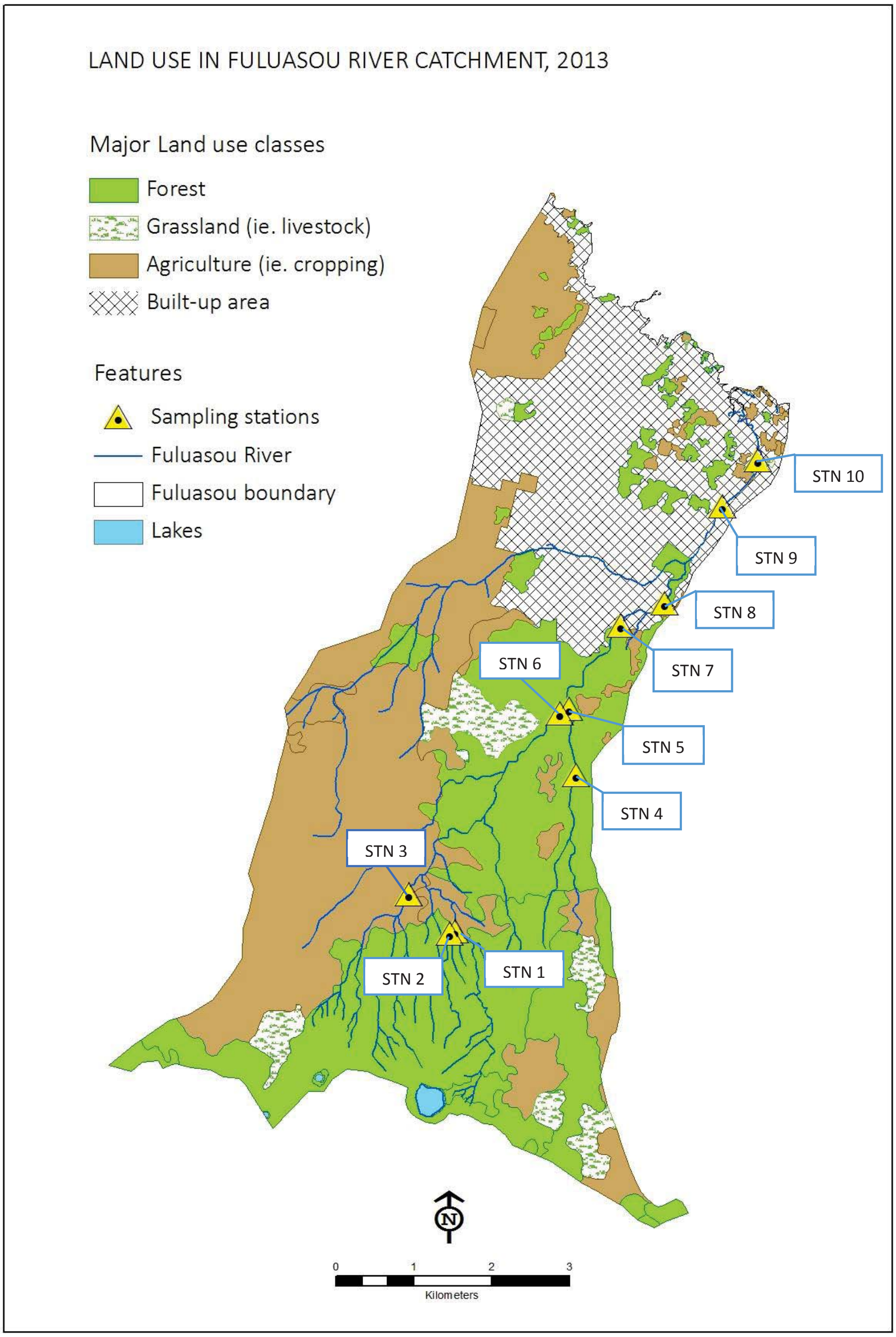


Figure 31. Major Land use classification constructed of FRC, 2013

5.3 Catchment delineation & Land use distribution

The result of GIS catchment delineation analysis is shown in Figure 32 where ten sub-catchment were defined by each corresponding station, therefore a total of ten sub-catchments were delineated to analyse the four major land use types composition: forest, agriculture, grassland and built-up areas within each sub-catchment to be used in the land use analysis.

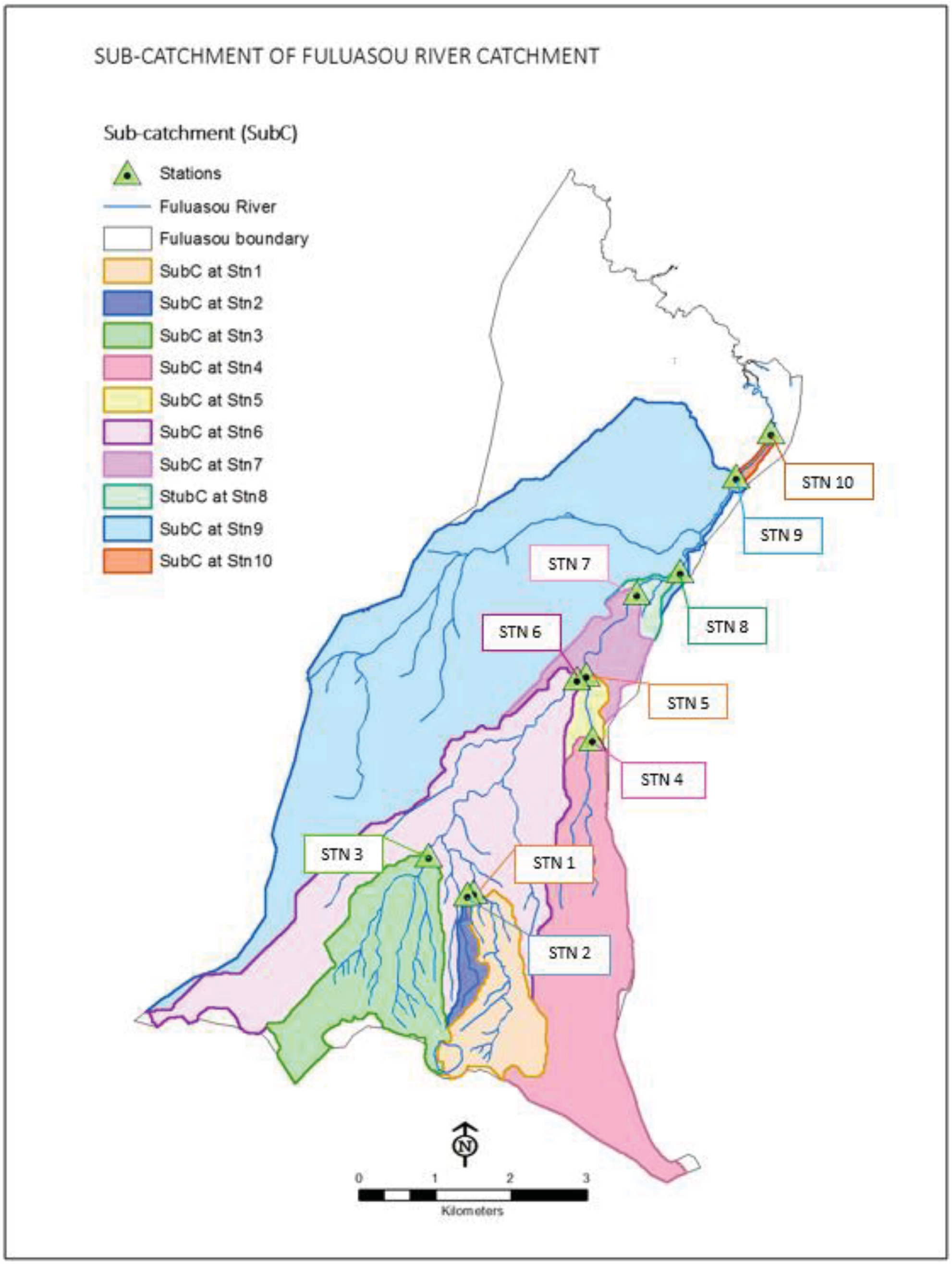


Figure 32. Map of 10 sub-catchments delineated at each sampling station (STN)

The ten water sampling stations (STN1-STN10) for this study were located across a range of land uses within the catchment (Fig. 31). The study focused on four main types: forest (FO), agriculture (AG), grassland (GR) and built-up area (BUA) as land use indicators. Each sampling station corresponds to one or more types of land use. Hence, the FRC was first delineated into 10 sub-catchments, each defined by a sampling station. Land use area, in percentage (%) of each land use for each sub-catchment, was extracted and presented in Fig. 33 as a result of ArcGIS sub-catchment delineation analyses.

Figure 33. Proportion (%) of different main land use types within each sub-catchment

Forest is the dominant land use in the upper catchment of the FRC with STN1-STN3 comprising forest land use area of 87.8%, 99.9% and 79.9% respectively (Fig. 33). There were relatively small areas of agriculture activities, such as mixed cropping, for example taro and banana plantations, identified upstream from sampling stations STN1, STN2 and STN3, with a proportion of land use area of 12.2%, 0.10% and 16.6% respectively. These agriculture lands are currently cultivated by families who own those lands under customary rights.

At STN2, forest almost entirely covers the sub-catchment upstream, except 0.09% of the current land is cultivated for mixed banana and taro plantations, in addition to a watercress farm located in the stream path approximately 30 metres upstream from STN2. On the western side of STN2, a family taro plantation is located on the edge of a land drop off from a 70° slope down to STN2 and the plantation was observed extending further upland.

The STN1 and STN2 were located in the upper part of the catchment about 30 metres upstream from the two water supply intakes, Chinese 1 and Chinese 2. Both intakes are currently untreated water supply systems and they are recorded in the SWA Drinking water safety plan for Fuluasou (DWSP) as unprotected intakes (SWA, 2011). These intakes serve mostly the western part of the catchment for people residing in those areas.

The medium catchment segment indicates a decrease in forest areas, descending downstream, with agriculture area increasing from 12.2% in STN1 to 29.8% in STN6 and 37.86% in STN10. The majority of the stations located in the mid-catchment (STN4-STN7) have more than 20% of agriculture, compared to 12.18%, 0.09% & 16.65% in STN1 to STN3 in the upland catchment. This change of land use proportion can be explained by agriculture activities (such as plantations and mixed cropping) increasing from the upper catchment to the medium catchment. Also, following the same trend, moving downstream, more families are living in the mid-catchment, compared to the upper-catchment, where only families who have land reside close to their lands. Grassland (indicating cattle farms and livestock development) are also commonly found in the mid-catchment, with the largest grassland area of 14.18% in the sub-catchment defined by STN4 (Fig. 33). The STN4 and STN5 record more than 13% of grassland, which is referred to in this study as livestock grazing and cattle farming areas. The topography of the mid-catchment, where most of the lands are capable for agriculture and cattle farming on nearly flat areas, can also help to explain the increase in agriculture land downstream. The same situation occurs, with more families cultivating taro and banana plantations, which results in an increase in the use of agriculture lands descending downstream to the lower catchment. Furthermore, the lower catchment, where STN8 to STN10 were located, indicates a continuous increase in agriculture land use areas with STN9 and STN 10 comprising over 37%, compared to 29.8% in STN6 as a maximum agriculture land area in the middle segment. The surrounding land use type around these stations is more noticeable for built-up areas, mainly residential, business ventures and government infrastructures, due to the land's suitability for such development (including forests) because of its flat characteristics. Consequently, people cut down trees and allow developments, such as agriculture, cattle farming and the extension of residential areas with new houses. Moreover, the government is extending its infrastructure development at its major sport compound at Vaitele. Therefore, the number of forested areas has decreased from the upper catchment moving downstream to the lower catchment (Fig. 33).

5.4 Flow Discharge

Measuring river discharge is important for water management and the allocation of water for developments, for example irrigation for agricultural use. In order to monitor water quality and pollution levels of a river system, it is important to know how much water flows into the system. Flow plays an important role, as flow affects the level of water quality concentrations that may lead to pollution levels. Moreover, any dramatic drop in flow discharge, causing low flow across the system, would affect aquatic biodiversity and the ecological health of the river system.

The unreliable and inconsistent with the historical hydrological data as identified in the available hydrological datasets from the Water Resources Division of the Ministry of Natural Resources and Environment could not be used as an existing river flow analysis that could include data from wet seasons for comparison analysis. However, the river flow data presented and discussed in this chapter is based on the flow discharge measurements for the Fuluasou River during the dry period from August to October, 2013. The rainfall data during the three months sampling period were not available from the Meteorology Office which therefore couldn't be able to conduct further river flow discharge analysis against rainfall.

In this study, the river flow discharge was measured at every STN, in order to monitor flow discharge throughout the three months period of the field work. During the sampling period, there was a 'cut off' period of more than two months for STN1, due to low flow that ended up dried out throughout the lower reaches of the catchment before reaching the STN10 in most of the sampling events. The discharge was monitored throughout the six sampling events at every STN, except STN10 (it managed only two measurements for the first month of sampling), STN9 (only four measurements) and STN8 (five measurements). These stations had 'no water' during field monitoring, due to the river being dried out towards the lower stretches of the lower catchment during these sampling dates: 11/09/2013, 25/09/2013, 9/10/2013 and 23/10/2013 (Table 8).

Table 8. Flow Discharge of Fuluasou River across different STNs over three months (Aug-Oct), 2013

Sampling STN	Discharge (m^3/s)						Mean (mean±std)
	14/08/2013	28/08/2013	11/09/2013	25/09/2013	9/10/2013	23/10/2013	
STN1	0.016	0.067	0.025	0.042	0.030	0.0207	0.034 ±0.019
STN2	0.023	0.030	0.044	0.018	0.020	0.0208	0.026 ± 0.010
STN3	0.008	0.016	0.013	0.008	0.009	0.004	0.010 ± 0.004
STN4	0.536	0.270	0.272	0.287	0.247	0.227	0.307 ± 0.114
STN5	0.015	0.027	0.027	0.081	0.029	0.025	0.034 ± 0.023
STN6	0.132	0.160	0.211	0.152	0.119	0.055	0.138 ± 0.052
STN7	0.093	0.136	0.100	0.059	0.025	0.020	0.072 ± 0.046
STN8	0.027	0.086	0.037	0.015	0.013	*	0.030 ± 0.030
STN9	0.022	0.060	0.019	0.019	*	*	0.020 ± 0.022
STN10	0.001	0.047	*	*	*	*	0.008 ± 0.019

*No river flow measurement taken due to river dried out at lower reach of the lower catchment

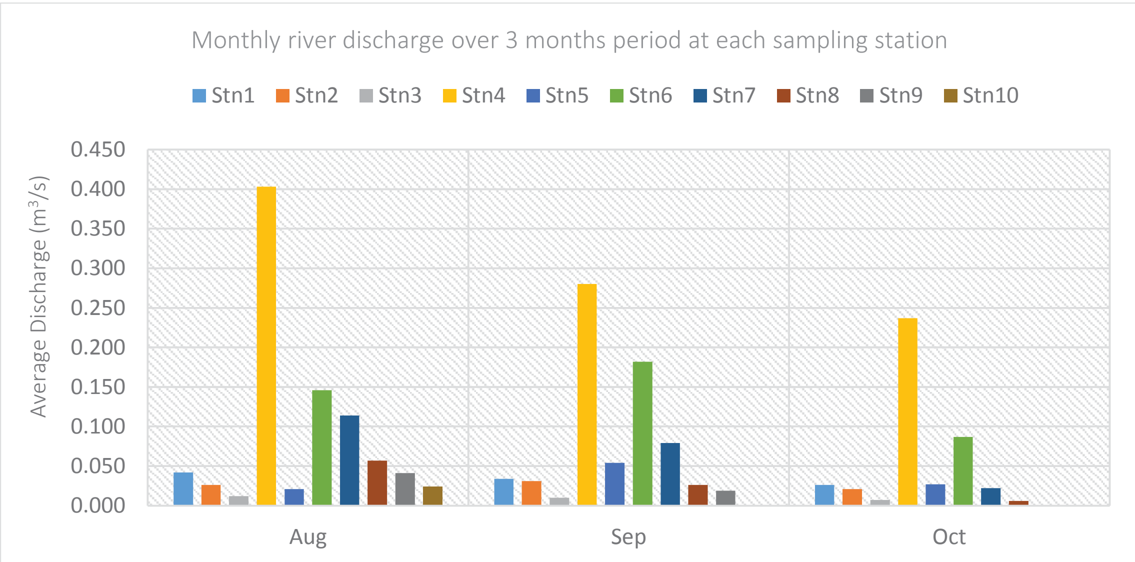


Figure 34. Monthly average flow for Fuluasou River during sampling period

The analysis of flow discharge by STN varied between 0.008 ± 0.019 and 0.307 ± 0.114 over the three months (Table 8). However, the STN4 has the highest flow discharge of all, with a mean of 0.307 ± 0.114. Since the lower catchment STNs (8-10) had only a few measurements because the river dried out at the lower reaches of the catchment during monitoring over the three months, these STNs at the lower reach (eg. STNs 8-10) were omitted from the river discharge analysis. Therefore, it can be stated that the flow discharge of the FRC varied between 0.034 ± 0.023 (STN5) and 0.307 ± 0.114 (STN4). There is obviously a decreasing trend of river discharge at every STN over the three months, as shown in Figure 34. The reason may be explained by the fact that, during the course of monitoring, there was a number of government development activities identified that could have affected the normal flow regime of the catchment from different tributaries upstream. For instance, the two separate river tributaries that feed the two water supply intakes on the upland, where STNs 1 and 2 were located, were observed to be diverted due to construction work by the contractor working on the renovation project of SWA for the two water intakes (Chinese 1 & 2) and for construction of the road ford to allow accessibility to the two intakes. River discharge in STN3 was affected towards the end of the monitoring, due to the opening of the newly established SWA treatment plant that feeds from the same tributary, but further upstream. This can be seen through a significant drop in the average flow in STN3 from 0.009 m^3/s to 0.004 m^3/s at the last measurement (Table 8). Other climatic factors could also have affected the measurement, such as rainfall on the upland area, but observations towards the end of the monitoring found the flow level in STN3 decreased significantly when SWA opened its treatment plant a week before the last monitoring. This disruption of flow regime upland at STN3 could also explain the drop of river flow at STN 6 downstream during the same period from 0.119 m^3/s on the 9th Oct, 2013 to only 0.055 m^3/s. The river tributary where STN6 is located is a main branch formed by several tributaries from upland, where STNs 1-3 were located. Furthermore, STN5 is evident of flow reduction, as a result of the SWA water supply intake feed by the Fuluasou eastern branch. This can be explained by a significant difference in the average flow at STN 4 (0.307 ± 0.114) located above the water intake, and sampling STN 5 (0.034 ± 0.023) located downstream on the same river branch. The disruption continues to STN7 to STN10 located downstream at the lower catchment. During the field monitoring, the main reason behind this disruption of the river normal flow regime was affected by what has been identified as the old Electric Power Corporation Hydro Dam (Figure 20b), a major development obstruction identified that disrupt the natural river flow regime affecting the environmental flow of the catchment at its lower reaches because the dam retains most of the water with less overflow to feed the lower reaches of the catchment. This is similar to the study of Poff et al. (1997) who found a dam as being the most obvious direct modifiers of river flows. The old EPC hydro dam is severely affecting the flow of water downstream at the lower catchment, especially during a prolonged dry period. This could be the result of having no water reaching the STNs located further down the lower catchment (STN8-STN10) into the last 3 months of the dry period as reflected in the reduction of results of river flow discharge towards the lower reach of the lower catchment.

5.5 Status of river water quality of FRC and its tributaries

5.5.1 Concentrations of water quality parameters relative to their benchmark values

The status of water quality in the Fuluasou River has not been assessed fully, despite the current water quality monitoring conducted by some government ministries (e.g. MNRE, MoH and SWA). Assessing water quality status is crucial, comparing the measured water quality parameters with the water quality standards for public health and ecosystem health risk management.

Table 9 summarise descriptive statistics analysis of measured water quality parameters of the water samples in ten sampling stations. The values have been analysed and presented as a total mean concentration for each water quality parameter for all 53 measurements assessed during the month period, August, September and October, 2013. The highest mean concentration that exceeds the water quality guidelines, as summarised in Table 8 implies degrading conditions and a potential threat to public health and ecosystem health of FRC.

In order to summarise the performance of compliances for each water quality parameter as a result of the measured mean concentrations in Table 9, the results have indicated all water quality parameters have their mean concentration values below the permissible standards, except pH which total mean concentration values of 8.4 ± 0.48 is relatively above the allowable unit range of 6.5-8.5 (WHO, DWSNZ/ANZECC & SNDWS), and Total coli and E. coli found exceeds more than their allowable units (eg. 0/100 mL) (Table 9). These results suggest that out of 53 water quality parameters tested for pH, 26 samples did not comply with drinking and aesthetic water standards and that revealed 49% of non-compliances. For Total coliform and E. coli, all the 53 water quality samples tested and analysed exceeds 100% non-compliances. All samples for both parameters were failed to comply with the drinking and aesthetic standards, which drinking must not be detected in any 100 mL sample (SNDWS), must be less than 1/100 mL (WHO & DWSNZ/ANZECC), and for aesthetic standards that must be <260 (DWSNZ/ANZECC).

The measured turbidity, NO_3^- and TSS have recorded their coefficient of variation (CV) values of 44.4%, 38.9% and 37%, respectively. Their CV values are observed to be very high, compared to the other parameters (Table 8). This indicates a high degree of variability of these parameters amongst their measured values between sampling stations representing different segments of the catchment (e.g. upland, medium and lower catchment). The coefficient variation values for other water quality parameters: Temperature, pH, Conductivity, TDS, DO, Total P, Total N, Total coliform and E. coli, were found to be 5.7%, 20.7%, 20.7%, 6.2%, 19.9%, 6.7%, 18% and 18.1%, respectively. These results indicate a very low variation amongst their measured values at different sampling stations. Similar coefficient variation results for pH, TDS and Conductivity were recorded in the water quality study by Heydari et al. (2013) in Kashan city in Iran.

Since pH is not valid to calculate mean values at or below 7 for acidic condition with pH values at or above 7 for alkaline condition, the 'true average value' for pH was defined by using -log_10[ΣC_i)/(n)], where '*C*' is the concentration of hydronium ion and '*n*' is the number of measurements. Thus, the true average for pH was calculated to be 8.3 in which its mean concentration falls within the acceptable level ranging from 6.5 to 8.5 for both drinking standard and aesthetic according to the World Health Organisation (WHO) (WHO, 2008) guidelines and the Drinking Water Standards of New Zealand (DWSNZ) (Ministry for Environment, 2003) and the National Drinking Water Quality standard for Samoa (SNDWS) (Ministry of Health, 2009). All other water quality parameters except Total coliform and E. coli have less concentration values and they are within the standards and guidelines of the WHO, SNDWS and DWSNZ for both drinking and recreational purposes.

The level of Total coliform and E.coli are two important characteristics of water quality for drinking and recreational purposes. The results show Total coliform mean (± sd) of 9923 ± 1782 higher than the permissible limit for both drinking standards and aesthetic guidelines, and is similar with E. coli, with a mean (± sd) of 7431 ± 1347 for all water samples. This is an indication of a high level of microbial pollution in the FRC. This situation can be explained by the number of point sources of waste discharge that have been identified along the edge of the river and possible discharges from agriculture cattle farms located on the upper catchment. These waste discharges are from nearby houses located along the edge of the river and from a pipe source extending from a community and church congregational hall (Harvest Centre at Lotopa). Those point sources were identified along the river bank between STNs7 and 9. A similar results to the ones that describes a septic tank discharge as a human pollution source as stated in the Drinking Water Safety Plan (DWSP) of the Fuluasou water supply system (SWA, 2011).

Feral animals, such as pigs, roam the lower catchment especially by the riverbank, where several animal resting spots under scrubs and tree shades were identified. Similar observations noted that feral animals, such as wild pigs, are mentioned in the DWSP plan (SWA, 2011). Moreover, families living along the riverbank have their pigsty located just across from the edge of the riverbank (near Station 9). Further upstream in the medium catchment, approximately 50 metres from STN6, is a medium-scale poultry farm for commercial production and a cattle farm. Further above from STN5 approximately 200 meters upstream, animals, such as horses, are owned by families living around the area and they are used by local people as their mode of transportation to their farmland. Cattle farms owned by families living on the upper catchment and located upstream from STNs 1, 3 & 4 could also contribute to higher E.coli and Total coliform values.

The implication of these high values of T.coli and E.coli for public health safety is crucial, as two of the sampling stations (1 and 2) were located upstream from the two SWA's untreated water intakes. These intakes (Chinese 1 and Chinese 2) are not only untreated, but they are open sources (unprotected) of water supply (Figure 35-38). Given the high counts of both Total coliform and E. coli, immediate attention from the government is required, as these two intakes serve the majority of western parts of the catchment for families living around those areas. The Samoa National Drinking Water Standards (2008) standard values, states that the bacteriological quality of drinking water for both treated and untreated water entering the distribution system, E. coli and Total coliforms must not be detected in any 100 mL sample (0/100 mL) (Ministry of Health, 2008). Thus, the results for example the E.coli suggests more than 7,000 times higher than the acceptable standard values. This requires some serious consideration for risk management from the Ministry of Health, SWA and the Ministry of Natural Resources and Environment (MNRE).

Figure 35. Chinese 1 water intake overlooking upstream

Figure 36. Chinese 1 water supply entry point

Figure 37. Chinese 2 water intake view from upstream

Figure 38. Chinese 2 where river water flows into the intake

Table 9. Descriptive statistics of total mean concentrations of 12 water quality parameters with standard measures

Water quality parameter	Units	Drinking Water Standards			Aesthetic Standards		Mean (± Std)	CV (%)	Range	
		[1]WHO Guidelines	[2]DWSNZ/ ANZECC	[3]SNDWS	DWSNZ/ ANZECC	SNDWS[3]			Min	Max
Temp	(°C)	-	-	-	-	-	27 ± 3.521	13.0	21.3	36.2
pH	-	6.5-8.5	6.5 – 8.5	-	6.5-8.5	6.5 - 8.5	ϕ8.3 (True AVG)	5.7	6.9	9.3
COND	µS/cm	1000	**	-	**	1000	124.2 ± 25.73	20.7	60.5	163.1
TDS	mg/L	1000	-	-	1000^	1000	62.1 ± 12.88	20.7	30.3	81.6
DO	mg/L	-	-	-	-	-	8.96 ± 0.558	6.2	8.08	10.06
TUR	NTU	5	-	<5	<2.5	5	1.3 ± 0.557	44.4	0.35	3.04
TOTAL P	mg/L	45	-	-	-	-	0.01 ± 0.0026	19.9	0.01	0.021
TOTAL N	mg/L	10^^	-	-	0.6	-	0.24 ± 0.0159	6.7	0.208	0.268
NO_3^-	mg/L	50	50	50	-	-	0.01 ± 0.0032	38.9	0.002	0.016
T coli	no/100ml	<1	-	0/100	-	†	9923 ± 1782	18.0	6700	15000
E. coli	no/100ml	<1	<1	0/100	<260@	†	7431 ± 1347	18.1	3800	9700

[1] World Health Organization Guidelines for Drinking Water Quality, 2006
[2] Drinking water standard for New Zealand 2005 (Revised 2008)/ANZECC (1992)
[3] Samoa National Drinking Water Standards, 2008
- Not available
^ Taste may become unacceptable from 600-1200 (NZDWS, 2005)
^^US-EPA Drinking water standards
The '±' indicates standard deviation of the mean
**Conductivity standards for health and ecosystem related were not available in DWSNZ, however, there are aesthetic guidelines for TDS in the DWSNZ.
@Microbiological water quality guidelines for marine and freshwater recreational areas
Red values: indicate water quality concentration exceeding the established standard values
† Samoa National Drinking Water Standards, 2008 only have T. coli & *E.coli* standards for Drinking Water for treated water (0/100mL) and untreated water entering the distribution system.\
ϕArithmetic average calculated as: Σ pH / n; whereas the **'true average'** defined as: -log_10[ΣC$_i$)/(n)], where 'C' is the concentration of hydronium ion and 'n' is the number of measurements

5.5.2 Spatial variation of water quality parameters among sampling stations

This research assessed the status of the Fuluasou River on a catchment scale, as a holistic approach to how water quality varied across the catchment, from upland to lowland areas. The following section presents the spatial variations trend of water quality concentrations at the different sampling stations. The ten stations were defined by different segments of the catchment: upper catchment (i.e. STNs1-3), medium catchment (i.e. STNs4-7), and the lower catchment (i.e. STNs 8-10). Physicochemical results of analysis can explain the comparison between these three main segments. The difference through varied concentrations across sampling stations signifies the spatial variability of water quality change across the catchment over space and time.

Table 9 summarise the total mean concentration values of each water quality parameter with the coefficient of variation values (CV) for the Fuluasou River. Water quality permissible standards values (WHO, DWSNZ/ANZECC & SNDWS) for drinking and aesthetic purposes also presented in Table 9 to compare with results of water quality analysis. Table 10 and 11 presents the mean values and standard deviation for every water quality parameter at every station in different segments of the catchment. Figure 39 (i-xi) presented a graphical representation of water quality variability amongst sampling stations across the catchment.

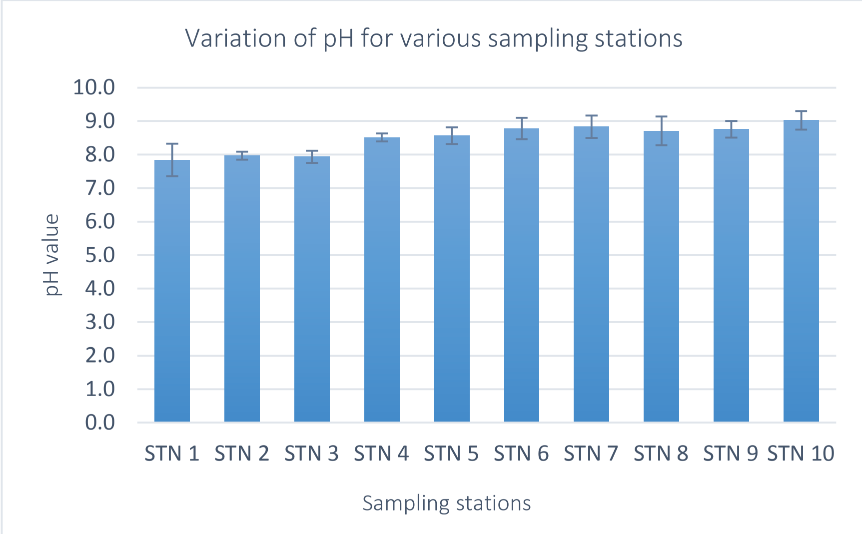
The standard variations were calculated using the *'Pivot charts'* tools in *'Table function'* of Excel 2013 and then incorporated, as seen on each graph, which gives an indication of how much variability occurs within the data set of each parameter's measurement for every station. Table 10 also summarise the standard variations that will be later referred to in the discussion.

Table 10. Mean concentrations of water quality parameter for every sampling station and flow discharge across different parts of the catchment

Catchment segment	Stations (STN)	Temp °C	pH	COND *(µS/cm)*	TDS *(mg/L)*	DO *(mg/L)*	Turbidity *(NTU)*	Total P *(mg/L)*	Total N *(mg/L)*	NO_3^- *(mg/L)*	T.Coli *(cfu/100ml)*	*E.coli* *(cfu/100ml)*	Discharge *(m^3/s)*
Upper	STN 1	22.7	7.84	74.7	37.4	8.56	1.53	0.013	0.233	0.006	11267	7350	0.03369
	STN 2	23.7	7.97	97.7	48.8	8.32	1.86	0.013	0.227	0.005	11417	7492	0.02607
	STN 3	26.8	7.93	116.5	58	8.51	0.95	0.013	0.228	0.006	9742	7417	0.00972
Medium	STN 4	24.5	8.51	149.5	74.8	8.61	1.09	0.012	0.232	0.009	10025	7667	0.30669
	STN 5	26.3	8.57	153.6	76.7	8.74	0.95	0.013	0.232	0.010	10842	8492	0.03386
	STN 6	28.2	8.78	129.9	65	9.44	1.05	0.013	0.235	0.011	8908	7492	0.13827
	STN 7	28.9	8.83	135.6	67.9	9.76	1.03	0.014	0.235	0.009	8233	6308	0.07192
Lower catchment	STN 8	31.2	8.71	130.6	65.8	9.63	1.13	0.014	0.248	0.010	8970	7640	0.0356
	STN 9	31.7	8.76	130.8	65.4	9.07	1.69	0.016	0.256	0.010	11150	8175	0.02966
	STN 10	31.2	9.03	129.9	65	9.45	1.68	0.011	0.252	0.002	6925	4825	0.02433

Table 11. Standard deviation (Std) of water quality parameter across sampling station

	Temp (°C)	pH	COND (µS/cm)	TDS (mg/L)	DO (mg/L)	Turbidity (NTU)	Total P (mg/L)	Total N (mg/L)	NO_3^- (mg/L)	T.Coli (cfu/100ml)	*E.coli* *(cfu/100ml)*	Discharge (m3/s)
STN 1	1.30	0.49	9.15	4.54	0.16	0.73	0.004	0.01	0.00	1976.8	1248.2	0.02
STN 2	0.87	0.12	4.64	2.33	0.15	0.75	0.002	0.01	0.0008	781.5	1645.4	0.010
STN 3	2.27	0.18	7.36	3.90	0.04	0.57	0.0033	0.0076	0.0016	865.7	1762.9	0.004
STN 4	0.35	0.12	7.71	3.84	0.13	0.32	0.0014	0.0122	0.0008	1714.9	969.9	0.11
STN 5	1.76	0.25	7.39	3.79	0.31	0.38	0.002	0.009	0.003	2139.3	646.9	0.02
STN 6	2.98	0.32	15.04	7.47	0.25	0.35	0.0031	0.0114	0.0011	1303.6	639.9	0.05
STN 7	1.78	0.33	14.43	7.22	0.24	0.38	0.0014	0.0269	0.0047	1195.7	1341.1	0.05
STN 8	3.33	0.43	13.73	6.82	0.49	0.26	0.0022	0.0159	0.0030	778.3	911.3	0.03
STN 9	3.02	0.24	11.39	5.70	0.17	0.41	0.0038	0.0166	0.0014	749.4	1071.2	0.02
STN 10	1.06	0.28	2.26	1.13	0.33	0.03	0.00000	0.02263	0.00000	106.1	1449.6	0.03



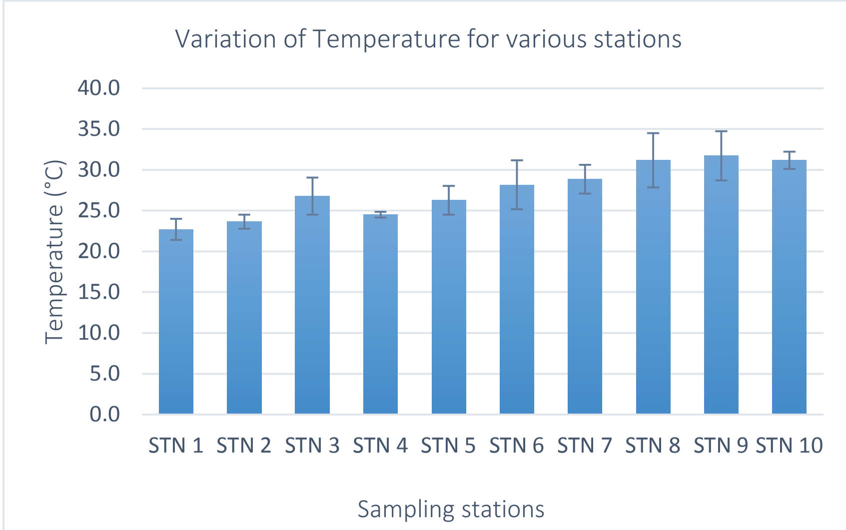
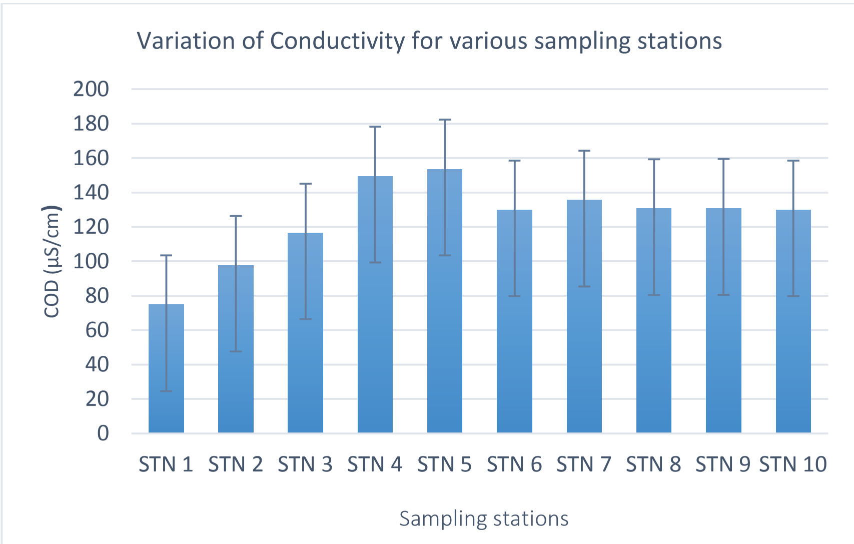
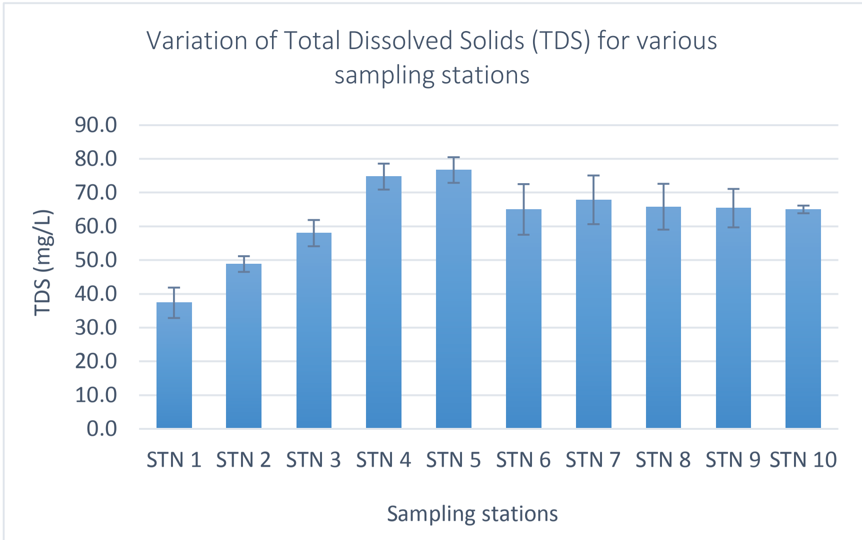
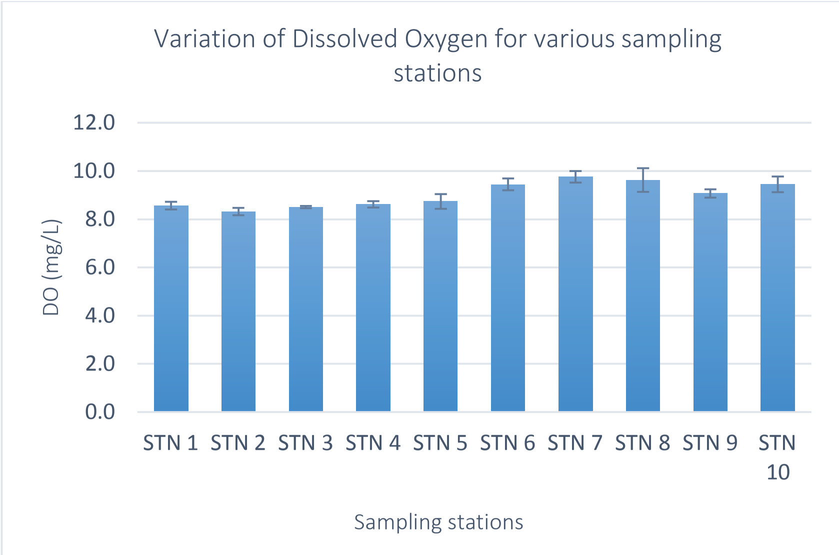


Figure 39 (i-xi) (i) pH (ii) Temperature

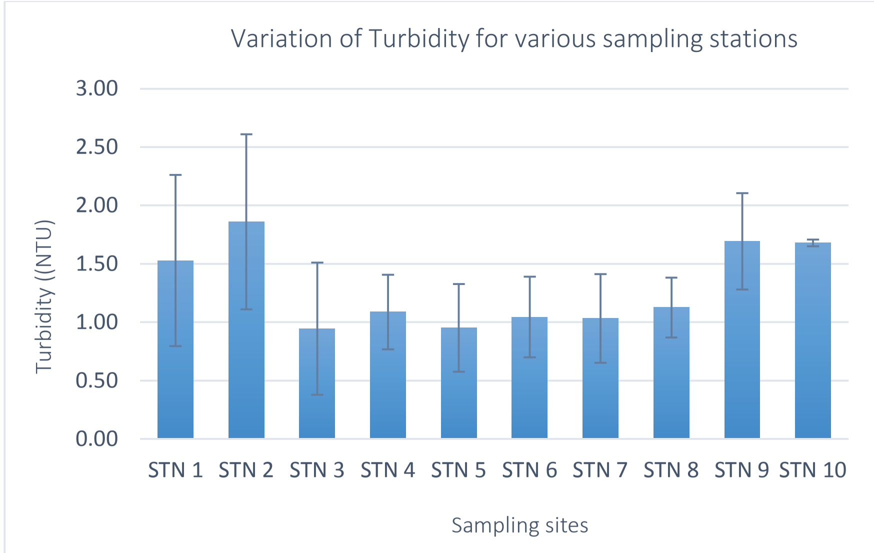




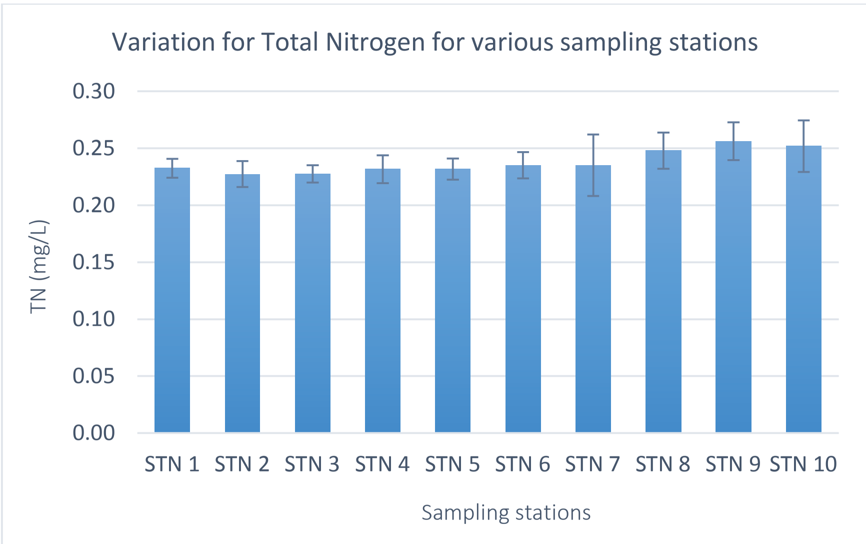
(iii) Conductivity (iv) Total Dissolved Solids



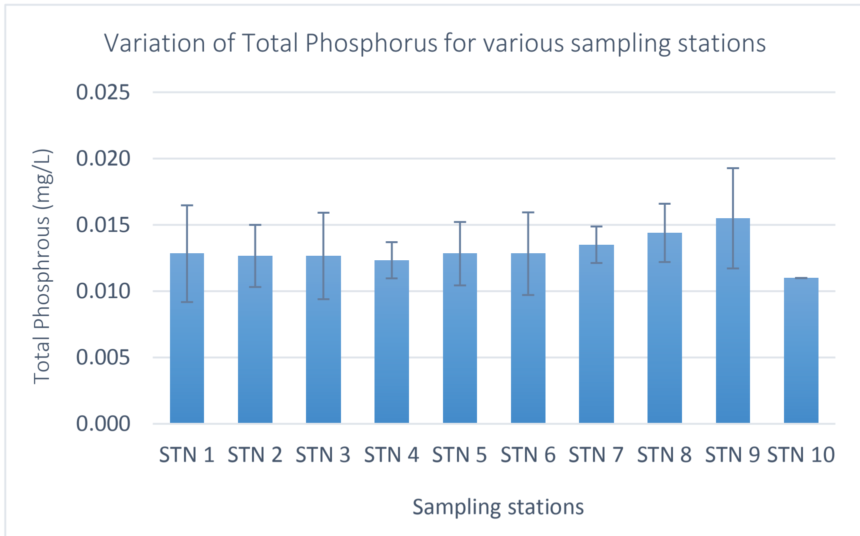
(v) Dissolved Oxygen



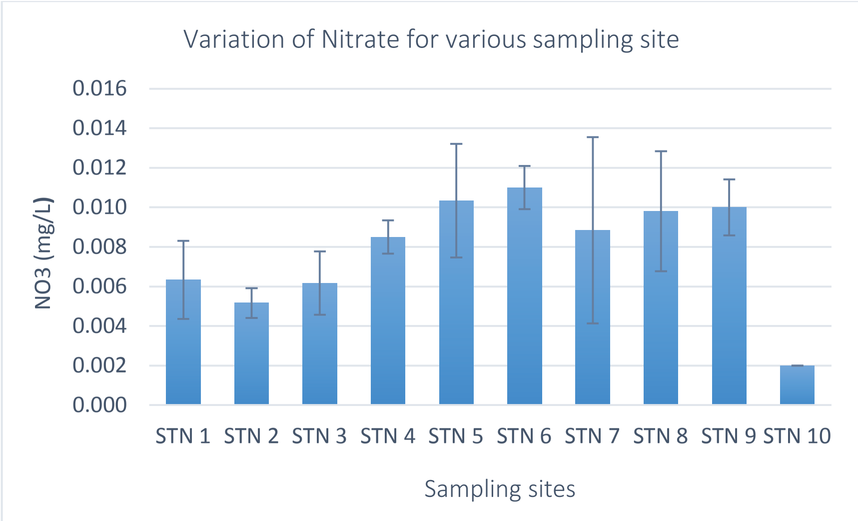
(vi) Turbidity



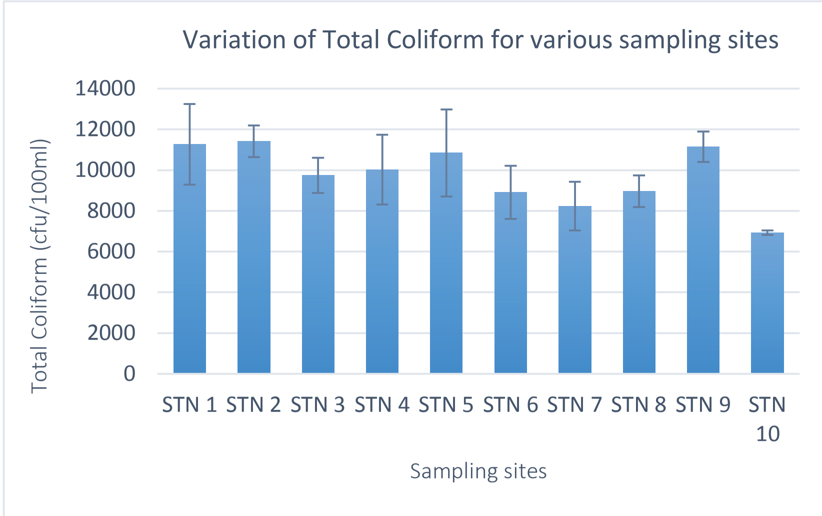
(vii) Total Nitrogen



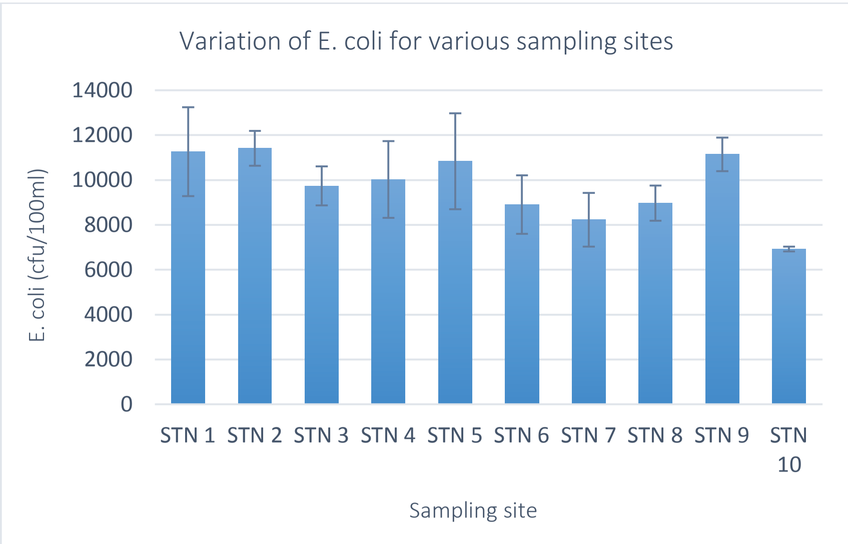
(viii) Total phosphorus



(ix) Nitrate



(x) Total coliform



(xi) E.coli

5.5.2.1 pH

The pH is an indicator to measure how acidic and alkaline is the condition of water status (Zeb et al., 2011). The pH standard of water for any purpose ranges from 6.5 to 8.5 (Chergui et al., 2013). When pH level is extremely high or very low from the standard of 6.5-8.5 it makes the water unsuitable for human purposes and sensitive to organism survival. For Fuluasou River, the measured pH amongst stations varied between 7.84 ± 0.49 and 9.03 ± 0.28 (Table 10-11, Fig. 39 (i)) indicating a moderately alkaline water condition. Figure 39 (i) shows a slightly increasing trend of pH from upland (STN1-STN3: 7.84, 7.97 & 116.5) going downstream (STN4-STN7: 8.51, 8.57, 8.78 & 8.83) to lower catchment (STN8 & STN9: 8.71, 8.76). The coefficient of variation of 5.7% for pH indicates less variability across the catchment. However, the highest pH mean value of 9.03 is recorded at the Station 10 located in the lower stretch of the catchment, while the lowest mean pH value of 7.84 is recorded at the Station 1 in the upper catchment. The increasing trend of pH from upland to lower catchment appear to be associated with increasing in settlements along the river banks, indicating a possible increasing use of alkaline detergents by the locals who often use the river for bathing and washing. This practice has been identified along the river especially from the mid to lower catchment (eg. man-made bathing pool with signs of soap and detergents labels). Increasing pH levels towards the lower reach of the catchment to STN10 could also be a result of solid waste disposal most commonly observed at the mid to lower catchment near residential areas. Also observed at the lower catchment was drainage from the main road into the river that may carry chemical contaminants into the system. The geology make-up of the underlying water source may also contribute to the change in mean pH levels across the catchment.

5.5.2.2 Temperature (TEMP)

Temperature has a significant effect on the ecological life of rivers, by affecting the solubility of oxygen in water (Kataria et al., 2011). In this study, the mean (± std) temperature varied between 22.7 ± 1.30°C and 31.7 ± 3.02°C, with higher temperature levels recorded in the lower reaches of the catchment at STN 9 (31.7 ± 3.02°C) and STN 10 (31.2 ± 1.06°C), and the lowest value of temperature was recorded at STN 1 in the upper catchment (forested area) (Figure 39 (ii)).

Temperature follows an increasing trend from the upland to lower catchment as indicative of more agricultural developments and build up areas were observed moving from the upland to the lower part of the catchment. With the increase in families living around the mid-catchment further down to lower parts, solid waste littering in the river was observed and evident in these areas that may play a part in the increase in river temperature towards the lower reach of the catchment. Trees were scattered providing open space in the riparian zone of the river along the lower catchment – this allows much direct sunlight into the river that could increase the temperature, as compared to the dense vegetation of riparian and influent cooler groundwater of the upper catchment. The same spatial trend was recorded in a study of the Ruvu River watershed in Tanzania, by Ngoye and Machiwa (2004), where temperature values were lower in the forested areas and higher in the lower plains, where the air temperatures were higher.

5.5.2.3 Conductivity (COND)

Conductivity is an important indicator of total dissolved ions in water and can be affected by the presence of inorganic dissolved solids such as nitrate, chloride, phosphate anions, calcium aluminium cations, sodium and magnesium (Chergui et. al., 2013). More often, it is a good indicator of a range of natural and anthropogenic effects on water, which can indirectly measure the concentration of dissolved substances, e.g. salts (Stevenson et. al., 2010). Conductivity in rivers could be affected primarily by natural factor such as the geology underlying the formation of the catchment through which the water flows. Others include anthropogenic activities such as agriculture that could possibility discharge fertilizers runoff affecting the conductivity of the water.

In this study, the results show significantly different values for conductivity amongst the STNs and mean ($\pm$ std) conductivity values varied between 74.7 ± 9.15 µS/cm and 153 ± 7.39 µS/cm. Higher conductivity values were recorded at the STN5 (153 ± 7.39µS/cm) and STN 4 (149.5 ± 7.71µS/cm), both in the mid-catchment (Figure 39 (iii)). The two stations were located on the same river tributary, with the STN4 located upstream approximately 1km from the STN5. The higher conductivity at STNs 4 & 5 may be explained by the intensity of anthropogenic activities and the effects of new residents, both encroaching riparian zones upstream from the STNs4 & 5 on the upper catchment. While the two stations (STN4 and STN 5) located on the same tributary that the water flows through the same geological formation (eg. Salani formation) (Fig. 3), but different parts of the catchment, could explain dissolved solids released by soil and rocks into the river, which therefore could determine conductivity of certain parts of the catchment. Conductivity can be also affected by the temperature as warm temperature recorded towards the lower reach of the catchment, the higher the conductivity.

A study by Zeb et al. (2011) of the Siran River in Pakistan found conductivity values higher at stations near settlement areas. This can be explained as perhaps being influenced by conductivity levels from the wastewater from anthropogenic activities into the river water (Zeb et al., 2011). This could be the case at the FRC around the STNs 4 & 5, as these sites (compared to other stations) were located just downstream from residents living on the upland eastern slope of the catchment with their agriculture activities extending into the catchment boundary. Stevenson et al. (2010) in their water quality study in Canterbury, New Zealand, also found similar conductivity trends, where streams in lower plains in both rural and urban areas had the highest range of conductivity. This could be explained as likely due to high conductivity groundwater inflows, where ions were picked up as water flows through soils and contaminants inputs from surrounding intensive agricultural and urban land uses (Stevenson et al., 2010). There were no other activities except settlements, agriculture cropping and patches of livestock farming identified upstream from STN4 and STN5. This could also possibly have discharged waste water leakage (eg. Sewage system) that could raise conductivity level due to presence of chloride, phosphate and nitrate. Similar trend in which conductivity increases as expected in downstream stations around more developed areas as experienced during by Elbag's (2008) in his study of impact of surrounding land uses on surface water quality. Despite this variation of conductivity amongst stations, all stations had less conductivity values that are way below the critical limits of 1000 µS/cm (Drinking Water Quality: WHO, 2006; Aesthetic: Ministry of Health, 2008).

5.5.2.4 Total dissolved solids (TDS)

The Total Dissolved Solids (TDS) is used to describe the inorganic salts and small amounts of organic matter present in water. The presence of TDS in water in high concentrations greater than 1000 mg/L (WHO, 2006; DWSNZ, 1992 & SNDWS, 2008 for both drinking and recreational purposes) may affect its taste and suitability for public use. However, TDS level of extremely low concentrations may also be unacceptable for human health, due to its flat, insipid taste which at such low levels often causes corrosion to water supply systems (WHO, 1996). The TDS levels for streams are typically range between 50 to 250 mg/L and from 100 to 20,000 mg/L in rivers (Lehigh University, 2011). The drinking water quality standards under WHO Drinking Water Standard guidelines and the Drinking Water Standards of Australia and New Zealand (DWSNZ/ANZECC) are both 1000 mg/L. For aesthetic standards, the National Drinking Water Standards (SNDWS) for Samoa and DWSNZ/ANZECC both have acceptable TDS values of not more than 1000 mg/L (Table 9). The TDS can be sourced from anthropogenic activities (eg. fertilizers & pesticides from agriculture) capable of producing ions that may contribute to increasing TDS values. The same with runoff from roads channel by road drainage that link to the river could possibly collects salt ions that ends up into the river (Fig. 40) Possible discharge of wastewater from nearby residents could also contribute to higher levels of nitrate and phosphate ions. If the levels of TDS are high in the river due to dissolved salts, it would pose severe threats on the survival of aquatic life. Aquatic life requires a constant level of minerals to live where any changes to the amount of dissolved solids could be harmful.

This study observed that the mean ($\underline{+}$ std) TDS concentrations at the different STNs varied between 37.4 ± 4.54 mg/L and 76.7 ± 3.79 mg/L (Figure 39 (iv)). The conductivity of water is directly related to the concentration of dissolved solids in the water. Thus, the relationship of TDS and specific conductance of water can be estimated by *TDS* (mg/L) = k *EC* (us/cm @25 degree Celsius) where TDS can be expressed in mg/L and EC is the electrical conductivity in micro Siemens per centimetre at 25 degree Celsius. While water in general can conduct electricity, it is the presence of dissolved solids that actually conducts electricity in the water. Thus, more dissolved solids in water would have more conductive the water could become. The variation of TDS results show a general increasing trend from upland stations 1-3 (37.4 ± 4.54; 48.8 ± 2.33 & 58 ± 3.90 mg/L) to mid-catchment at STN 4 (74.8 ± 3.84 mg/L): and STN 5 recorded the highest TDS values. This trend slightly decreased again down to the STNs in the lower catchment. A similar TDS trend was recorded in Zeb et al’s (2011) study of the Siran river in Pakistan, in which TDS level increased from upstream to downstream until reaching maximum value at Site 8 (S-8), then slightly decreasing down to Sites 9-11. The possible reasons for having maximum TDS values at a site is explained as the possible mixing of pollutants in the river from anthropogenic activities by nearby residents of

Mansehra. This is similar case of the two stations (STN 4 & STN 5) of the FRC, as explained earlier. Overall, TDS values, as a result of the analysis of this study, were very low compared to the standards of 1000 mg/L.

5.5.2.5 Dissolved oxygen (DO)

Dissolved oxygen is a basic requirement for a healthy aquatic ecosystem. Dissolved oxygen is required by fish and other aquatic life for survival. Nearly all biological and chemical processes within water bodies can be influenced by oxygen (Massoud et al., 2004). Zeb et al. (2011) explained a high level of DO in rivers indicates high re-aeration rates and rapid aerobic oxidation of biological substance. Since dissolved oxygen is indicative of aquatic life, it's supporting capacity in river water makes DO an important measure of water quality and a fundamental part of water quality assessment. The levels of DO in river can be affected by a variety of factors. The temperature fluctuations can greatly affect the amount of DO in the water. The warmer water holds less DO compared to cooler water and this can also be affected by the weather and the time of the day. The DO also varies from low to higher altitude due to low atmospheric pressure on higher altitude that slightly decreases DO solubility.

In this study, the level of DO in the water was measured in the morning going into the early afternoon. The mean (+ std) DO concentrations varied between 8.32 ± 0.15 mg/L and 9.76 ± 0.24 mg/L (Figure 39 (v)). Results show less variability of DO across stations. This less variability of DO, indicated by its low coefficient of variation, is observed around 6.2%. Despite having no standards for DO in the current SNDWS for Samoa and DWSNZ, Chapman (1996) explained that DO concentrations below 5 mg/L may adversely affect the functioning and survival of biological communities, whereas DO values below 2 mg/L may lead to the threshold level of most fish lives (Chapman, 1996). Environment Canterbury Regional council regulate DO value above 4 mg/L to ensure fish species survival. Despite having no health-based value of DO, ANZECC (1992) has a recreational standard for DO of 6 mg/L. Comparing DO among sampling stations found they were all above the permissible level at all stations. However, a slightly increasing trend of DO from upland stations to the lowland of the catchment was evident, and this may be due to low atmospheric pressure found at higher altitudes which may decrease the solubility of DO. While DO values seem to be low at the upland STNs (1-3) in comparison to other STNs downstream, their actual DO concentrations values (8.56, 8.32, & 8.51 mg/L) do not exceed the DO trigger value of 6 mg/L (ANZECC, 1992) for recreational purposes. The less DO values at upland STNs (1-3) may also indicate some level of pollution, due to anthropogenic activities identified on the upper catchment above from STN1 and STN3. Similar DO conditions experienced by Zeb et al. (2011) in their water quality study assessment of Siran River in Pakistan. Another possible explanation of less DO levels at the upland STNs could be the result of the influence in oxygen partial pressure with altitude. Thus, higher altitudes decreases the partial pressure of oxygen, which then reduces oxygen solubility in the water at those STNs at the higher elevation. The variation of DO levels among STNs could also be due to the nature of the flow at those STNs, where fast flowing sites tend to have higher DO levels than slow moving ones. Also, steeper slopes at those stations (STNs4-6) with high flows, contribute to fast moving water that may increase DO levels, due to higher re-aeration of water.

5.5.2.6 Turbidity

Turbidity is an important water quality indicator of how clear or transparent the water can be from the impact of sediment inputs (suspended sediments). High turbid water reduces the amount of light available to aquatic plants and organisms. It can also affect the amenity and aesthetic values of rivers with high turbidity levels. Significant supplies of sediments from top surface erosion carried by high flow during heavy rains can increase turbidity levels in water, thus causing poor clarity for human use and this also affects the river's ecological health. Factors such as soil erosion, urban runoff, increased flow rates, waste discharge, flooding, construction works can influence the turbidity of river water in the catchment.

Turbidity in this study shows a significant variation amongst the sampling STNs, with 44% of coefficient of variation (Table 9). The mean ($\pm$ std) turbidity across the sampling stations varied between 0.95 ± 0.38 NTU, both recorded for STN3 and STN5, and 1.86 ± 0.75 NTU at STN2, with higher turbid levels measured at the STN2 upland (1.86 ± 0.75 NTU). The high levels of turbidity recorded upland could be the result of soil erosion from agriculture activities (eg. taro and banana plantations) identified further upland from STN1 and STN2. The Water Resource Division of the Ministry of Natural Resources is currently dealing with families living around these areas to allow these land to come under the state reforestation program in which trees are supplied by the

Ministry to replant riparian zones along the river banks. The decrease in turbid levels from upland to lowland could explain by low flow of water during the dry period of sampling from the last 3 months of the dry period (Aug-Oct) in Samoa.

The turbidity permissible range, according to both WHO and SNDWS drinking and aesthetic targets, are <2.5NTU (drinking) and <5 (recreational) which mean (± sd) turbidity level of FS 1.3 ± 0.557 is less than both allowable standards.

Figure 40. Road drainage as pathway of stormwater from the main road of Tuana'imato into the river

5.5.2.7 Total phosphorous (Total P)

Phosphorus is essential for aquatic life and its environment (Daniel and Lemunyon, 1998). However, the presence of phosphate in excess concentrations in water can be harmful to aquatic life (Mahdi, 2012). Phosphorus contamination in rivers is often associated with eutrophication problems of surface water. High concentrations of TP can cause algae growth in rivers, which makes the water unsuitable to support aquatic life. High phosphate concentration levels can be sourced from human activities as in agriculture by fertilizer runoff, or detergents contained phosphate and waste discharge through leaked septic systems that may ended up in the river as a result of surface runoff or direct discharge. Thus, the test for total phosphorus is a good indicator of water quality that may be affected by domestic sewage, industrial, and agricultural effluents with fertilisers.

This study recorded a mean (± sd) of total phosphorus concentrations varied between 0.011 ± 0 at STN10 and 0.016 ± 0.0038 at STN9. This less variability in TP levels (eg. CV is 19.9%) among the

STNs show a more constant trend of TP across the different segments of the catchment. This could be the result of agriculture practices for mixed cropping and plantations most commonly identified across the catchment that are without intensive use of fertilisers. Most of these agriculture plantations are for local consumption in which the use of fertilisers and pesticides may not significant, due to expensive inputs and application operations. Therefore, this could reduce any TP source of contamination into the river system. Other considerations for less variability of TP levels can be explained by the low flow conditions of the river during the dry period of monitoring period where less surface runoff and sediment erosion could experience due to less rainfall conditions over the last 3 months of monitoring in the dry period (Aug-Oct). The TP readings could have been higher if sampling and monitoring were done during wet season that could have higher surface runoff from agriculture lands and residential areas. Despite having no current wastewater treatment for domestic sewage system for families living along the river bank of Fuluasou River, the possibility of waste discharge through leaked system cannot be ruled out. This could explain the slight increase in TP levels at the lower catchment that is dominated by local residents and businesses.

The recommended WHO drinking water standards of 45 mg/L found TP results for the Fuluasou River are below permissible TP levels.

5.5.2.8 Total Nitrogen (TN)

Nitrogen is one of the essential nutrients for plants and animals, but its availability in excessive amounts in water can alter dissolved oxygen levels and become a problem to the health of aquatic plants and organisms. Possible sources of nitrogen in waterways include runoff from agriculture lands, where fertiliser is highly applied; possible leakage from septic systems; waste treatment plants; runoff from animal manure; and discharges from industrial zones (Gullatt, 2013).

This study recorded the mean (± std) total nitrogen concentrations varied between 0.227 ± 0.01 (STN2) and 0.256 ± 0.017 (STN9). This shows a constant trend of TN concentration from upland to lower catchment except the last three STNs (8-10) of the lower catchment, where slightly higher TN levels (0.248 ± 0.015; 0.256 ± 0.017 & 0.252 ± 0.023) were observed, compared to the upstream stations. While there is no current standard for TN in the SNDWS, the permissible limits of 10 mg/L recommended by the US-EPA Drinking water standard (Table 9) found the mean (± sd) TN level of FS of 0.24 ± 0.0159 below acceptable limits.

5.5.2.9 Nitrate (NO_3^-)

Nitrates are essential for plant growth. However, its availability in excess amounts can cause significant water problems. This condition favours the growth of algae and further proliferation of growth to nuisance levels as a result of high nutrient concentrations. Moreover, when nitrate is at high concentrations in drinking water, it may result in a toxicity condition for human purposes and this usually occurs when nitrate concentrations exceeds acceptable standards. Several factors can influence the amount of nitrate in river water. When decomposition of plants and animal occurs, the amount of dissolved oxygen decreases and can cause nitrate concentrations to increase in rivers. Nitrates can also source from human activities through agricultural (eg.) fertilizer runoff and from untreated waste water and septic systems.

The mean (± std) nitrate concentrations in this study varied between 0.005 ± 0.001 mg/L and 0.01 ± 0.017 mg/L. High nitrate levels were recorded in lower catchment at the STN5 (0.010 mg/L) & STN6 (0.011 mg/L), whereas the lower values were recorded in the forested area on the upland at STN2 (lowest as 0.005 mg/L) and STN 1 and 3 are the same (eg. 0.006 mg/L). Although the STN10, in the lower catchment, had a nitrate level recorded as the lowest as 0.002 ± 0.023 mg/L, it is omitted in further interpretation of nitrate, as the STN 10 only received two sets of measurements, due to the water drying out at the lower reaches of the catchment during the remaining sampling period.

The nitrate levels at other STNs 2-6 show a slight increase trend of nitrate from upland to mid-catchment where more agricultural activities are evident around the area that could possibly discharge fertilizer runoff into the river. Regardless of the slight increase of nitrates recorded for FRC, the total mean (± sd) concentrations of 0.01 ± 0.0032 mg/L of nitrates recorded for FRC is below acceptable standard limits of 50 mg/L. (WHO Drinking Water Standard, DWSNZ/ANZECC and SNDWS) (Table 9).

5.5.2.10 Total coliform (T.coli)

Total coliform is one of the important indicators of pathogens present in water. Their presence in high numbers suggest the need for risk management to water quality. Total coliform applies more to drinking water quality standards, than the recreational water quality standards. Unlike E. coli as a major species in the faecal coliform group and a good indicator of water being exposed to human and animal waste, total coliform include total bacteria associated with soil, in the water as well as animal and human waste. Early detection of total coliforms in river water system sends out a warning of possible contamination of the system with faecal contamination. High total coliform counts is when there is a health risk alert, due to the possible presence of waterborne pathogens usually associated with faecal contamination, which requires immediate attention, in order to protect human or animal consumers of water. While total coliform can represent bacteria present around our environment, most of which are not reported dangerous to human health. However, as a good indicator of harmful organisms, it is important to measure for public health safety especially for drinking water. For recreational purpose of river water as in fishing and swimming, total coliform could be a good indicator of primary bacteria present in the water to give out warning of possible contamination.

The total coliform counts in the Fuluasou River samples varied across the catchment from 8233 ± 1195.7 cfu/100mL and 11267 ± 1976.8 cfu/100mL (Table 10 & Figure 39 (x)). The higher values were recorded at STN1 (11267 ± 1976.8 cfu/100mL) and STN2 (11417 ± 781.5 cfu/100mL) in the upper catchment. Although this is a rare case considering that forested areas expects less contamination from such causes of total coliform, it is nonetheless an indication of the presence of some form of human activity around the area (e.g. expansion of new settlement upland & agricultural activities). Observations in the field had identified the two STNs located downstream from patches of new agricultural lands currently cultivating for taro and banana plantation including a watercress farm (Fig. 41) located about 40 metres above from STN2. Also there are new settlements with locals living around the area to work their lands. These are the current activities around the two stations (STN1 & STN2) that could possibly discharge wastes of faecal origins (eg. pit latrines identified at household) that accounts for such a high total coliform count recorded for the two stations. Steep slopes further upstream could contribute to severe soil erosion and sedimentation from agriculture activities that could also contribute to high levels of total coliform of the water. Easy accessibility to the area when government built new road (Fig. 43 & 44) to service the two untreated SWA water intake (Chinese 1 & Chinese 2) as part of upgrading and renovation project of the two intakes encourage locals to move into area for cultivation agriculture and build new settlements. The topography of the area with its high slopes (e.g. 65°-70°), on both sides of the gully, could provide quick access pathway of sediments as habitat for microbial growth that contributes to the high values. Also households were observed living under shacks conditions on top of these hills and work their plantations along these steep areas (eg. steep slope on the western side of STN2). During dry seasons when water level is low could cause sediment accumulation as a possible source of total coliforms. Similar case to Besner et al. (2001) study where they identified sediment accumulation in a low-flow condition as a possible source of total coliforms in a sampling point on "B Street" in Montreal. Other possible reasons could be the effect of weather related events such as rainfall and high temperature. Significant amount of rainfall events, prolong droughts and excessively warm weather could contributed to high levels of total coliforms in water. Evidence of such have witnessed in positive samples of total coliform in Bristol, Connecticut (Bristol Press, 2005) and Yamhill County in Oregon (Oregon Department of Health Services, 2006).

5.5.2.11 Escherichia coli (*E. coli*)

Escherichia coli are a harmless type of bacteria that lived in the guts of mammals and birds (Wright, 2012). E.coli is usually employed as an indicator of the presence of faecal matter in water. Their presence in high levels in water indicate not only the presence of faecal material (e.g. sewage or from animal effluent), but also other disease causing microorganisms (e.g. campylobacter). In order to ensure a drinking water supply is safe for human consumption or an acceptable water condition for safe recreational activity, guidelines and standards for E.coli are established both at national and international levels to evaluate water quality for risk management to human and ecosystem health.

This study assesses *E.coli* concentrations from the different STNs and the results find the *E.coli counts* varied between 6308 ± 1341.1 cfu/100mL and 8492 ± 646.9 cfu/100mL among the STNs (Figure 39 (xi) & Table 9). These results are extremely high and they exceed, by 60% to 80%, the acceptable level for drinking water: <1/100 mL or <1 cfu/100 mL (WHO drinking standards), 0/100 mL (SNDWS for Samoa) and <1/100 mL for DWSNZ/ANZECC). In comparison to aesthetic standards, the E. coli values range between 6308 ± 1341 cfu/100mL and 8492 ± 647 cfu/100mL, are also very high in accordance to DWSNZ/ANZECC and SNDWS aesthetic standards as follows: <260/100 mL, 0/100 mL (Table 8).

The range of variation of E.coli concentrations among the STNs from the upland to lower catchment indicates a high level of faecal bacteria contamination in the FRC. The highest E.coli count was recorded in the mid-catchment at STN5 (8492 ± 647 cfu/100mL), while the lowest was also recorded further down in the mid-catchment at the STN7 (despite higher values of counts for all STNs. The possible source of higher concentrations at STN5 (6308 ± 1341 cfu/100mL) was due to the high establishment of sub-divisions upstream from the sampling site. Also, an extension of cattle farms and livestock paddocks upstream along the headwaters of the specific tributary that links to STN5 could be a possible reason. The STNs 4 and 5 were located on the same tributary with STN4 located higher upstream. One of Samoa Water Authority's water supply intake (Eastern branch) is on the same tributary just below 30m from STN4. While most of these lands are customary owned, with some families living on the lower catchment, the mode of transportation to farmland and plantation was identified as horses (Fig. 46). Several horses observed tied up (Figure 45) along the river bank between the two stations. Possible faecal contamination from horse waste washed into the river during raining days. The same situation occurs for STNs 1 and 2. The point discharge of sewage systems and waste discharge from a community and church hall (e.g. Harvest Community centre) located along the edge of the river bank have been identified between STNs 7 and 10. Also, identified during the survey and monitoring was general waste, such as baby diapers and animal guts (e.g. cattle intestine) dumping into the river most evident and commonly identified along the stretch of STN7 going downstream that could contribute to high E. coli from STN 7-STN9.

The results of microbiological parameters reveal similar case for SWA's water quality monitoring (SWA-DWSP, 2011) that support the explanation of why E. coli has recorded higher in STN4 and STN5 (Table 10). According to the Samoa Water Authority Drinking Water Safety Plan (DWSP) for the two Water Treatment Plants (Fuluasou FR & EU Water supply systems) supplied by the Fuluasou water intake eastern branch (just below sampling station 4), it states:

"The results indicate that the raw water has poor microbial quality. This means that there is contamination occurring in the upper catchments. This is likely to be faecal contamination from cattle farming and residential development now starting. Poor microbial quality of the intake water means that treatment process downstream will need to work effectively to remove this contamination and ensure the water supplied to the public is safe" – SWA-DWSP (2011).

Figure 41. One of the families 'Watercress' farm (yellow arrows) for commercial purpose located upstream from STN2.

Figure 42. View upstream from Chinese intake No. 2 where STN2 was located.

(NB: Note mixed cropping (taro and banana) plantation in the background)

Figure 43. A road ford & eastern view to the newly built road accessing the SWA water intakes

Figure 44. Newly built-road to Chinese 1 & Chinese 2 SWA water intakes upstream
Also shows the newly constructed stream path (i.e. diversion) from the river's usual path.

Figure 45. View of mixed cropping banana and taro plantation in the background uphill from STNs 1 & 2

Figure 46. Horse sighted tied by river and owned by the locals and used for transportation

5.6 Statistical Analysis

5.6.1 Pearson's *r* correlation among water quality parameters

Pearson's *r* correlation values were calculated to determine the degree of association between different water quality parameters. This test measures the linear correlation which the analysis gives a liner correlation coefficient *r* between the two parameters (ie. pairs of parameters). The outputs of this correlation analysis are presented in correlation matrix in Table 12. The correlation coefficient values were calculated using the 'Basic Statistics' function of Minitab 16 statistical software, to provide the *r-value* as an output for each pair of parameters, and a *p-value* to determine the 'significance' of the correlation. Thus, the *p*-value will be considered statistically significant at or below 0.05 or a probability level (e.g. 95% confidence level) that will be used in the following discussion of the analysis.

The Pearson's *r* statistical correlation, when measuring the effect of the correlation between any two variables, should always between -1 and 1. The -1 shows a strong inverse correlation, compared to 1 that shows a strong direct correlation between any two variables. No relationship exists when *r* = 0.

The results in each cell of the correlation matrix in Table 12 show Pearson's correlation coefficients ^(r-value), and the *(*p*-value) of the analysis for each pair of water quality parameters measured.

Table 12. Pearson correlation matrix with '*r*' and '*p* values' of water quality correlation analysis

	Temp (°C)	*pH*	*COND (µS/cm)*	*TDS (mg/L)*	*DO (mg/L)*	*Turbidity (NTU)*	*Total P (mg/L)*	*Total N (mg/L)*	*NO3 (mg/L)*	*T.Coli (cfu/100ml)*	*E.coli (cfu/100ml)*
Temp	1										
	0.00										
pH	**^0.738**	1									
	*0.037	0.00									
COND	**0.511**	**0.780**	1								
	0.037	0.022	0.00								
TDS	0.519	**0.787**	**1.000**	1							
	0.187	0.021	0.000	0.00							
DO	**0.863**	**0.836**	0.389	0.399	1						
	0.006	0.010	0.341	0.328	0.00						
Turb	**-0.600**	-0.596	**-0.752**	**-0.750**	-0.467	1					
	0.116	0.119	0.031	0.032	0.243	0.00					
Total P	**0.707**	0.345	-0.057	-0.049	**0.719**	**-0.088**	1				
	0.050	0.402	0.893	0.909	0.044	0.835	0.00				
Total N	**0.744**	0.590	0.232	0.246	**0.754**	-0.275	0.596	1			
	0.034	0.124	0.581	0.556	0.031	0.510	0.119	0.00			
NO_3^-	0.662	**0.926**	**0.768**	**0.774**	**0.719**	-0.685	0.173	**0.605**	1		
	0.074	0.001	0.026	0.024	0.045	0.061	0.682	0.112	0.00		
T.Coli	**-0.848**	**-0.751**	-0.486	-0.492	**-0.880**	**0.650**	-0.520	-0.541	**-0.620**	1	
	0.008	0.032	0.222	0.215	0.004	0.081	0.187	0.166	0.101	0.00	
E.coli	-0.183	-0.093	0.261	0.259	-0.439	-0.079	-0.450	-0.033	0.186	0.534	1
	0.750	0.374	0.243	0.536	0.276	0.853	0.263	0.938	0.660	0.173	0.00

Note: Each pair of variables listed the correlation coefficient value **^**(r-value) and the *(p-value)
Statistically significant at or below 0.05 probability level: *****(p<0.05)

The correlation analysis results (Table 12) show Temp has strong significant positive correlation with pH (r = 0.738; $p < 0.05$), COND (r = 0.511, p <0.5), DO (r = 0.863, $p < 0.05$), Total P (r = 0.707, $p < 0.05$), and Total N (r = 0.744, $p < 0.05$). This indicates, an increase in the values of tem*p*erature, the values of these parameters also relatively increase. Although Temp shows positive correlation with TDS (r = 0.519) and NO_3^- (r = 0.662), and an inverse correlation with Turbidity (r = -0.600), their *p* values are more than 0.05 which show the correlation is not statistically significant. A strong inverse correlation has shown between Temp and T. coliform (r = -0.848, $p < 0.05$), and a weak inverse correlation between Temp and E.coli (r = -0.183), although the association is not statistically correlated given *p* value of 0.750 is more than 0.05.

A suspect correlation of Temp and DO found is interesting, given the two would expect an inverse relationship. This suspected correlation may be influenced by having different sampling stations on different tributary of the river at different segments especially on the upper (STNs 1-3 on different tributary) and mid-catchment (STN4 & STN5 on the same tributary & STN 6 on different tributary). Despite having Temp recorded increasing in downstream direction with increase in DO level, the consideration of having less DO in water on higher elevation (upper catchment) than water at low elevations could be the result of decreasing in air pressure. Other possible factors that could influence the DO levels include the level of organic matter content taken during decomposition of organic matter that lower the oxygen content of water in the upper catchment, as well as the velocity and turbulence of the river flow varied with different tributary across different segment of the Fuluasou River.

The pH showed significant positive correlation with COND (r = 0.780, p < 0.05), TDS (r = 0.787, p <0.05), DO (r = 0.836, $p < 0.05$), NO_3^- (r = 0.926, $p < 0.05$). Total P and Total N show positive but weak correlation, and with their *p* values more than 0.05 are not statistically significant. Similarly, with TURB having negative correlation with $p > 0.05$. The slight increasing trend of the pH level downstream may have resulted having decaying of the domestic waste littering as you descend downstream contributing to the mild alkalinity conditions of the river. This may influence the mean concentration of other parameters resulting with variation nature of their correlation.

Conductivity (COND) found strong positive correlation with TDS (r = 1, $p < 0.5$) is an indication of a very strong association between the two water quality parameters. It also shows a significant negative correlation with Turbidity (r = -0.752, $p < 0.05$), and a positive correlation with (NO_3^-) (r = 0.768, $p < 0.05$) and pH (0.780. p <0.05). Conductivity is generally proportional to total dissolved solids and can be related given increase in total dissolved solids, increase electrical conductivity in the water. Intensity of anthropogenic activities as agricultural and settlements from upland to lowland could possibly increase in discharge of fertilizers and waste runoff that influence the conductivity concentration of the water. This also affects its association with other parameters for example TDS.

Total Dissolved solids (TDS) show a significant negative correlation with Turbidity (r = -0.750, $p < 0.05$), and a positive correlation with NO_3^- (r = 0.774, $p < 0.05$). With p values more than 0.05, the correlation between TDS and Total P, Total N and DO shown are not statistically significant.

Dissolved oxygen (DO) shows a positive correlation with Total P (r = 0.719, $p < 0.05$), Total N (r = 0.754, $p < 0.05$), and (NO_3^-) (r = 0.719, $p < 0.05$).

For Turbidity, although showing a significant negative correlation with Total P (r = -0.088), Total N (r = -0.275) and NO_3^- (-0.685), their *p* values indicate more than 0.05, in which the correlation is not statistically significant.

Total phosphorus (Total P) shows a positive correlation with Total N (r = 0.596) and (NO_3^-) (r = 0.173) and a negative correlation with T. coli (r = -0.520) and E.coli (r = -0.450), all of their p values were found more than 0.05. Hence, their correlations were not statistically significant.

Although Total N shows some positive and negative correlation with (NO_3^-) (r = 0.605), T.coli (r = -0.541) and E.coli (r = -0.033), their p values found more than 0.05 in which all these parameters were not statistically significant with Total N.

Nitrate (NO_3^-) also showed negative correlation with T.coli (r = -0.620) but p value is more than 0.05. The same with E.coli with r = 0.186 with p value more than 0.05 (ie. 0.173). Therefore, their correlation is not statistically significant.

Total coliform shows positive correlation with E.coli, however their relationship is not statistically significant with its *p*-value more than 0.05.

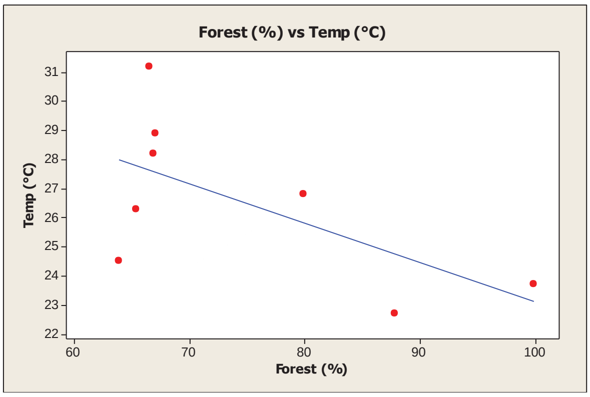
5.6.2 Relationship between land use and water quality

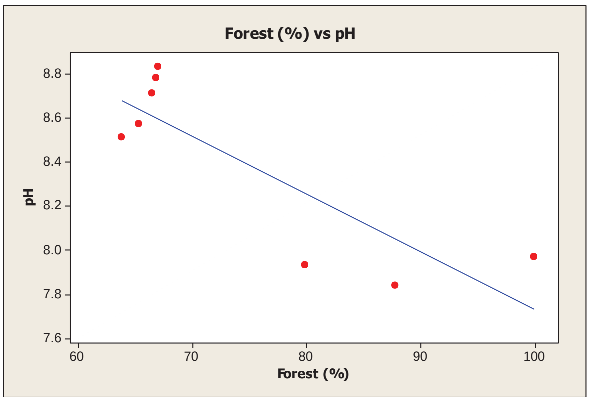
The relationship between land use and water quality was first assessed by scatter plots in order to graphically present possible relationships that coexist between four main land use types and the measured water quality parameters. The nature of these relationships was further tested statistically using a linear mixed effects model to verify the significance of these relationships. This result is presented later in this section, following the presentation and discussion of possibility of association between land use types and measured parameters using scatter plots.

In the following analysis, the results of the two last STNs 9 and 10 at the lower reaches of the catchment are not included. This is because the STN9 only managed to have four out of six measurements, and the STN10 only managed two out of six measurements, due to having no water reaching those stations as monitoring progressed during the course of the three months of field work (Note: last three months of dry period). This is to avoid misrepresentation of the data due to having only a few measurements for water quality parameters at these two stations.

5.6.2.1 Forest (%) vs water quality parameters

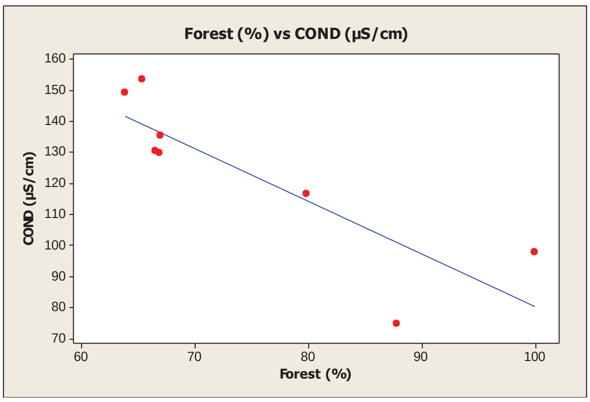
The following graphs present the relationship between the forest cover in percentage and the mean water quality parameters selected for the study analysis for Fuluasou River Catchment.

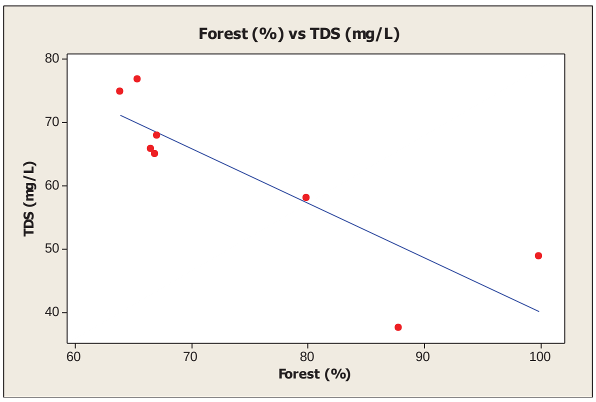




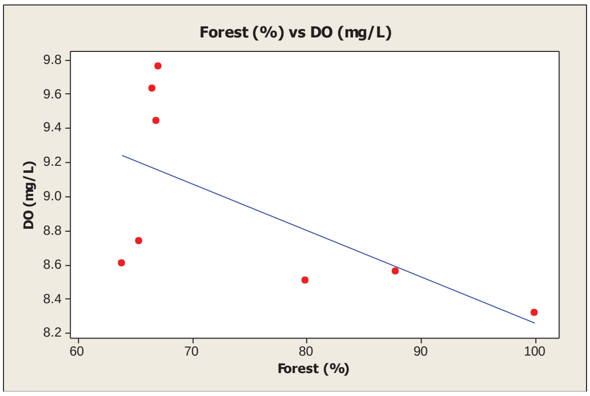
(i) (ii)

Figure 47. Forest (%) against water quality parameters (i-xii)

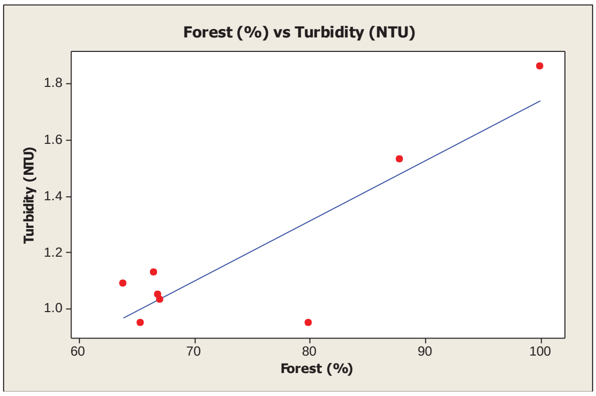




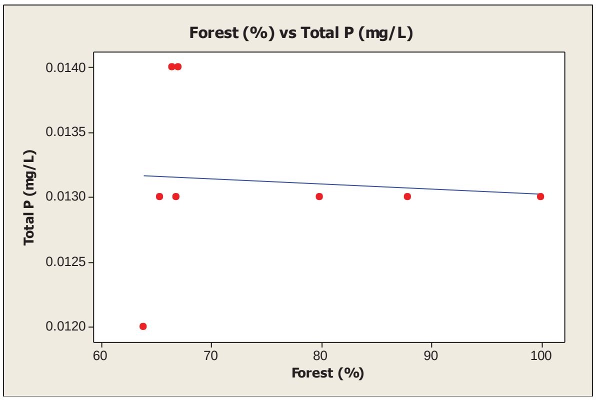
(iii) (iv)



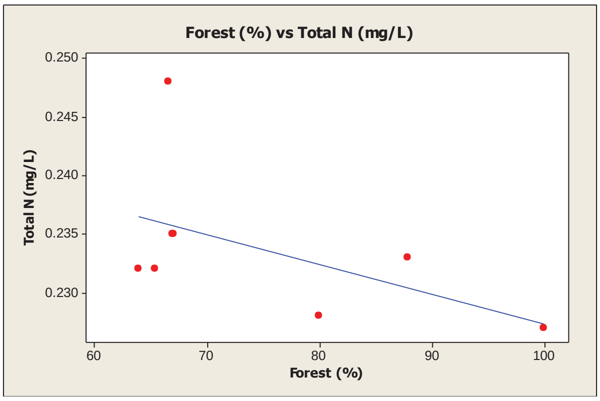
(v)



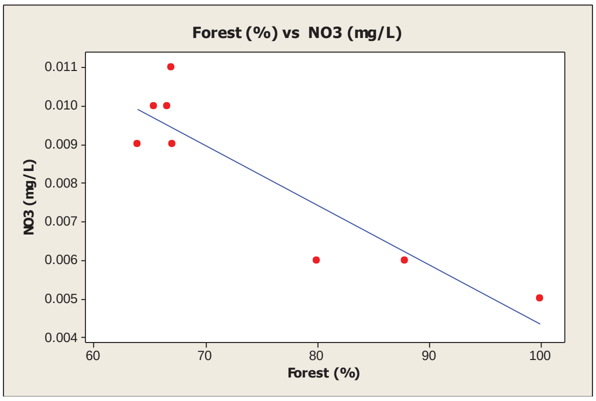
(vi)



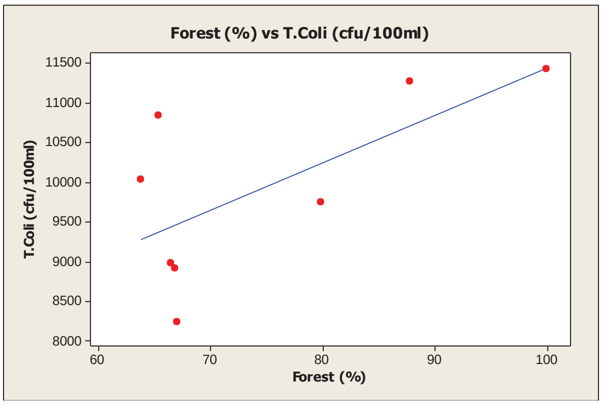
(vii)



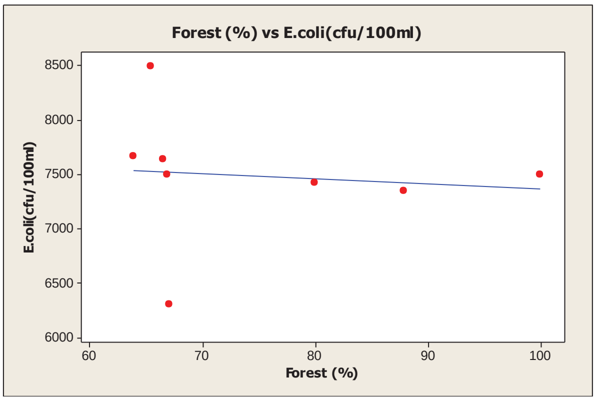
(viii)



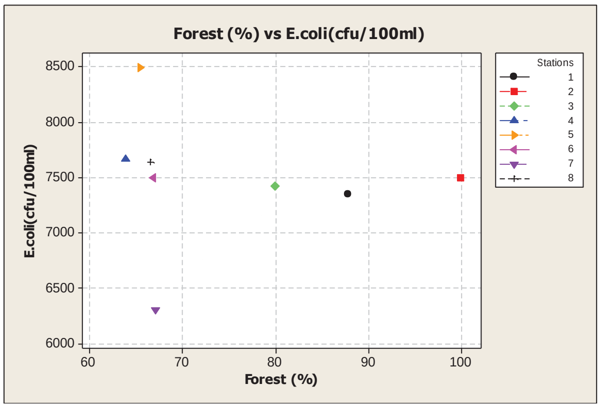
(ix)



(x)



(xi)



(xii)

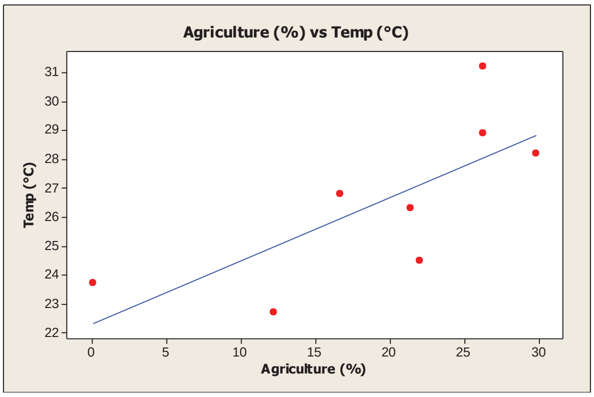
The scatterplots of the % Forest cover vs Temp, pH, COND, TDS, Total N, NO_3^- illustrate that high forest land use areas tend to be associated strongly with decreasing values of these parameters. For example, total nitrogen and nitrate tend to decrease as forest land increases. There is a similar trend with conductivity and TDS, where less forested areas are associated with high conductivity and TDS concentrations.

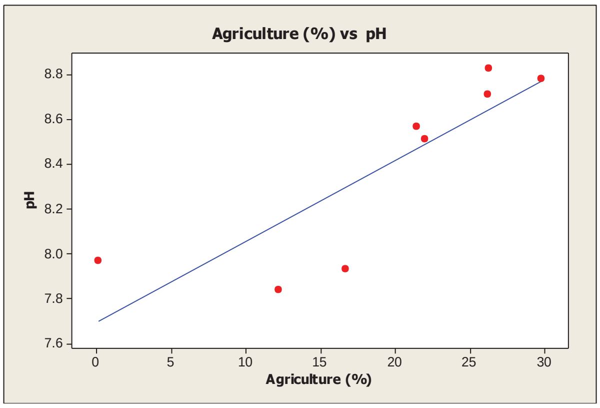
However, forest tends to be positively associated with Turbidity and Total coliform, according to the results of these parameters in which their association is quite unusual. However, for Turbidity, most of the STNs (STN 5 – STN 8): 0.95NTU, 1.05NTU, 1.03NTU, and 1.13NTU appeared to be receiving low turbidity values in less forested areas, when they should be higher. Despite having agriculture and settlement areas associate most with these STNs at the mid to lower reaches of the catchment. While conventional expectations for these parameters is usually the inverse trend, the current trend may be due to the influence of low river flow that caused slow water movement at most of the STNs located towards the mid to lower reaches of the catchment. Other interesting relationships have noticed at STNs 1-3 (11267, 11417, 9742 cfu/100mL for Total coli) indicating increased Total coli and E.coli levels in areas with high forested cover. Despite having these two stations located on the upper catchment, their influence may be varied due to having these three stations on a separate tributary from the headwaters upstream with degree of association with intensity of cattle farming and grazing observed and identified on the eastern (for STNs 1 & 2) and western part of the upper catchment (for STN3). The result of developed sub-division of lands for settlements and expansion of cattle grazing activities upstream from these stations could result in high level of faecal contamination especially the E. coli at these stations from possible leak and runoff into the river. Possible contamination from land birds and wild animals (e.g. wild pigs) commonly roam in the wild in Samoa cannot be ruled out. For Total coli, given the steep topographical terrain on the upper catchment could elevate sediments deposits as habitat for microbial growth into the river. The relationship between different land uses and Total coliform and E.coli would best be explained in built-up areas and grassland (e.g. livestock), as the two potential sources. This will be explained later in the respective sub-sections.

The other surprising relationship is the scatter plot of DO against forest land use, where DO tend to increase in less forested areas. This association is very unusual as DO, in general, increases in most forested areas with cool temperatures and less agricultural activities. The results of the scatter plot shows most STNs located in the mid (STN4: 8.61mg/L & STN5: 8.74mg/L) to lower catchments (STN 6-STN8: 9.44, 9.76 & 9.63mg/L) received higher DO, compared to STNs located in the uplands (STN1-STN3). While the atmosphere as a major source of dissolved oxygen in river water, oxygen can also be produced by rooted aquatic plants and algae through photosynthesis that favours the open tree crown cover conditions that often identified at mid to lower catchment which allows direct sunlight to the river. The effect of elevation on DO level which usually associate with decreasing in air pressure on higher elevation could also explain less concentration values of DO in the upper catchment. Decomposition of organic matter which usually associate with less DO concentrations in the water at higher elevation may also help with the explanation of this suspect relationship.

5.6.2.2 Agriculture (%) vs water quality parameters

The following scatter plots are indicative of the relationship between the agriculture land use cover (%), and the mean water quality parameters selected for the study analysis for Fuluasou River Catchment.

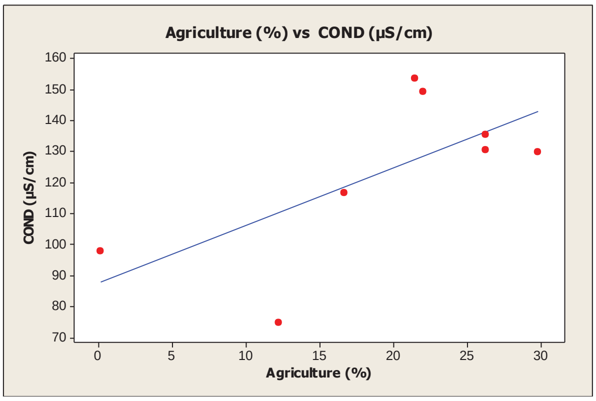


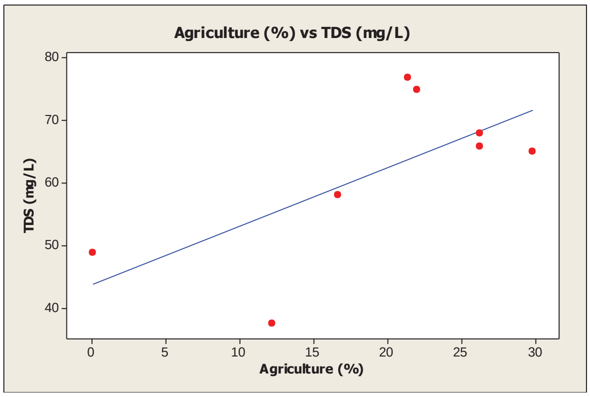


(i)

(ii)

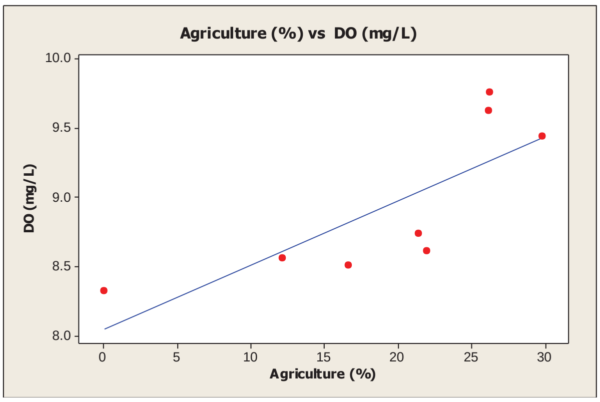
Figure 48. Agriculture (%) against water quality parameters (i-ix)

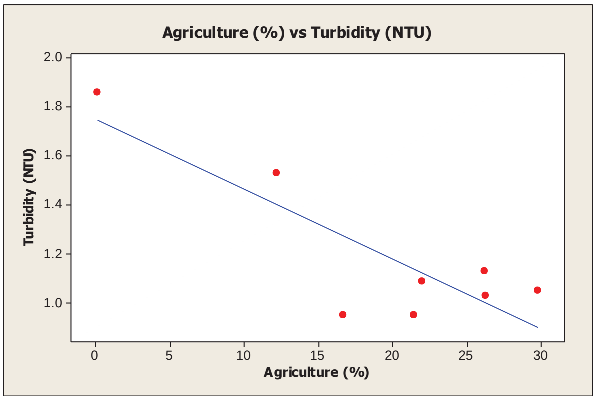




(iii)

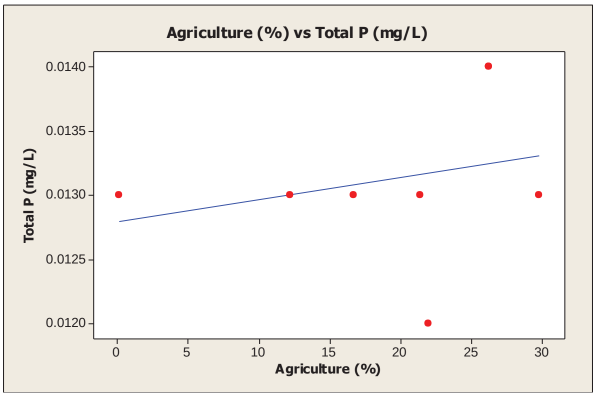
(iv)



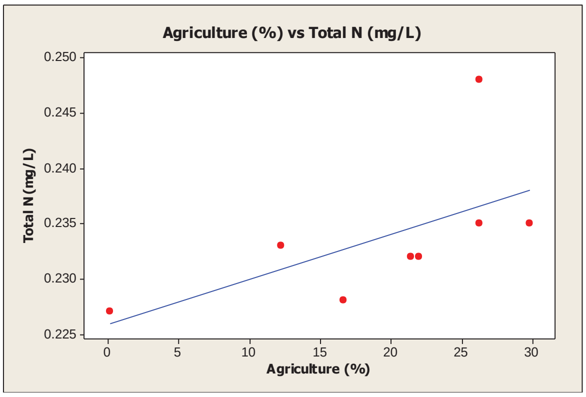


(v)

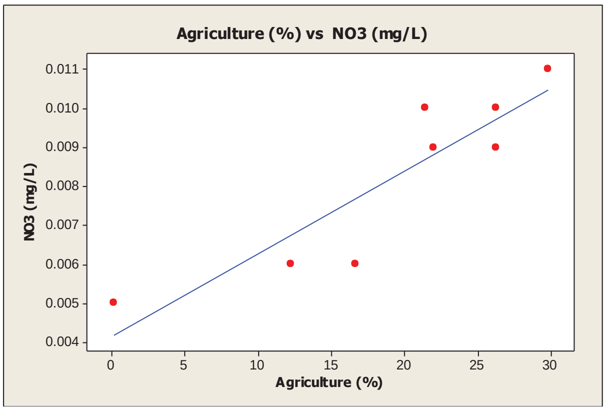
(vi)



(vii)



(viii)



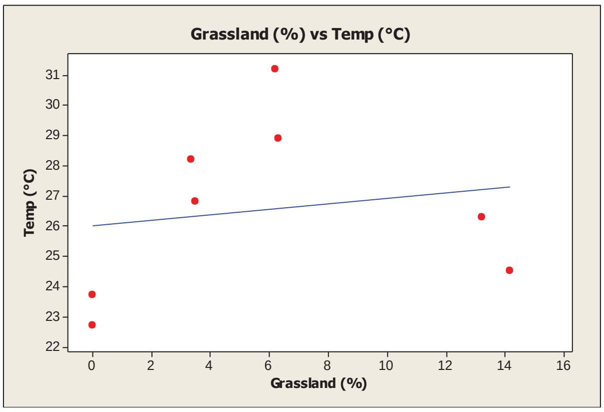
(ix)

The scatter plots of % agriculture cover against water quality parameters demonstrate that agriculture positively influences Temp, pH, COND, NO_3^-, TDS, Total N and Total P, though exhibiting a weak relationship with Total N and Total P. This suggests an increase in the percentage of agricultural land that tends to be associated with higher values of these water quality parameters through possible runoff and discharge of fertilizers and nutrients. Intense cultivation of land to allow such development could result in soil instability for possible soil erosion when raining, and that increase in sedimentation runoff into the river. A similar experience has been found in the study of Ngoye et al. (2004) in Thailand, where concentrations of nutrients (NO_3^- & Total P) were quite high at STNs in both agricultural and urban areas, as a result of waste input into the river. The same experience was recorded in the study of Ogden (2013) in South Africa, with high conductivity found in areas with high crop development and also in urban areas.

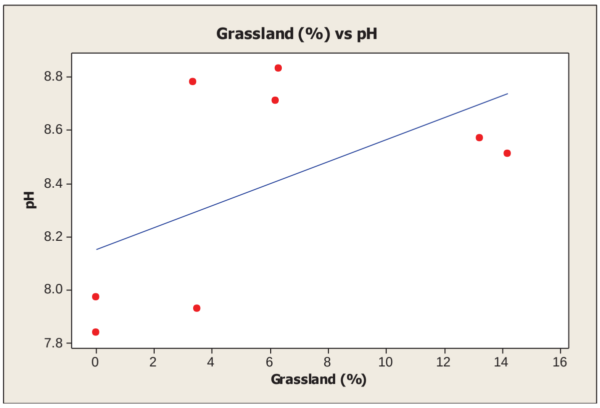
Unlike the case for forest and turbidity, a suspect relationship between agriculture is found negatively associated with turbidity. This indicates an increase in agricultural land which tends to reduce turbidity values in accordance to the results. This inverse relationship may be associated with disturbances in the stream as a result of existing developmental infrastructures such as the old EPC Dam in the middle of the river located just below the intersection of STN5 and STN6 before STN 7, and the water supply intake that pipe most of the water just below STN4. These government infrastructures are identified as causing reduction in water flow which reflected in the result of river discharge decreased from STNs 7-10 (0.07192 m^3/s, 0.0356 m^3/s, 0.02966 m^3/s & 0.02433 m^3/s), despite having high proportion of agricultural lands associated within the range of the mid to lower catchment where these sampling stations have located.

5.6.2.3 Grassland (%) vs water quality parameters

The following scatter plots illustrate the relationship between the grassland land use cover (%), and the mean water quality parameters selected for the study analysis for Fuluasou River Catchment.

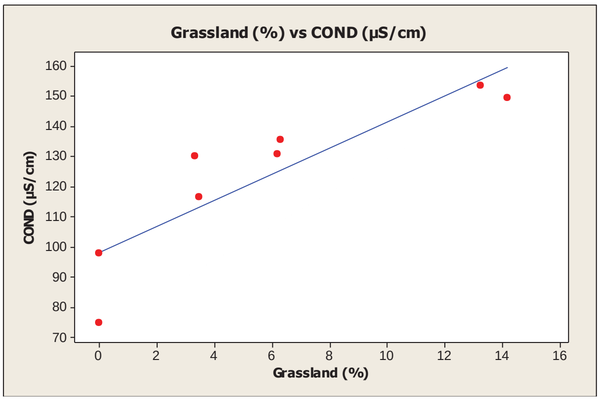


(i)

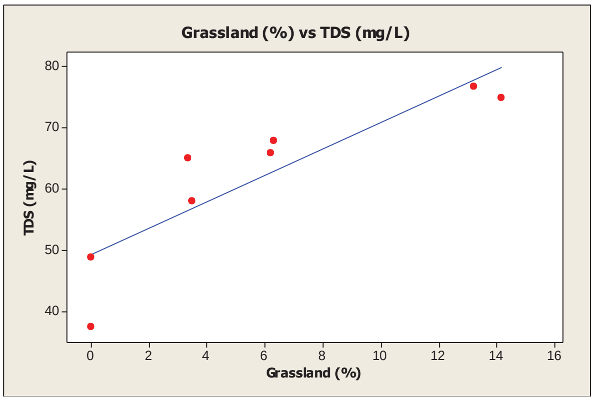


(ii)

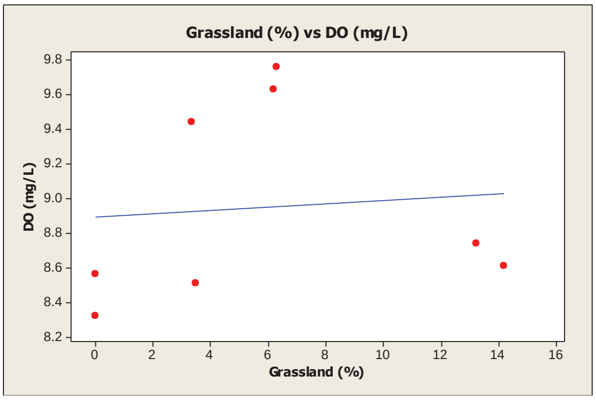
Figure 49. Grassland (%) against water quality parameters (i-xi)



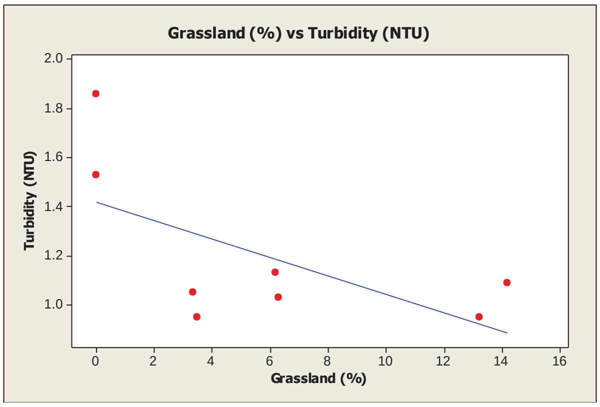
(iii)



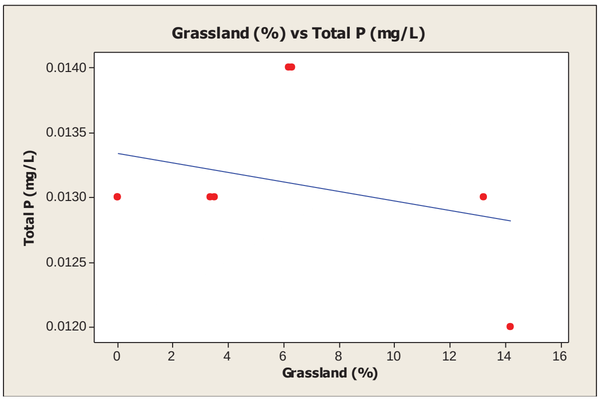
(iv)



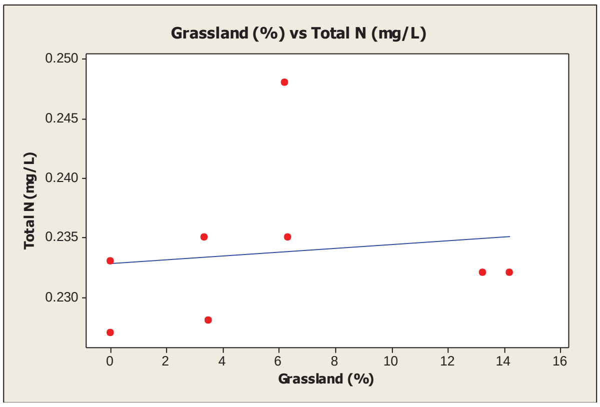
(v)



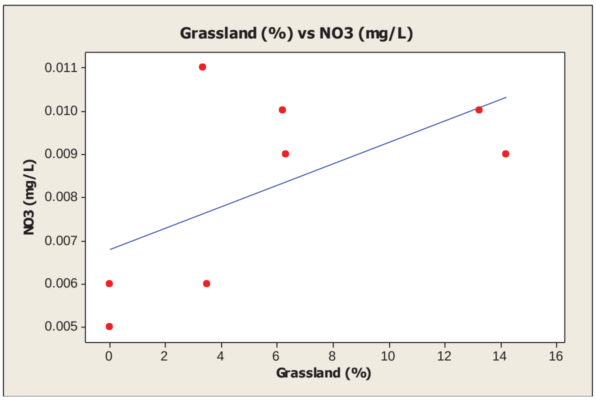
(vi)



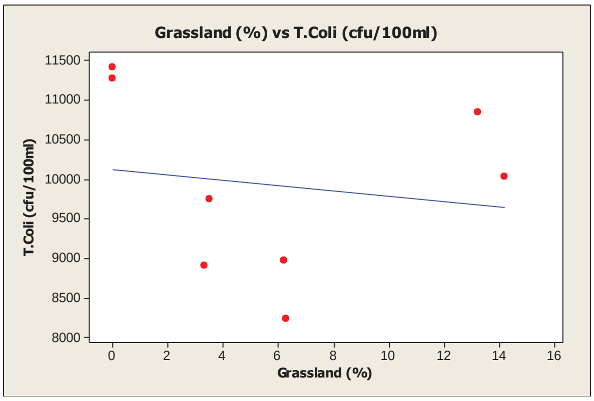
(vii)



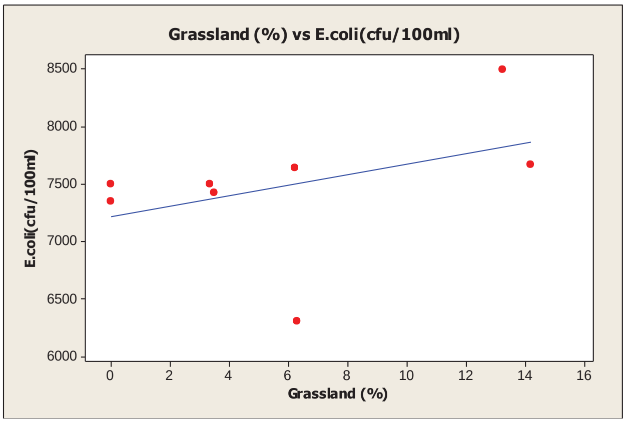
(viii)



(ix)



(x)



(xi)

The scatter plots of grassland type of land use (e.g. livestock/cattle farms) against water quality parameters demonstrates that high proportion (%) of grassland areas tend to be associated with increasing pH, COD, TDS, NO_3^-, E.coli, Temp, Total N, Total coli, and E.coli, while areas with less grassland or livestock activities were generally link to decreasing values of these parameters. This can be possibly associated with nutrients and waste discharge from these lands through surface runoff into the river. Similar results were noted in the study of Gildea (2010) with significant relationships between Total N and Total P and pasture land. An increasing trend of E.coli with an increase in grassland areas indicate possible pollution from waste discharge from cattle farms located upstream of the catchment. Total coliform tends to have a weak negative association with forest, as illustrate by varied concentrations across the catchment. This may be due to possible waste discharge ending up in the river from different parts of the catchments, where livestock developments were located: STN 1 and

STN 3 were located downstream from a cattle farm. Similarly with STNs 4 and 5 located downstream from livestock developments and cattle paddocks.

5.6.2.4. Built-up area (%) vs water quality parameters

The GIS analysis shows only four stations have land use proportions for built-up areas (BUA) (Table 7). These stations were STN7-STN10 and located towards the lower reach of the catchment where most people are living. Because of having only few land use proportions, the relationship between BUA and water quality parameters would not be graphically presented in this section by using scatter plots. Instead, this relationship will be determined and discussed using the Pearson's *r* correlation analysis and the linear mix effect model in the next section.

5.6.2.5 Pearson's correlation amongst the four main land use type

Land use types, such as agriculture (ARG), forest (FO), grassland (G) and built-up areas (BUA), describe the four main type of land use of interest to this study. The Pearson's correlation analysis was explored, in order to assess the correlation between different landuse types in the catchment. The Pearson's correlation matrix between the four main land use types of the 10 STNs shows the following results:

Table 13. Pearson's correlation matrix among the major land use types

	Agriculture	Forest	Grassland	Built-up
Agriculture	1			
	0.00			
Forest	**^ -0.964**	1		
	0.000	0.00		
Grassland	0.326	-0.476	1	
	* 0.358	0.165	0.00	
Built-Up	**0.697**	**-0.756**	-0.045	1
	0.025	0.011	0.903	0.00

Note: Each pair of variables listed the correlation coefficient value ^(r-value) and the *(p-value)Statistically significant at or below 0.05 probability level: *(p<0.05)

From the results, most types of land use are highly correlated with each other. For example, agriculture shows a very strong negative correlation with forest (r = -0.964, $p < 0.05$). There is a strong indication that when agriculture proportion increases, forest proportion decreases and vice versa. This correlation can be explained because most forest areas were cut down to allow the agriculture activities to take place. Forest and built-up areas also have a negative correlation with r = -0.756, p <0.05. As the forest proportion increases the built-up area proportion decreases.

Agriculture and built up areas have a positive correlation with r = 0.697, p <0.05. This shows that when agriculture proportion increases so does the built-up proportion. This may be the case where increases in built-up areas, in terms of local residences, also increases the possibility of having mixed cropping or family plantations around their places, as is the case in Samoa with patches of taro and banana plantations as stable food that is cultivated in people's backyards or located at family lands near their homes.

The absolute values of the correlations between agriculture, built-up areas and forest are high: all are almost equal to or larger than 0.7, with their p <0.05 indicating significant positive correlations. However, this leads to a multicollinearity effect, which means that, if a STN has a large agricultural proportion, then it will also have a large built-up proportion and a small forest proportion. Due to this multicollinearity effect, several attempts were made to distinguish an individual land use effect were found difficult.

Hypothetically, if STNs with large agriculture, large built-up areas and small forest proportions are associated with an increase in TEMP, for instance, it is difficult to determine which of the three land use types is causing this change in this case. In comparison to the above results, grassland has relatively smaller correlations with the other land use types. It has correlation of 0.326 with agriculture, -0.475 with forest and -0.045 with built-up area. This means that the effect of grassland could be investigate separately from other land use effects, to see if these correlations are real as all their p values are more than 0.05.

5.6.2.6 Linear mixed effects model (LMEM)

Eleven water quality parameters (Temp, pH, COND, TDS, DO, TUR, Total P, Total N, NO_3^-, Total coliform, E.coli), each with 53 measurements, were considered for the 'linear mixed effect model' together with the station (STN) number. STNs were used to describe the STN numbers (1-10) of the 53 corresponding measurements. The four major Land uses (agriculture (AG), forest (FO), built-up area (BUA) and grassland (G) describe the land use types and each type represents the percentage (%) of its land use type for the corresponding STN. Thus, the four proportions should sum up 100 for each STN.

The 'linear mixed effect model' was fitted on each of the water quality parameters, with 'Land use' considered as the '*fixed effects'* and the 'STNs' as the '*random effect'* (R Core Team, 2013; Pinheiro & Bates, 2000). This is because land use is the non-random quantity, but 'STN' is a source of random variation in the water quality measurements.

Table 14 contains the '*p-value'* of the model results and the outputs summary for each water quality parameter for each individual land use type. These have been extracted from the water quality individual model output, for instance the output of temperature presented following this discussion as highlighted in 'RED', and with more details of the individual model outputs are presented in Appendix 1. General interpretation of a *p*-value less than 0.05 (p-value < 0.05) will have its variable a *significant effect*. Due to an identified problem of multicollinearity encountered during the catchment delineation of sub-catchment, in which the net effects of both, the proportion (%) of each type of land use and the land use area in hectares (ha) of the upper catchment to the sub-catchment of the mid and lower catchment, restrict the possibility of having the effect of each individual land use type on water quality. Therefore, the application of the output here as a result of the LMEM analysis for each land use type on water parameters will therefore, when a water quality parameter or variable is found having a significant relationship, it is interpret as an association and not causation which could have indicated the possible cause of pollution. An example of the interpretation of the LMEM output of analysis is as follows:

For example: LMEM output analysis of Temperature

1. Temperature (Temp)

```
[1] "Temp"

Linear mixed-effects model fit by maximum likelihood
 Data: NULL
     AIC      BIC    logLik
  258.77 282.4135 -117.385

Random effects:

 Formula: ~1 | Station
        (Intercept) Residual
StdDev:    1.250552 1.996387

Fixed effects: WaterQuality ~ LandUse
                      Value Std.Error DF    t-value p-value
(Intercept)        3414.341  5978.005 38  0.5711506  0.5713
LandUseAgriculture  -33.650    59.750  5 -0.5631899  0.5976
LandUseForest       -33.912    59.785  5 -0.5672389  0.5951
LandUseGrassland    -34.424    60.475  5 -0.5692327  0.5938
LandUseBuiltUp      -33.936    59.877  5 -0.5667530  0.5954


Number of Observations: 53
Number of Groups: 10
            numDF denDF   F-value p-value
(Intercept)     1    38 2557.7925  <.0001
LandUse         4     5    5.9573  0.0384
```

Table 14: The summary of output results from the *'linear mixed effects model'*.

	Week	Land use	Agriculture	Forest	Grassland	Built-up
Temp	0.708817	**0.038412**	0.597623	0.59507	0.593815	0.595376
pH	0.02386	**0.005582**	**0.03277**	**0.033**	**0.032907**	**0.03307**
COND	1.16E-07	**9.35E-03**	6.79E-01	6.81E-01	6.73E-01	6.81E-01
TDS	2.19E-07	**9.15E-03**	6.63E-01	6.65E-01	6.58E-01	6.65E-01
DO	0.016449	**0.030193**	0.203838	0.205428	0.206538	0.207082
TURB	0.03946	**0.02863**	0.171183	0.170318	0.170832	0.167692
Total P	0.004105	0.741076	0.81671	0.81602	0.81522	0.81685
Total N	0.07779	0.068578	0.830415	0.831904	0.83271	0.827282
NO_3^-	0.034866	0.09027	0.48846	0.49052	0.48985	0.49389
T coli	0.3687274	0.2816593	0.8217237	0.8240704	0.8254154	0.8262956
E.coli	1.86E-05	6.63E-01	5.66E-01	5.67E-01	5.68E-01	5.67E-01
Discharge	0.14448	0.39263	0.74306	0.7434	0.7409	0.7453

The linear mixed effect model for TEMP as presented above as, has shown *'p-values'* for 'Landuse' variable as a whole and each row correspond to the individual 'Landuse' types. The landuse variable has a '*p-value*' of *0.038* in the temperature model, but the individual landuse '*p-values*' are around *0.59*. This implies that, while the landuse variable is significant (*p*-value < 0.05) as a whole, it cannot be stated which particular type is significant because of the 'multicollinearity' effects as discussed earlier. Also, while landuse is significant in the model, it may just be a location effect. Furthermore, this significance shows a strong association but it cannot be said that different 'Landuse' types caused a change in temperature.

Because of multicollinearity issue identified that interfere with possible correlation between different land use types to have individual effect on water quality, several attempts were made to resolve the problem. This included consideration for the use of the land area as in hectares (ha) for each land use instead of using the proportion (%) of land use types. The results have found higher correlation coefficient in all land use types which relate back to the results of using the land area in hectares (ha), which have similar values when using the proportion (%) of land area. These are summarised in Table 15 below.

Table 15. Comparison of correlation coefficient of land use consideration in hectare (ha) and percentage

Land use consideration (ha)	Pearson correlation coefficient (*r*) Land use area (ha)	Pearson correlation coefficient (*r*) Land use proportion (%)
FO vs Combined AG & GR	0.90746	-0.9674
FO vs Combined AG & BUA	0.96345	-0.9637
FO vs Combined AG+GR+BUA	0.96380	-1
FO vs Combined GR+BUA	0.96947	-0.90065

Key: Forest (FO), Agriculture (AG), Grassland (GR) & Built up area (BUA)

Given the results in Table 15, of different land use consideration for land use area (ha) and land use proportion in percentage, the actual effect of each individual land use type on water quality parameter could not be examined as the majority were close to ± 1. This could be the result of the net effect of overlapping sub-catchment where the areas (ha) or proportions (%) of the sub-catchments located downstream would have a net effects of sub-catchment delineated upstream. This could be considered further in future research of the catchment.

However, the results of the model summarise in Table 14 briefly explained the association of the land use effects on water quality in terms of *p* values and their correlation coefficient values. Generally it shows a strong relationship of land use as a whole to water quality parameters despite having not being able to determine each individual effect due to multicollinearity issue as a result of net effect of proportion of each land use type.

The p-value of 0.0384 < 0.05 for 'Landuse' indicates that 'Landuse' as a group is significantly associated with temperature. However, their individual type '*p-values'* are 0.5976, 0.5951, 0.5938 and 0.5954, are all larger than 0.05, thus implying insignificance. This contradicts with the significant group *p-value* of 0.0384. This is due to multicollinearity. Thus, because of the multicollinearity, it is meaningless to interpret the coefficients, -33.650, -33.912, -34.424 and -33.936. The following interpret the effects of water quality response for the rest of the water quality parameters.

2. pH.

The p-values for 'Landuse' is 0.0056 that shows significant for Conductivity. However, the individual land use effects have '*p-values'* of 0.0328, 0.0330, 0.0329 and 0.0331, which are small enough to be significant. However, due to multicollinearity, coefficient values of 15.5678, 15.5445, 15.7369 and 15.5594 cannot be trusted.

3. Conductivity

The p-values for 'Landuse' is 0.0093 which is significant for Conductivity. The individual land use effects have large p-values, 0.6787, 0.6805, 0.6735 and 0.6806 which imply insignificance. Again, with multicollinearity effects, the coefficient values of 149.963, 149.963, 154.476 and 149.334 cannot be trusted.

4. Total Dissolved Solid (TDS)

The 'p-values' for 'Landuse' is 0.0091 which is for Total Dissolved Solids. The individual Landuse effects have large p-values of 0.6631, 0.6649, 0.6580 and 0.6651, thus implying insignificance. Also, this is due to multicollinearity. Hence, coefficient values, 170.292, 170.392, 172.358 and 170.646 cannot be trusted.

5. Dissolved Oxygen (DO)

The ‘p-values’ for ‘Landuse’ is 0.0302, so it is significant for Dissolved oxygen. The individual land use effects have large ‘p-values’, 0.2038, 0.2054, 0.2065 and0.2071, thus implying insignificance. However, this is due to multicollinearity. Hence, the coefficient values, 13.8537, 13.8043, 13.9233 and 13.7656 cannot be trusted.

6. Turbidity (TUR)

The ‘p-values’ for ‘Landuse’ is 0.0286, it is significant for Turbidity. The individual Landuse effects have large ‘p-values’, 0.1712, 0.1703, 0.1708 and 0.1677, thus implying insignificance. However, this is due to multicollinearity. Hence, the coefficient values, 10.4388, 10.4707, 10.5762 and 10.5669 cannot be trusted.

For the ‘p-value’ of ‘Landuse’ associate with Total P (0.7411), Total N (0.0686), NO_3^- (0.0903), Total coli (0.2817) and E. coli (0.6632), were all found not significant as they have more than 0.05 ($p<0.05$).

CHAPTER 6: CONCLUSION & RECOMMENDATION

This study assessed the current status of water quality, in relation to spatial landuse distribution pattern within the Fuluasoa River catchment. This assessment was made possible through the collection and analysis of water quality samples from the Fuluasou River during the dry period (August to October, 2013). A total of 53 water quality samples from ten sites across upper, mid and lower catchment were collected and analysed for physico-chemical (Temp, pH, COND, TDS, DO, Turbidity, Total P, Total N, & NO_3^-) and microbiological (Total coliform, E. coli) parameters. The relationship amongst water quality parameters and major land use types were determined by using GIS and statistical analysis. The findings of this study are summarised in accordance with the research objectives:

- *To determine the current status of the Fuluasou River Catchment through measurement and analysis of the physico-chemical and microbiological parameters of the river water, and to compare the results with water quality regulatory standards, in order to identify any major pollutant(s) of concern.*

This study measured and determined the levels of physicochemical (Temp, pH, COND, TDS, DO, TUR, Total P, Total N, & NO_3^-) and microbiological (Total coliform, E. coli) water quality parameters during the dry period from August to October, 2013. The results of the analysis found the mean (± sd) concentrations levels of Temp (27 ± 3.521), pH (8.3 ± 0.276), 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), NO_3^-(0.01 ± 0.0032), T coli (9923 ± 1782), and E. coli (7431 ± 1347) respectively. These findings suggest that all parameters have their total mean concentrations below their permissible standards, except 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 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) suggesting a 100% of non-compliances. The findings are indicative of high levels of microbiological contamination all across the catchment, which revealed very poor microbial water quality of the Fuluasou River. This conclude that Fuluasou River is not safe at all for drinking especially the current untreated water supply from Chinese 1 and Chinese 2 intakes administered by the SWA, unless otherwise treated. Moreover, the Fuluasou River water is also not safe for any recreational activities, especially contact recreation as swimming. Therefore, Total coli and E. coli can be listed as the two major pollutants of great concern in the Fuluasou River.

- *To determine the spatial variation pattern of water quality responses, relative to the land use distribution across segments of the catchment: the upper, mid and lower parts of the catchment.*

The assessment, for determination of the spatial variation pattern of the water quality response to the land use distribution of the catchment, has revealed a great variability of some water quality parameters across different segments of the catchment. The most evident parameters found to be increasing, from the upland to the lower catchment, were Temp, pH, Total N, Total P, and NO_3^-. The increasing trend of these parameters are mostly associated with an increase in land use development, such as agricultural activities (e.g. mixed cropping and plantations) moving from upland to low-land. The increasing values of COND and TDS, from the upland to the mid-catchment, slightly decreasing again towards the lower catchment, could be the result of mix pollutants in the river from anthropogenic activities, as the proportion of agriculture land increases towards the mid-catchment. Microbiological parameters are varied across the catchment and this result signals the impact of the presence of both cattle farming and feral animals (SWA, 2011), with possible faecal contamination occurring from nearby residents and those who live and develop areas for new sub-divisions of land on the upper catchment. 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. Disruptions in the river system due to existing government infrastructures such as old EPC dam (mid-catchment) and road (in the upper and mid-catchment) could impact on the natural system of the river flow regime which in turn influence the spatial variability of water quality across different segments of the catchment.

- *To determine the status of potential correlations amongst physicochemical and microbiological water quality parameters of the Fuluasou River water.*

Pearson correlation analysis shows an appreciable significant positive correlation has been recorded for COND with TDS & NO3, pH, Total P with Total N & NO_3^-, TEMP with pH, COND, Total P and Total N. While conductivity is generally proportional to total dissolved solids, and can be related given increase in total dissolved solids, also increase electrical conductivity in the water. Intensity of anthropogenic activities as agricultural and settlements from upland to lowland may responsible for any increase in discharge of fertilizers and waste runoff that possibly influence the conductivity concentration of the water. This also affects its association with other parameters. Furthermore, a positive correlation is recorded for pH with COND, TDS, DO, NO_3^-. A significant negative correlation is recorded between TDS and TURB, and COND with TURB. With pH slightly increase as you descend downstream is a result of having domestic waste littering as identified evident in the downstream direction that may contribute to the mild alkalinity conditions of the river. This may influence the mean concentration of other parameters resulting with variation nature of their correlation.

Temperature found a strong significant positive correlation with pH, COND, DO, Total P and Total N with their *p*-values less than 0.05. A strong indication of an increase in temperature will also relatively increase the levels of these parameters. A correlation of interest recorded for Temp and DO in which both increases towards downstream direction as should be expected an inverse relationship that could be the result of decreasing in air pressure that decrease DO levels on higher elevation compared to low elevations. Overall, the correlation amongst the water quality parameters analysed is mainly influence by the possible causes of land use pollution that affects the nature of water quality response across different segments of the catchment.

- *To determine possible changes in land use development based on the year 1999 and 2013, and determine up to date land use characterisation of the FRC.*

The assessment of the land use change over a 14 year period between 1999 and 2013 to determine possible changes in land use development has revealed forest (FO) as the dominant land use, which accounted for 36.6%: and agriculture (ARG) the second with 32.1% of the current total land use area of the FRC. The study also reveals that between 1999 and 2013, 12.7% of FOR was lost and ARG lands increased by 10.8%. This finding demonstrates that forested areas are under threat from an increase in agriculture lands for mixed cropping and agricultural plantations with cattle grazing activities, despite a slight decrease of grassland areas for cattle farm by 0.50%, due to previous land occupied by cattle farming has now been taken over by agricultural development. This result shows that when agricultural land increases, forested areas decreases. However, the slight increase of 2.4% for BUA has contributed to the loss of some of these forested lands. In addition, an increase in developmental infrastructure at the lower to mid-catchment has been partly responsible for the loss of some forested areas.

- *To determine the potential land use relationship with the river water quality and their degree of association and if possible, to identify any key land use category that may strongly influence water quality in the catchment area.*

The output of the linear mixed effect model revealed the status of the land use relationship with river water quality. The findings have indicated a positive relationship between 'landuse' as a group, is significantly associated with temperature, conductivity, pH, total dissolved solids, dissolved oxygen and turbidity. Interestingly however, the findings have not been able to present which of the four land use types (forest, agriculture, grassland and built-up areas) may have been responsible for causing water quality pollution by having a known individual effect on each of the water quality parameter analysed. This was the result of a multicollinearity problem encountered during the delineation analysis in which a net effects of the proportion (%) of land use areas upstream have influenced the results of the delineation of sub-catchments in the mid and the lower catchment. While every effort was made to consider other alternatives, by trialling several combinations of land use types relative to their proportions (%) and land use areas (ha), the problem of multicollinearity still remains. Therefore, the study concludes that, while there is a significant positive correlation between land uses as a whole/group and the identified water quality parameters as above-stated, the individual effect of each land use type on water quality cannot be determined. This would be an improvement in future progress of this study.

- *To contribute to knowledge in the field of land use impact and its relationship with river water quality on a site-specific location, as is the case of FRC in Samoa.*

Given this study is the first attempt to determine land use impacts on the water quality of Fuluasou River water quality and their relationships in Samoa, this research could be used as a baseline and provision of reference data, when considering possible further developments associated with human activities. This consideration could be crucial, as provision of research baseline information and data on the current situation of how land use may have impacted on water quality has not been published in the case of the Fuluasou River Catchment. This baseline information and data could help in developing a better understanding of the existing conditions and status of the river water quality, in relation to the land composition of the river catchment. The findings of the physicochemical and microbiological analysis of this study as stated earlier have indicated their mean concentrations were all less than their critical standards values, except for Total coli and E. coli having failed 100% compliances for both drinking and recreational purposes. This is crucial information to understand that Total coli and E.coli are the two major pollutants of concern for Fuluasou river water that should come under serious consideration by the state in future water resource and pollution prevention programs at the catchment level. While the findings have shown 100% non-compliance for Total coliform and to have failed more than 9000 times, while E. coli to have failed more than 7000 times during the term of monitoring, is a strong indication of future commitment is needed from all key stakeholders to ensure microbial contamination in Fuluasou river is minimized to acceptable standards for both drinking and recreational purposes. Subsequently, this will also help protect river ecosystem health of the Fuluasou river environment. In addition to the outcome of the water quality analysis, understanding of how much forest that were cleared over space and time to allow agriculture activities such as mixed crop plantation, cattle grazing and livestock development, settlement areas, community and government infrastructures as the most common land use practices in Samoa, will help with future land use planning purposes. This baseline information is vital to facilitate future engagements with communities at village levels and the government to help protect forest areas to enhance the protection of catchment areas as source of water supply.

6.1 Limitations of the study

This research has encountered some challenges that prevented the presentation of a more comprehensive analysis and detailed insights of how land use modification over space and time, and the current land use pattern of Fuluasou River Catchment, may have impacted on its river water quality. Some of these challenges that have been identified from the experiences of this study are as follows:

Historical hydrological and water quality data: Initial attempts were made, in consultation with the Water Resources Division of the Ministry of Natural Resources and Environment (MNRE) and the Ministry of Health in Samoa, to allow the use of historical hydrological and water quality data for the Fuluasou River. This was to obtain more robust datasets to allow for comparative analysis to see possible temporal changes and relationship with land use modification over space and time that could therefore have determined the influence of land use changes on the water quality of the Fuluasou River.

However, the major issue identified was a great deal of missing data for an extended period of time, without any measurements of some of the water quality parameters. Therefore, the analyses present in this study were onlymade possible through the datasets collected during the three months implementation term of this study. A comparative analysis component could allow for more convincing results of the impacts of Fuluasou land use pattern on its river water quality.

Given the importance of this study to water pollution prevention at the source level, the involvement of the Ministry of Health in regulating water supply to ensure consumer compliance in line with the existing water quality standards is vital for their current water quality surveillance monitoring.

Unfortunately, this project request for availability of such information and the possible release of epidemiological records of water borne diseases were (for a possible spatial distribution of reported cases and correlation analysis) not made possible during the period of data collection due to lengthy process taken by the Ministry for such request to process for approval despite several follow-up.

The availability of such important epidemiological records/data of water borne diseases would be ideal to establish a spatial distribution analysis to see any possible correlation of cases reported for water borne diseases (illness) and faecal-indicator bacteria concentrations from those residing within the boundary of Fuluasou River Catchment. This analysis could have been appropriate especially the microbiological analysis in this study recorded to be very high exceeding the standards on both drinking and recreational purposes. This could be determined given the broad coverage of the water supply system sourced from Fuluasou River Catchment. However, the researcher is determined to further this aspect, as part of the next stage of this study in the future.

Limited water quality measurements conducted – shorter time period (only three months): This research was allowed to implement its field activities within the time limit of a three months period, as a result of terms and conditions of the sponsored scholarship, to which this research was carried out in accordance to the home located research policy of the sponsor (NZ, MFAT, 2012). These three months were from August to October in 2003 and last three months of the dry period in Samoa (May-October). It would be interesting to see possible changes to the results as to the status of the measured water quality parameters across the catchment, if given the project implementation extended to include the wet season given the level of possible land-based discharges could have been higher during raining season compared to dry period to get a better understanding of possible sources of river pollution.

Sampling design & site selection: The multicollinearity issue identified in this study is a problem that was overlooked during sampling design for this study until later in the process of catchment delineation analysis. This may have been caused by overlapping the area of each

sub-catchment defined by the selected sampling sites resulting in a high correlation between the land uses relative to their proportions and areas. This was noticed with the sub-catchments delineated for the mid and the lower parts of the catchment which encompassed the same areas of the sub-catchments delineated upstream resulting in a possible net effects causing multicollinearity problem. The same multicollinearity situation that was identified in Hanipah (2012) study of Leith River in Otago, New Zealand. The analysis could be better without this limitation in order to provide a better understanding of an individual effect of each land use type as possible source of pollution corresponding with the nature of the analysed water quality parameters.
Regardless of this multicollinearity issue, it could be avoided had been considered in the pre-planning stage where the search of appropriate sampling design for site selection would show more specific land use classification type (e.g. Livestock instead of Grassland, or Plantation instead of Agriculture) defined by each sampling point considered for each river tributary, rather than having a broad landuse selection defined by having two or more sampling point on the same tributary.

GIS Spatial information: As the world advances with the use of GIS and remote sensing technology, to provide thorough assessments of natural resources and watershed development issues, their use in Samoa is limited. This could be a result of slow development of spatial information due to limited technical capacity and advance knowledge at state level. The only available GIS spatial information for Samoa is the 1999 MapInfo GIS data that some were validated during the 2004 ground-truthing survey. Also a 10m contour data was available for the project use in which, the GIS analysis faced some difficulties through the delineation process in aligning the river feature with the available DEM created from the 10 m contour lines. Several attempts were made online in search for better DEM for Samoa to use for the study analysis were unsuccessful. A better DEM which could provide correct alignment with the actual GIS layers of Fuluasou River system could have made possible with a 5m contour lines with high chance of accuracy. Also with the land use change analysis, should be any chance of having another year of GIS data (e.g) 2006 would give a better comparison of how much land use change over the space of time that could see the pace of deforestation and the intensity of developments across the catchment over the years.

6.2 Recommendations

It is not the intention of this research, with its individual results and overall conclusions, to provide all the answers as a ‘one fits all’ solution to the current water pollution problems of the FRC. However, it presents the current status of water quality conditions of the FRC to provide scientific based evidence in relation to its land use distribution pattern that could assist with the management strategies and the improvement of operational monitoring for water resource management and protection of catchment areas in Samoa.

The study was set with the purpose to enhance water quality performances and pollution control within the catchment level, in order to offer a safe water supply and to support the ecological health of the river’s ecosystem. In saying this, there are several areas that need to be considered that require further review, assessment and investigation, and this would be the ideal basis for future improvements to current water quality monitoring, and research opportunities. In order to address these areas, this research recommends the following:

- Experiencing the multicollinearity issue in the delineation analysis in this study requires a different approach to selecting water quality sampling site. It is recommended for better results of catchment delineation, the selection of sampling sites shall consider for each tributary, and to ensure each site correspond to a particular land use type that could identify as potential source of pollution.

- Consider the inclusion of a wet season study, in which discharge of pollutants (e.g. concentrations of water quality parameters in relation to land use as discharge of pollutants during the rainy season) could be higher, compared to the dry season. This would give a fair representation of how land use could affect river water quality, in regards to pollution prevention and sound management within the catchment level. Comparison analysis between the two seasons would make it possible and ideal to generate more interesting information in this regard to help with future management and pollution control at the source level.

- The government needs to take further steps in revising its current National Drinking Water Standard, 2008, in particular its aesthetic section and to consider having ecosystem and environmental standards to include benchmarks for rivers, lakes and streams as most critical parameters to regulate recreational activity and river ecosystem health, are not included in the current SNDWS. This revision is crucial to safeguard public health and to allow consideration for good ecological health of freshwater resources and ecosystem in Samoa.

- The results of microbiological analysis in this study revealed great risk of Fuluasou River from microbial contamination especially the two untreated water supply system known as Chinese 1 and Chinese 2, administered by the Samoa Water Authority (SWA). Therefore, it is strongly recommended to include a special review of Drinking water quality in Samoa as part of the on-going 'Annual Review for Water and Sanitation Sector' despite having the Ministry of Health only reporting on its current Drinking water quality monitoring program for surveillance and compliances purposes. This would assist the Ministry of Health in evaluating the effectiveness of its policies and current 'Drinking Water Quality Monitoring Program', and any public health risk management plans to ensure effective regulatory framework are in place to improve water quality through surveillance and compliances purposes.

- The government needs to take into consideration strict measures to control water quality and hydrological field monitoring operations, in order to improve on their data collection and management, with a strong emphasis on scientific data analysis and updates. Resources allocated to field monitoring need to be more reliable to avoid inadequacy in the current water quality monitoring system. Strict control measures should be incorporated in any current water quality monitoring framework within responsible government ministries to ensure useable and reliable data are collected and analysed in a timely manner. This can provide more practical information and data that could inform and strengthen water resource management policy. Available of affirmative action policy statements with strong scientific evidence-based would help guide practical and sound management strategies and plans of action (PoAs), which would result in a firm, public commitment from all key stakeholders (especially from the government) to undertake positive actions in addressing current water pollution issues in Samoa.

- In future research development as the next stage of this study, it is recommended to conduct an epidemiological study component to assess a spatial distribution and correlation analysis between the water-borne diseases cases or illness reported, and feacal-indicator bacteria concentrations from those who resides within Fuluasou River Catchment or those whose households are serviced by the water supply system sourced from Fuluasou River.

- It is recommended for the Water Resources Division of MNRE to consider relocating their water flow logger and suggest their water flow monitoring to be located perhaps just after the eastern (after STN5) and middle river branch (after STN6) met before the EPC old dam. This would give a more holistic approach to the flow discharge of FRC rather than having it monitor at only one river tributary on the upper catchment (eg. at STN3).

- Given the flow discharge of Fuluasou River recorded a significant low flow towards the lower catchment, and the disruption of a nature flow regime of the river identify caused by the existing old EPC hydro dam in the middle of the mid-catchment, it is strongly recommended for the government to consider possible demolition. This would allow water to flow naturally in the system that could prevent pollution accumulation associated with low flow at the lower catchment. Also to ensure sufficient environmental flow for the survival of aquatic life downstream, and could probably help with river drying out at the lower reach of the catchment during the dry period.

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Appendix 1.

Outputs of the Linear mixed effects model

1. Temperature (Temp)

```
[1] "Temp"

Linear mixed-effects model fit by maximum likelihood
 Data: NULL
      AIC      BIC    logLik
  258.77 282.4135 -117.385

Random effects:

 Formula: ~1 | Station
        (Intercept) Residual
StdDev:    1.250552 1.996387

Fixed effects: WaterQuality ~ LandUse
                       Value Std.Error DF    t-value p-value
(Intercept)         3414.341  5978.005 38  0.5711506  0.5713
LandUseAgriculture   -33.650    59.750  5 -0.5631899  0.5976
LandUseForest        -33.912    59.785  5 -0.5672389  0.5951
LandUseGrassland     -34.424    60.475  5 -0.5692327  0.5938
LandUseBuiltUp       -33.936    59.877  5 -0.5667530  0.5954


Number of Observations: 53
Number of Groups: 10
            numDF denDF   F-value p-value
(Intercept)     1    38 2557.7925  <.0001
LandUse         4     5    5.9573  0.0384
```

2. pH

```
[1] "pH"
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
        AIC      BIC    logLik
  31.44825 55.09176 -3.724127

Random effects:
 Formula: ~1 | Station
        (Intercept)  Residual
StdDev:  0.08471881 0.2481808

Fixed effects: WaterQuality ~ LandUse
                         Value Std.Error DF    t-value p-value
(Intercept)         -1546.5926  532.2332 38 -2.9058550  0.0061
LandUseAgriculture     15.5678    5.3196  5  2.9265025  0.0328
LandUseForest          15.5445    5.3228  5  2.9203871  0.0330
LandUseGrassland       15.7369    5.3842  5  2.9227948  0.0329
LandUseBuiltUp         15.5594    5.3312  5  2.9185445  0.0331


Number of Observations: 53
Number of Groups: 10
```

```
             numDF denDF   F-value p-value
(Intercept)      1    38 30314.042  <.0001
LandUse          4     5    14.814  0.0056
```

3. Conductivity (COND)

```
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
       AIC     BIC    logLik
  388.7875 412.431 -182.3937

Random effects:
 Formula: ~1 | Station
        (Intercept) Residual
StdDev:    8.223266 6.058982

Fixed effects: WaterQuality ~ LandUse
                        Value Std.Error DF   t-value p-value
(Intercept)        -14839.481  34150.21 38 -0.434536  0.6664
LandUseAgriculture    149.963    341.33  5  0.439349  0.6787
LandUseForest         149.162    341.53  5  0.436748  0.6805
LandUseGrassland      154.476    345.47  5  0.447147  0.6735
LandUseBuiltUp        149.334    342.04  5  0.436599  0.6806


Standardized Within-Group Residuals:
       Min         Q1        Med         Q3        Max
-2.5812960 -0.4619617  0.1816114  0.7352096  1.2831564

Number of Observations: 53
Number of Groups: 10
             numDF denDF   F-value p-value
(Intercept)      1    38 1679.3237  <.0001
LandUse          4     5   11.7472  0.0093
```

4. Total dissolved solids (TDS)

```
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
       AIC      BIC    logLik
  316.9584 340.6019 -146.4792

Random effects:
 Formula: ~1 | Station
        (Intercept) Residual
StdDev:    4.093727 3.089338

Fixed effects: WaterQuality ~ LandUse
                       Value Std.Error DF   t-value p-value
(Intercept)        -7797.458 17037.807 38 -0.457656  0.6498
LandUseAgriculture    78.766   170.292  5  0.462536  0.6631
LandUseForest         78.360   170.392  5  0.459879  0.6649
LandUseGrassland      81.055   172.358  5  0.470269  0.6580
LandUseBuiltUp        78.438   170.646  5  0.459653  0.6651


Number of Observations: 53
Number of Groups: 10
             numDF denDF   F-value p-value
(Intercept)      1    38 1686.9613  <.0001
```

```
LandUse          4     5   11.8651  0.0091
```

5. Dissolved Oxygen (DO)

```
[1] "DO"
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
      AIC      BIC      logLik
  24.4661 48.1096 -0.2330497

Random effects:
 Formula: ~1 | Station
        (Intercept)  Residual
StdDev:   0.2235644 0.2014829

Fixed effects: WaterQuality ~ LandUse
                        Value Std.Error DF    t-value p-value
(Intercept)        -1372.1929  948.6761 38 -1.4464293  0.1563
LandUseAgriculture    13.8537    9.4820  5  1.4610628  0.2038
LandUseForest         13.8043    9.4875  5  1.4549990  0.2054
LandUseGrassland      13.9233    9.5970  5  1.4507926  0.2065
LandUseBuiltUp        13.7656    9.5018  5  1.4487386  0.2071


Number of Observations: 53
Number of Groups: 10
            numDF denDF   F-value p-value
(Intercept)     1    38 11261.350  <.0001
LandUse         4     5     6.729  0.0302
```

6. Turbidity (TUR)

```
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
       AIC      BIC     logLik
  76.02472 99.66822 -26.01236

Random effects:
 Formula: ~1 | Station
         (Intercept)  Residual
StdDev: 6.922023e-06 0.3952885

Fixed effects: WaterQuality ~ LandUse
                        Value Std.Error DF    t-value p-value
(Intercept)        -1045.1600  654.0397 38 -1.5980070  0.1183
LandUseAgriculture    10.4388    6.5370  5  1.5968770  0.1712
LandUseForest         10.4707    6.5409  5  1.6008063  0.1703
LandUseGrassland      10.5762    6.6164  5  1.5984669  0.1708
LandUseBuiltUp        10.5669    6.5516  5  1.6128665  0.1677


Number of Observations: 53
Number of Groups: 10
            numDF denDF  F-value p-value
(Intercept)     1    38 432.8522  <.0001
LandUse         4     5   6.9103  0.0286
```

7. Total Phosphorus (Total P)

```
[1] "Total.P"
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
        AIC       BIC   logLik
  -479.6344 -455.9909 251.8172

Random effects:
 Formula: ~1 | Station
         (Intercept)    Residual
StdDev: 8.035373e-08 0.002090804

Fixed effects: WaterQuality ~ LandUse
                        Value Std.Error DF   t-value p-value
(Intercept)         0.8605457  3.459420 38  0.248754  0.8049
LandUseAgriculture -0.0084470  0.034576  5 -0.244300  0.8167
LandUseForest      -0.0084845  0.034597  5 -0.245238  0.8160
LandUseGrassland   -0.0086208  0.034996  5 -0.246334  0.8152
LandUseBuiltUp     -0.0084591  0.034654  5 -0.244106  0.8168

Number of Observations: 53
Number of Groups: 10
            numDF denDF   F-value p-value
(Intercept)     1    38 1686.5877  <.0001
LandUse         4     5    0.4970  0.7411
```

8. Total Nitrogen

```
[1] "Total.N"
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
       AIC       BIC   logLik
  -292.501 -268.8575 158.2505

Random effects:
 Formula: ~1 | Station
         (Intercept)   Residual
StdDev: 3.817406e-07 0.01221859

Fixed effects: WaterQuality ~ LandUse
                       Value Std.Error DF    t-value p-value
(Intercept)        -4.288344 20.216725 38 -0.2121186  0.8331
LandUseAgriculture  0.045593  0.202062  5  0.2256399  0.8304
LandUseForest       0.045212  0.202183  5  0.2236185  0.8319
LandUseGrassland    0.045513  0.204518  5  0.2225358  0.8327
LandUseBuiltUp      0.046557  0.202514  5  0.2298944  0.8273

Number of Observations: 53
Number of Groups: 10
            numDF denDF   F-value p-value
(Intercept)     1    38 16010.943  <.0001
LandUse         4     5     4.374  0.0686
```

9. Nitrate (NO_3^-)

```
[1] "NO3"
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
        AIC       BIC   logLik
  -471.6223 -447.9788 247.8111

Random effects:
 Formula: ~1 | Station
         (Intercept)    Residual
StdDev: 0.0008999699 0.002118205

Fixed effects: WaterQuality ~ LandUse
                       Value Std.Error DF    t-value p-value
(Intercept)        -3.730176  5.019491 38 -0.7431382  0.4620
LandUseAgriculture  0.037496  0.050169  5  0.7473985  0.4885
LandUseForest       0.037331  0.050199  5  0.7436692  0.4905
LandUseGrassland    0.037825  0.050778  5  0.7448957  0.4898
LandUseBuiltUp      0.037086  0.050278  5  0.7376134  0.4939

Number of Observations: 53
Number of Groups: 10
            numDF denDF   F-value p-value
(Intercept)     1    38 312.04322  <.0001
LandUse         4     5   3.73959  0.0903
```

10. Total coliform (T. coli)

```
Linear mixed-effects model fit by maximum likelihood
 Data: NULL
       AIC      BIC    logLik
  944.7732 968.4167 -460.3866

Random effects:
 Formula: ~1 | Station
        (Intercept) Residual
StdDev:    760.7006 1301.878

Fixed effects: WaterQuality ~ LandUse
                      Value Std.Error DF    t-value p-value
(Intercept)        883910.9   3719295 38  0.2376555  0.8134
LandUseAgriculture  -8827.3     37174  5 -0.2374593  0.8217
LandUseForest       -8713.7     37196  5 -0.2342640  0.8241
LandUseGrassland    -8745.4     37625  5 -0.2324339  0.8254
LandUseBuiltUp      -8614.4     37254  5 -0.2312368  0.8263

Number of Observations: 53
Number of Groups: 10
            numDF denDF  F-value p-value
(Intercept)     1    38 859.5183  <.0001
LandUse         4     5   1.7181  0.281
```

11. E. coli

```
[1] "E.coli"
Linear mixed-effects model fit by maximum likelihood
 Data: NULL 
       AIC      BIC    logLik
  900.6209 924.2644 -438.3104

Random effects:
 Formula: ~1 | Station
        (Intercept) Residual
StdDev:    677.5782 819.6775

Fixed effects: WaterQuality ~ LandUse 
                       Value Std.Error DF   t-value p-value
(Intercept)        1856364.6 3017497.7 38  0.615200  0.5421
LandUseAgriculture  -18511.8   30159.6  5 -0.613794  0.5662
LandUseForest       -18502.4   30177.4  5 -0.613122  0.5666
LandUseGrassland    -18651.3   30525.6  5 -0.611006  0.5679
LandUseBuiltUp      -18528.8   30223.4  5 -0.613062  0.5666

Number of Observations: 53
Number of Groups: 10 
            numDF denDF  F-value p-value
(Intercept)     1    38 735.7558  <.0001
LandUse         4     5   0.6287  0.6632
```