Assessment of Upstream Farming Intensification and Its Impact on Soil and Downstream Water Quality in Yusipang Hongtso Watershed

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MASTER OF SCIENCE IN ENVIRONMENTAL DESIGN AND PLANNING
MAEJO UNIVERSITY
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A THESIS SUBMITTED IN PARTIAL FULFILLMENT
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ชื่อเรื่อง การประเมินผลกระทบของเกษตรกรรมพื้นที่ลุ่มน้ำตอนบน ที่มีผลต่อดินและคุณภาพน้ำของพื้นที่ลุ่มน้ำยูสิปัง ซองโช ตอนล่าง ประเทศภูฏาน

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บทคัดย่อ

พื้นที่ดำเนินการวิจัย ณ ลุ่มน้ำยูสิปัง ซองโช ประเทศภูฏาน เพื่อศึกษาประเมินประเมินผลกระทบของเกษตรกรรมพื้นที่ลุ่มน้ำตอนบน และการชะล้างพังทลาย ที่มีผลต่อดินและคุณภาพน้ำของพื้นที่ลุ่มน้ำตอนล่าง รวมทั้งสำรวจต้นกำเนิดของมลพิษทางน้ำ เพื่อออกแบบแนวทางการพัฒนา โปรแกรมภูมิสารสนเทศถูกนำมาใช้ศึกษาการประโยชน์ที่ดินและลักษณะกายภาพของพื้นที่ พื้นที่เกษตรกรรมถูกจำแนกชั้นความลาดชัน 4 ชั้น ประกอบด้วย (0-4%, 4-8%, 8-12%, 12-16% ตัวอย่างดินจำนวน 27 ตัวอย่างถูกเก็บเก็บกระจายตามชั้นความลาดชันและวิเคราะห์เนื้อดิน ธาตุอาหารหลัก และค่าความเป็นกรดด่าง ในห้องปฏิบัติการ สำหรับคุณภาพน้ำจำนวน 4 ตัวอย่าง กำหนดจุดเก็บตัวอย่างโดยพิจารณาแหล่งกำเนิดมลภาวะ และทดสอบคุณภาพ 8 ตัวชี้วัดด้วยเครื่องมือภาคสนาม การชะล้างพังทลายของดินวิเคราะห์สมการสูญเสียดินสากล ทดสอบสารเคมีกลุ่ม Organophosphate และ Carbonate โดยสถาบันรับรองคุณภาพและมาตรฐานการเกาตรมหาวิทยาลัยโจ้ (IQS) ส่วนข้อมูลการเกษตรกรรม สถานภาพทางเศรษฐกิจสังคม รายได้ครัวเรือนและการใช้สารเคมีการเกษตร การอนุรักษ์ดินและน้ำ รวบรวมข้อมูลข้อมูลด้วยเครื่องมือและการวิเคราะห์ชุมชนแบบมีส่วนร่วม รวมทั้ง สัมภาษณ์เชิงลึกด้านรายได้รายจ่ายภาคเกษตร จากประชากรจำนวน 11 ครัวเรือน

พืชสวนเป็นเกษตรกรรมเด่น ประกอบด้วยพืชที่สร้างรายได้หลักคือมันฝรั่ง กะหล่ำปลี กะหล่ำดอก และมีไม้ผลคือแอปเปิล ด้วยความต้องการผลผลิตของตลาดผลักดันให้เกษตรกรปรับเปลี่ยนวิถีการเกษตรเป็นเกษตรพาณิชย์ ที่ต้องเพิ่มปัจจัยการผลิต ทั้งนี้สารเคมีคือปัจจัยการผลิตที่ใช้ทั่วไป รายได้ภาคเกษตรทชมีสัดส่วน 74% และสัดส่วนที่เหลือเป็นรายได้นอกภาคเกษตร การชะล้างพังทลายจากพื้นที่เกษตรบนความลาดชัน 0-4 % เท่ากับ 2.15 ตัน/เฮกตาร์/ปี และ 8.24 ตัน/เฮกตาร์/ปี บนพื้นที่ลาดชัน 12-16 % คุณสมบัติของดินมีความเป็นกรดปานกลาง (ค่าเฉลี่ย 5.5) ปริมาณฟอสฟอรัสและโพแตสเซียมของพื้นที่เกษตรมีค่า 77.28 และ 340.66 mg/kg ซึ่งอยู่ในระดับสูง เมื่อเทียบกับพื้นที่ป่าไม้ ขณะที่ค่าเฉลี่ยปริมาณอินทรีย์สูงมากทั้งพื้นที่เกษตรกรรม (10.47

%) และพื้นที่ป่า (10.31 %) ขณะที่ค่าไนโตรเจน (0.19) มีแนวโน้มลดลงสำหรับดินที่เหมาะสมเพื่อการเพาะปลูก สำหรับพื้นที่ต้นน้ำมีคุณภาพน้ำดี และลดลงอย่างมีชัดเจนเพื่อไหลลงสู่พื้นที่ตอนล่าง พิจารณาได้จากน้ำมีค่าความเป็นกรดสูง พบบริเวณใกล้เคียงพื้นที่เกษตรกรรม

ผลการประเมินพบว่า การใช้สารเคมีการเกษตร มีผลให้ดินมีธาตุอาหารไม่สมดุล ธาตุอาหารที่ตกค้างจากพื้นที่เกษตรตอนบน ของเสียแคมป์กรรมกรและฟาร์มหมูมีผลต่อคุณภาพน้ำในลำธาร อย่างมีนัยยะสำคัญ และไม่เหมาะเพื่อการอุปโภคบริโภคและการบริการด้านนิเวศ ปริมาณสูงของสารอนินทรีย์จากพื้นที่เกษตร พื้นที่ลุ่มน้ำตอนบน และคุณภาพน้ำผิวดินที่มีความเป็นกรดสูง แสดงถึงผลกระทบของพื้นที่เกษตรกรรมตอนบนต่อคุณภาพน้ำตอนล่าง ดินที่มีธาตุอาหารไม่สมดุล ตลอดจนวิธีการเกษตรจำเป็นต้องมีการพัฒนาให้ทันการณ์ เทคโนโลยีแบบเชง (The Sheng’s technology) และแนวทางการพัฒนาพื้นที่เกษตร ปี ค.ศ. 2017 เป็นวิธีการที่เหมาะสมสำหรับการอนุรักษ์ดินชั้น บนพื้นที่ลาดชัน การใช้ปุ๋ยอินทรีย์และการควบคุมแมลงโดยชีววิถี ต้องได้รับการส่งเสริม เพื่อปรับปรุงระบบนิเวศเกษตร และลดมลพิษทางน้ำ เช่นเดียวกับบำบัดของเสียจากฟาร์มเลี้ยงหมู และนำมาเป็นปุ๋ยอินทรีย์ที่เป็นประโยชน์

คำสำคัญ : ลุ่มน้ำ, พื้นที่ต้นน้ำ, การวิเคราะห์จำแนกเกษตรกรรม, พื้นที่ท้ายน้ำ, การชะล้างอยู่กับที่, คุณภาพน้ำ

Title	Assessment of Upstream Farming Intensification and ItsImpact on Soil and Downstream Water Quality inYusipang Hongtso Watershed
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Degree	Master of Science in Environmental Design and Planning
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ABSTRACT

The study was conducted in Yusipang and Hongtso Watershed in Bhutan to assess; upstream farming intensification, onsite soil erosion, point source of water contamination, its impact on soil and downstream water quality, and design guidelines for improving the farmland and quality of stream water. The land use and site characteristics were analyzed using GIS software, the information on farming practice, socio-economic condition, use of agrochemicals, soil conservation works, and water use were collected using PRA and RRA tools, 11 households were interviewed for in-depth study. The farmland was divided into four different slope categories (0-4%, 4-8%, 8-12%, 12-16%), and a total of 27 soil samples were collected from different slope classes. 3 soil samples were collected from the nearby forest area using a purposive sampling method to compare the result. The samples were examined in the Laboratory for its texture, macronutrients, pH and organic matter content. The annual soil loss from agriculture land was determined by using the USLE model. The water quality was assessed in four predetermined sample points using a field testing kit, eight parameters were studied. The water sediment testing for the presences of Organophosphate group and Carbonate group was done in the Institute of Product Quality Standardization, Maejo University.

The horticulture is the epitome of agriculture practice, farmers grow apple,

potato, cabbage, and cauliflower as cash crops. The increasing market demand for agriculture products has forced the farmers to switch over to small commercial farming. Farmers use agrochemicals on a regular basis to upturn the production to meet the increasing demand. The horticulture is the primary occupation of the farmers as it constituents 74% of the total household income. The annual soil loss in the agriculture land varies from 2.15tons/ha/year in the slope class 0-4% to 8.24 tons/ha/year in the slope class 12-16%. The soil is moderately acidic (average pH 5.5), the average Phosphorus (P) and Potassium (K) content are 77.28 mg/kg and 340.66 mg/kg respectively which is very high compared to the accepted standard. The Nitrogen (N) percentage was 0.19 which is on the verge of depletion as compared to ideal agriculture soil condition. The average percentage of organic matter content is very high in both agriculture and forest soil which stands at 10.47 and 10.31 respectively. There is a progressive decline in water quality from upstream towards the downstream. Water acidity level was found to be high near the farmland and sewage from piggery farm has significantly affected the water quality at the outlet.

The use of agrochemicals has negatively impacted on the soil quality of the farmland. The stream water quality was influenced by high nutrient residues in the upstream farmland, waste from the labour camp, and the sewage from piggery farm. These sources were found to have significantly contaminated the water rendering it unsafe for human consumption and ecological services. The evidence of high inorganic mineral content in the upstream farmland and increased surface water acidity indicates that upstream farming effects the water quality in the downstream. Amendment of existing soil nutrient imbalance and improving farmland in the upstream was found to be timely and necessary. The Sheng's technology and Agriculture Land Development Guideline (ALDG) of 2017 are appropriate to conserve topsoil on the slopy land. Use of organic-based fertilizers and biological pest control approach must be promoted to improve agro-ecosystem and reduce water pollution.

It is recommended that the sludge from the piggery farm must be treated or converted into useful organic manure.

Keywords : Watershed, Upstream, Downstream, Farming Intensification, Water Quality, Soil Erosion

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Kinzang Namgay

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Acronym

ALD	Agricultural Land Development
ALDG	Agriculture Land Development Guidelines
DoFPS	Department of Forest and Park Services
FNCA	Forest and Nature Conservation Act 1995
FYP	Five Year Plan
GHG	Green House Gas
IPCC	Inter-governmental Panel on Climate Change
MoAF	Ministry of Agriculture and Forest
NEC	National Environment Commission
NPPC	National Plant Protection Center
SLM	Sustainable Land Management
USLE	Universal Soil Loss Equation
WMD	Watershed Management Division
WRB	Wang Chhu River Basin
WRBMP	Wang Chhu River Basin Management Plan

CHAPTER 1

INTRODUCTION

1.1) Problems and Research Importance

The watershed management program in Bhutan has gained substantial impetus over the past two decades, the program recognizes the intrinsic value of water and concerns for its use by the people. The emphasis is to mainstream watershed management activities into the national and local developmental planning process, as past experiences have indicated that standalone operational setup and independent management did not yield a positive result. Legal documents have been formulated for supporting watershed management initiatives. The Water Act 2011, directs NEC to improve water security through rigorous planning. The Constitution of Bhutan demands prudent environmental conservation. Likewise, Forest Policy 2011 stipulates effective management of all watersheds for sustainable livelihoods and a reliable supply of high-quality water. The future direction towards operationalizing watershed management programs is charted out in 'Road Map for Watershed Management in Bhutan' prepared by Watershed Management Division (WMD) in 2011. The National Integrated Water Resources Management Plan 2016, stress water security as a developmental goal for Bhutan and defined five major river basins.

The government's effort towards this initiative is timely and most fitting for the reason that rivers in Bhutan are the national treasure, it's the main source of clean energy. At present, hydroelectricity alone contributes to 32.4% of the nation's total export (Poindexter, 2018), and 13.22% of the GDP (National Statistical Bureau, 2018) it will be the highest revenue earner in the near future. As Bhutan is situated in the Third Pole region it provides water to one-fifth of the world's population. Besides, Bhutan is a predominantly agrarian society, more than 60% of the total population practice subsistence farming for their livelihood, though, some traditional farmings are giving way to small scale commercial farming. Thus, accessibility to water is not an exception. Although Bhutan's per capita mean annual flow of fresh water is 109,000 M^3 (National Environment Commission, 2016b), making it one of the highest in the region yet, geophysical condition and highly dispersed settlements are a limitation to optimal utilization of water resources for drinking and irrigation. Water scarcity has been an emerging issue in Bhutan and will be further aggravated especially towards the end of the dry season, when snowmelt from the northern high-altitude regions, largely accounts for the river base flow (Kinlay Choden, 2018). It was compiled from various scientific papers that reduced water quality due to pollution is one of the main cause of water scarcity.

Watershed conservation has evidently become a very important agenda in the country because of its significance to the country's economy and level of threat it is facing at the current rate of global warming. There are several threats causing watershed deterioration, studies have shown that agriculture is one of the main sources of pollution across the globe, damaging soil and water. Use of synthetic agrochemicals in the commercial and rural agriculture farming have intensely polluted the water bodies rendering it unsafe and triggered numerous ecological problems. It is more likely that the use of agrochemicals will increase in the future as warming of the earth will favor more pest and insect growth. Sediment eroded from agricultural land can be a major pollutant and a carrier of polluting chemicals like pesticides and plant nutrients, excessive sedimentation in water conveyance structures reduces the productive potential capacity of cropland by the decrease of soil productivity. Excessive sedimentation can exert both onsite and offsite environmental impacts. Another factor responsible for watershed damage is soil erosion, it is more serious in mountain areas due to the steep slope and heavy monsoon. Surface runoff can easily wash away fertile topsoil and leave behind unproductive mountain subsoil.

The rapid classification of watersheds in 2011, indicated, watersheds under Thimphu district need periodical monitoring as they are mostly in 'Normal' class, however many watersheds are classified as 'critical by function'. Thus, Wang Chhu basin was prioritized as a focal area for starting a 'Basin Level Management Planning' to resolve inter-district issues related to water management such as upstream-downstream effects of interventions related to water abstraction, effluent discharge, and pollution (Comission, 2016). Yusipang Hongtso watershed is situated in the upstream of the basin and discharges 0.38 m^3 of water every second. Unquestionably, it is an important watershed for people living inside the catchment and also for the basin as one of the main tributaries. The farmers living in the upstream grow commercial crops. They use agrochemicals in the field to boost their crop production. Use of excess chemicals has a bad effect on economic and contamination of water sources by increased chemical residues in the sediment has a negative effect on human health, ecosystem. There is a need to evaluate soil nutrient status in the agriculture field and downstream water quality within the catchment. A timely intervention would save the cost of restoring the watershed to larger scale biogeochemistry, treating surface and groundwater, which would be very expensive for Bhutan given the geopolitical and economic situation

There is a gap in determining and quantifying the cause-effect relationship between activities and outcomes in watershed especially the causal connections between upstream farming and downstream water parameters. It is becoming more urgent to understand these relationships, so, this study was intended to assess the farming intensification in the upstream and its impact on soil and water resources in the downstream in Yusipang and Hongtso watershed.

1.2) Research Objectives

The study aims to achieve the following objectives:

1.2.1) Study upstream farming intensification, onsite soil erosion and its impact on soil and water quality[1] for establishing a connection between upstream farming practices and downstream water quality

1.2.2) Investigate significant point sources of water contamination which are affecting the water quality

1.2.3) Design guideline for improving upstream farming practice and protect downstream water quality

1.3) Scope of Study Area

In Bhutan, watershed management activities should be those activities that contribute directly to the key watershed outcomes of maintaining and improving water quality and quantity, linked where possible to sustainable livelihood enhancement (Watershed Management Division, 2011b). Yusipang Hongtso Watershed (number 68) is a part of the larger Wang Chhu basin, the basin has been piloted to develop an integrated management plan. This watershed is an important source of water for local residents within the catchment and also for growing town in south Thimphu. It has high relevance in providing safe drinking water and meeting irrigation demand for upstream horticulture activities, growing large scale fruit trees and vegetable cultivation. The water sources must be free of contamination from agriculture residues to provide safer drinking water for the residents and at the same time enhance agriculture production by good management practice. It is a perfect site to investigate the impacts of farming on soil and water quality. There is a need for a situational study to underline the important issues and potentials for developing management interventions accordingly, it will maintain the natural

[1] It is the quality parameters set for drinking water, such as chemical, physical, and biological characteristics. The maximum permissible limit for each of the set parameter shall be in conformity with Bhutan Drinking Water Quality Standard 2016.

productive capacity of the watershed. The quality of the water depends on the soundness of watershed and its ecosystem.

1.4) Scope of research

The World Bank publication of June 28, 2018, indicated that South Asia is highly vulnerable to climate change, it will have a huge impact on agriculture, health, and productivity directly affecting 800 million people living in the region. The warming rate in the Himalayas is higher than the global average. Bhutan's location in the eastern Himalaya is exposed to all possible risks. The fragile mountain landscape is vulnerable to soil erosion, landslide, flash flood, from heavy monsoon and glacial. As Bhutan heighten the course towards creating an environment more resilient to climate change effects, the conservation of watershed is very relevant as it epitomizes the country's entire landscape. The key concern in agriculturally dominated rural landscapes and Urban areas in Bhutan have a water shortage. The land use change and intensive farming in upstream are a threat. Thimphu being the capital city have the highest population, the need for proper water resource management within the vicinity is imperative to meet the increasing demand in the future. This research investigates significant factors responsible for soil and water quality deterioration and design improvement measures.

The scope of this study extends from understanding the watershed dynamics, structural and functional characteristics to policy and legal arrangements over its sustainable management. Watershed is dynamic, a clear understanding of the unique blends of the landscape in the spatial and temporal term is crucial for proper tailoring and harmonizing the intervention(s) to suit the changes by involving relevant stakeholders in decision-making processes. The study focuses on identifying key issues and its significant impacts on soil and water quality due to intensive farming, that links to understanding the wide array of topics such as soil and agriculture, water and sediments, ecosystem, hydrology, farming, land conservation, etc. It also investigates significant point source(s) of soil and water pollution by sample testing in the Lab and field examination using field testing kit. The Laboratory analysis of soil samples and water sediment determines the current nutrient and water quality respectively. Soil loss calculation by erosion gives an idea about the future scenario using the current trend of farming practices and morphological characteristics of the watershed. The findings will contribute to the understanding of the watershed scenario, and serve as a reference for starting similar research in other critical watersheds. It will also provide guidelines on how to identify significant soil and water polluting factors to help the planning process. The recommendation may incite relevant agencies to come up with a suitable watershed management plan for Yusipang and Hongtso watershed.

1.5) Water Contamination and Sediment Quality investigation for consumption and ecological purpose

The water sampling is to get a snapshot of existing water quality information, consistent and comparable data to describe the status and trends of the water resources. The quality can be compared to international and local standards. Samples from strategic locations help to generate reliable information which can be used to make informed decision to address emerging water quality issues and determine quality compliance with health standards. Safe, adequate and accessible supplies of drinking water combined with proper sanitation are the essential components of primary healthcare in Bhutan. The Bhutan Drinking Water Quality standard 2016 is the primary guidelines for determining the water quality in Bhutan, there are standard parameters to be followed. The guideline presents minimum threshold levels of physical, chemical, and microbiological parameters safe for consumption. The water quality standard for urban and rural are clearly charted out for monitoring, by municipal authority and Gewog (village community) or Dzongkhag (district) respectively. The water sediment analysis is for determining the presence of chemical residues from non-point and or point source pollution. The samples are analyzed in the laboratory.

1.6) Soil erosion mitigation measures

The foremost step in the planning processes to mitigate soil erosion of vulnerable soils in any form and extent is to carry out the monitoring and modelling of erosion processes. So that the cause of soil erosion is understood and predict under a range of possible conditions. The soil loss prediction can be done using USLE. Accordingly, preventive and restoration works can be planned. The very effective soil erosion preventive measure would be increasing the vegetation cover of the catchment, the vegetation regulates the surface runoff and increases percolation in the sub-soil thereby recharging the underground water. One important method would be to improve the farming technology which restores and prevent soil loss.

1.7) Guidelines for upland framing practices.

Unsustainable agricultural practices are the single greatest contributor to the global increase in erosion rates (National Research Council, 2010). Mountain landscapes are more susceptible to soil erosions because of the steep topography. In Bhutan Agriculture is predominantly of integrated farming, growing cereal crops and keeping livestock at the same time. The farming requires a water supply, they rely on irrigation as well as on monsoon, rain-fed farming is common in the country. Proper management of upstream agriculture would reduce runoff. Some of the improvements to be incorporated in traditional agriculture would include terracing, growing live windbreaks, mixed cropping, crop rotation, and bioengineering works where necessary. The Agriculture Land Development Guideline (ALDG) 2017, is the best guidelines developed for agriculture land management in Bhutan.

1.8) Significant Keywords:

Watershed, Upstream, downstream, Farming intensification, water quality, Soil erosion.

Watershed *is a natural waterscape from the combination of the hydrology and topography of the landscape with a human perspective (Watershed Management Division, 2011b).*

Upstream *is also known as headwaters, it is characterized by low flow (less volume), often steep slope, greater erosion, and lesser sediment deposition.*

Downstream *or also known as end's or depositional zone, where water volume is at its highest and slope is gentle. The deposition of sediment is the main feature and significantly exceeds erosion.*

Farming Intensification or Agriculture intensification *can be technically defined as an increase in agriculture production per unit of inputs (which may be land, labour, time, fertilizer, feed or cash) (Vanacker, 2004)*

Water quality *is used to describe the condition of the water, including chemical, physical, and biological characteristics, usually with respect to its suitability for a particular purpose such as drinking and swimming (Diersing, 2009)*

Soil erosion *is the displacement of the upper layer of soil, one form of soil degradation. In agriculture, soil erosion refers to the wearing of field's topsoil by the* *natural physical forces of water, and wind or through forces associated with farming activities such as tillage (Jim Ritter, 2012)*

CHAPTER 2
Literature review

2.1) Watershed Perspective in Bhutan

Bhutan is located in the Eastern Himalayas and has the land feature of a continuous rugged mountain with different ecological settings. With the exception of few plain areas in the southern foothills, the undulating valleys, rising mountains, plunging gorges, snow-capped mountains, fast flowing rivers, define the physical outlook of the country. The average altitude ranges from 350 meters in the southern foothills to a staggering 7500 meters in the north. The southwest monsoon brought from the Bay of Bengal controls most of its climate and weather condition. This unique landscape gives rise to diverse biological diversity and mosaic of numerous watershed ecosystems in the country. In Bhutan, the watersheds exhibit a huge variety of climatic conditions, soils, hydrology, geology, and human aspects that influence the condition and output of watershed ecosystem services.

Watershed is defined as an area of land that drains water, sediment, and dissolved materials to a common receiving body or outlet. The term is not restricted to surface water runoff and includes interactions with subsurface and groundwater (Watershed Management Division, 2011b). It is the morphological characteristic that defines this area of land. The noticeable natural structure of watershed in Bhutan include; upstream or headwaters characterized by low flow, steep slope, and greater erosion; transfer zone the middle range of the stream where more flow appears, the slope flattens, and deposition and erosion are both significant processes; downstream or depositional zone, where water volume is at its highest and slope is gentle. The geomorphological and physical characteristics give rise to numerous functions; hydrological, ecological, social and economic functions. There are five major river basins in the country; Amochu, Wangchu, Punatsangchu, Drangmechu, Mangdechu, and 186 watersheds which can be further divided into numerous sub-watersheds for management purpose. Most of the rivers have their origin in the Himalayas and flow towards India in the south. The different eco, agro, rainfall and the altitudinal range is suitably represented based on the national forest classification module as follows:

Table 1: *Altitudes and ecological regions of Bhutan (compiled from agro-ecological zones of Bhutan, RNR statistics 2015, MoAF Bhutan and Ecological Regions of Bhutan from World Atlas)*

Altitudinal range	**Agro-ecological zone**	**Rainfall (inches)**	**Ecological regions of Bhutan**
Subtropical < 1800 MASL	Humid Subtropical (600-1200 MASL low/mid)	1200-2500	Brahmaputra Valley Semi-Evergreen Forest
			Himalayan Subtropical Broadleaf Forest
	Dry sub-tropical (1200-1800 MASL mid)	850-200	Terai-Duar Savanna and Grasslands
			Himalayan Subtropical Pine Forest
Mid Montana 1800 – 4000 MASL	Dry Sub-Tropical (1800-2600 MASL mid)	850-1200	Eastern Himalayan Subalpine Conifer Forests
	Warm temperate (1800-2600 MASL high)	650-850	Northeastern Himalayan Subalpine Conifer Forests
	Cool Temperate (2600 – 3600 MASL high)	650-850	Eastern Himalayan Broadleaf Forests
Alpine >4000 MASL	Snow line		Eastern Himalayan Alpine Shrub and Meadows

2.2) Main Watershed Ecosystem Function Highlights of Bhutan

The watershed ecosystem is an interaction between biotic and abiotic components in a geographically discrete drainage area within which there is a flux of energy, materials, and organism. The natural processes of the watershed are its capacity to transfer and store, cycle and transform, and ecological succession influence by its normal events like hydrologic and biochemical cycles. The structural and functional characteristics of these watersheds influence the very coexistence of human with natural communities. In Bhutan's context, these interactions are so essential for people's wellbeing and national security, their livelihood is determined by health and intricacy of these systems. The watershed in Bhutan is the cradle of people's very existence, it is the source of livelihood and future security. It plays a vital role in the lives of the people and rural farming, so it is often used as a planning or management unit.

Bhutan has a population size of less than 0.8 million, the arable land is 2.93 % of the total geographical area (Ministry of Agriculture and Forest, 2015). The settlements are mostly along the river valleys and use water in many ways for drinking, irrigation, generating electricity, and numerous other services. In Bhutan, where the total landscape is predetermined by a mosaic of watersheds the human's relationship to its ecosystem is immeasurable and its positive outcomes are beneficial to the surrounding environment. The country's massive forest cover (71%) regulates stream flow throughout the year, it is a very important factor determining the condition of the watershed and its ecosystem function. The varying altitudinal range from hot subtropical to cold alpine zone with diverse biological components give rise to the different morphological and biological setting of the watershed. All these biophysical setting and functional characteristics uniquely affect human interaction and coexistence within the given landscape and time. Bhutan being largely a farming community, the watershed ecosystem provides the people residing within or outside river basin with numerous tangible and intangible benefits. A sound watershed provides continuous water and other services to the people.

The understanding of the watershed ecosystem, its structural and functional physiognomies holds the answer to exploring possibilities and deal issues connected to safeguarding, restoration, and sustainable utilization of natural resources within the catchment. Any intervention undertaken should not alter or affect the natural processes and functional characteristics of the watershed.

2.3) The Emergence of Watershed Management in Bhutan

The water source management is not a new concept in Bhutan, it was a part of the farming system, taken up either implicitly or explicitly. Traditional water user groups still exist to these days. They protect water sources and distribute the resources among them during the cultivation. Most of the water sources and natural landscapes are still revered by the people, that contributed towards maintaining the overall condition of the watersheds.

The project-based watershed management program was initiated in the 1990s to solve specific water-related issues/conflict and improve the living condition of the people living within the watershed by providing material and technical inputs. Such projects were Limuteychu, Radhi, and Wang Watershed Management Project (WWMP). WWMP had multi-dimensional aspects aimed at improving the overall condition of the basin. After the creation of WMD under DoFPS in 2009 and Water Resources Coordination Division in 2010 under NEC, the watershed program steered up. The present approach is more holistic, largely accepting impact-level assessment to improve the overall bio-physical condition, hydrological and ecosystem services of the watershed, with the impetus to involve human component as central to multidisciplinary processes.

Watershed management plan charts a path for closing the gap between actual and desired watershed condition, integrating biophysical elements with socioeconomic objectives and ecosystem maintenance (Watershed Management Division, 2011b). The first River Basin Management plan for Wangchhu River was developed in 2016, with the involvement of local, regional and central agencies. They will be using iterative and adaptive planning spiral mechanism to evaluate the progress after every five years. WMD is mandated to develop a management plan for all the critical watersheds in the country, the impact of this new approach is yet to evaluate. The bottom-up planning in the watershed as a contemporary decision-making paradigm promotes people-decision to suit the overall national purpose of devolving power to the people and decentralizing authority to the local levels. The new approach is still in its initial stage to make any comments on its success and shortcomings.

The watershed management in Bhutan have three management goals:

1. *To restore, protect and improve watershed management conditions through participatory, integrated and adaptive management strategy built into a coordinated management plan*
2. *To support sustainable livelihood including options thereof, and enhance the quality of life of local watershed communities*
3. *To secure watershed services used to fuel the socio-economic development of the country*

2.4) Critical Watershed Classification in Bhutan

Classification of the critical watersheds and preparation of management plan are in progress; it is part of the process to operationalize management programs under the lager integrated frameworks for major river basins. There are 186 watersheds in the country delineated with a threshold of 5000 ha (50 km2) and 19 of them are inside Wang Chhu River Basin. The three main categories of watershed conditions in Bhutan are:

1. Pristine watershed; The watershed is in its natural form, there is no human interference.
2. Normal watershed; The watershed is in good condition, maximum of its natural features are still intact, but anthropogenic activities are visible. Timely monitoring is important for this kind of watershed,
3. Degraded/Critical watershed; The watershed is in unstable condition, degradation is taking place, there is evidence of human interference. It is very likely that the natural productivity of the area has been damaged. This type of watershed requires immediate intervention to revitalize its normal form. There is another form of a critical watershed, the watershed with high pressure for drinking is categorized as critical watershed ‘by function’. The new guideline prepared by WMD considers 26 criteria for determining watershed condition, it is further grouped under 4 domains: Biophysical (12 criteria), Socio-economic (12 criteria), Climate (1 criterion), Demography (1 criterion).

A more technical and complete way of approaching watershed classification would be looking at two broad classes of criteria:

1. Static criteria: those are the parameters that cannot be altered over time, for instance, the geomorphology of the watershed (elevation, slope, landforms, climate, etc.)

2. Dynamic criteria: those variables that change over time for instance population dynamics, forest cover and land use change.

Combination of static and dynamic criteria to identify critical watersheds seems more appropriate than solely using static criteria. Watersheds identified as critical using static criteria alone do not necessarily require watershed management interventions (Mekong River Commission, 2015). Following forms of the watershed have been mentioned in the document:

Watershed Class 1	Watershed Class 2	Watershed Class 3	Watershed Class 4	Watershed Class 5
Protection Forest	Commercial Forest	Agroforestry	Upland Farming	Lowland Farming

A quality assessment of the river in 2012 revealed that upstream of Wang Chhu (Cheri, about 30 km from the study site) have no pollution, critical to heavy pollution was recorded in Babesa (about 15km from the study site), the water quality improves further down the river at Khasadrapchu (about 20km downstream). A similar study done in 2007 indicated that all most all the tributaries feeding Wang Chhu were observed to be more polluted. The report on rural drinking water quality also showed that only 17% of stream water sources and 28% of spring water sources were safe for use as drinking water (National Environment Commission, 2016a).

2.5) The Present State of Water Quality in Asia and Farming impacts

The uncontrolled release of sewage, industrial wastes, and agricultural run-off continue to affect Asia (Evans, 2012). Farms along the riverbanks have an impact on the water quality in the river, it is recommended that there should be close monitoring of the activities of the farms on riverbanks to minimize their impacts on the natural ecosystems that they interact with (Chimwanza, 2005). The Asian region continues to face serious water quality issues that contribute to freshwater scarcity, ill-health, and even deaths (Alexandra E. V, 2012). It is rather peculiar to note in his article that traditional agriculture-based economies of Asia are giving way to industrial economics. This transformation is having serious environmental side effects particularly in the case of pollution. Agriculture pollution has increased to 62% within the period of 1990 to 2002, consumption of mineral fertilizers has increased by 15%. Use of pesticides grew to 750% in India from the 1900s to the present. Disposal of unused pesticides, equipment washing, poor storage has devastated surface water quality in Srilanka. Non-point source pollution predominantly from agriculture field and industries are causing 42% of the deaths due to lack of safety or inadequate supply of sanitation and hygiene. In central Asia, Pakistan, Iran, and India, the salinity of water both ground and surface are caused by the poor agriculture drainage system. It was also found that the annual water withdrawal and return flows are highest in Asia. In Africa and Asia, an estimated 85-90% of all freshwater used is for agriculture. According to estimates for the year 2000, agriculture accounts for 67% of the world's total freshwater withdrawal, and 86% of its consumption (Government of Canada, 2014). As agriculture stands out to be one important factor affecting freshwater quality, for an agrarian and mountainous country like Bhutan the impact would be significant.

2.6) Inappropriate Farming Practices and Its Impacts on Soil and Water Quality

Agriculture may affect water quality directly[2] or indirectly[3] (Joseph Holden, 2015). The nutrient Sediment eroded from agricultural land can be a major pollutant

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[2] Direct impacts may include soil, nutrients, pesticides transferred to watercourse from the field during rainfalls.

[3] Indirect would be for instance upland improper drainage design which lead to erosion and downstream sediment problems. Or nutrient enrichment in the streams causing eutrophication

and a carrier of polluting chemicals like pesticides and plant nutrients. The contamination of water by agriculture residue refers to surface runoff from agriculture, that is, pesticides, chemical fertilizers and manures that enter into water resources and leaching of nitrogen, phosphorus into groundwater. Rendering the water unfit for human consumption due to elevated chemical residues. In Bhutan, agriculture is the primary source of livelihood for more than 2/3 of the population. The total arable land is just 2.93% as per the RNR statistical report of 2015, this indicates that intensive farming is most likely to be the only option to enhance the production. The excessive use of chemicals may have short term benefit like enhanced yield but in the long run, the soil quality will be affected by altering its physical, biological and chemical composition.

2.7) Soil Erosion and Sedimentation

Soil erosion is a common phenomenon in mountain landscapes, there are many factors influencing its occurrence; climate, soil structure, and composition, vegetation cover, topography, human activities, etc. it could be categorized as natural happening or manmade. It is a serious setback to the environment, socioeconomic, natural ecosystem, and hydrological processes. With the change in climatic condition across the globe, erratic monsoon and increase in the intensity of rainfall induce flood and excessive sedimentation in water conveyance structures (natural and manmade). Soil fertility would be lost due to nutrient leaching, thereby reducing the productive capacity of cropland. In agriculture, soil erosion refers to the wearing of field's topsoil by the natural physical forces of water, and wind or through forces associated with farming activities such as tillage (Jim Ritter, 2012). This situation is more serious in the mountains due to the steep slope and shallow soil, surface runoff can easily wash away fertile topsoil and leave behind unproductive mountain subsoil. The factors influencing soil erosion are rainfall and runoff, tillage practice and cropping pattern, slope gradient and length, vegetation, soil compaction, Low organic matter, loss of soil structure, poor internal drainage, salinization, soil acid problems. If the topsoil is displaced elsewhere within onsite, the sediment builds up over time, if carried offsite it fills drainage channels. The movement of sediments into the water bodies exerts environmental effects both onsite and offsite. Onsite impacts are the removal of topsoil and applied manures. Direct effect on crop emergence, growth, and yield. Removal (displacement) of seeds and plants. Affect soil quality, structure, stability, texture, and the water holding capacity of the soil. Offsite impacts involve eroded soil gets deposited downslope, inhibits or delay of the emergence of seeds, damage of drainage, water reservoir, roads, and other structures, accelerate bank erosion of stream/ watercourses and sedimentation, degrade downstream water quality, etc.

Water quality problems can arise from suspended solids, which cause turbidity and form deposition of solids called sedimentation. Sediment that enters fresh water is usually the result of wind and water erosion from cultivated areas or stream bank erosion, which can have a variety of causes (Government of Canada, 2014).

2.8) Appropriate Farming Practices on an Upland/Steep Slope

According to British land capability classification slope over 15° are not suitable for arable crops, with slopes over 20° being difficult to plough, lime or fertilize (Jarasiunas, 2016). As compiled in ALDG report 2017, some of the agriculture-related problems in Bhutan are (i) more than 31% of the total agricultural land is situated on slopes as steep as 50% or more, (ii) annually about 21-ton ha^{-1} of fertile topsoil is being lost due to soil erosion, (iii) according to IPCC mountainous countries will experience a decline in crop yield due to increase in water stress and land degradation (Department of Agriculture, 2017). The government initiated Sustainable Land Management (SLM) programs in vulnerable areas by introducing appropriate ALD technologies. The 11^{th} FYP (2013-2018) and 12 FYP (2018-2023) emphasize on addressing land degradation problems and elevate rural poverty. The important aspect of developing land management guidelines is to understand the physical characteristics of the area; soil quality, slope, water resources, erosion risk, rainfall, cropping, and land use, etc.

In Bhutan hilly undulating agriculture landscapes with steep slopes are very common, thus improper farming practices can have numerous problems including negative impacts. Famers improvised their own technology, for a wetland (paddy cultivation) terracing is the prominent technique to retain water in the field. For dryland (rainfed) terracing is not very common. The terrain is an important spatial determinant of cropland systems, which influence the management constraints (Verburg, 2012). Soil conservation programs are an urgent need in the hilly agriculture areas natural handicapped by steep slope constraint (Jarasiunas, 2016). There are numerous prototypes and guidelines for farming hilly land, the pertinent technology for Hongtso Yusipang where dominant land use is an orchard would be Sloping Agriculture Land Technology (SALT). It is developed by Mindanao Baptist Rural Life Centre (MBRLC), way back in 1971. SALT is a packaging technology on soil conservation and food production, integrating different soil conservation measures in just one setting (Mindanao Baptist Rural Life Center, 2007).

SALT technology considers the following advantages:

- ✓ *Control soil erosion and restore soil structure and fertility*
- ✓ *Efficient food crop production applicable to hillside farming*
- ✓ *Easy to apply using local resources and it's culturally acceptable and workable in a relatively short time*
- ✓ *Have the small farmers as the focus and food production as a priority*
- ✓ *Require minimum labor and economically feasible*

SALT technology is an agroforestry scheme to diversify farming system. Rows of permanent shrubs and other fruit trees are grown, alternate with strips of cereals, vegetables, and Legumes. This cyclical cropping provides farmers some harvest throughout the year. Also, timber and firewood species are planted on the boundaries. The technology has variations, the common ones that are suitable for sloping landscapes are:

Simple Agro-Livestock Land Technology

It is small livestock based agroforestry with land use of 40% agriculture, 20% Forestry, and 40% Livestock. Hedgerows of different nitrogen-fixing plants are established on the contour lines

Sustainable Agroforestry Land Technology

This technology incorporates food production, fruit production and forest trees that can be marketed. The plants in the hedgerows are cut and pilled around the fruit trees for mulching and fertilizer, it is also done for soil conservation purpose.

Small Agro-fruit Livelihood Technology

It is based on half a hectare of sloping land with 2/3 devoted to fruit trees and 1/3 intended for food crops. Hedgerows of different nitrogen-fixing trees and shrubs are planted along the contours of the farmland.

2.9) Soil and Water Conservation Practices to Reduce Soil Erosion and Sedimentation

According to FAO, many Asian countries have 20% or more of their lands considered as “degraded” lands with some countries approaching 50% of land degradation (Mindanao Baptist Rural Life Center, 2007). But there are several traditional measures like reforestation, terracing, multi-cropping, contouring, cover cropping and bioengineering works to control the soil degradation. Some common activities to achieve soil and water conservation strategies are:

1. Protecting and replacing native vegetation
2. Promoting perennial crop cultivation system and use of ground cover while cultivating annual crops
3. Practice crop rotation where possible to retain soil fertility and enhance production
4. Construct Terraces, contour barriers, contour ditches such as drainage and infiltration ditches, waterways from draining excess water
5. Gully prevention and control by plugging with appropriate technology
6. Promoting integrated pest management and integrated soil fertility management

2.10) Upstream and Downstream relation in Watershed

Upstream activities can either positively or negatively influence the outcome of downstream services although, this relationship is very difficult to determine and quantify. Often, plausible causal connections between upstream watershed conditions and downstream water manifestations are looked at as the best way to determine the connection. It is a concept of using an indirect method to measure cause and effect connections between land use and disturbances to watershed condition, biogeochemical yields, and socioeconomic consequences. There is less research on identifying plausible causal connections between upstream land use changes and downstream water parameters in clarifying and qualifying the link between upstream conditions/actions and downstream services (Watershed Management Division, 2011b). While the links between forests and human well-being in Bhutan, as defined by the GNH framework, are conceptually robust, the literature falls short on providing direct empirical evidence for many of the causal relationships, particularly between upstream land use and downstream conditions (Robin R Sears, 2017).

However, there are studies done elsewhere in the world, a comparative assessment of water quality in River Tano in Ghana showed a higher level of Phosphate and Fluoride in the downstream than upstream. The phosphate was due to human activities such as the use of pesticides in farming and the use of detergents (Jackson Adiyiah, 2013). Agricultural intensification impacts to water quality through the release of nutrients and other chemicals into the water environment through biological contaminations (Joseph Holden, 2015). A study conducted in River Windrush (UK), about nutrient load delivered in water bodies, the observed concentration of both nitrate and phosphate over the period of 1973-1989 have increased (Heathwaite, 1997). Symptoms of eutrophication were noted as evidence of nutrient leaching in a number of the tributaries. A similar study in Calopooia River Basin of Western Oregon concluded that agriculture practices, including tillage, fertilization and residue management can affect surface runoff, soil erosion, and nutrient cycling (Mueller-Warrant, 2012). It is mentioned, that key concerns in the agriculturally dominated landscape include soil erosion, off-site movement of fertilizer nutrients, altered hydrology, removal or impairment of critical habitat used by wildlife and global climate change through production/sequestration of GHG.

A study in the middle mountain region of Nepal has found, upland farming sustainability achievement has been made through intensive cultivation practices such as increased use of agrochemicals and hybrid seed, that have led to declining of soil fertility and increasing dependency of farmers on external inputs in commercial (Krishna, 2008). The livelihood of the majority of the population in the uplands of Hindu Kush-Himalayan region countries (Nepal, Bangladesh, Bhutan, Pakistan, India, China, Myanmar, and Afghanistan) revolve around agriculture. Here the land is the nucleus of all socio-economic activities (Partap, 2004). This indicates that there is a correlation between the upstream activities and outcome of downstream services.

2.11) Agrochemical Regulation in Bhutan

The pesticides Act of Bhutan, 2000 allows importing those pesticides that are harmless to human or animal health, and no undesirable effect on the environment. The competency of procuring and supplying the pesticides rests with the National Plant Protection Centre (NPPC), a government agency. No pesticides are allowed to be imported and sold by any company or individuals, the only designated government agents are permitted to import herbicides like Butachlor, Sencor, NC311, Mogeton, Sanbird and synthetic fertilizers like Urea, SSP, Suphala to sell directly to the farmers.

Table 2: *List of agrochemicals banned and allowed to import in Bhutan.*

Type/Kind	**Agrochemicals**	**Remarks**
The pesticides that are totally banned in Bhutan	1. Aldrin 2. Aluminum Phosphide 3. BHC 4. Captafol 5. Carbofuran 6. Ekalux 7. Agallol 8. Methyl Parathion 9. Red Lead 10. Thimet 11. Temik	Due to the high toxicity level and ill effects on the environment
Agrochemicals that are imported by NPPC in Bhutan	*Insecticides:* Chlorpyrifos 20 EC, Cypermethrin 10 EC, Dimethoate 30 EC, Malathion 50 EC, Malathion 5 D, Fenvalerate 0.04 D, K-Obiol 2.5 WP, *Bacillus thuringiensis* *Fungicides*: Captan 50 WP, Carbendazim 50 WP, Copper Oxychloride 50 WP, Mancozeb 75 WP, Ediphenphos 50 EC, Isoprothiolane (Fungi-one), Probenazole 8 GR (oryzernate), Kasurabcide 71.2 WP (Kasugamycin), Pyroquilon 5 G (Coratop), Tridemorph 80 EC, Hexaconazole 5 EC,	

Type/Kind	Agrochemicals	Remarks
	Blasticidin 1 EC, Kitazin 48 EC, Copper Sulphate, Ridomil 72 WP, Calcium Hydroxide, Carboxin 75 WP, Baycor *Herbicides:* Glyphosate 41 EC, Oxyfluorfen 23.5 EC, Metribuzin 70 WP *Rodencites: Zinc* Phosphide 80W/W *V. Acaricides:* Danitol 1 EC *NON-TOXIC*: Sandovit (sticker), Linseed oil, Tree spray oil (TSO), Protein hydrolysate	

(Source: Ministry of Agriculture and Forest website)

2.12) Research Framework

The global climate change experience has coerced national and international organizations to initiate numerous plans and programs to create a resilient local environment. One specific initiative is watershed management which is defined to solve the water crisis by conserving it. This could be achieved by understanding the underlying issues, factors/indicators, and involving local stakeholders to come up with an inclusive decision. Out of a number of factors, this study identified upstream farming intensification as causes of water and soil deterioration. Figuring out its impact on soil and water would contribute towards materializing the idea of wholesome watershed management policy. The output from this study suggests improving upstream land management that reduces soil erosion and water pollution without compromising production.

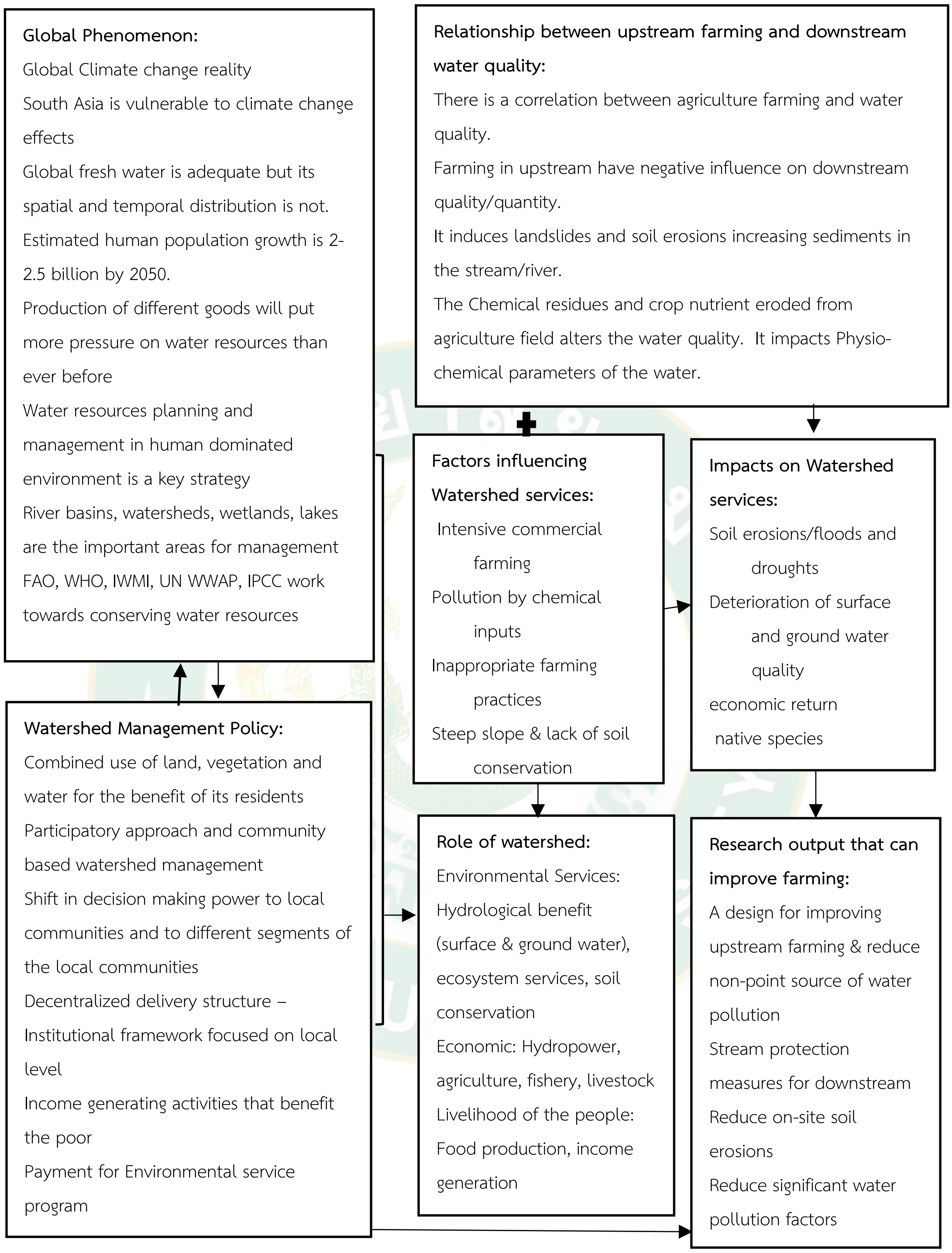


Figure 2: *Research Framework*

CHAPTER 3

Materials and Methods

3.1) Study Site

Watershed number 68 is located in Thimphu district in western Bhutan and it is one of the critical watersheds by function. The sub-watershed number 4 within this watershed was chosen to be the site for field activities, as it is third highest in slope percent (31.96%) and have maximum settlement compared to other sub-watersheds (60 permanent households). The cultivated land covers 75 hectares, 21.51 hectares being dry land and 53.55 hectares being an orchard.

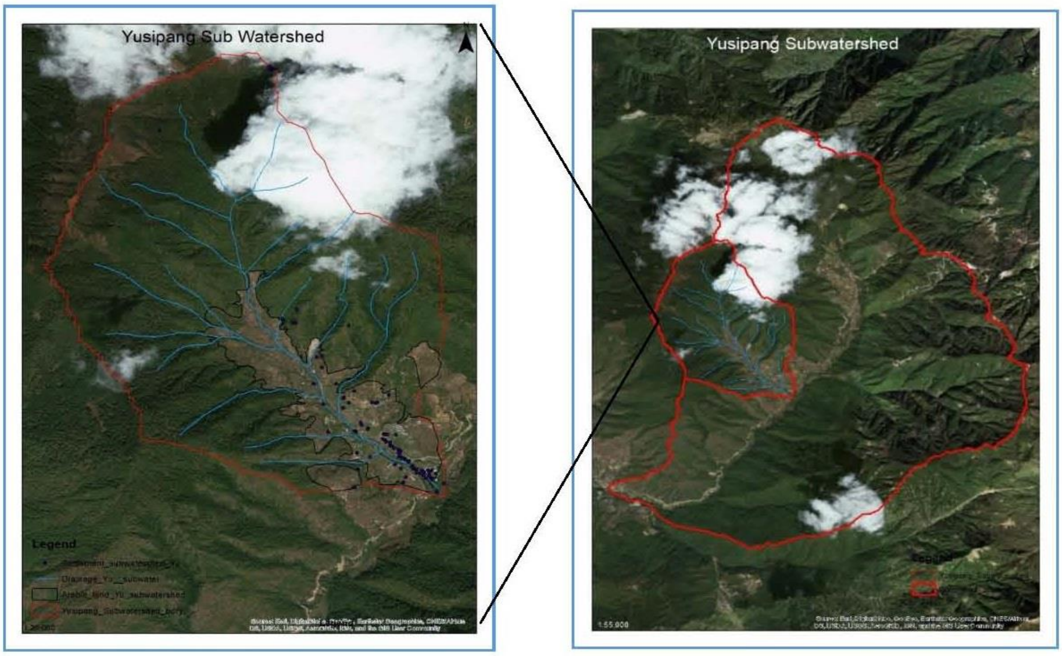


Figure 3: *Survey site Sub-watershed (Yusipang) inside Yusipang Hongtso watershed*

3.2) Materials

The materials used for the field data collection are a map of the study site, Global Positioning System, field water testing kit, plastic bags and rubber bands, ziplock, soil sample collection kits, soil auger, double ring soil infiltrometer, camera, flora guide book, Questionnaire formats.

3.3) Methodology

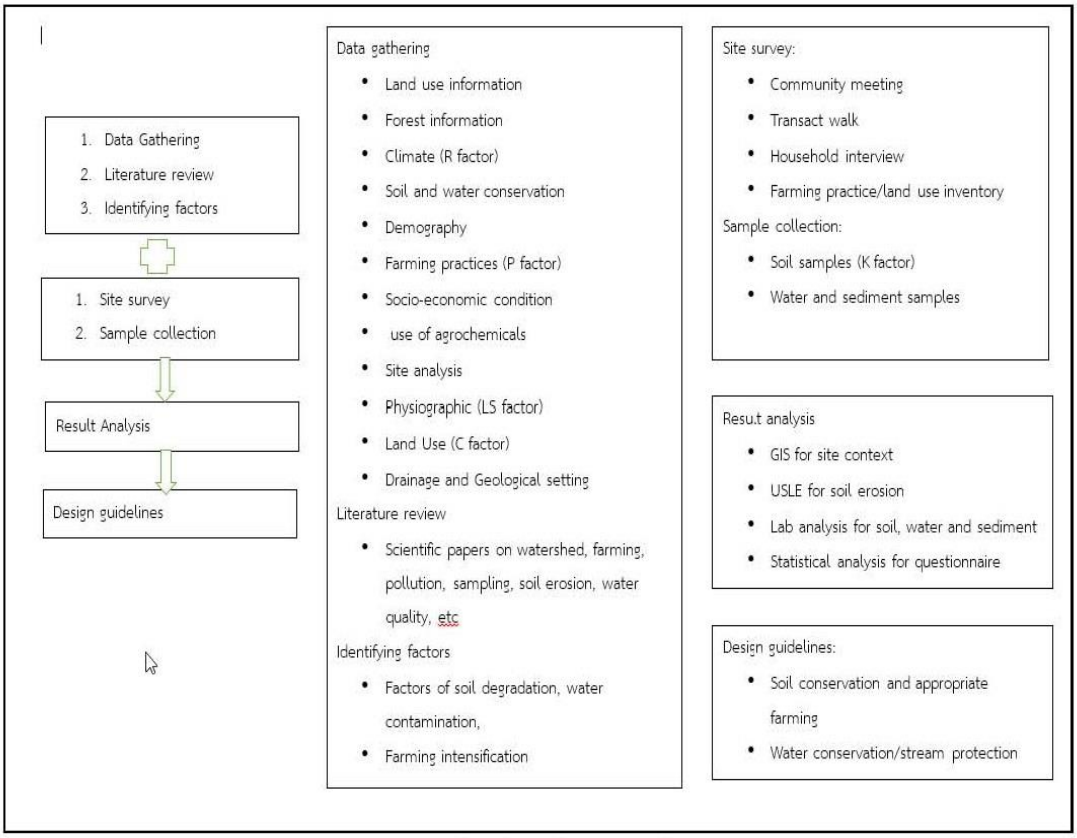


Figure 4: *Method and Research process*

3.4) Site survey:

3.4.1) Community Meeting

The community meeting was steered in collaboration with local government officers, research personnel and village headman, they played a key role in arranging and organizing the meeting. The meeting was coordinated in the month of December 2018, for two villages viz. Hongtso and Yusipang, both the villages are under Chang Geog (village community) in Thimphu district. The meeting was convened at two separate locations for the convenience of the participants. The important activity of the community meeting was identifying of marginalized households within the village. Open discussions were conducted to sort out common issues and identify solutions by giving all members an equal opportunity to give their opinion. Informal discussions were also held where possible to gather views and suggestions about various topics related to watershed programs, farming, livelihood, income generation, water, and soil conservation issues. some of the specific outcomes of the meeting were:

- Identifying transect walk site for proper comprehending of land use zone, river buffer, agriculture field, forest area, conservation zones, community resource management site, etc. The transect walk site was decided across the middle of sub-watershed that represents the maximum landforms.
- Categorization of farmers into different social groups based on income, properties, land, machinery, savings, etc.
- Timeline of land use trend highlighting the major changes in land use types. Record of the flood, drought, soil erosion, and landslides and its frequencies over the past 10 years.
- Cropping calendar for major crops was prepared in consultation with the farmers, the information is used for C-factor analysis in soil loss modeling.

- Listing the native plant species grown by the farmers in their land for various purposes such as food, fuelwood, soil conservation, leaf litter, etc. and its trend over the last 50 years. It is to get a rough idea about how agriculture intensification has impacted on native plant species
- Individual or community-based soil/water conservation activities initiated by the farmers themselves and by the government for them. Also information on forest conservation programs such as community forestry, private forestry. This information is used for P-factor in analyzing soil loss modeling.
- The trend of farmland irrigation over the past 20 years, and farmer's initiatives in managing the water resources in the lean season. The information was generated by asking open-ended questions and discussions.
- Use of agrochemicals by the farmers and record of any health issues related to water pollution.
- Product marketing procedure

3.4.2) Transect walk

The next RRA activity was to walk through the transect line, identified during the community consultation meeting. The activity included visual observation and physical evaluation, information on all the activities along the transect line were recorded. One group was formed for this work consist of two elderly people from the local community who provided guidance and information. The subject of the inquiry was clearly defined and participants were informed before the walk. The purpose of the activity was to comprehend the watershed situation in better perspective and develop a cross-section plan with different activities. It also supports participatory local resource mapping and prioritization matrix by directly complementing and validating the data collected through consultation meeting. The focus of major events was on the evidence of the landslide, soil erosion, water turbidity, farming works, soil deterioration, land management activities, water source conservation works, use of agrochemicals in the field, etc.

3.4.3) Focus group interview

This method was proposed to get specific information related to different social and gender groups; it was to understand their perception on existing farming practices, water problems, soil conservation works, developmental programs, equity, etc. The target groups for this exercise were village key informants, local leaders, extension officers, male and female group. Social stratification was classified in consultation with the farmers, they were regrouped according to their social status; rich, mid-income and poor. A separate interview was held for each group to find out their strength, problems, weakness, and opportunity. Farmers were also grouped into different genders and interviewed them. The extension officers like Agriculture, Forestry, Livestock have lots of information about the site and the situation.

3.4.4) Household interview

The household interview was administered to 11 households out of the permanent residents living inside the subwatershed. The households were selected based on purposive sampling method, to represent the different slope category. A pre-tested semi-structured questionnaire was used to interview each household. The questions were focused on socio-economic, soil and water-related issues, intensive farming and its problem, conservation efforts and initiatives, etc. Initially, the idea was to select households for interview based on farming criteria such as (i) Intensive farming, (ii) Normal Farming and (iii) Traditional Farming. however, after field truthing it was found that all the farmers do intermediate farming (between intensive and normal farming), they have trailed passed traditional farming but have not fully reached intensive farming or fully mechanized farming. The information was collected from the individual by interacting with the respondent using both open-ended and closed-ended questionnaire. The effort was made to involve the head of the household with the premise that they have lots of experience and knowledge on farming and related issues.

3.4.5) Soil sampling for nutrient content and physical property analysis

Soil samples were collected from the forest as well as from agriculture field for comparative analysis in the laboratory. The samples were selected based on purposive sampling technique, each land category under different land use was selected for collecting the soil samples. The households from who's farmland soil samples were collected were interviewed accordingly. The soil samples from the forest area were collected from a nearby forest area using soil probe auger. The sample collection was categorically avoided from the fields where lime, fertilizer or manure was recently added. The average sampling depth was 7 inches, ten composite samples were taken from the different site within the sample area and mixed thoroughly to make it about 1/2Kg for the Lab. Each sample was carefully coded with a distinct name representing the land use types and slope categories. The samples were dried at room temperature and made into small particles separating 0.425 mm and 2mm for analysis.

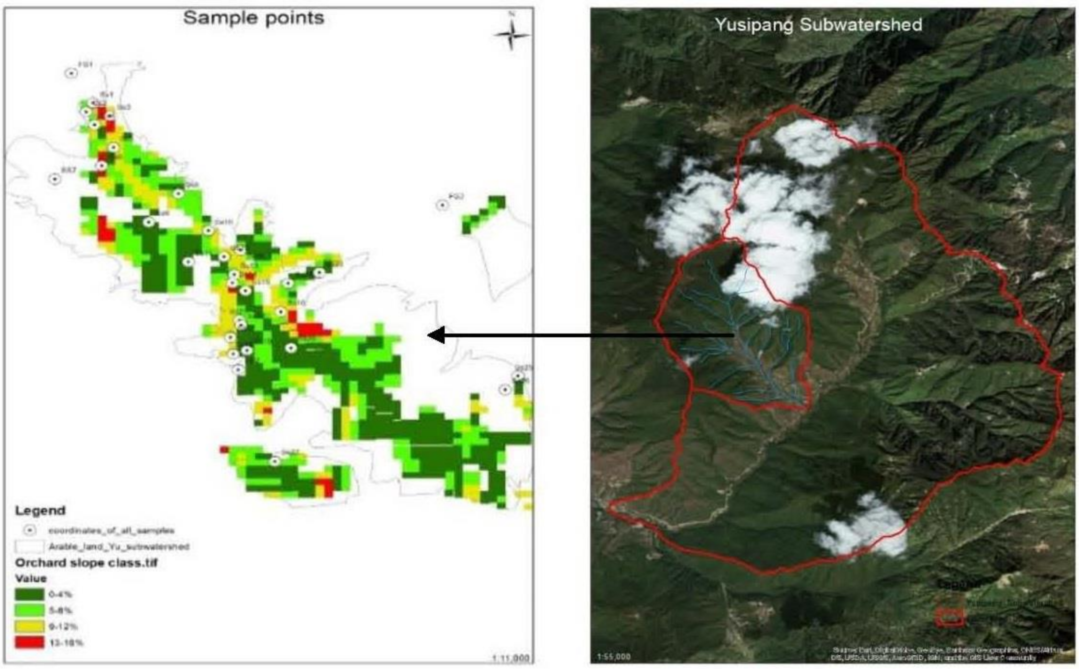


Figure 5: *Soil sample collection points*

Table 3: *Number of samples taken from each land and slope category*

No. of samples	Slope category	Land Use Category	Remarks
11	0-4%	Orchard	
7	4-8%	Orchard	
6	8-12%	Orchard	
3	12-16%	Orchard	

3.4.6) Core soil sample for bulk density

The soil bulk density is the dry soil mass per unit of bulk volume including air space. The soil bulk density is different for different soil types and it is greatly affected by management practices like land use activities, tillage, grazing by cattle, forest cover, etc). For instance, the presence of organic matter in the soil lowers the bulk density whereas compacting of the soil increases the bulk density. It is important to assess whether land use activities are affecting the soil bulk density in the agriculture fields. The general bulk density of mineral soil range from 1.0-1.8g/cm^3. The bulk density of the soil indicates its physical, chemical and biological functions, such as solvent and solute movement within soil particles and absorption by the root system, structural support, soil aeration. It is an indicator of quality assessment and comparisons between different management systems. Higher bulk density shows soil compaction and reduced soil porosity, in such condition, there is less movement of water and air through the soil and cause restriction to root growth. Compaction can reduce water infiltration into the soil leading to increased runoff and erosion in slopping land or waterlogged in plain areas. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect soil from erosion (Arshad M.A., 2011).

Core method was chosen for this purpose because the soil is not very coarse in all the fields (particles > 2mm occupy less than 25%). Core ring made of steel measuring 6 cm length and 6 cm diameter was designed to remove a cylinder core of soil. The cylinders were driven into the soil by a drop hammer, the cylinder containing undisturbed soil core is then removed and trimmed to the end with a thin metal sheet or knife to have a uniform volume calculated from its length and diameter. Three consecutive core layers were taken from the same sample spot, the total core sample taken was 90. The samples were carefully coded with representative names and transported to the Laboratory at Yusipang for drying inside the electric oven at 105^{o}C. The weight of these core samples was measured after drying it inside the oven for about 18-24 hours using an electric weighing machine.

The wet and dry bulk density of the cores were calculated using the following formula:

Bulk density (g/cm^3) = Dry soil weight (g)/Soil volume (cm^3)

The volume of the soil core can be determined by using the formula

Area of a core $A = \pi r^2$

Volume = $\pi r^2 x\ h$ (whereas *'h'* is the height of the core)

3.4.7) Soil Infiltration Rate

It is to determine the rate or speed at which water enters into the soil. A double ring infiltrometer was used to measure the water entering the soil, it is measured by the depth in mm of water that can enter the soil in one hour. The standard ring infiltrometer of 8" diameter outer ring and 6" diameter of inner ringer joined together to maintain equi-distance between the outer and inner ring. The ring was hammered 8 cm into the soil, keeping the ring perfectly vertical. The water was poured into the inner ring and outer ring until the depth was 100 mm. A stopwatch was used to record the time when the test began, water level was noted on the measuring scale, note was taken every after 1-2 minutes and added water to bring the level back to approximately the original level at the start of the test, same water level was maintained in the outer ring as well. The time interval for recording was increased as the procedure continues until such time when no further infiltration happens. The test was continued until the drop in water level was the same over the same time interval. The infiltration was tested in all the soil sample area i.e 30 samples and recorded the information in the format.

Figure 6: *(Left) Improvised double ring infiltrometer, (Right) taking note*

3.4.8) Water and Sediment Sampling

The water and sediment samples were selected from areas such as headwater (no settlement), banks of the seasonal streams, below the cultivated land, below piggery farm, from the confluence at the outlet to compare the effects of effluents on physical characteristics of the water. The sample collecting sites were selected base on purposive sample method. A total of 4 water samples and sediment samples were collected to see the physical and chemical change in water and the presence of agro-chemical residues in the sediments. Eight parameters of physical and chemical aspects of water have been determined by using portable field water testing kit, the reading was taken at strategic points: point 1 at low settlement area, point two at the high cultivated area, point 3 at the outlet and point 4 above the settlement in the forest.

3.4.8.1) Parameter 1: Water Transparency

The transparency of water decreases as suspended particles and dissolved materials and microbial loads increase. The materials provide attachments site for toxic chemicals which is not suitable for drinking purpose, and it also inhibits photosynthetic activities of the organisms at the bottom of the water by obstruction of light penetration. It was measured by using simple transparency paper, there are four different color intensity numbers, 1 being darkest (more prominent) and 4 being the least dark (less prominent).

3.4.8.2) Parameter 2 Temperature

Increase and decrease of water temperature have a deleterious effect, increase temperature decreases the solubility of oxygen in the water, increases the growth rate of the aquatic microorganism so they consume dissolved O_2 faster, at a lower temperature the efficiency of disinfection process is highly reduced.

3.4.8.3) Parameter 3 Water pH

Water pH indicates the acidity and alkalinity of water, it is a measure of the relative amount of free hydrogen and hydroxyl ions in the water. More free hydrogen ions mean water is acidic whereas more free hydroxyl ions mean water is basic., the pH of water is an important indicator of chemical change in water.

3.4.8.4) Parameter 4 Total Dissolved Solute

Total Dissolved Solute (TDS) in the water is the amount of mineral salts, cations or anions and metals dissolved in water. The TDS primarily consist of inorganic minerals like Calcium, Sodium, Potassium, Chlorides, bicarbonates, and Sulfates and some organic matters. The measurement of TDS gives an idea about the presence of this mineral in the water

3.4.8.5) Parameter 5 Total Dissolved Oxygen

The Total Dissolved Oxygen (OD) is important for aquatic life, the dissolved oxygen is used by the aquatic animals for respiration. when OD level drops below 5.0 mg/l the aquatic life is put under stress. It has been noted in some studies that Oxygen level that remains below 1-2mg/l for a few hours can result in large fish kills.

3.4.8.6) Parameter 6 Oxygen Saturation

Dissolved Oxygen (OS) will remain at 100% air saturation in a stable body of water. 100% air saturation means that the water is holding as many dissolved gas molecules as it can in equilibrium, at equilibrium, the percentage of each gas in the water would be equivalent to the percentage of that gas in the atmosphere i.e. its partial pressure (Fondriest Environmental Learning Centre, 2013). The aquatic respiration can lower the OS level high photosynthesis and aeration can increase the OS level in the water.

3.4.8.7) Parameter 7 Electrical Conductivity

The EC (electric conductivity) is due to ionizable inorganic compounds, pure water has low conductance, higher the conductivity indicates increased dissolved ionizable inorganic substances in water. The EC of distilled water is 1μ mho.

3.4.8.8) Parameter 8 Salinity

Salinity is the measurement of all dissolved salts in the water. Freshwater should have salinity less than 500 milligrams of salt per litre (Government of Western Australia, 2017).

3.4.8.9) Taste and Odour

The drinking water should be tasteless and odorless. The taste and color of the water are caused by chlorination, the presence of inorganic salts like NaCl, KCL, or H2S. Due to the negative health implication caused by these substances, the water should be free of these substances

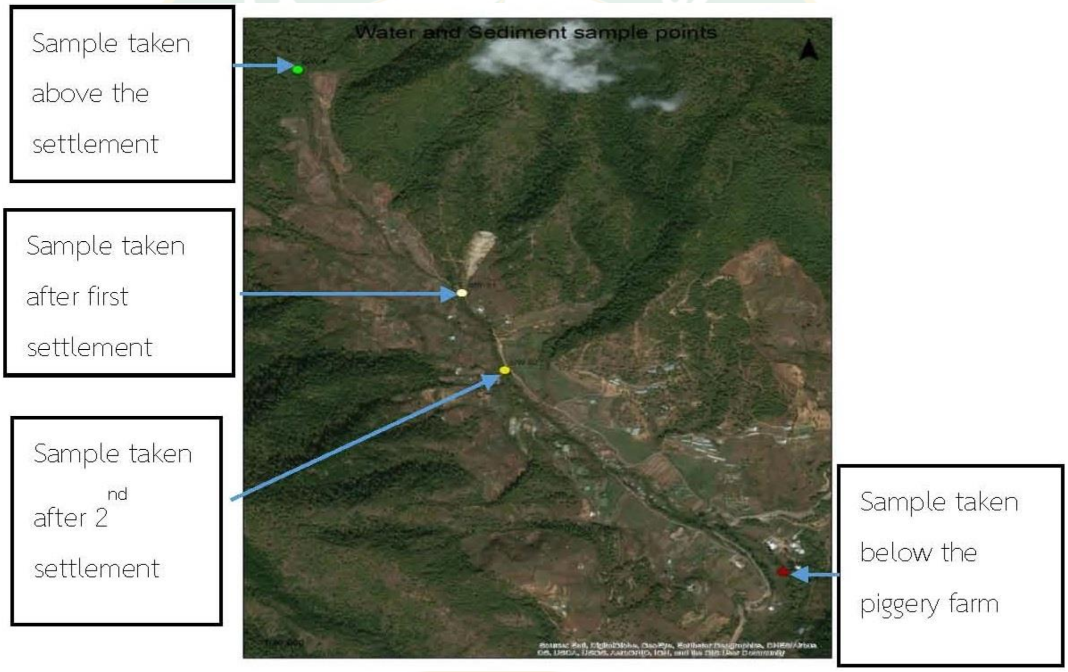


Figure 7: *Water and Sediment sample point*

Figure 8: *Using a portable field water testing kit*

3.4.9) Secondary Data

The information about the forest was extracted from the National Forest Inventory database and processed using Microsoft Excel. The climate data such as rainfall information, temperature, wind, humidity, cloud cover, etc. were requested from National Centre for Hydrology and Meteorology (NCHM), Bhutan. The information was analyzed using Microsoft Excel. Important government policies and legal documents were requested from relevant agencies in the country.

3.5) Information/data analysis

3.5.1) Site analysis

GIS software was used to analyze land use types, slope, elevation, drainage, hill shade, settlement, build up, non-built up areas, and contours of the study site. The National Land Use Information 2016 and Digital Elevation Model of Bhutan was used as input information to generate the required output. The boundary of the proposed study site (watershed) was digitized on the google earth pro in 3D view and transferred to GIS software for analysis.

The Google Earth and Greens hot software were used to produce a topography map of the study site with the finest detail possible. Series of Arial photographs of the study site less than 1 km eye height were taken from the google earth pro and processed in PS Adobe Photoshop. Photos were rearranged, grouped and boundary file of the watershed was overlaid on topo map by a geo-referencing technique in the GIS software.

The slope classification for the watershed was done using FAO 2006 reference, there are five slope classes (0-7%, 7-15%, 15-20%, 20-30%, >30%). The slope data extracted from the DEM was reclassified using the Spatial Analyst tool in GIS. The land use types like cultivated land (orchard and dry land) and built up areas were overlaid and combined with reclassified slope using 'Union' tool to see the suitability of each land use type.

Stream cross-section analysis was done for each sub-watershed to calculate TP (Time axis as a fraction of the time-to-peak) and QP (Ordinates as a fraction of the peak discharge). The sub-watersheds were identified using contour lines and drainage as a reference to digitizing its boundary. A 3D line was created by interpolating height from the selected stream to find stream distance and elevation difference. The slope % of each stream is calculated by using the formula:

Slope = vertical distance (elevation)/horizontal distance (stream length) x 100%

3.5.2) Cost and benefit analysis (Socio-economic condition)

The IBM SPSS was used to analyse the household questionnaires. This method was used to determine the correlation between different parameters; the agriculture farming, its profitability and sustainability of the existing income-generating activities.

3.5.3) Assessment of onsite soil erosion

The field survey for onsite soil erosion was carried out in December 2018 and January 2019 after the fruit crops and vegetables were harvested. When most of the land was fallow (without cover crop) due to cold winter months which doesn't favour much of field activities. Soil samples were collected from arable land, representing 50 hectares of the orchard and 21 hectares of dryland. Total 27 samples were collected using the criteria for collecting samples to cover the range of variations in physical land characteristics (slopes), land use types and crop cover. Samples were collected from selected plots of the orchard and dry land. For every sampling location, one composite soil sample at 15 cm deep was taken. Double-Ring Infiltrometer, a standard field test method for infiltration rate of soils was used for each plot to determine the permeability of the soil (K-index). The soil samples were collected for soil fertility and erodibility testing, the same samples were also used for determining physical properties such as soil texture.

The GIS database of National Land Use information 2016 was applied to interpret land use types and its extent, drainage pattern, slope percent, slope length within the defined boundary of the watershed (study site). The rainfall data collected from NCHM was used to analyse the R factor. The soil conservation activities and cropping systems applied by the farmers were determined by RRA and PRA.

The soil erosion process was predicted by using a mathematical model: Universal Soil Loss Equation Model (USLE) by Wischmeier and Smith, 1978. The model uses six factors to predict the long term average annual soil loss in a ton (A)

A=RKLSCP

Where: **R is the rainfall erosivity factor**, it is the average annual rainfall of multiple years, in this case, 20 years' rainfall data has been analyzed. It measures the kinetic energy and rainfall intensity to explain the effect of rainfall on soil erosion. Both rainfall and runoff factors are important and must be considered while assessing water erosion. The type of soil aggregates and its structure affects the impact of raindrops on the soil surface, lighter materials such as sand, silt and clay, and organic particles can be easily displaced by raindrop splash and surface runoff, while larger raindrop and stronger surface runoff are required to move larger sand and gravel particles.

The rainfall factor was calculated using the equation developed by Rambabu et.al 1979 for Dehradun, India. This place has been chosen because of its proximity and similar morphological characteristics to Bhutan:

$$R = 22.8+0.6400*MAP$$

MAP is the Mean Annual Precipitation (of 20 years)

K is soil erodibility factor, which is the susceptibility of the soil to erosion, it is an estimation of the soil to resist erosion. It is predominantly controlled by physical characteristics like soil particles, structure, the presence of organic compounds, etc. soils with higher infiltration rates like sandy loam and loam textured soils have high resistant to erosion than silt, clay, and very fine sandy soil. In the agriculturally dominated landscape this phenomenon can be affected by tillage and cropping system, which deteriorates soil structure, loss of soil organic matters (OM) resulting in soil compaction, increase surface runoff and decreased infiltration rate. The K-factor was analysed by using % organic matter calculated in the soil samples. And Infiltration rate to determine the permeability of the soil. The value of K-factor ranges from 0.02 to 0.69. The table used for determining the K factor was developed by Agricultural Research Service, United States Department of Agriculture (ARS-USDA) and Office of Research and Development, United States Environmental Protection Agency (ORD-EPA) in 1975

L and S are the topographic factors, the slope length, and slope gradient factor, these two factors are considered as one. Soil loss increases more rapidly with slope steepness. The LS-factor is the effect of slope length (L) on erosion and the slope gradient factor (S) is the effect of slope steepness on erosion. The GIS version 10.2.2 was used to classify the slopes into different categories, the slope length of agriculture land under each slope class was measured in meter using google pro software. The format developed in 2012 by the Ontario government, Ministry of Agriculture, Food and Rural Affairs was used to determine the LS factor based on Slope percent and slope length.

C-factor is the cropping management factor; this factor indicates how cropping practice can affect the annual soil loss. Crops grown for a major portion of the year can reduce soil erosion. Tillage operation also affects soil erosion potential, depending on direction, depth, and timing of ploughing, equipment used intensity of ploughing. Less disturbance of vegetation or residue cover at the surface and ploughing along the contour line is a more effective practice to reduce soil erosion. C-factor is usually the ratio of soil loss from the field with specific cropping and management from the fallow condition on which the factor K is evaluated. For this study, factor C was obtained from using the C-Factor chart depending on plant cover, developed in 1990 by the Land Development Department, Thailand.

P-factor is the soil conservation practices, which reflects the impacts of supporting practices on soil erosion. A combination of appropriate farming practice and soil conservation measures might be necessary when cropping management alone doesn’t work. The P-factor was also obtained from standard P factor table.

Microsoft Excel for basic descriptive statistics and simple tables, charts, graphs, etc were used to explain the farming practices and land use change. The findings from key informants and direct observations were closely reviewed for additional information to provide more depth and illustrations. The correlation between OM% and soil texture was studied using Pearson 2 tailed correlation.

3.5.4) Water quality and sediment analysis

The water samples were assessed in the field using portable water testing kit, the instrument measured five parameters such as pH, Total Dissolved Solutes, Total Dissolved Oxygen, Water Temperature, and Electric Conductivity. The physical attributes such as transparency, odour, colour were also observed in the field. The water quality is compared to Bhutan Drinking Water Quality Standard prescribed by the government. The sediment samples collected from pre-determined sample areas along the streams are brought to Maejo University and tested in the laboratory for the presence of any agrochemical residues. A GT Pesticides Test Kit was used to test pesticide residues, Organophosphate group, and Carbonate group. The result was compared with standard international and local permissible limits.

The sample collection was planned after the crop cultivation and in the winter when the water discharge is at its lowest, it facilitates the proper gathering of samples from the predetermined sampling plots. Purposive sampling was largely used to get the desired result of the study. The samples were collected from a selected sub watershed from various strategic locations viz. near the forest, below the settlement, below piggery farm, and at the outlet. The result of the different water samples and sediment samples were compared to its quality and presence of chemical components. The coordinates and altitude readings of the sample points were taken using GPS.

CHAPTER 4
Result and Discussion

The assessment of upstream farming intensification, its impact on soil and downstream water quality was carried out using existing data from National Land Use Information 2016, On-Site Soil Erosion Modelling, soil, water, and sediment sample analysis collected from one of its sub-watersheds in Yusipang Hongtso watershed. The hydrological data used for this assessment was requested from the Department of Hydro mat and meteorology. Result obtained from this study are as follows:

4.1) Site Analysis

Yusipang Hongtso watershed is one of the 19 sub-watersheds in the Wang Chhu basin. The identification number is 68 coded by WMD, it is located in Thimphu district within longitude of 89^{o} 40'E to 89^{o} 45'E and latitude of 27^{o} 25'N to 27^{o} 31'N. The watershed is about 15 km from Thimphu city towards North East and has an area of 57.4 km^2. There are about 518 households living inside this catchment including temporary shelters. The stream of this watershed is one of the main tributaries of the Wang Chhu basin. It is the main source of water for 232.31 hectares of arable land and provides natural hydrological benefits to 5700 hectares of land. It is the main drinking water source for local residents within the catchment as well as south Thimphu town.

4.1.1) Situational Study of Wang Chhu Basin

As reported in WRBMP, there is an increasing trend in annual rainfall toward the 2060s by about 3-7% from the present 751-1500 mm annual rainfall in Chang community (study site). Likewise, the average temperature will also increase by <1.30^{o}C toward the 2060s from the present average temperature of 5-10^{o}C. This impacts the hydrology, average monthly maximum flows of the basin are expected to increase significantly from April and July being the peak season. However, the number of consecutive dry days[4] is expected to increase. It was forecasted that 100 years return-period of the flood will occur every 5 years on average by 2060s, the water volume is also expected to increase from 1189m^3/s at present to 1818m^3/s by 2060s. The pattern of flow frequency is expected to be erratic, the frequency of minimum flow increases and the frequency of maximum flow decreases, this shift towards lesser flow is accompanied by the low frequency of high outflow. The UN Falkenmark index for internal dependable water estimated that Chang geog would fall from water scarcity in 2015 to absolute water scarcity in 2030. Chang community has been rated as the 2nd highest potential for water stress.

Wang Chhu basin is one of the five major river basins, it supports 24% of the country’s population and covers 12% of the country’s geographical area. The basin has high economic relevance for the country; there are two functional mega Hydroelectricity Plants; Chukha and Darla and many small Hydroelectric power plants. Sustenance of these projects will highly depend on a reliable supply of water both in quality and quantity. Watershed and its quality is the determining factor for the success of the hydro-projects. The basin has a high population density of 41.6 people/km^2 and forest cover of 43.4% (Watershed Management Division, 2011a) which is far below the minimum requirement of the constitution.

[4] Precipitation <1mm/day is considered dry day

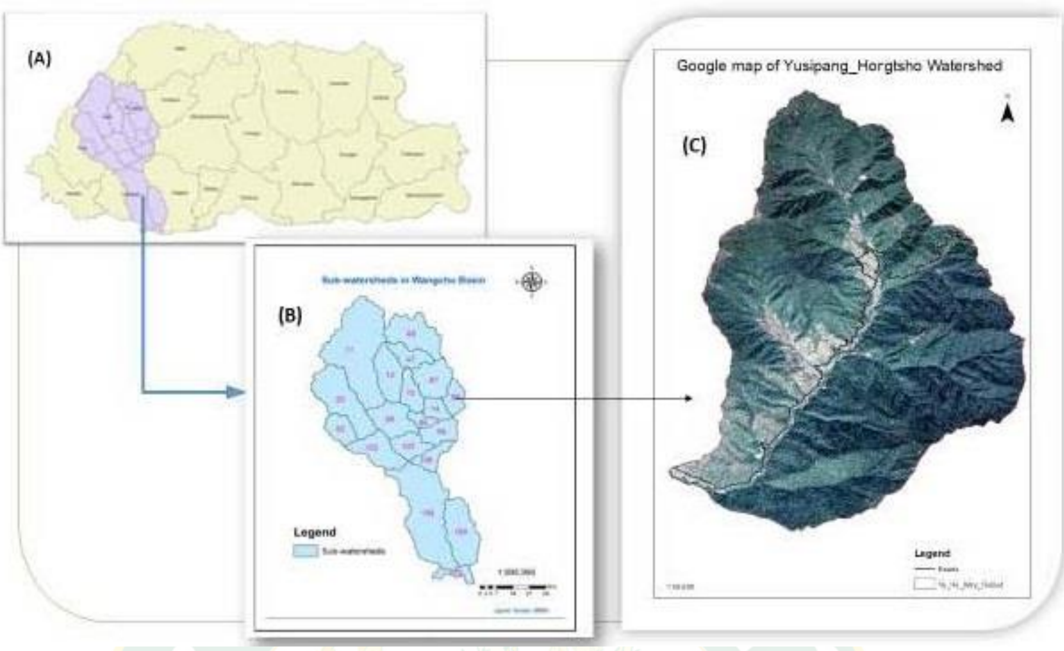


Figure 9: *(A) Bhutan map showing Wangchhu River Basin, (B) Wangchhu Basin showing 19 sub-watersheds, (C) google map showing Yusipang Hongtso Watersh*

4.1.2) Geological Characteristics

As per the geological map description of Bhutan 2011, the geological setting of the study site is characterized as a Lower metasedimentary unit (Neoproteronoic-Cambrian). Dominantly amphibolite-Facies, metasedimentary rocks including quartz and biotite – muscovite-garnet Schist and Para gneiss often exhibiting Kyanite, Silicate or Staurolite, and partial melt texture (Long, 2011). As mentioned in the report titled Rapid Classification of Watersheds in Wang Chhu Basin 2011, the central part of the basin (lower Paro and Thimphu), there is main Central Thrust called “Jaishidanda” inside the greater Himalayan sequence, which is stable in nature.

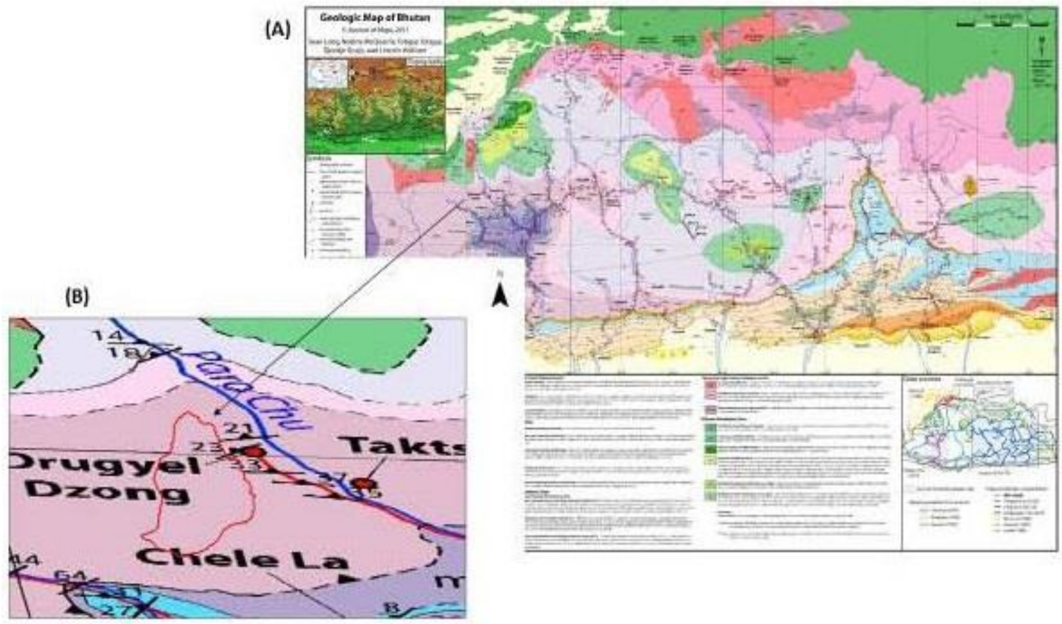


Figure 10: *(A) Geology map of Bhutan, (B) Geology map of the study site*

4.1.3) Physiographic characteristics of Yusipang Hongtso Watershed

The lowest point and highest elevation as analysed from Digital Elevation Modelling was found to be 2301 meters above mean sea level, recorded at the outlet point near Semtokha bridge and 4000 meters above mean sea level recorded at Northwest ridge of the watershed boundary respectively. The cross-section profile analysed from google pro showed 7 km to be the width of the watershed. The slope percent is 0-3 in the lowest valley bottom and >30 in many parts of the watershed. The watershed has an area of 57.4 KM^2 (5740 hectares), it is outlined by prominent natural ridges like Trashigang Gonpa, Thadra Gonpa. The watershed is inhabited by 518 households (permanent and temporary) forming cluster communities like Yusipang, Hongtso, Phenteykha, Changgaphu, etc.

4.1.4) Land use

The land use data is extracted from Bhutan land use information of 2016 with the help of ArcGIS software. The information on each type of land use is analysed from the attribute table. The land use information of the watershed area is as follows:

Table 4: *Land use categories, area, and percentage*

Sl. No	Land Use Type	Percentage %	Area (Ha)	Remarks
1	Blue pine Forest	41.96	2402.92	Forest area (94.22%)
2	Broadleaf Forest	0.38	21.80	
3	Fir Forest	7.8	447.18	
4	Mix conifer Forest	39.51	2264.44	
5	Scrubs	4.21	241.78	
6	Meadows	0.36	20.82	
7	Built up	1.66	95.17	Settlement/constructions (1.74%)
8	Non Built up	0.08	4.72	
9	Rain fed (*Kamzhing*)	1.42	81.64	Cultivated land (4%)
10	Orchard	2.62	150.67	
	Total	100	**5731.18**	

Maximum land use type is a forest; Blue pine, Mix Conifer, Broadleaf, Fir and Scrub combine to make 94.22% of the total surface area. The cultivated area consists of 4% of the total area, the orchard, and dry land are the two types of predominant agriculture land use. Remaining 1.74% of the land is under meadows, built up and non-built up category.

4.1.5) Forest

Mix conifer forest constituents 39.5% of the total watershed area it is the second largest forest type next to Blue pine stand. The dominant species found in this forest category are; Spruce (*Picea spinulosa*), Hemlock *(Tsuga demosa*), Larch (*Laris grifithii)*, the undergrowth are Rhododendrons, bamboo, and other shrubs. This forest is normally found between 2,000 m to 2700 m above sea level.

Forest meadows occupy less than 1% of the watershed area, it is negligible by area but is important from the ecological point of view. It is an open area with grass and non-woody vegetation

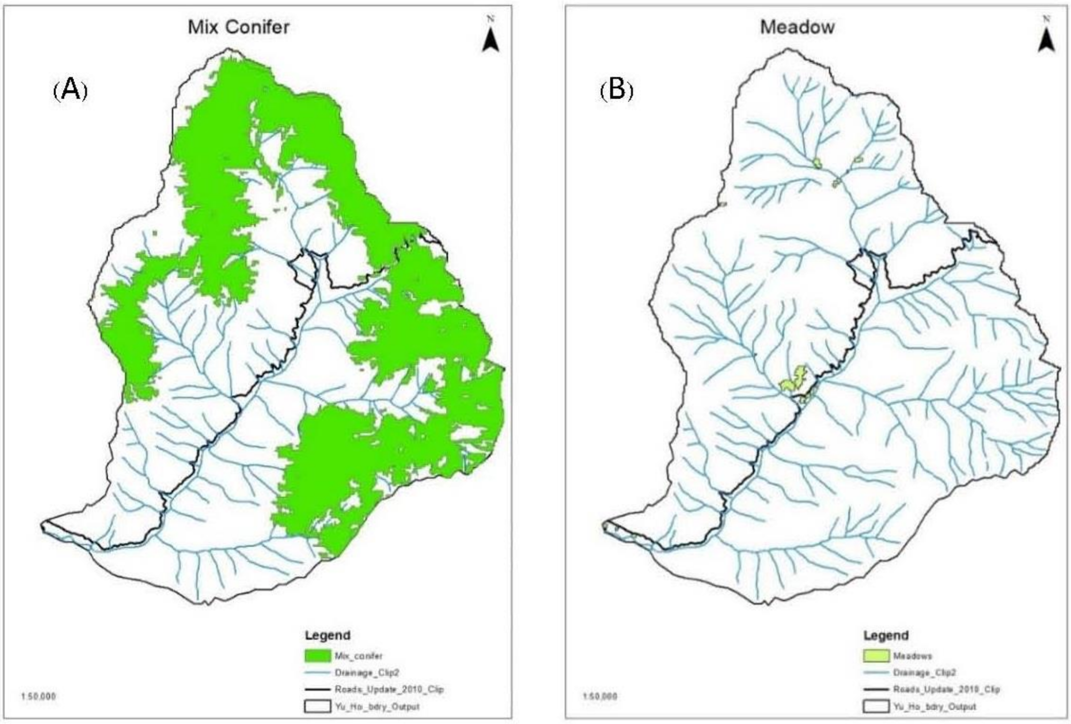


Figure 11: *(A) Mix Conifer Forest, (B) Meadows*

The Fir Forest occupies about 8 percent of the watershed area, it is found on the higher ridges of Dochula, Chamgang, Thadrana. The altitude range for this forest type is between 2700 m to 3800 meters above sea level. It grows in high precipitation zones, Rhododendron, sub-alpine bamboo, *Bryocarpum hamalaicum* are predominantly the undergrowth but hemlock, birches may also be found in this forest. It grades into alpine scrubs (*Juniper* and *Rhododendron* scrubs) as it ascends towards the tree line.

Cool broad-leaf Forest occupies a very meagre area, less than 1% of the watershed, it the characteristics of wetter hill slope and consist of species like Maple, *Castonopsis spp*, oak, *Michelia spp*, *Betula spp,* etc.

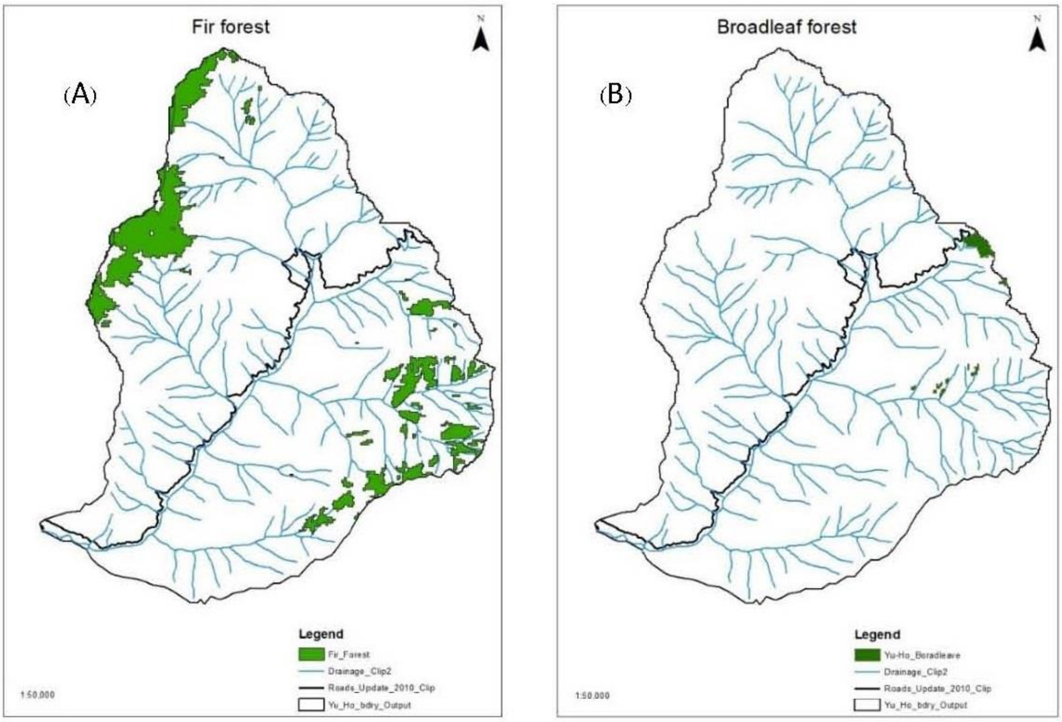
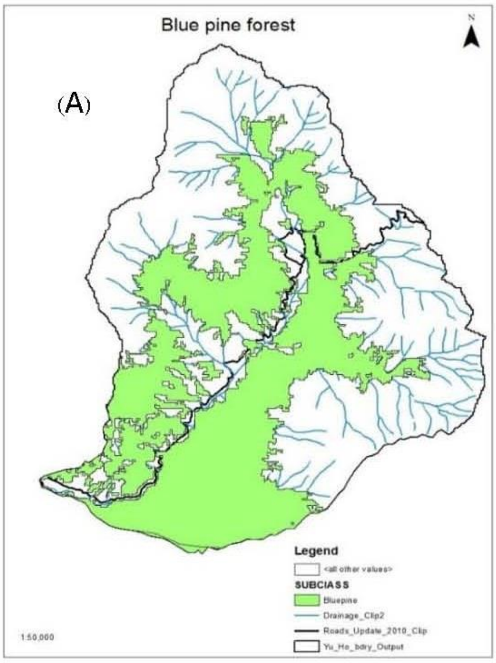


Figure 12: *(A) Fir Forest (B) Broadleaf forest*

Blue pine (*Pinus wallichiana*) is the dominant forest in the watershed, it occupies 42% of the watershed area. The forest is found between the altitude of 1800 to 3000 meters above sea level. It is mostly found near the settlement, in open areas and demonstrates a fast colonizing behavioural. It is a pioneer species probably a secondary type, the original might probably have been a dry oak forest with scattered blue pine. Broadleaf species like *Quercus semicarpifolia*, *Populus spp,* *Rhododendron spp,* and stunted shrubs.

The subalpine shrub occupies 4.2% of the watershed, it mostly stretches along the valley and concentrates on the slope facing east, where the slope is comparatively drier. The dominant species found in this forest are stunted *Quercus spp*, *Lionia* species, *Populus spp Cortenester,* etc.



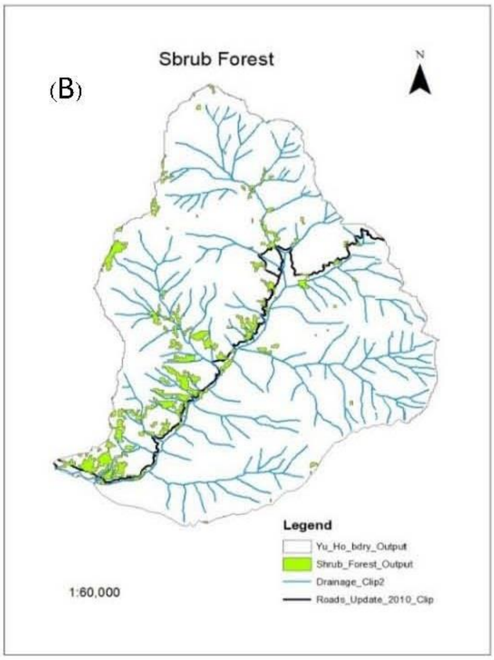


Figure 13: *(A) Blue pine Forest, (B) Shrub forest*

4.1.6) The function of Forest in the watershed

The 94.22 % of vegetation cover plays a key role in hydrological processes in the watershed, it is estimated that 70% of the world's accessible freshwater is from forested mountain and upland watersheds. Forest can maintain quality and influence volume of water, it regulates surface and groundwater flow. It helps reduce water-related risks like soil erosion, landslides, floods, droughts and prevent desertification and salinization. Forest can mitigate extreme weather and reduce the impacts of climate change on water resources (Food and Agriculture Organization, 2018) by cooling effects, the interception of precipitation, and water infiltration. The minimum forest cover to be maintained in all the situations is 60% by the constitution of Bhutan, by this standard the watershed is in good condition, however, the dominant vegetation is pine forest (Blue pine). This forest normally grows on east and southeast facing slopes of the dry temperate region and it is prone to forest fires in dry winter months. There is evidence of forest fires in this region, Blue pine trees easily succumb to fire, yet, scrub forest, broadleaf forest, and mix conifer forest are fire hardy. Repeated forest fires change the forest ecology, the scrub forest being fire hardy takes over the high forest in such a situation. The scrub forest (5%) could have been the result of repeated forest fire and human disturbance. It has a lesser role in water discharge and hydrological function. Blue pine is a pioneer forest; secondary vegetation may succeed over time. Blue pine and scrub forest are found near the settlement and along the streams, intervention by artificial plantation with mix native plant species preferably of broad leave forest may be promoted. However, at the stream sources most of the vegetation is mix conifer forest (42%) which is a good indication, as complex and mix species of forest are necessary for proper hydrological functioning.

4.1.7) Settlement

The settlement is concentrated along the river valley, there are 518 households as per the information analysed from National Land Use data. The settlement includes permanent farmhouses, temporary shelters, monasteries, shops, and other structures. The far-flung dotted settlements are monasteries, situated on secluded hilltops overlooking the valley. The settlement is categorized as a village, and are entitled to subsidized rural facilities like free electricity, subsidized timber, and firewood. There are grocery shops, restaurants and vegetable/fruit vendors along the road selling their products to commuters and local residents.

***Table 5**: villages and its corresponding households*

Sl. No	District	Village block	Sub village	Household
1	Thimphu	Chang	Debsi	43
2	Thimphu	Chang	Hongtso	338
3	Thimphu	Chang	Yusipang	137

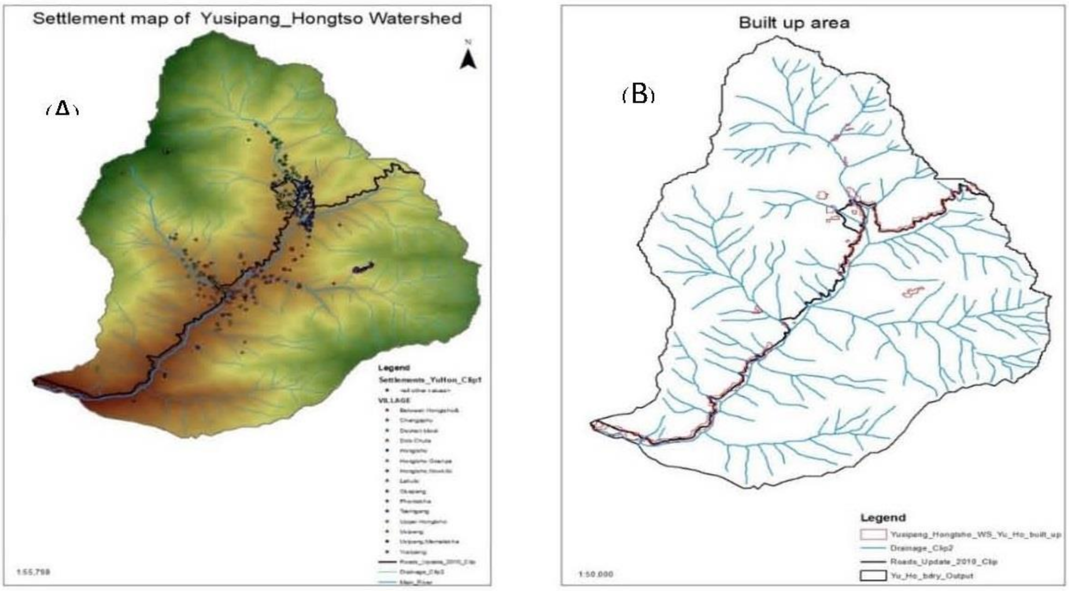


Figure 14: (A) Settlements, (B) Built-up areas

4.1.8) Roads

National High way passes through the watershed connecting other eastern districts to the Capital city. The road has been widened and upgraded to a double lane in recent year. There are numerous feeder and farm roads connecting the villages and temples, many of these roads are not metaled (blacktopped) and very susceptible to landslides and erosions during rainy days.

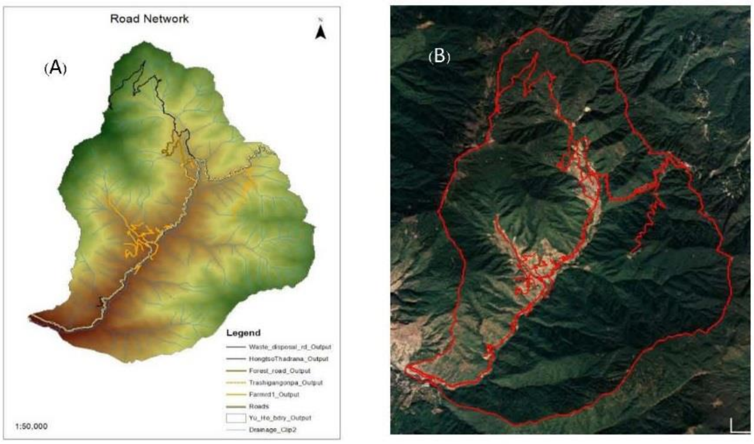


Figure 15: *(A) Road network in GIS map, (B) Road network in google map*

4.1.9) Cultivated area

There are two categories of cultivated land in this watershed, dry land which in local dialect is called *Kamzhing,* it is used for growing annual cash crops. The other land category is orchard which is used for growing assorted fruit trees. Often, it is found that these two crops are grown together in the same plot of land, fruit trees as a perennial crop and annual cash crop as a cover crop.

Table 6: Arable lands and its area

Land category	Area in Hectare
Dryland (Kamzhing)	81.64
Orchard	150.67

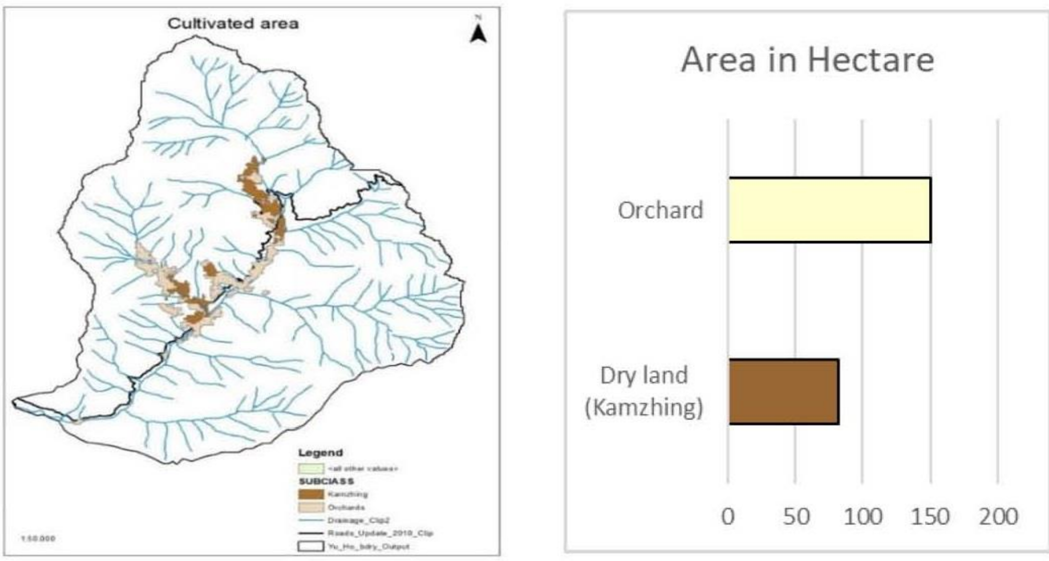


Figure 16: *Arable land categories and the extent*

4.1.10) Geomorphological characteristics of the drainage system

The geomorphology of the river system is dendritic. The main river flows from north to south, the tributaries and sub-tributaries flow from east to west or west to east joining the main river body. The valley formed by this drainage is a 'U' shape, the agriculture field and settlements occupy the valley bottom as the soil is fertile and accessible to water. The length of the main river is about 14 KM starting from the river head till the outlet.

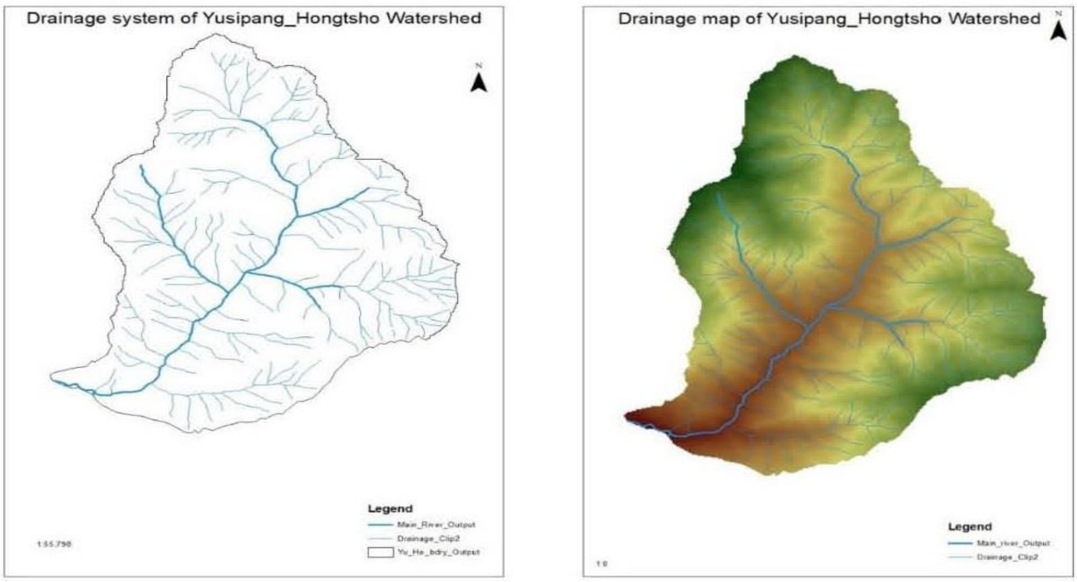


Figure 17: *Drainage system of Yusipang Hongtso Watershed*

The farmers in this watershed grow mix vegetable under apple trees. The perennial crop is fruit trees and the seasonal crops are potato and vegetables. These crops are primarily for commercial purpose. Total cultivated land analysed from land use information is 232.31 hectares, out of which 81.644 hectares are rainfed (*Kamzhing*) and 150.673 hectares as an orchard.

4.1.11) Slope classification of the watershed

The reference for the slope categories is based on FAO 2006, there are six different categories (as mentioned in the table). In all the slope categories the land use is dominated by forest, blue pine forest has the highest coverage of 24 Km^2 followed by Mix conifer forest with 22 Km^2. Other forest types like Fir and Shrub are less significant with an area covering 4.4 Km^2 and 3.4 Km^2 respectively. The orchard which is an important cash generating crop for the farmers covers 1.5 Km^2 and rain-fed 0.8 Km^2.

The orchards are spread across different slope categories from 0% to 20% while dry land cultivation is concentrated in valleys and foothills (0-17%). The forest cover is highest in the lowest slope (0-7%) and decreases as the slope increase, the slope >30% have only 0.02066 Km^2 covered by forest (Fir, Blue pine and Mix conifer). Human activities are significantly absent beyond 20% which is a good indication for the watershed.

Table 7: *Slope categories with corresponding land use extend*

Slope Category	The area in KM^2 against slope categories							
	0-7 %	7-15%	15-20%	20-25%	25-30%	>30%	Info not recognized	Total
Blue pine	16.26	6.92	0.69	0.13	0.01	0.00	0.02	24.03
Broadleaf	0.16	0.05	0.00	-	-	-	0.00	0.22
Built up	0.54	0.35	0.06	0.01	0.00		0.00	0.95
Fir	2.43	1.79	0.18	0.04	0.01	0.01	0.02	4.47
Kamzhing (rain fed)	0.69	0.12	-	-	-	-	0.00	0.82
Meadows	0.15	0.05	0.00	0.00	-	-	0.00	0.21
Mixed conifer	13.45	8.18	0.77	0.15	0.03	0.01	0.06	22.64
Non Built up	0.02	0.03	-	-	-	-	-	0.05

Slope Category	The area in KM^2 against slope categories							
	0-7 %	7-15%	15-20%	20-25%	25-30%	>30%	Info not recognized	Total
Orchards	1.13	0.36	0.02	-	-	-	0.00	1.51
Shrubs	1.49	0.80	0.09	0.03	0.00	-	0.00	2.42
(blank)	0.04	0.04	0.00	-	-	-	-	0.08
Grand Total	**36.35**	**18.70**	**1.81**	**0.35**	**0.05**	**0.02**	**0.11**	**57.39**

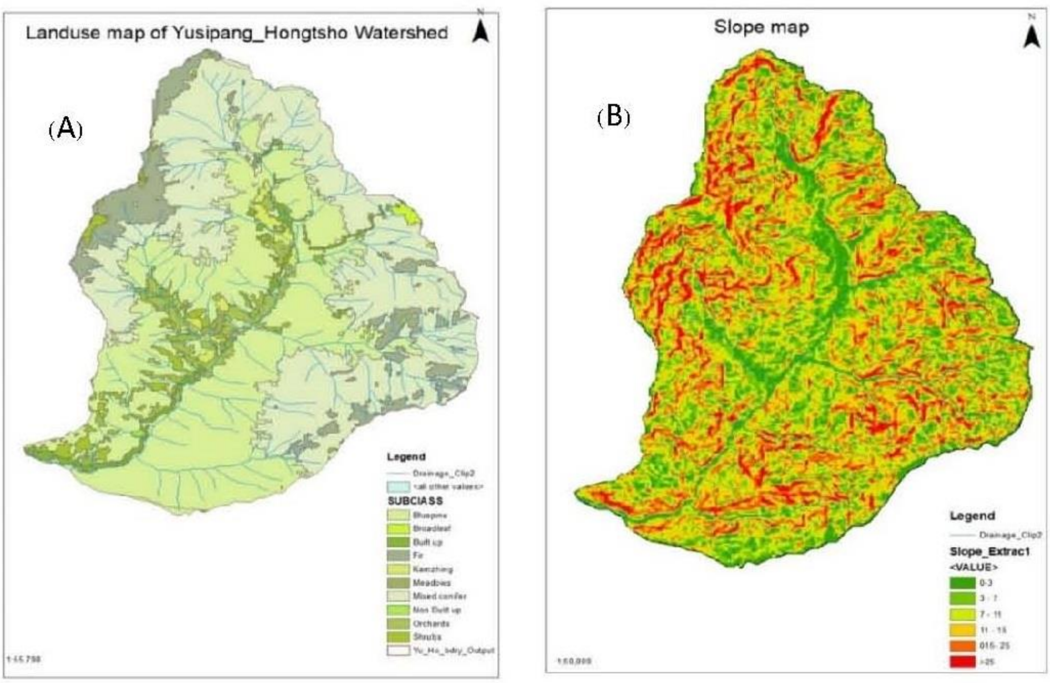


Figure 18: *(A) land use map (B) Slope categories*

4.1.12) Sub-watersheds and their gradient

There are 14 sub-watersheds and the boundary for each subwatershed was delineated based on the contour lines and its morphological characteristics. The size and shape of sub-watersheds differ from one another. The landscape and corresponding slope percent of the sub watersheds were calculated using simple mathematical formula i.e:

Slope = vertical distance (elevation)/horizontal distance (stream length) x 100%.

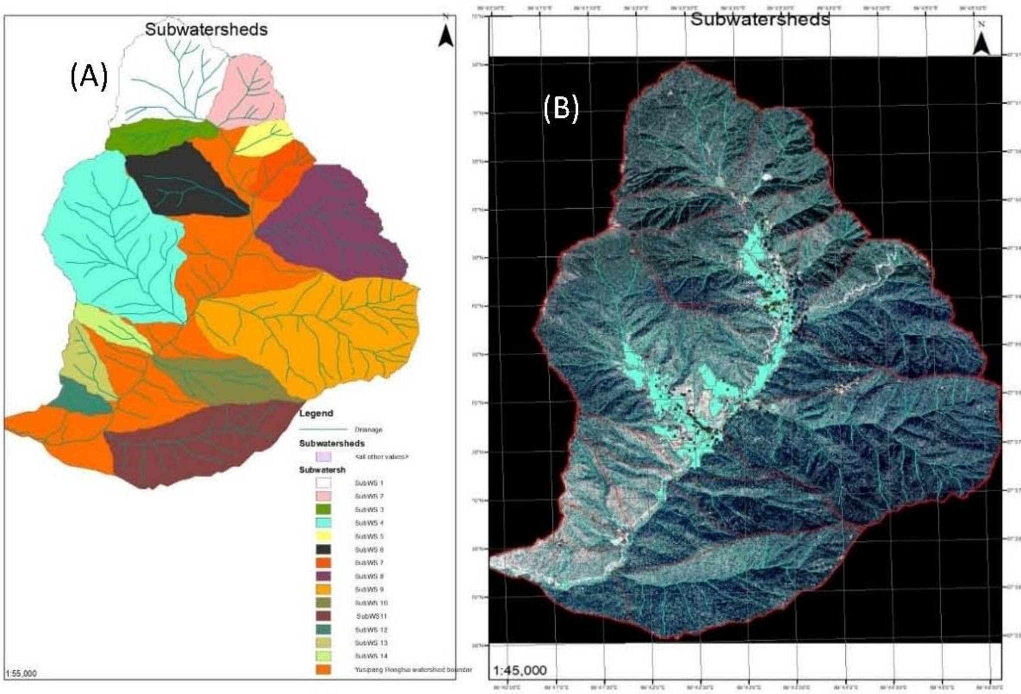


Figure 19: *(A) sub-watersheds (B) Topo map showing the boundaries of sub-watersheds*

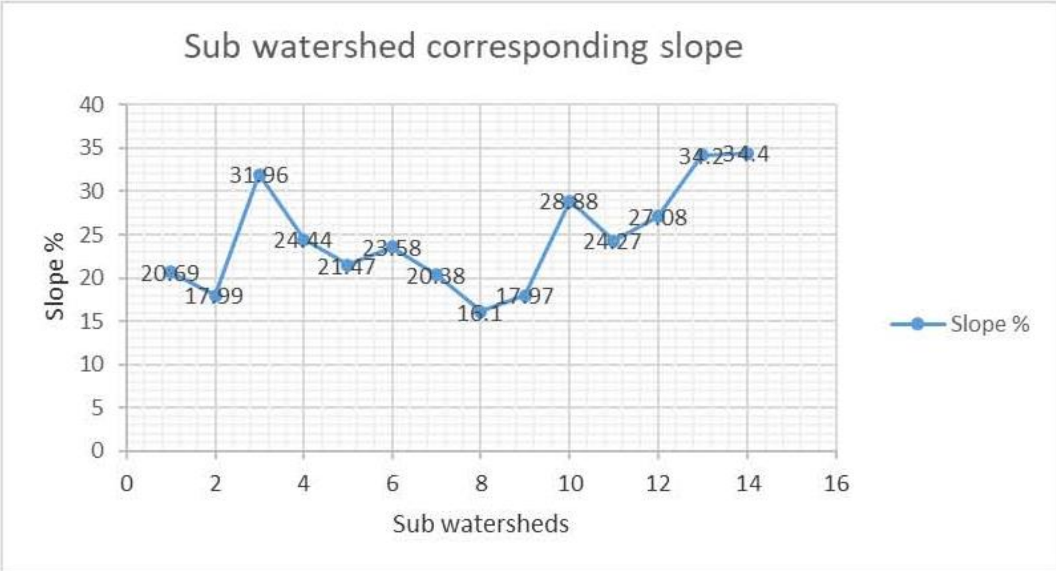


Figure 20: *Sub watersheds with their corresponding slop percentage*

The figure shows the different slope of each sub-watershed, all the watersheds have different slope gradient. Highest is 34.4 % for sub-watershed number 14 and the lowest is 16.1 % for sub-watershed number 8. The velocity of the stream flow depends on the slope steepness; the steeper the slope, more rapid the stream flow. Sub-watershed number 13 and 14 have the highest slope percent, which means more erosions are likely in these watersheds. However, these two sub-watersheds are not significant in terms of use by the people, there is no settlement and cultivated land, the sub-watersheds are sufficiently covered by vegetation predominantly of Blue pine forest.

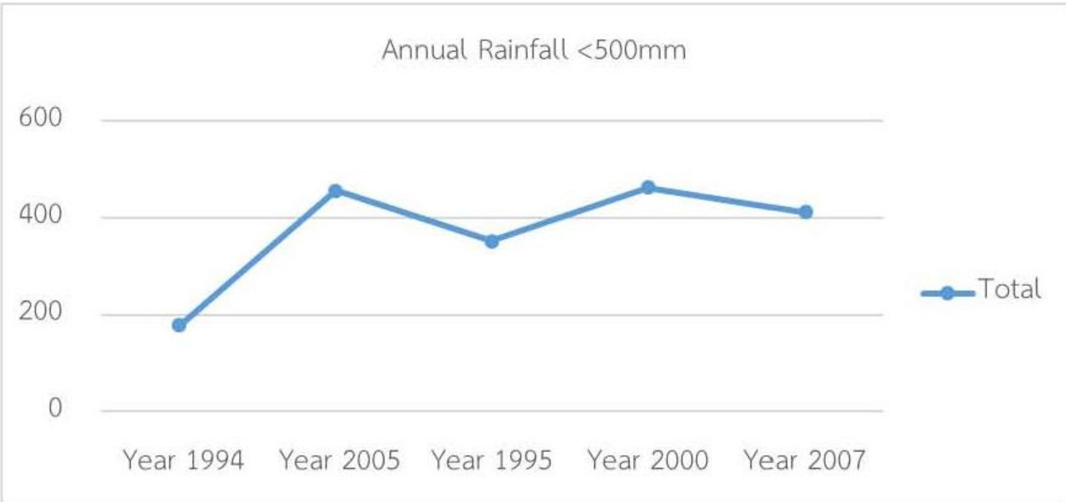
4.1.13) Climate

The average altitude of this watershed is about 2700 meters above sea level. There are four distinct seasons in a year; Spring has a mild cold and dry weather; Summer is characterized by moderate to heavy rainfall and warm temperature; Autumn is characterized by fall of leaves and dropping in temperature; Winter is characterized by snowfall and cold dry weather. The variation of temperature is

13.8°C throughout the year, July and August are the hottest months of the year while January is the coldest. The average temperature would be around 11.6°C.

***Table 8**: Average monthly temperature of Thimphu district*

Average Temp (C°)	January	February	March	April	May	June	July	August	Septembe	October	November	December
Min	-3	1	4	7	13	15	15	16	15	10	5	-1
Max	12	14	16	20	23	24	25	25	23	22	18	15



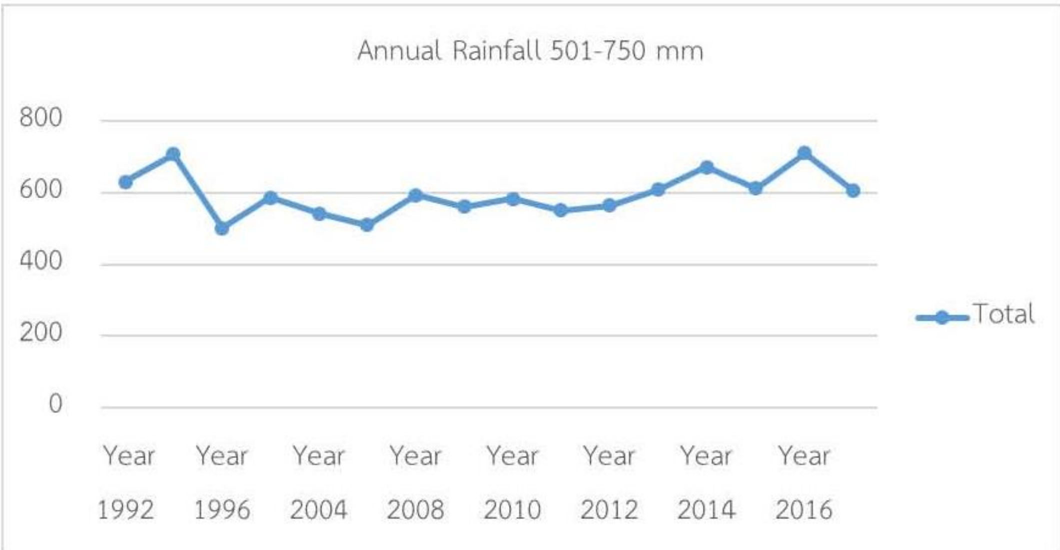


***Figure 21:** (above) annual rainfall <500mm and (below) annual rainfall 501-750mm*

The annual precipitation is lowest in December and highest in July; December is the driest month of the year with an average precipitation of 4 mm, July receives the highest rainfall with average up to 364mm.

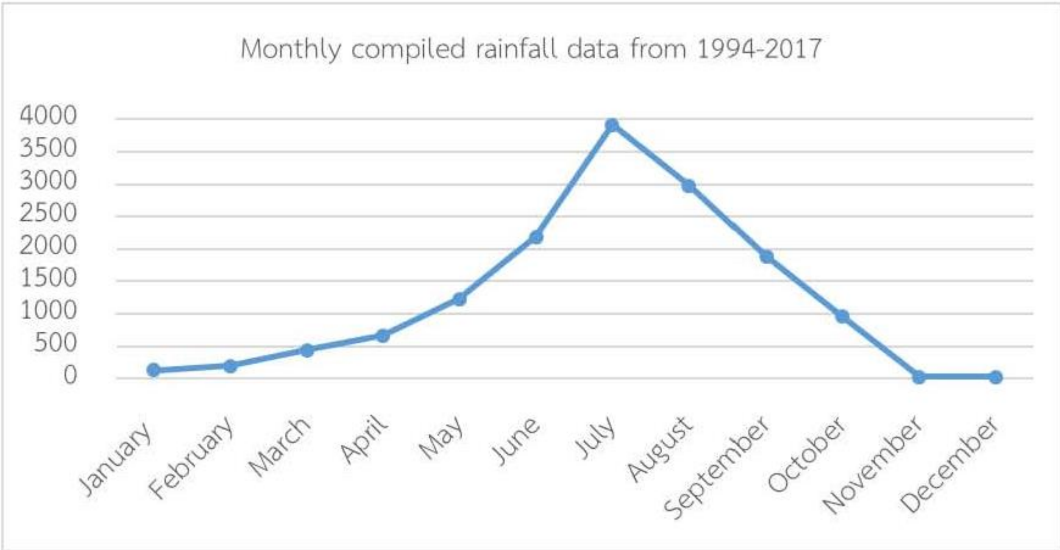


Figure 22: *Hydrological graph of 25 years*

The 25 years of rainfall data analysis indicated the highest rainfall received in the month of July for all the years and lowest in the month of December. In general, June, July, and August is the monsoon season and November, December, and January are the dry seasons which is the winter.

4.2) Objective One

Study upstream farming intensification, onsite soil erosion and its impacts on soil and water quality for establishing a connection between upstream farming practices and downstream water quality

4.2.1) Agriculture Land Use System

Horticulture is the main agriculture in this watershed, they grow apple and varieties of temperate vegetables for cash income. Land use information of 2016 showed two different categories of arable land; Orchard and dryland/rainfed (Kamzhing). But farmers have converted the land into an orchard, the 232.3 hectares of arable land have similar Landuse feature. Apple is the epitome of fruit trees, a form of mono-cropping, but with an occasional assortment of peach, pear, and walnut. Temperate vegetables are grown under the apple canopy as a cover crop. Potato, cabbage, cauliflower are the major crops grown at large scale, it occupies the largest portion of the land. These crops are grown separately to ease the management works, however, farmers also practice crop rotation to minimize pest infestation. The minor vegetables are grown at small scale for household consumption or sell in the local market in small quantity. Some of these vegetables are usually mixed together on the same plot, for instance, green leaf, radish, chili, and beans. Many farmers use a certain portion of their land for vegetable cultivation, although farmers with less than one acre of land use whole plot.

4.2.2) The Proportion of Farmland to Other Land-use Types

There are three major land use types in this watershed; forest, cultivated land and built up/non-built up area (settlement, constructions). As forest cover the largest chunk (94%) of the watershed, it is found on the mountain range, hilltops stretching towards settlement and surrounding the agriculture land. The other form of land use constituents about 1.7 % of the land mass. This land category is used for public infrastructural development, space for house construction, natural water bodies and drainage systems. The cultivated Land (4%) although it is insignificant by extent yet it plays a major role in providing a livelihood to more than two thousand people living inside this catchment. About 350 acres within this watershed is occupied by Renewable Natural Resource, Research, and Development Centre, the center is mandated to promote organic cultivation across the country. The area also has a Dairy Research Farm, Regional Pig Breeding Centre, and Agriculture and Food testing laboratory under the Ministry of Agriculture and Forest.

***Table 9**: Land use categories and percentage*

Land Use	**Percent %**	**Remarks**
Forest	94.22	Six different forest types
Built up & Non-Built-up	1.74	Roads, settlements, public infrastructure
Agricultural land	4	Predominantly orchard
Total Area 5731.18 hectares		

***Figure 23:** Google map showing arable land and settlement inside the Watershed*

4.2.3) Agricultural farmland and its distribution along the different slope gradient

The more than 78% of agriculture land is in slope category 0-7%, twenty percent of the land is in slope category 7-15% and less than one percent of the land is in slope category 15-20%. There is no farming in the slopes exceeding 20%, it is either state forest or community forest. According to FAO, agriculture cropping beyond 20% is not recommended for various reasons. It is well under the permissible slope limit in this watershed. However, it is very likely that the expansion of agriculture land will occur in the near future.

Table 10*: Slope categories and corresponding arable land*

Land category	The area in KM^2 against slope categories						
	0-7 %	7-15%	15-20%	20-25%	25-30%	>30%	Total
Rain fed (Kamzhing)	0.69	0.12	0	0	0	0	0.81
Orchards	1.13	0.36	0.02	0	0	0	1.51
Total	**1.82**	**0.48**	**0.02**	0	0	0	2.32

4.2.4) Forest & other land-use distribution along different slope gradients

The forest cover is maximum in the slope category 0-7%, by area Blue pine forest is the highest. The forest cover decreases as the slope increase, the slope >30% have 0.02066 Km^2 covered by Fir and Mix conifer. Human activities are significantly absent beyond 20% which is a good indication for the watershed.

Table 11*: Slope categories with corresponding land use extent*

Slope Category	The area in KM^2 against slope categories							
	0-7 %	7-15%	15-20%	20-25%	25-30%	>30%	Info not recognized	Total
Blue pine	16.26	6.92	0.69	0.13	0.01	0.00	0.02	24.03
Broadleaf	0.16	0.05	0.00	-	-	-	0.00	0.22
Built up	0.54	0.35	0.06	0.01	0.00		0.00	0.95
Fir	2.43	1.79	0.18	0.04	0.01	0.01	0.02	4.47
Meadows	0.15	0.05	0.00	0.00	-	-	0.00	0.21
Mixed conifer	13.45	8.18	0.77	0.15	0.03	0.01	0.06	22.64

Slope Category	The area in KM^2 against slope categories							
	0-7 %	7-15%	15-20%	20-25%	25-30%	>30%	Info not recognized	Total
Non-Built up	0.02	0.03	-	-	-	-	-	0.05
Shrubs	1.49	0.80	0.09	0.03	0.00		0.00	2.42
(blank)	0.04	0.04	0.00	-	-	-	-	0.08
Total	**36.35**	**18.70**	**1.81**	**0.35**	**0.05**	**0.02**	**0.11**	**57.39**

4.2.5) Land Tenure

Out of 11 households interviewed, 9 households have land registered in their name, and 2 households are landless. Of the two landless households, one has leased in 5 acres of land at an annual rental rate of Nu. 60,000.00 (sixty thousand) and other household have to contribute labour to prune the apple trees, applying pesticides/fungicides and preparing basins around the fruit trees for his landowner. This form of arrangement is common in this watershed, some regular farm attendants (working for research centre) leased in land from resident farmers for free to cultivate vegetables. The land holdings of the 11 households are as follows:

***Table 12**: Land holdings of the respondent households*

Respondent h/h	**Land size (acres) used by farmers**	Remarks
Tandin Namgay	4.75	
Ham Raj Gurung	2	
Birkha Bhdr Gurung	2	Leased in
Jamyang Lhamo	0.55	
Santa Badhadur	5	Leased in
Kencho Lhamo	15	

Respondent h/h	Land size (acres) used by farmers	Remarks
Sangay Duba	4	
Phurpa	0.5	
Pasang Om	0.5	
Pema Tobgay	0.5	
Tshering Yangchen	5	
Total	**39.8**	
Average	**3.62**	

The average land holding per household is 3.62 acres, the highest being 15 acres and the lowest being 0.5 acres.

4.2.6) Farm Labour Arrangement

There is a system of hiring and exchange of labour during planting season within the community. Exchanged labourers in 2018 stand at average 17.82 per household, the total exchanged labourers per year in the community is 196. Hired labour for the whole community in a year is 459 days, the average is 41.73 days. The average regular family labourers engaged throughout the year is 67.36, the highest being 240 days and lowest being 5.

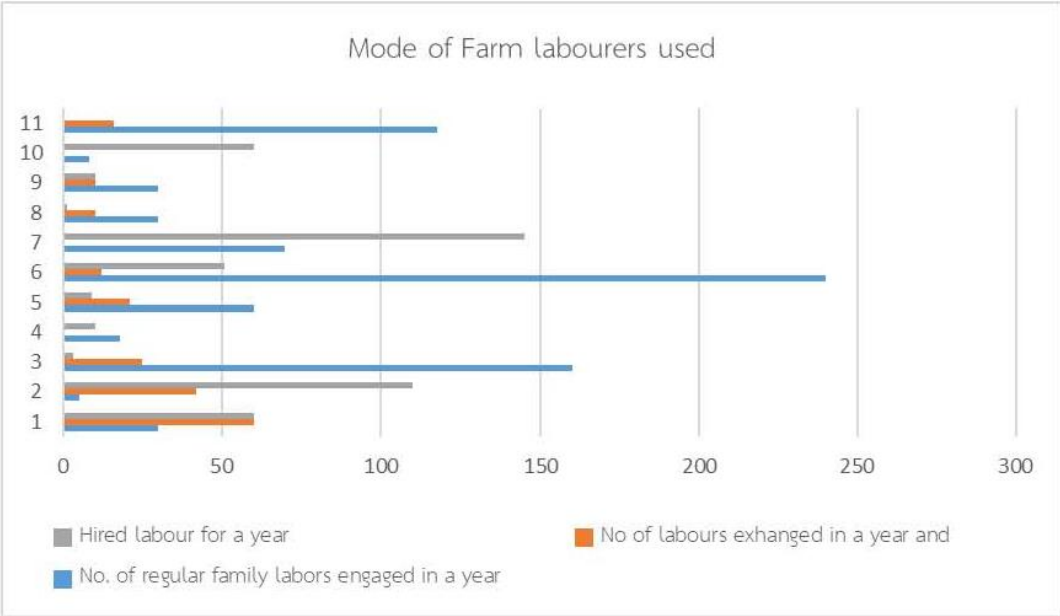


Figure 24: *Three different ways of using farm labourers*

The hired labourers are paid Nu[5]. 300-500/ day, the total payment made in 2018 was Nu. 155700, the average household labourer hiring charge was 14154.55. The highest was Nu. 43500 and lowest was Nu. 300

4.2.7) The Cropping or Farming Pattern

The annual farming cycle is characterized by four seasons: Spring, Summer Autumn, and Winter. The Onset of each season brings into life intricately vibrant farming patterns creating an array of sequential exquisiteness and existence. Spring season has a mild cold and dry weather, the majority of soil preparation, sowing of seeds start in this season. Summer is characterized by a moderate rainfall and warm temperature; maximum farm activities are carried out in this season. Autumn marks the end of summer, monsoon recedes and temperature drops, many vegetables are still harvested in this time. Winter is characterized by snowfall and cold dry weather, the temperature drops to freezing point in this area, during this season lands are left

[5] 1 US $ is equal to Nu. 69 (Bhutanese currency)

fallow for 3 months or more till early months of spring as dry cold winter do not favour growing vegetables.

***Table 13**: Cropping calendar of important cash crops*

<table>
<tr><th rowspan="2">Crop</th><th colspan="2">Winter</th><th colspan="3">Spring</th><th colspan="3">Summer</th><th colspan="3">Autumn</th><th>Winter</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th></tr>
<tr><td>Major Crops</td><td colspan="12"></td></tr>
<tr><td>Orchard (apple)</td><td colspan="12">Perennial crop</td></tr>
<tr><td>Potato</td><td colspan="9">one harvest</td><td colspan="2"></td><td></td></tr>
<tr><td>Cabbage</td><td colspan="5">1st harvest</td><td colspan="3">2nd harvest</td><td colspan="4">3rd harvest</td></tr>
<tr><td>Broccoli</td><td colspan="5">1st harvest</td><td colspan="3">2nd harvest</td><td colspan="4">3rd harvest</td></tr>
<tr><td>Cauliflower</td><td colspan="5">1st harvest</td><td colspan="3">2nd harvest</td><td colspan="4">3rd harvest</td></tr>
<tr><td>Minor Crops</td><td colspan="12"></td></tr>
<tr><td>White Radish</td><td colspan="5">1st harvest</td><td colspan="3">2nd harvest</td><td colspan="4">3rd harvest</td></tr>
<tr><td>Red Radish (local Variety)</td><td colspan="2"></td><td colspan="3"></td><td colspan="7">One harvest in a year</td></tr>
<tr><td>Turnip</td><td colspan="2"></td><td colspan="3"></td><td colspan="7">One harvest in a year</td></tr>
<tr><td>Carrot</td><td colspan="5">1st harvest</td><td colspan="6">2nd harvest</td><td></td></tr>
<tr><td>Green leaf</td><td colspan="12">Grow year round</td></tr>
<tr><td>Beetroot</td><td></td><td colspan="4">1st harvest</td><td colspan="5">2nd harvest</td><td></td><td></td></tr>
<tr><td>Tomato</td><td></td><td colspan="9">One harvest</td><td></td><td></td></tr>
<tr><td>Chilli</td><td colspan="2"></td><td colspan="2"></td><td colspan="6">One harvest</td><td></td><td></td></tr>
<tr><td>Maize</td><td></td><td colspan="9">One harvest</td><td></td><td></td></tr>
<tr><td>Beans</td><td></td><td colspan="5">1st harvest</td><td colspan="5">2nd harvest</td><td></td></tr>
</table>

4.2.8) Agriculture in Transition and Onset of Intensive Farming

Traditional agricultural farming has evolved to modern small scale commercial farming in this watershed in recent years. It started around two decades ago when the demand for vegetables and apple gradually increased. The primary push factor was market access; the government facilitated auctioning of potato/vegetables and export of apples to Bangladesh. The apple export to Bangladesh has increased over the years but it has declined in very recent years. The other important factor was the government's subsidy on inputs. In the 1990s synthetic fertilizers and insecticides were heavily subsidized by the government, later the subsidy was lifted to discourage the farmers from using it because of the health and environmental risk. However, farmers have access to chemical fertilizers and fungicides from the commission agents across the country. The inputs like improved varieties of vegetables, apple seedlings, and farm machinery are still subsidized by the government to the farmers. The proximity to the capital city played a key role in intensifying agriculture as demand for vegetables increased by many folds compared to 20 years earlier. Farmers try to keep up with the market demand by producing more vegetables through enhanced inputs. It is more likely that farming in this watershed would evolve further into fully mechanized and technologically enhanced agriculture as human labour seems to be on the decline.

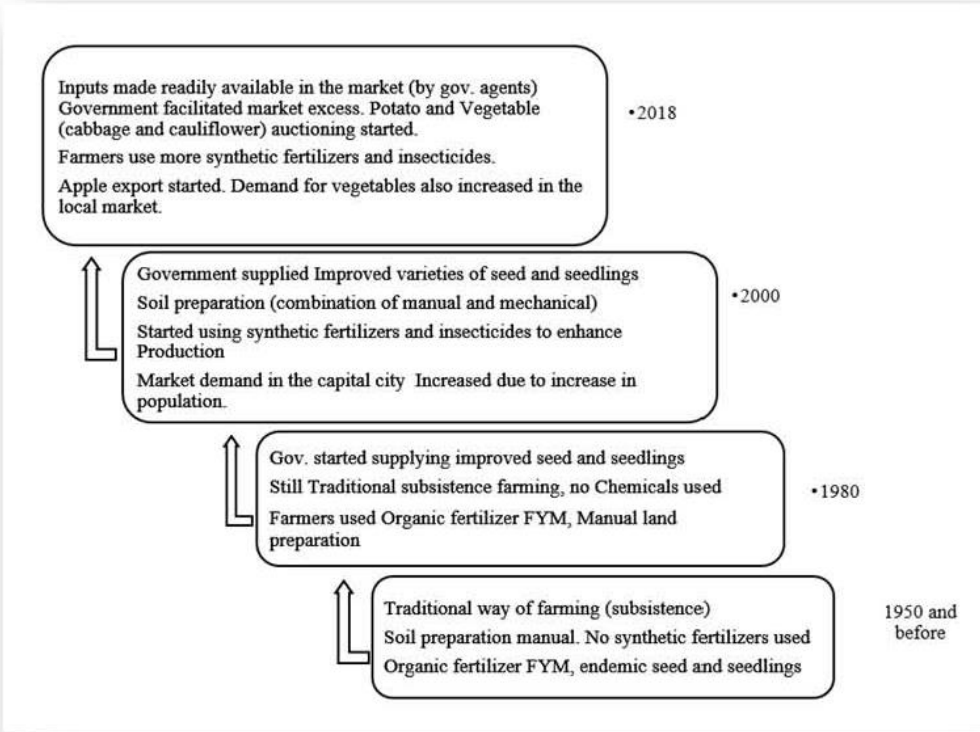


Figure 25: *Transitional phases of agriculture in Yusipang*

4.2.9) Use of Agrochemicals (inorganic fertilizers, pesticides, and herbicides)

The farming intensification is driven by an increase in demand of both local and international market. As such farmers increase products by increasing inputs, the most popular inputs are synthetic fertilizers and pesticides. The farming intensification equates to increase in the number of inputs and its frequency of use. The record of agro-chemicals used in the year 2018 was as follows:

Table 14: Inorganic minerals, insecticides, fungicides and herbicides used in the field

Record of inorganic minerals used in the year 2018	Chemical fertilizer			Insecticides		Fungicide			Herbicides
	Urea 46% N (Kg)	Suphala NPK 15:15:15 (kg)	SSP 16% P2o (kg)	Cypermethrin 10EC (litres)	Fevelerate 0.4 D (kg)	Mancozeb 75WP (kg)	Captan 50 WP (Kg)	Carbendazim 50 WP(kg)	Punch (kg)
Average/acre	5.18	0.2	8.94	0.43	1	0.4	0.15	0.3	3.02
Sub-Watershed	1400	1600	1550	17.2	39.8	16	6	12	20
Whole Watershed	20193.32	23074.8	22351.6	246.8	574	229.6	86.1	172.2	1733.5

Considering the fact that most of the families use only some portion of their land for vegetable cultivation and some landowners live in other parts of the country leaving their land fallow, the cumulative amount of agrochemical used in the farmland is high. The frequency of its use differs according to the nature of the chemical, the fungicides are normally applied three times a year. Single Super Phosphate (SSP) and Suphala are applied once a year during the soil preparation time, while Urea is applied as and when farmers feel it is required.

Farmers do apply organic fertilizers and fungicides in their field every year. The Farm Yard Manure (FYM), cow urine, Tree Spray oil, and Neem oil are all organic base ingredient safe for the health and environment.

Table 15: Organic manure and fungicides used by farmers in 2018

Organic minerals used in 2018	Farm Yard Manure Kg	Cow Urine litre	Tree Spray oil (TSO) litre	Neem oil (litre)
Average	56	25	83	2
Sub-watershed	2250	1000	3316	79
Whole Watershed	32,144	14350	47,833	1158

4.2.10) Soil/Land preparation

Land preparation is an important aspect of the agriculture activity, the majority of the land preparation is done in the spring season and continues till Autumn according to the crop requirement. The land preparation consists of mechanical and manual. The government has heavily subsidized the cost of power tillers to the farmers. There are few households who owns power tiller which makes land tilling and transportation convenient. The government has also supplied a pool power tiller in the community, that can be used by the farmers on hour payment system. The cost of hiring is cheaper than the private's ones, so farmers are availing the facilities. The families who have less landholding continue to use manpower for land preparation. It was observed that terracing is the popular technique to reduce the slope steepness, it makes cultivation and crop management easier. Mother beds and raised beds are made for sowing the vegetable seeds. The manual terracing doesn’t conform to the technical design. The basins around apple trees are not satisfactory and in some fields, the vegetable beds were made along the slope which is technically incorrect.

4.2.11) Water Sources and Irrigation

The main source of water for drinking and irrigation is from the main Hongtso river and its tributaries in this watershed. The combined discharge is 0.38m^3 of water per second (Watershed Management Division, 2011), which makes 32832m^3 of water every day (24 hours), and annual cumulative discharge of 11983680m^3. The total population in this watershed is roughly 2176 (518 households *4.2 persons) based on the average household size in the country which is 4.2 (National Statistics Bureau of Bhutan, 2017). This makes water availability per person at 5507.2 m^3 per year which is “abundance” according to UN-Falkenmark criteria for water availability.

Table 16: Falkenmark criteria for water availability (source: Wang Chhu Management Plan)

Classification	Water availability m3/capita/year
Abundance	>1700
Stressed	<1700
Scarcity	<1000
Absolute Scarcity	<500

For irrigation farmers use polythene pipes and traditional water channels, the drinking water is brought from upstream where water is relatively pure and free of contamination. Although water consumption rate was not measured, use for agriculture is relatively less as compared to paddy cultivation in low land. All the households use the same source for drinking and irrigation The same stream is used by government agencies in the research field, dairy farm and piggery farm owned by the Ministry of Forest and Park Service

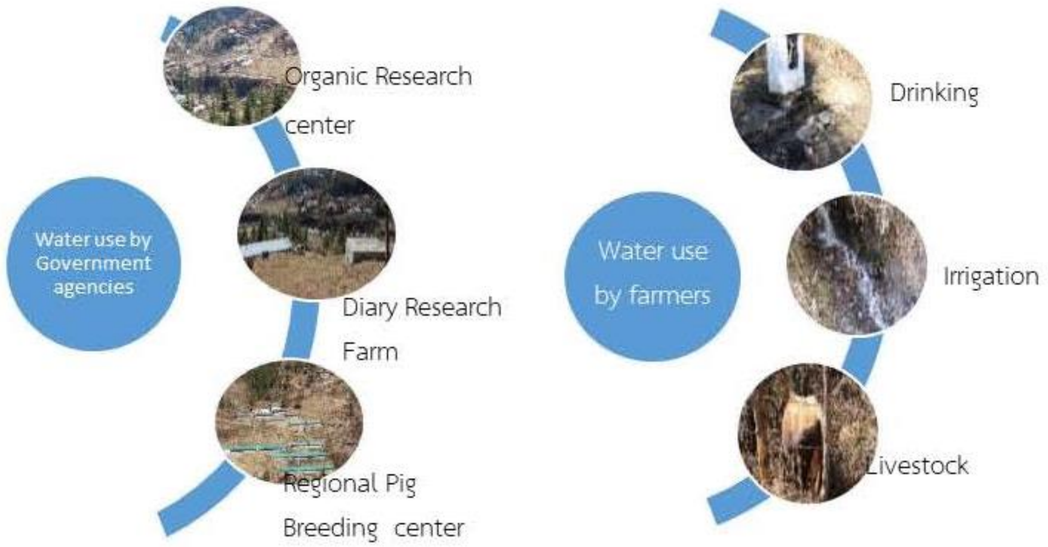


Figure 26: *Water use*

4.2.12) Economic Return from Agriculture

Apple and vegetables are the primary sources of income for the people living inside this watershed. The agricultural landscape is dominated by apple trees with an occasional assortment of peach, pear, and walnut. Temperate vegetables like potato and green vegetables are an important commercial crop. Although, the annual farming cycle is characterized by four different seasons with distinct cropping pattern yet farmers have adopted some modern technologies like installation of the plastic greenhouse to produce offseason vegetables. The production varies from orchard to orchard according to various factors. The best quality apples are purchased by the exporter and inferior grades are sold in the local market at a cheaper rate. The other fruits such as peach, pear, and cherry are grown at a smaller scale. Livestock rearing is not very common, but some households keep one or two cows for dairy products. Although farmers don't grow rice due to unfavourable climate condition yet their staple food is rice, both Indian rice and local rice consist of their supply for the year.

4.2.12.1) Annual Investment in Agriculture and Living cost

***Table 17**: Annual Expenditure of the households interviewed*

Annual expenditure for the year 2018								
Sl. No	Respondent h/h	crop production	Labour hiring charge	Input cost	firewood cost	Exp. On livestock	Food and other living cost	**Total expense (nu)**
1	Tandin Namgay	10500	18000	30180	0	0	217000	**275680**
2	Ham Raj Gurung	6000	33000	43530	90	20000	130000	**232620**
3	Birkha Bdhr Gurung	35000	900	3749	6500	0	130000	**176149**
4	Jamyang Lhamo	30000	3000	6044	90	0	200000	**239134**
5	Santa Badhasur	15000	2700	25540	90	0	38000	**81330**
6	Kencho Lhamo	22500	15300	13690	300	35000	170000	**256790**
7	Sangay Duba	35000	20000	0	6500	0	15500	**77000**

Annual expenditure for the year 2018								
Sl. No	Respondent h/h	crop production	Labour hiring charge	Input cost	firewood cost	Exp. On livestock	Food and other living cost	**Total expense (nu)**
8	Phurpa	2000	300	3059	0	0	35000	**40359**
9	Pasang Om	47000	3000	8187	90	10000	30000	**98277**
10	Pema Tobgay	3500	30000	4230	90	0	111000	**148820**
11	Tshering Yangchen	35000	0	9523	90	0	277000	**321613**
	Total	**241500**	**126200**	**147732**	**13840**	**65000**	**1353500**	**1947772**
	Average	**21954**	**11472**	**13430**	**1258**	**5909**	**123045**	**177070**

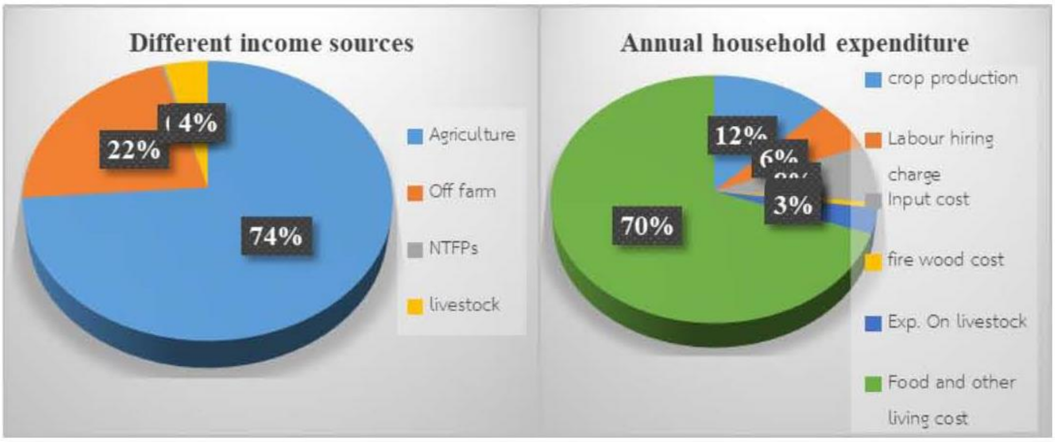


Figure 27: *Different household incomes sources and annual expenditure*

The food and other living costs (education, clothes, annual rituals, etc.) require the highest expenditure (70%), followed by agriculture investment (26% crop production cost, inputs, labour hiring combined).

4.2.12.2) Annual income

Each family is making good monetary income from agriculture and off-farm activities combined. The average family income for the year 2018 was Nu 407463.64 and the average household saving was Nu. 230393.45.

Table 18: *Showing income from different sources*

Annual income for the year 2018 in Nu						
Sl. No	Respondent h/h	Agriculture	Off farm	NTFPs	livestock	**Total**
1	Tandin Namgay	286000	60000	0	0	**346000**
2	Ham Raj Gurung	400000	7500	8000	150000	**565500**
3	Birkha Bdh Gurung	210000	0	0	0	**210000**
4	Jamyang Lhamo	200000	120000	0	0	**320000**
5	Santa Badhasur	348000	80000	0	0	**428000**
6	Kencho Lhamo	1130000	220000	0	30000	**1380000**
7	Sangay Duba	81100	100000	0	0	**181100**
8	Phurpa	50000	50000	0	0	**100000**
9	Pasang Om	60000	40000	3500	7000	**110500**
10	Pema Tobgay	68000	100000	0	0	**168000**
11	Tshering Yangchen	476000	194000	3000	0	**673000**
	Total	**3309100**	**971500**	**14500**	**187000**	**4482100**
	Average	**300827**	**88318**	**1318**	**17000**	**407463**

As represented in the chart the agriculture (74%) remains the primary source of income of the farmers, however, off-farm activities cannot be undermined as it represents 22% of the total household income.

4.2.12.3) Agriculture production

***Table 19**: Agriculture production per acre in terms of monetary value*

Respondent h/h	Total agriculture Production in Nu.	Land size (acres)	Production in monetary/acre Nu.	Remarks
Tandin Namgay	286000	4.75	60210.53	Landowner
Ham Raj Gurung	400000	2	200000.00	Landowner
Birkha Bdh Gurung	210000	2	105000.00	Leased in
Jamyang Lhamo	200000	0.55	363636.36	Landowner
Santa Bdh Gurung	348000	5	69600.00	Leased in
Kencho Lhamo	1130000	15	75333.33	Landowner
Sangay Duba	81100	4	20275.00	Landowner
Phurpa	50000	0.5	100000.00	Landowner
Pasang Om	60000	0.5	120000.00	Landowner
Pema Tobgay	68000	0.5	136000.00	Landowner
Tshering Yangchen	476000	5	95200.00	Landowner
Total	**3309100**	**39.8**	83143.22	
Average	**300827**	**3.62**	83101.38	

4.2.12.4) Income Security from Agriculture Production Alone

Although a large chunk of income was derived from cash crops alone, it was found that agriculture alone doesn't provide a stable income for 3 households as annual saving was ≤ Nu. 10,000.00. Three households have gone into loss by a big margin by investing into agriculture. The highest amount of loss was Nu. 80,820.00, followed by Nu. 39314.00 and 28,277.00, this clearly indicates that cash crop alone doesn't ensure income security for some households. So, each household has other source(s) of income to augment their living cost. However, for 4 households the cash crops made a huge profit over the last year.

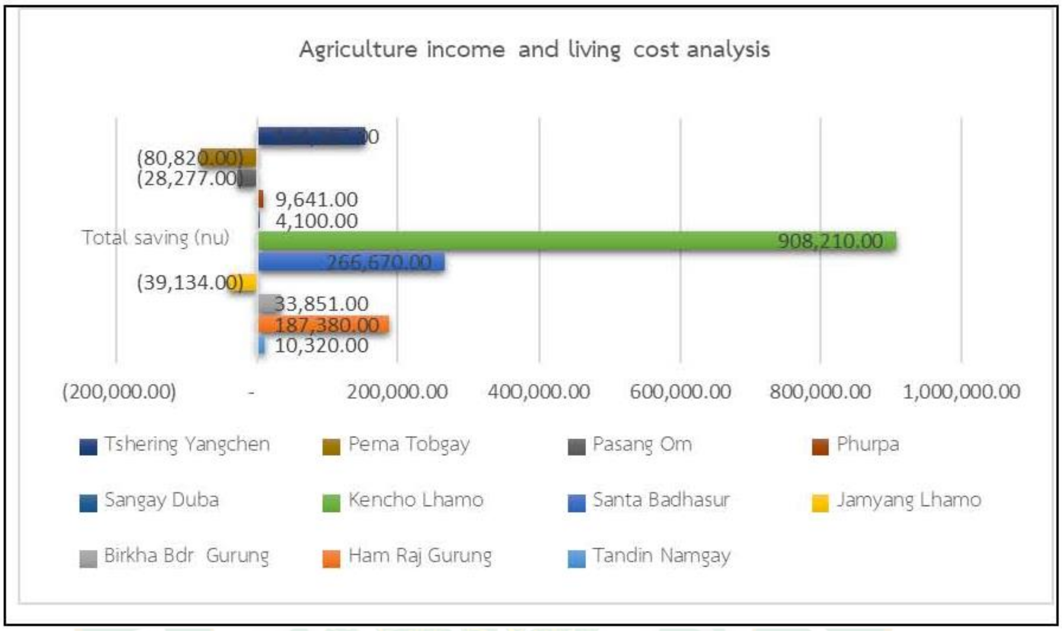


Figure 28: *Income from cash crop production*

Table 20: *Correlation between annual income and land size*

		Annual income for Agriculture	Land size (acres)
Annual income from Agriculture	Pearson Correlation	1	.924**
	Sig. (2-tailed)	-	.000
	N	11	11
Land size (acres)	Pearson Correlation	.924**	1
	Sig. (2-tailed)	.000	-
	N	11	11
**. Correlation is significant at the 0.01 level (2-tailed).			

The correlation is significant at a 99% confidence level between Annual income from agriculture and Land size. The household with landholding less than one acre did not make a good income, however, two families who are landless but has leased in more than 2 acres of land made a good profit margin. This clearly indicates that land size is a big factor in income generation.

4.2.13) Food security

It's important to look at the food security arrangements as it is the most pressing concern of the government when climate change becomes reality and the majority of Bhutanese heavily depend on agriculture which is climate sensitive. In this watershed, cash crop is the main income for the farmers, with the income they buy rice from the nearby market, some travel to the border town of India to buy the stock sufficient for one year. Other essential items include cooking oil, salt, milk powder, dry chili, clothes, etc. are purchased from local markets. Some families work as the tenant of rich landlords, but food shortage is not an issue with them, they make enough money in a year to support their family. Some households have pickup trucks used for transporting their products to the market and also generate income by hiring out to other people. The agriculture and off-farm works combined have made enough income for the family, there is hardly any record of occasional food shortage for any family within the study area.

4.2.14) Onsite soil erosion

During the field reconnaissance survey, evidence of soil erosion was not observed in the forest and in the farmland. Farmers did not use enough soil conservation measures as it didn't affect them significantly. The onsite erosion or amount of annual soil loss was estimated using USLE model, it was calculated under different slope classes considering various factors such as rainfall, topography, soil type, crop or vegetation covers, and land management practices.

Table 21: The soil loss in tons per ha from different slope class in agriculture land

Slope class	LS factor	R Factor	C Factor	K Factor	P Factor	A(ton/ha/year)	A(ton/ac/year)
0-4%	0.3	419.17	0.3	0.19	0.3	2.15	0.87
4-8%	1.35	419.17	0.3	0.19	0.1	3.23	1.3
8-12%	1.95	419.17	0.3	0.21	0.12	6.18	2.5
12-16%	1.95	419.17	0.3	0.21	0.16	8.24	3.34

Table 22: Correlation between slope class and the amount of soil loss

Correlations			
		Slope class in percentage	Soil loss A(tons/ha/year)
Slope class in percentage	Pearson Correlation	1	.987*
	Sig. (2-tailed)	-	.013
	N	4	4
Soil loss A(tons/ha/year)	Pearson Correlation	.987*	1
	Sig. (2-tailed)	.013	-
	N	4	4
*. Correlation is significant at the 0.05 level (2-tailed).			

The Pearson Correlation indicated a very strong positive relationship between slope steepness and soil loss in tons per hectare per year. The steeper the slope higher the soil loss is; the soil loss in slope between 0-4% is 2.15 tons/ha/year while it is 8.24 tons/ha/year between slope 12-16%.

Table 23: Different Potential soil loss rates

Soil Erosion Class	**Potential Soil Loss tones/hectare/year (tons/acre/year)**
Very low (tolerable)	<6.7 (3)
Low	6.7 (3)–11.2 (5)
Moderate	11.2 (5)–22.4 (10)
High	22.4 (10)–33.6 (15)
Severe	>33.6 (15)

(Robert P. Stone, 2012)

By this standard, the soil loss through rill, sheet erosion or runoff is at a very low (tolerable) level for slope categories 0-4%, 4-8%, and 8-12%. For slope category 12-16% the soil loss is low. The acceptable level of soil loss in the agriculture field would be due to the presence of high organic matter content and good soil infiltration rate.

4.2.15) Soil Bulk Density

Total of 90 core samples was taken from 30 samples (27 agriculture land and 3 forest land). The samples were grouped under different slope class and average soil bulk density was taken to get an idea on general soil type under different slope classes. The result is as follows:

Table 24: Soil bulk density

Slope class	Soil Bulk Density g/cm^3
0-4%	1.26
4-8%	1.23
8-12%	1.15

Slope class	Soil Bulk Density g/cm^3
12-16%	1.15
Forest Soil	1.41

The accepted general relationship of soil bulk density to root growth based on soil texture is as follows:

***Table 25**: Standard soil bulk density for different soil texture*

Soil Texture	Ideal bulk density for plant growth (g/cm3)	The bulk density that restricts root growth (g/cm3)
Sandy	<1.60	>1.80
Silty	<1.40	>1.65
Clayey	<1.10	>1.47

(Arshad M.A., 2011)

By this standard, the Bulk Density of the sample is low indicating high soil porosity, good aeration, and soil aggregates. Which means organic content of the soil is high ideal for growing agriculture crops and other vegetation.

***Table 26**: Correlation between soil texture and OM percentage*

		%OM	Soil texture (Clay)	Soil texture (Silt)	Soil texture (Sand)
OM%	Pearson Corr.	1	-.787**	-.787**	.829**
	Sig. (2-tailed)	-	.004	.004	.002
	N	11	11	11	11
Soil texture (Clay)	Pearson Corr.	-.787**	1	1.000**	-.911**
	Sig. (2-tailed)	.004	-	.000	.000
	N	11	11	11	11

Soil texture (Silt)	Pearson Corr.	-.787**	1.000**	1	-.911**
	Sig. (2-tailed)	.004	.000		.000
	N	11	11	11	11
Soil texture (Sand)	Pearson Corr.	.829**	-.911**	-.911**	1
	Sig. (2-tailed)	.002	.000	.000	-
	N	11	11	11	11
	**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed)				

The correlation indicated that there is a strong positive correlation between the presence of OM% and soil texture 'sand'. Whereas there is a strong negative correlation between the soil OM% and Soil texture 'silt & clay'. The soil organic matter improves the soil aggregation, aeration water infiltration and resistance to soil erosion.

4.2.16) Soil infiltration rate

The soil infiltration data was collected from all the sample plots using double ring infiltrometer, the result showed that the infiltration rate in the agriculture field and forest soil was exceptionally good compared to basic infiltration rate. The average infiltration rate in the agriculture soil was 70.62 mm/hr and in the forest soil was 62.5 mm/hr.

Table 27: Standard infiltration rate

Soil type	Infiltration rate
Clay	1 to 5 mm/hr.
Sandy Loam	12 to 25 mm/hr.
Silty Loam	4-7 mm/hr.
Sandy soils	25-200 mm/hr.

(Ryczkowski)

The lowest infiltration rate was recorded in plot number 29 (forest soil), which is in a dry Blue pine forest, it was recorded 43 mm/hr, nevertheless, it conforms to high infiltration quotient comparing with the standard. This could very well be linked to the presence of high Organic matter content which enhances the soil porosity thus positively impacting water infiltration.

4.2.17) Impacts on soil quality by intensive farming

The soil samples of the farmland were analysed in the laboratory to determine nutrient content and compare it with forest soil. Excessive use of synthetic fertilizer damages the soil physical, chemical, and biological properties, causing soil nutrient imbalance. The synthetic/inorganic fertilizers contain components like Nitrogen, Potassium, Sulphur, Calcium, Magnesium and so on, these chemicals and minerals, although help in boosting the growth of plants, they also have their drastic side effects in the long run (Enviro Editor, 2018). The inorganic minerals in the agriculture field have a deleterious effect on the soil and surrounding environment. The result of 30 soil samples collected from a predetermined sampling area, representing agriculture land and surrounding forest area are as follows;

Table 28: Lab result of soil chemical and physical analysis

Samples	Avg. soil pH	Avg. %OM	Avg. P (mg/kg)	Avg. K (mg/kg)	Avg. N %	Soil Texture
Agriculture-Soil	5.55	10.47	77.28	340.66	0.19	Sandy clay loam
Forest -Soil	5.54	10.31	14.45	186.33	0.29	
Ideal	5.5-7[6]	2-6[7]	30-55[8]	100-250[9]	1.75 -	Loamy

[6] Department of Primary Industries and Regional Development, Government of Western Australia

[7] Sustainable Agriculture Research and Education National Institute of Food and Agriculture, U.S. Department of Agriculture

[8], [5] Government of Alberta, Agriculture and Forestry

[9] Moderate soil texture, meat and Livestock Australia (mla)

condition for agriculture crops	3[10]	soil

The average pH for both the forest and agriculture soil is moderately acidic. The acidity of forest soil could have been caused by many factors, this region is known to have Gneiss rocks which tend to increase soil acidity, the Blue pine forest thrives well in Gneiss minerals. In nature, the ideal soil pH range for Blue pine forest is between 5.5-6. The natural mineralization process of the pine needles is also known to have caused soil acidity. Conifers generally lowered soil pH and broadleaves raised it (Thomson, 2014).

Despite the high percentage of Organic Matter (OM), the acidity in the agriculture field is similar to forest soil, this could be due to the use of inorganic minerals. NPK fertilizer treatment significantly decreased soil pH, whereas organic manure treatments significantly increase soil pH (Si Ho Han, 2016). The survey result showed that farmers are using lots of inorganic fertilizers, insecticides, fungicides, and herbicides in their field. Laboratory analysis of soil samples showed a similar trend, that can be linked to the use of agrochemicals. Phosphorus (P) and Potassium (K) level are very high while the N level has been almost depleted. The P content of the agriculture soil is more than 5 times higher than the forest soil, similarly K level of agriculture soil is almost 2 times higher than the forest soil. However, the Nitrogen (N) level in both the forest and agriculture soils are very low. None of the test results from agriculture land is within the permissible limit as compared to ideal soil condition for agriculture crop.

The excessive residue of P and K in the soil could have been due to the application of inorganic minerals like Suphala (NPK 15:15:15) and SSP (16% P2o). The depleted level of N in the agriculture soil could be due to the continuous cultivation of vegetables as N is the most vital mineral required by the plants. Urea is generally used as a top dressing in the crops, as it can be easily dissolved and release the nutrient instantly.

Table 29: NPK status in different slope class

Slope class	Average values			
	OM (%)	P (mg/kg)	K (mg/kg)	N (%)
0-4%	11.04	90.91	366	0.19
4-8%	11.3	63.69	361	0.19
8-12%	9.3	79.41	331	0.2
12-16%	7.45	50.27	149	0.21

In the different slope classes, it was found that P, K content and OM**%** of the soil is inversely proportional to the slope gradient**.** As the slope increases the level of P, K and OM drop**.** However, N**%** was found to be increasing as the slope steepness increases**.**

Table 30: *Correlation between different slope classes and soil nutrient level*

Correlations						
		Different Slope	Avg. % of Soil OM	Avg. P level in the soil	Avg. N level in the soil	Avg. K level in the soil
Different Slope classes	Pearson Corr.	1	-.924	-.770	.944	-.854
	Sig. (2-tailed)		.076	.230	.056	.146
	N	4	4	4	4	4
Avg. % of Soil OM	Pearson Corr.	-.924	1	.611	-.998**	.930
	Sig. (2-tailed)	.076		.389	.002	.070
	N	4	4	4	4	4
Avg. P level	Pearson Corr.	-.770	.611	1	-.651	.774

Correlations						
		Different Slope	Avg. % of Soil OM	Avg. P level in the soil	Avg. N level in the soil	Avg. K level in the soil
in the soil	Sig. (2-tailed)	.230	.389	-	.349	.226
	N	4	4	4	4	4
Avg. N level in the soil	Pearson Corr.	.944	-.998**	-.651	1	-.934
	Sig. (2-tailed)	.056	.002	.349	-	.066
	N	4	4	4	4	4
Avg. K level in the soil	Pearson Corr.	-.854	.930	.774	-.934	1
	Sig. (2-tailed)	.146	.070	.226	.066	-
	N	4	4	4	4	4
**. Correlation is significant at the 0.01 level (2-tailed).						

As indicated, there is a strong negative correlation between soil OM %, P, and K with slope steepness; these nutrients level drops as the slope increase. Whereas, N has a positive correlation with slope steepness, the level of Nitrogen in the soil increases as the slope steepness increase.

***Table 31**: Comparison of Cypermethrin used by farmers with standard dosage*

Crop	The normal dosage of Cypermethrin	Applied by farmers
Apple, pear and other fruit trees	10ml/100 liters of water (HV 250 to 350 ml/ha)* two times	1062.1 ml/ha (average 0.43 liters/acre or 1.062 liters/ha)
Beans and other vegetables	150 ml/ha *two times	Famers are using almost 2 times more in apple and >3 times in vegetables

Among the number of insecticides Cypermethrin is widely used by the farmers to control a variety of pests in the apple and vegetable, the recommended dosage is hardly being followed. The survey result showed that farmers are using 2 times more in apple and 3 times more in vegetables than the recommended dosage.

No Significant correlation (either positive or negative) has been indicated between the use of agrochemicals and soil pH, NPK or OM**%.** This is probably because of the one-time sample collection, a minimum of four sample collection at different seasons before and after the application of the agrochemicals in the field might give an accurate result. However, it is clear that impact of agrochemicals on NPK in the agriculture field is evident from the presence of higher level of P, K in the agriculture field than nearby forest soil which was used as a reference.

***Table 32**: Correlation between the use of agrochemicals and soil nutrients*

		Chemical fertilizer &pesticides	PH	%OM	P	K	Total N (%)
Chemical fertilizer &pesticides	Pearson Corr.	1	.373	.234	-.146	.209	.199
	Sig. (2-tailed)		.259	.488	.669	.538	.557
	N	11	11	11	11	11	11
PH	Pearson Corr.	.373	1	-.347	-.421	.492	.054
	Sig. (2-tailed)	.259		.296	.197	.125	.875
	N	11	11	11	11	11	11
%OM	Pearson Corr.	.234	-.347	1	.189	-.086	.288
	Sig. (2-	.488	.296		.578	.802	.390

	tailed)						
	N	11	11	11	11	11	11
P	Pearson Corr.	-.146	-.421	.189	1	.346	-.404
	Sig. (2-tailed)	.669	.197	.578		.298	.217
	N	11	11	11	11	11	11
K	Pearson Corr.	.209	.492	-.086	.346	1	.068
	Sig. (2-tailed)	.538	.125	.802	.298		.842
	N	11	11	11	11	11	11
Total N (%)	Pearson Corr.	.199	.054	.288	-.404	.068	1
	Sig. (2-tailed)	.557	.875	.390	.217	.842	
	N	11	11	11	11	11	11
**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).							

4.2.18) Impacts on Downstream Water Quality

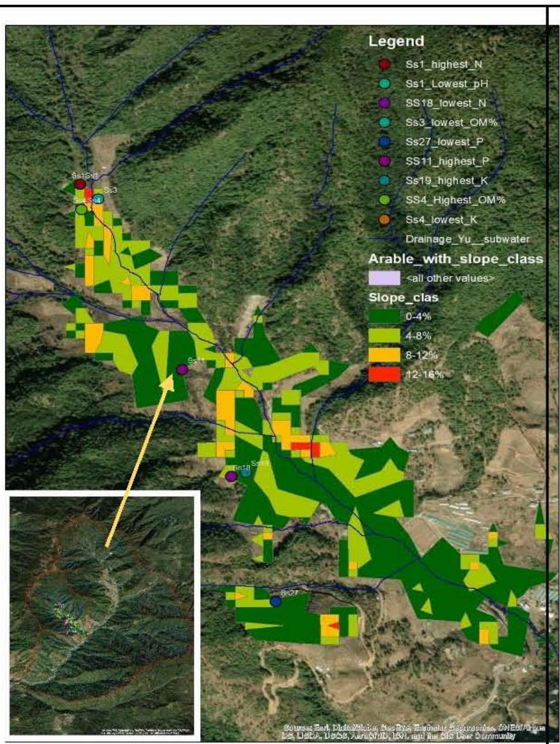
Agricultural intensification impacts to water quality through the release of nutrients and other chemicals into the water environment. To maintain the surface water quality of the natural stream in this watershed is important as people use it in different ways. It is the main source of drinking and irrigation for all households. There is evidence of very high soil nutrient content in the upstream farmland. P, K, and OM are the three main nutrients found relatively in high proportion than other nutrients in many of the sample points, and the stream water quality below the farmland was found to be more acidic than other sample points (more detail discussion in objective 2). This clearly indicates that the excess soil nutrients were eroded into the water bodies during the monsoon and raised water acidity due to chemical contamination.

4.3) Objective Two

Investigate significant point sources of water contamination which are affecting the water quality

4.3.1) Upstream Farming and Stream Water Contamination

The upstream farming has an impact on water quality, the water pH in sample number two, below the farmland, was found to be low. The stream water in this particular site is more acidic than any of the points recorded, the water sample above the settlement and at the outlet was found slightly alkaline. A significantly high level of P, K, and OM% was found in upstream farmland, in addition, the soil erosion process on the steep slopes (>16%) in the upstream was also high compared to other slope categories, these could have contributed to the increasing acidity level in the water. The casual use of inorganic minerals and soil erosion process in the upstream are the cause of water contamination, although no statistical relation could be established. The presence of Organophosphate group and Carbonate group residues in the water-sediment was tested at Institute of Product Quality and Standardization, Maejo University using GT Pesticide Test Kit however, no residues have been detected. The sediment samples were collected in the winter season when agriculture activities were minimum and the weather was very dry, this circumstance could have largely contributed to non-detection of the pesticide residues as there was no carrying agent like rain to erode the excess pesticides into the water bodies. It could also be attributed to the test method used, a Test Kit was used to detect two groups of pesticides, this may not have given a reliable result. The more reliable result can be generated by collecting samples in all the four seasons of the year and carry out complete Lab analysis for pesticides and inorganic mineral residues.



Parameter	Level	Sample point
Soil pH lowest	4.48	Ss1
Soil pH highest	6.54	Ss24
%OM lowest	2.69	Ss3
%OM Highest	14.68	Ss4
P lowest	25.69	Ss27
P highest	136.09	Ss11
K lowest	53	Ss4
K highest	861	Ss19
N lowest	0.08	Ss18
N highest	0.40	Ss1

Figure 29: *Samples with a significant level of nutrients*

4.3.2) Biological Source of Stream Water Contamination

It is evident from the physical characteristics of water in the sub watershed that the biological contamination is significant in the downstream. There are two locations from where the sources of contamination were detected; (i) Farm Labour Camps and (ii) Regional Pig Breeding Centre. The makeshift labour camps and pit toilets were built right next to the stream, no septic tank was constructed to store the human waste and dispose of safely. The daily activities of the people in the camps have knowingly or unknowingly contaminated the stream water. Likewise, the animal waste from the piggery farm was deliberately drained into the stream without safety measure, this has contaminated the water quality to an extreme point. The physical colour of the water has visibly changed from a crystal clear in the upstream to a murky whitish layer in the downstream. Consistent foaming with the sharp smell was detected at the outlet. The stream water at this point is unfit for human consumption as it does not comply with the Bhutan Drinking Water Quality Standard (BDWQS), in terms of taste, colour and the possible presence of Escherichia coli. The laboratory analysis of water samples would confirm the presence of E. coli.

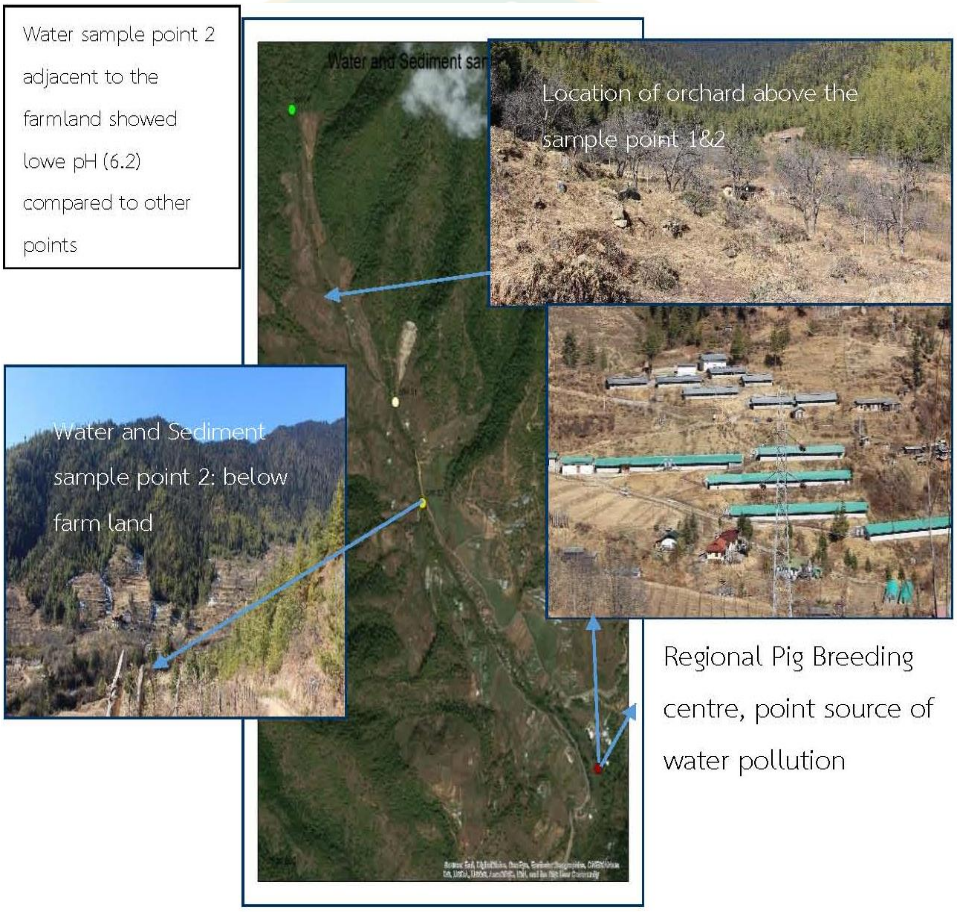


Figure 30: *The point sources of water contamination; agri-farming in the upstream and the sewage from piggery farm*

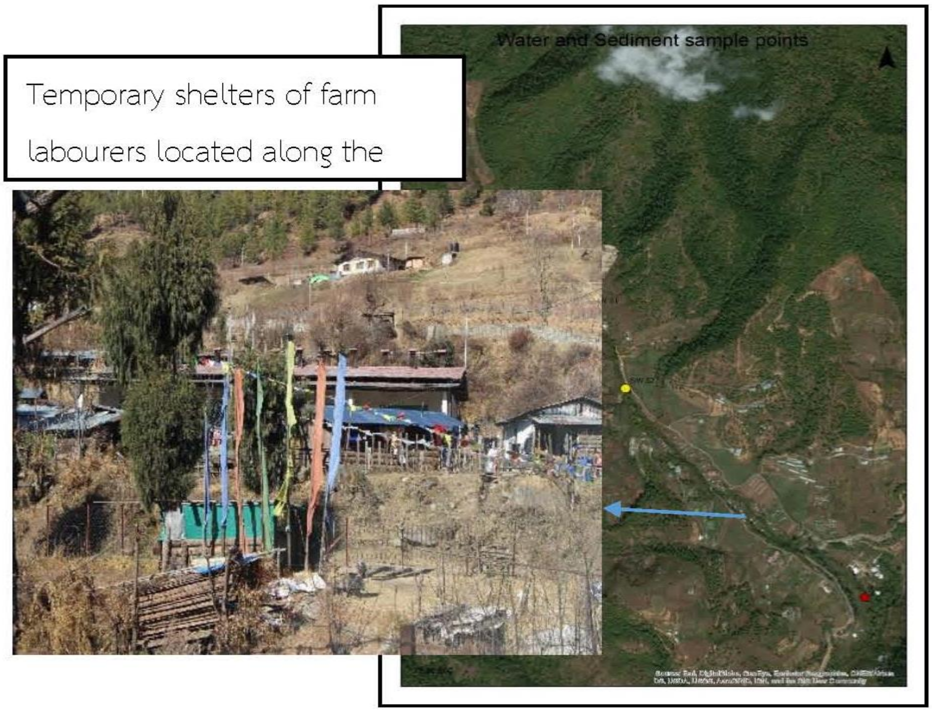


Figure 31: *The location of Farm labour camps along the stream*

With this evidence, we can draw an inference that upstream farming activities do influence the downstream water quality. The animal waste from the piggery and waste from labour camps have also significantly affected the quality of the surface water in the sub watershed.

4.3.3) Matrix Representation of Water Contamination Sources

The significant point source of surface water contamination in this sub watershed was determined using matrix. An arbitrary score (***, **, *, -) was given to every possible effect on water quality induced by each activity as given below.

Table 33: Matrix showing the point sources of surface water contamination

	Soil erosion	Water quality for drinking	Water quality for ecological services	Sediment contamination by Agrochemical residues	Sediment contamination by biological agents	Total rating
Upstream contamination source (agriculture land)						
Slope 12-16%	***	**	**	**	*	10
Slope 8-12%	**	**	**	**	*	9
Slope 4-8%	*	***	*	***	*	9
Slope 0-4%	*	***	*	***	*	9
Downstream contamination source						
Labour camp	-	***	**	**	***	10
Diary Research Farm	**	*	*	-	*	5
Regional Pig breeding centre	*	***	***	-	***	10
*** high neg impact ** Medium neg impact * low neg impact – no impacts						

The result shows that the upstream farming has a high negative impact on the water quality due to soil erosion process, chemical and biological contamination, the maximum contamination source was detected in the slope category 12-16% followed by the other slope categories with the same level of score. In the downstream, the main water contamination source was from the piggery farm located near the water outlet and from the labour camp located adjacent to the stream.

4.3.4) Water and Sediment Quality Testing

To substantiate the matrix result, eight parameters of physical and chemical aspects of water was observed in the field using portable water testing kit. It was investigated at two levels; water and sediment. The sediment analysis was done with a premise that agrochemicals used in the field would have been washed into the stream and contaminated the stream water. The water sediment test result indicated negative (no pesticides were detected). The result of water samples are as follows:

Table 34: *Readings of water quality parameters at different points*

Sample ID	Parameters									
	1	2	3	4	5	6	7	8		
	Temp. (°C)	pH	TDS (mg/L)	DO (mg/L)	OS (%)	EC (µs/cm)	Salinity (%)	Transparency	Elevation (m)	Time	Remarks
Water S1	5.6	7.27	15.79	8.42	94.3	33.8	0.01	4	2862	2:30PM	
Water S2	5.5	6.2	21.36	8.55	95.4	45.6	0.02	3	2700	3:00PM	
Water S3	5.1	7.44	43.2	8.46	92.4	91.6	0.04	2	2600	3:45 PM	Below the piggery

Sample ID	Parameters										
	1	2	3	4	5	6	7	8			
	Temp. (°C)	pH	TDS (mg/L)	DO (mg/L)	OS (%)	EC (µs/cm)	Salinity (%)	Transparency	Elevation (m)	Time	Remarks
Water S4	5.3	7.1	11.61	8.43	94.5	27.3	0.01	4	3055	9.30 am	above settlement
TDS: Total Dissolved solutes, DO: Dissolved Oxygen, OS: Oxygen Saturation, EC: Electroconductivity											

Comparing these indicators with BDWQS for Urban and Rural, the pH of sample 2 is lower than the accepted level, which indicates that the water at this point is unsafe for human consumption due to acidity. Water in sample 3 has a pungent smell and discoloration which is caused by animal waste, the presence of E. coli is very likely. The electroconductivity of all the sample points is within the permissible limit, however, sample number 3 has shown the highest EC level compared to other sample points, indicating more dissolved solutes.

Table 35: *Comparison of water quality with BDWQS indicators*

Sample ID	Water S1	Water S2	Water S3	Water S4	BDWQS	Remarks
pH	7.27	6.2	7.44	7.1	6.5-8.5	Point 2 is acidic
Odor	-	-	Pungent	-	Non-Objectionable	
Taste	Tasteless	tasteless	Unidentified taste	tasteless	-do-	safe
EC	33.8	45.6	91.6	27.3	1000	

Sample ID	Water S1	Water S2	Water S3	Water S4	BDWQS	Remarks
(µs/cm)						
Pesticides	Negative	Negative	Negative	Negative		

Comparing the result with International Water Quality Guidelines for the freshwater ecosystem (IWQGES) proposed by United Nations Environment Program (UNEP) in 2016, the water meets the standard except for the pH in sample number 2. However, there are numerous other indicators like Physical, Chemical, biological and hydrological functions which are beyond the scope of this research.

Table 36: *Comparison of Water Quality with IWQGES*

Indicators	Water S1	Water S2	Water S3	Water S4	IWQGES (category 1-high integrity)
Dissolved Oxygen Saturation	94.3	95.4	92.4	94.5	80-120
Dissolved Oxygen Concentration	8.42	8.55	8.46	8.43	7.3-10.9
pH	7.27	6.2	7.44	7.1	6.5-9
Temperature	5.6	5.5	5.1	5.3	No deviation from background value

The water near the settlement and agriculture field have indicated a drop in pH level, which is acidic as compared to other sampling points. By the standard of BDWQS and IWQGES, the water near the agriculture field and at the outlet is unsafe for drinking as well as for freshwater ecosystem services due to acidity and biological contamination respectively.

4.3.5) The Present Trend and Possible Future Implication

The present trend indicates a progressive decline in water quality from the upstream towards the downstream (outlet). This decline in water quality has a huge effect on human health due to the high risk of waterborne diseases, acidity, and alkalinity as there is no community drinking water treatment plant. The ensuing social implications would include freshwater crisis, a decline of income from agriculture and increase cost of health check-ups and treatment. It was forecasted that Yusipang and Hongtso villages fall into absolute water scarcity by 2030, the place is rated as the 2nd highest potential for water stress. Given the circumstances, the decline of surface water quality due to contamination is a bad indication as it will fuel the already anticipated problem.

The ecological implication, in the long run, would be lost of species diversity, a decline of a freshwater ecosystem, and impairment of ecological functions due to change in physical, chemical and biological properties of the water. There will be environmental effects like unmanaged effluent problems, water ecosystem damage, the decline in water quality and quantity for both consumption and natural function. The institutional and policy objectives of achieving future water security, safe drinking water for all the citizen, adequate water for irrigation would be seriously challenged.

4.4) Objective Three

Design a guideline to improve upstream farming practices and protect downstream water quality

4.4.1) Existing Soil and Land Conservation Practice

The existing land management practice is mostly conventional; no obvious soil conservation works are visible except for the research station where lands are mechanically terraced concurring to the landforms. Few activities adopted by farmers for soil conservation are manual terracing, planting legume plants, applying lime in the soil, making ridges and drains in the marshy areas to drain out water. The popular ones are multi-cropping, applying Farm Yard Manure (FYM), fallowing the land for 3 months in the winter and crop rotation.

Although, terracing is the popular soil and land conservation technique in the sloping lands, it was mostly done manually and doesn't comply with technical specification. The basins around the fruit trees are not adequate as per the recommended requirement. The contour bund along the terrace edges and use of live plants for soil stabilization are totally absent. In some fields, the crop beds are prepared along the slope which is technically wrong in sloppy lands. The picture reference given below is a typical example of terraces made along the slope. It is an isolated case, which is normally made within the larger terraces for raised bed crops. Power tiller is the only machine used by the farmers for land preparation, manual digging is also very much in practice.

Figure 32: *crop beds prepared along the slope gradient (arrows show slope direction)*

Figure 33: *Manual terraces in the farmer's field (picture taken in the winter season)*

4.4.2) Improving the Upstream Farming

The government's policy is to guide the country's farming into environmentally friendly high-value production and promote organic farming as a way of life among farmers. Bhutan envisions to become 'Organic' country and protect the environment at all times from pollutions. Although Bhutan is by large an organic farming community, the policy seems to have been challenged by change in farming practice from age-old subsistence farming requiring low inputs to commercial farming demanding high inputs. The use of agrochemicals in the upstream farmland has shown a higher level of nutrient residues in the soil. The casual use of agrochemicals by the farmers due to a wrong belief system that more use of chemicals would lead to high production has actually caused soil nutrient imbalance. It is bad for the crop and the soil ecosystem.

Planning is necessary for applying fertilizers as per the actual requirement of the soil, the excess minerals must be removed and deficit added. The excess P and K minerals in the soil should be naturally removed by repeated cultivation of crops, or by not applying inorganic P and K (SSP and Suphala) for a certain period of time. Reduce use of FYM or other animal manure as it seems to have a higher relative amount of phosphorus, which will add more to already excess P. These minerals are relatively slow to release and moves slowly through the soil compared to N.

The N level is very low in the soil, physical application of Nitrogen (urea) may be advised to correct severe deficit condition. The compost made from plant materials usually have seven times more nitrogen than phosphorus, the use of compost made from the plant should be chosen over animal waste particularly the FYM and cow urine.

Adding of lime in the agriculture field is essential to correct the soil acidity problem, the commonly used lime are; calcitic limestone (calcium carbonate) and dolomite limestone. It must be applied well before the cultivation to take the effect, the best time for the application would be in Autumn, it gives plenty of time to break down for spring planting. The traditional way to amend soil acidity is by adding wood ash repeatedly over a long period of time, it proved to be very effective.

The ALDG 2017 highlighted to make agricultural land more resilient to climate change and contribute towards enhancing national food and nutrition security. There is a need to align the farming technology to meet this national objective. The predominant orchard in this watershed is most fitting to create more resilient agriculture land and produce food. However, the existing practical hitches must be fixed to make it an ideal prototype. An apple dominated orchard is a form of mono-cropping, should there be an epidemic outbreak, it will be a complete disaster. The apple woolly aphid is a common problem at the moment, farmers are using fungicides and insecticides to curb this pest. The resistant varieties of aphids, in the long run, might prove catastrophic.

Not all the vegetables can be grown due to harsh climate condition, the selected vegetables that do well are potato, beans, cabbage, spinach, broccoli, radish, turnip, carrot. The products have a high market value because it comes in the late Summer and Autumn when all the vegetables in low lying areas are exhausted, it also has earned an organic tag, which in reality is untrue. The traditional practice of growing winter crops like wheat and barley has stopped altogether because rice is readily available in the market.

A. Mono-cropping although facilitates the easy management it has setbacks because of epidemic risk. Assorted fruit crops consist of soft shell walnut, improved breeds of pears and peach, cheery may be incorporated to reduce the risk.

B. Use of bio pesticides must be encouraged to bring down the use of pesticides and fungicides. Tree spray oil is effective against powdery mildew and rust, the bacterium Bacillus thuringiensis (Bt) is effective against cabbage worms, tent caterpillars, potato beetles, black fly and numerous insects belonging to Lepidoptera and others. These organic based pesticides do not have negative impacts on the surrounding environment and are available in the market at a reasonable cost.

C. All the households should build a greenhouse to grow vegetables in the winter, the winter vegetables are highly priced because green vegetables are very difficult to get around this time of the year. There is a huge potential for off-season vegetables given the market demand and accessibility.

D. There are fallow and empty arable lands, the traditional winter crops like wheat and barley must be reinstated to recover the native germplasm and enhance nutritional values in the family diet. This will not only revive the long lost farming tradition but also diversify the production.

4.4.3) Soil and land conservation

The ALDG 2017 emphasis on sustainable development of arable land, through a change in landform, for enhanced agricultural production and continuous agro-ecosystem services. They have identified 8 different soil and land conservation technologies suitable for Bhutan.

ALDG 2017 technologies:
i) bench terracing, ii) consolidation of existing small terraces, iii) orchard terracing, iv) removal of surface stones from agriculture fields, v) contour stone bunds, vi) orchard basin, vii) alley cropping, and vii) check dam.

In this watershed, orchard terracing is the best land management option. Sheng (1981) has specified a bench terracing technology as the most reliable and stable in sloping land. The main advantage of orchard terracing is that it enables better orchard management by increasing the ease of irrigation, fertilization, tree pruning, and fruit harvesting compared to the conventional orchard (Department of Agriculture, 2017). The terraces facilitate retention of soil moisture required for the orchard and under crops. It retains soil moisture, increases fertility by gathering biomass and enable easy management. The condition of the existing terraces is poor; it doesn't comply with the standard technical specification. Plantation of native multipurpose tree species along the land boundary is one form of ideal soil conservation method as it can lower the intensity of the surface runoff. The additional benefits, in the long run, would be the harvesting of small timbers, firewood, fruits, leaf litters, etc. The native plant species like Quercus grifithii, Borinda grossa, legume species, are good for the soil and water conservation, it adds nitrogen and manure into the soil, and provide raw materials.

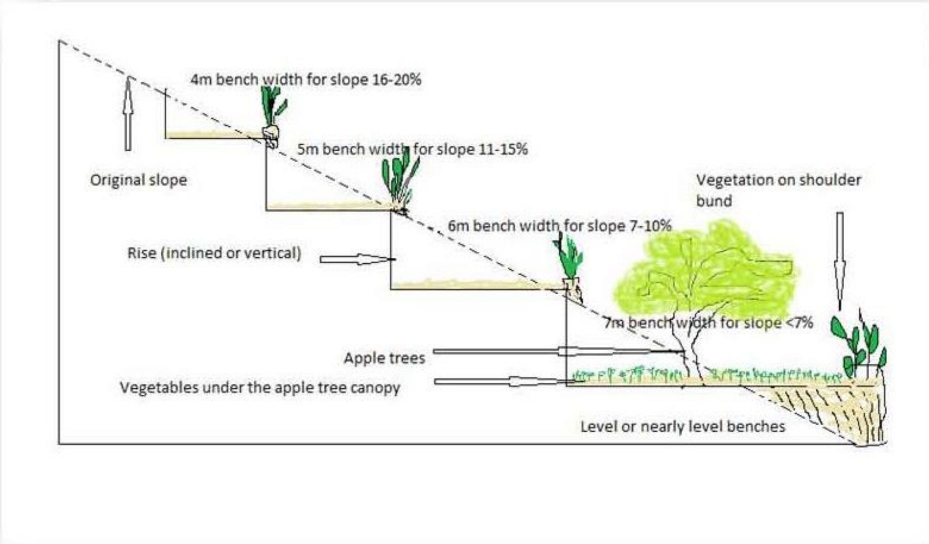


Figure 34: *An ideal terracing for the orchard on sloping land (Sheng's specification)*

Sheng's Technology:
7M bench width for slope less than 7%,
6M bench width for slope between 7-10%,
5M bench width slope between 11-15%, and
4M of bench width slope between 16-20%.

A slight variation of the technology to a somewhat sloping terrace base can be made in areas where waterlogging is a possible problem in the summer or for potato and vegetable that require less moisture.

Table 37: *Slope wise percentage of arable land*

Slope Percentage	Area of arable land (in ha)	Percentage
0-4%	22.14	9.60
4-8%	54.92	23.81
8-12%	57.75	25.04

Slope Percentage	Area of arable land (in ha)	Percentage
12-16%	43.22	18.74
16-20%	25.85	11.21
20-24%	14.57	6.32
24-28%	8.71	3.78
28-32%	2.67	1.16
32-34%	0.83	0.36

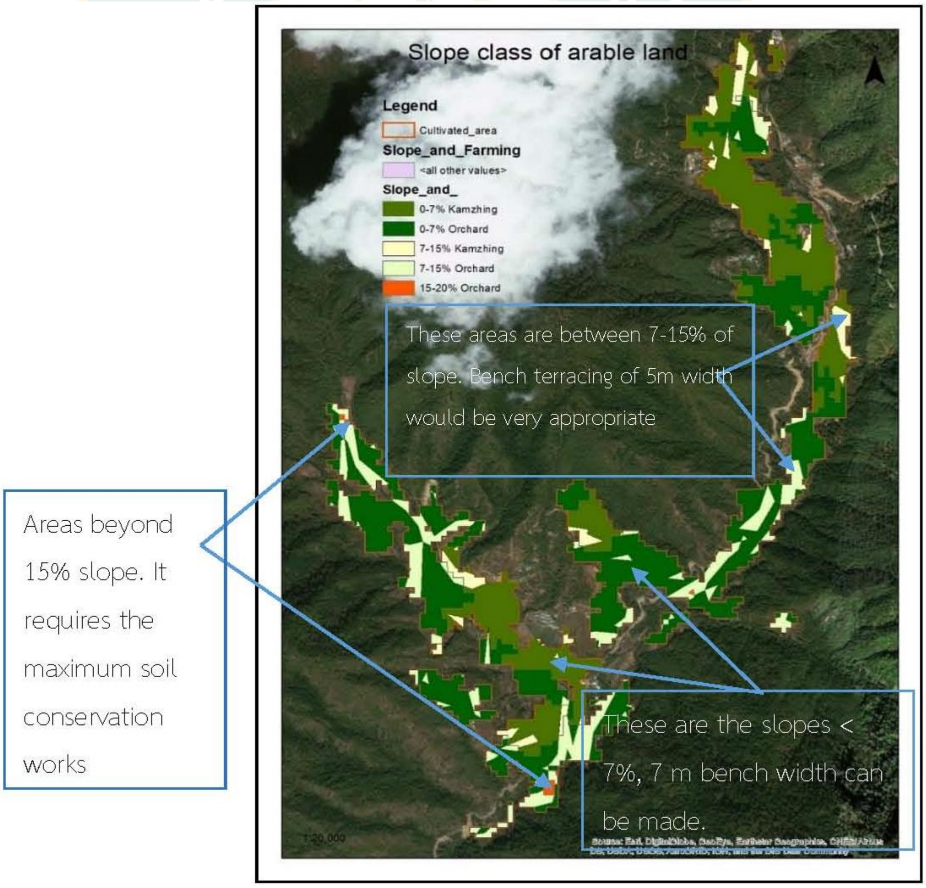


***Figure 35:** Specific areas for soil conservation works*

Table 38: Soil conservation activities and impact matrix

Conservation impact → Conservation activities ↓	Soil quality	Water quality	Soil erosion	Culture	Income	Surrounding	Ratings
Making of ridges/terraces	*	0	*	0	-	*	3
Planting fodder grasses/trees	*	*	*	*	*	*	6
Multi-cropping	*	-	*	0	*	-	3
Fallowing land	*	*	*	*	-	*	5
Applying lime	*	-	0	0	*	-	2
Applying FYM	*	-	*	*	*	*	5
Applying green manure	*	0	*	*	*	*	5
Burning crop waste and grasses	*	0	-	*	0	-	2
Crop rotation	*	0	*	0	*	*	4
Legume trees	*	*	*	-	*	*	5
Contour bund	*	*	*	*	*	*	6
Slashing the plot	*	0	-	*	-	-	2
Draining excess water by making drains	*	-	*	0	*	-	3
(*) indicates positive relationship (-) indicates negative relationship (0) neutral							

As shown in the matrix, planting of fodder grasses/trees and making of contour bunds scored the highest, fallowing of land for soil nutrient revival, applying

FYM, and planting legume trees scored the second highest, crop rotation falls in third place followed by ridges/terraces, multi-cropping, draining of excess water and slashing the plot, burning crops waste, applying lime. These are the popular soil conservation activities and more suitable ones that can be easily used by the farmers. The apple basins are not prepared correctly, many apple trees have become old and decreased the yield. There is a need for proper basin development and replacement of old trees with new improved breeds.

4.4.4) Conserving downstream water quality

The upstream farming and sewage from the piggery/labour camp is a potent threat to the stream quality. In the upstream, integrated soil fertility management approach must be incorporated into the existing farming practice to minimize the casual use of inorganic minerals and pesticides. Soil nutrient test in the farmland is important to optimize the use of both inorganic and organic minerals. More concrete soil conservation works have to be taken up in the upstream to stop the soil loss through erosion. A slush treatment plant for piggery waste should be installed to treat and dispose the waste in a safer place. Regulating the use of agrochemicals in the fields will keep the water free from contamination. The building of labour camps along the stream near the RNR Research Centre is unethical, the human waste and garbage are adding to water contamination.

4.4.5) Stream Source Conservation and Buffer Protection

Forest cover in this watershed is one of the highest in the basin, but anthropogenic activities are increasing, there is evidence of timber harvesting everywhere. It has been pointed out that there is a strong negative correlation between watershed conditions and population. The human population is increasing, the additional settlements and more public service structures will put more pressure on the forest affecting the stream quality. The stream in this watershed is fed by snow and monsoon. To maintain its quality, vegetation cover is vital, it helps to recharge groundwater and reduce overland runoff. The riparian vegetation plays an important role in providing for a healthy stream system by moderating the condition of the aquatic ecosystem. A multi-storied forest community will maintain healthy forest ecosystem services which include hydrological function.

Reclaiming of the riparian ecosystem along the stretch of settlement and agriculture land by planting Willow, native Populus, and Alnus trees which are adapted to marshy land would be more appropriate. *Yusiana spp* is more aggressive along the stream banks, it is considered weed by the farmers but it is a good stream protection vegetation because of its thick root network and ability to grow profusely. The vegetation along the stream serves as a buffer to capture and filters pollutants in overland flow from upstream farming.

CHAPTER 5

Conclusion and Recommendation

This chapter highlights the conclusion and the recommendation to improve the overall condition of the watershed by properly managing the arable land as it plays a key role in providing the livelihood to the people.

5.1) Upstream Farming Intensification

The 4% of the watershed area (232.31 hectares) has to support the livelihood of 518 households or more than two thousand populations. The projected population growth rate is 1.8%, considering the population density against the arable land size, the same land will have to support more population in the future, such circumstances will compel the farmers to grow more crops. It is imminent that increasing market demand for agriculture products coupled with population expansion will force farmers to go for more intensive farming. At the present rate of farming intensification farmer's dependency on agrochemicals to produce more food is inevitable, it will further deteriorate the soil and water quality to a larger extent in the next few years if timely measures are not taken. The soil sample analysis indicated a critical level of soil pH, OM%, NPK, in the farmland. There is a need to promote the concept of Sustainable Intensification of Agriculture developed by FAO which is 'doing more with less'. The farmers must produce more from the same area of land by using fewer inputs while producing greater yields, smart farming is an ideal example. Restoring the soil quality in the farmland by the use of organic-based soil nutrients and biopesticides is found to be urgent to restore the soil nutrient imbalance and improve the agro-ecosystem.

5.2) Onsite soil erosion

As compared to the ARS-USDA standard, the soil erosion process in this watershed is low. However, the mountain soils are shallow and infertile in nature, the recurrent annual soil loss will render agricultural land unsuitable for cropping in the near future. The average total soil loss from the arable land in the watershed is about 12,154.83 tons per year. The cumulative soil loss is huge from a small area of farmland on which the livelihood of the farmers depends so heavily. It's known that in mild temperature, the time taken for the nature to form 1cm soil is about 200-400 years, in order to accumulate enough substances to make it fertile, it will take 30,000 years. Conserving the topsoil is important to sustain the livelihood of the people as crops can grow only on topsoil. This needs to be checked through mechanical interventions by adopting appropriate soil conservation measures like terracing, growing of hedgerows, cover crops. There is a very strong positive correlation between slope steepness and soil loss, steeper the slope greater the soil loss in tons per hectare from agriculture land. The arable lands are concentrated below 20% slope. Soil conservation works must be implemented on a priority basis.

5.3) The Connection Between Upstream Farming Practices and Downstream Water Quality

The statistical result falls short on providing realistic evidence for causal relationships between upstream farming and downstream condition but there is evidence to prove that upstream farming influence the downstream water quality. The stream below the farmland has shown high acidity level, this is due to the release of nutrients and other chemicals into the water environment. On the other hand, the piggery farm has noticeably polluted the water to an extreme point, the water transparency has declined and foams were clearly visible. The total dissolved solutes were higher in the downstream compared to upstream. The water quality is declining towards the downstream, stream above the settlement remained safe. Thus, based on this evidence we can draw the inference that upstream farming can influence the outcome of the downstream water quality either positively or negatively.

5.4) Point Sources of Water Contamination

The use of agrochemicals in the upstream, waste from the labour camp and sewage of piggery farm were found to be the main source of stream water contamination in the sub watershed. The contamination has begun below the farmland and continued till the outlet, there is a change in the physical, chemical and biological properties of the water. In fear of faecal coliform infection, the farmers in the low land have brought in drinking water from above the settlement through synthetic pipelines. Stream water contamination is clearly becoming a social issue as people in the downstream has to invest more money and time to get fresh water. The result of water quality was based on one season sample, the accurate and more reliable result may be expected from four season samples as the different season has distinct farming pattern and use of agrochemicals differ significantly according to the crops. Regulating the use of agrochemicals in the upstream farmland was identified as a key indicator to keep the water safe from chemical contamination. Proper addressing of sewage from the piggery was found to be equally important in maintaining the water quality. The labour camps along the stream pose a threat to the stream quality by their daily activities and needs a relocation. The good indication is that the buffer zone is sufficiently maintained along the major stretch of the stream, it is covered by Yushiana (bamboo spp), blue pine trees and other vegetation, good riparian vegetation helps filter the water pollution.

5.5) Meeting the Institutional and Policy Mandates Regarding Watershed

The national objective is to mainstream watershed management activities into the local development plans for long term sustainability, there is a legal framework in place to guide the process. The policy highlights the effective management of watersheds for sustainable livelihood and a reliable supply of high-quality water. The critical watershed classification gives an idea on the current status and basis to take an informed decision for further initiatives.

The basin level planning for the Wang Chhu river is timely and most fitting for socio-economic and for conservation purpose. The basin supports the highest population in the country and bears the national economic lifeline (the hydropower). To continue providing the services, the condition of the basin has to be at its best. A collective effort by involving all the stakeholders and adopting best management practices is imperative. The shift of management paradigm from project-based stratagem to a need-based participatory approach is an achievement in realizing the vision of ideal watershed management. The river basin and watershed management planning for critical watersheds should be the priority for Bhutan as the whole country represents a giant network of watersheds. The watersheds are the cradle of human civilization and source of living for all the population, more than sixty percent are farmers and depend on agriculture for their livelihood. Watershed conservation and protection would meet two important national objectives; the ecological integrity and socio-economic wellbeing. The water security as a national goal cannot simply remain on the paper as a poise declaration, action-oriented initiatives driven by a clear understanding of the site context is a need of the hour.

The government emphasizes on carrying out periodical monitoring for normal watersheds and develop management plans for critical watersheds. The watersheds in Thimphu are the primary source of drinking water for the people in the city and the surrounding areas. Its management is not simply concerning the hydrological aspect but also the social, political, and ecological integrity of the landscape. Recognizing each component, their role and interaction between the components are fundamentally the right way to understand the structural and functional characteristics of the watershed. Appreciating the unique blends of the landscape in spatial and temporal terms is important to develop a realistic sustainable management plan. There is an acute shortage of scientific papers providing adequate empirical evidence of watershed process and function in Bhutan. Series of research on the subject would provide much-needed information. The evidence of farming impact on soil quality and downstream water properties presented in this paper is a fraction of information about the human-watershed interaction and its outcome.

5.6) The Present Watershed Condition of Yusipang Hongtso

The watershed was identified as critical by function, there is high pressure for drinking water, as such, it requires a plan to manage it properly. The pressure from the construction of the roads and infrastructural development was highlighted as a threat to the watershed condition. The road network is indispensable for catering social services but it certainly is a threat to the watershed, the National highway (Thimphu-Wangdue) passes through this watershed stretching along the river valley. There are 21 different roads of varying length, it includes feeder roads, farm roads, private access roads, and waste disposal road. The number of private roads is likely to increase in the future as more private house constructions are coming up.

Nevertheless, the overall condition of the watershed is undamaged, it can be attributed to the sensible choice of land use pattern, in which 94% of the total watershed is under natural forest, only 4% of the area is utilized for agriculture farming which is by choice located in slopes less than 20%. The agriculture practice is largely an orchard which is an agroforestry base, the growing of perennial agriculture trees is in conformity with the watershed conservation principles. The high forest cover is a good indicator for a healthy watershed. To maintain a good forest cover, a community forestry program was started under the community-based natural resources management initiative. This integrated resource management approach promotes people’s participation in forest management. Both Hongtso and Yusipang villages have a portion of government forest land registered in their name, they utilize the forest resource as per their own management plan. The status of community forests is relatively better, the regeneration is profuse in all the areas and forest stock is rich. The mix conifer forest, which is the main vegetation surrounding the stream sources are important for hydrological function.

5.7) Recommendation

A. Integrated Soil Fertility Management (ISFM) practice is an approach to improve the soil quality and efficiency of fertilizers and agro-inputs by effectively managing the soil nutrients and water use to increase agriculture production. The practice will save the soil and water from the negative impacts of casual use of agrochemicals.

B. Integrated Pest Management (IPM) or Integrated Pest Control (IPC), is another method to limit the pest below Economy Injury Level (EIL). The idea is to keep pesticides to a level that is economically justified and reduce risks to human health and the environment. The practice highlights natural pest control methods with minimum disturbance to agro-ecosystem and promotes healthy crops. Integration of biofertilizers and biopesticides into the existing practice must be persuaded to bring down the use of chemicals.

C. The government must provide technical and financial support to the farmers for periodical soil nutrient testing, accordingly application of fertilizer may be planned. More effective delivery of a smaller amount of fertilizer, better targeting of plants is essential to avoid unnecessary use.

D. High yielding varieties of vegetables must be supplied by the government on a regular basis to maximize the output so that farmers don’t remain too much dependent on agrochemicals. The winter crops should be reintroduced to provide additional nutrition to the family and also to save the germplasm of native crop varieties. Native species are more resilient and more adaptive to climate change.

E. Alley cropping and hedgerow must be promoted wherever possible, it enables creating a permanent avenue for farming of sloping agriculture land on a sustainable basis. The hedgerows are the live barrier, it traps sediments and reduces surface runoff, thereby improving the soil condition.

F. It is sensible to grow assorted fruit trees of different varieties so that there is income insurance of the farmers should one crop fail due to pest or natural calamities. The promotion of high yielding varieties of soft shell walnut, peach, pear, cherry, persimmon in a relatively equal proportion looks very promising.

G. The government must provide technical support and initiate land development in conformity with the standard design. Sheng technology is highly recommended in this watershed to improve the condition of agriculture land and reduce soil loss.

H. In-depth study of water quality is recommended to provide substantial empirical evidence, by covering all the aspects of chemical, physical and biological parameters. Likewise, sediment analysis for the presence of pesticide residues like Organophosphate group and Carbonate group must be studied in different seasons of the year according to cropping pattern.

I. To improve water security through effective planning and coordination among the stakeholders, critical watersheds must be prioritized for immediate intervention and normal watersheds should be the focus for similar action in the near future. Highest conservation obligation must be placed on pristine watersheds as it should remain unspoiled.

J. The water source protection must be implemented categorically, the mix conifer forest is the main vegetation surrounding the water sources, which plays an important role in the hydrological process. On the other hand, this forest is most preferred by the people for construction purposes due to its durability. As it happens to be in the proximity, the pressure on this forest is inevitable.

K. The sewage from the piggery farm should be properly managed. Converting the waste to organic manure would be most fitting as the product can be sold to the farmers and urban gardeners.

L. The government must make an arrangement to relocate the temporary labour camps outside the river buffer zone. The faecal coliforms are a potent threat to human health and their daily activities are adding to water pollution.

M. All the critical watersheds under the Wang Chhu Basin must have a management plan for immediate implementation. There are 15 critical watersheds out of 23 watersheds in Thimphu district alone, which is 65% of the total watersheds.

N. There is a need for the government to strictly regulate the unnecessary construction of private roads in the government forest. It is a growing concern for watershed deterioration, not only the road constructions are rampant but also most of them do not comply with the environment safety guidelines.

O. A series of field research may help build enough evidence to understand the interaction and outcome of watershed services to come up with an inclusive plan. This strategy will sustain the economy without compromising the watershed condition.

P. Stream protection regulation must be implemented strictly to protect the water sources.

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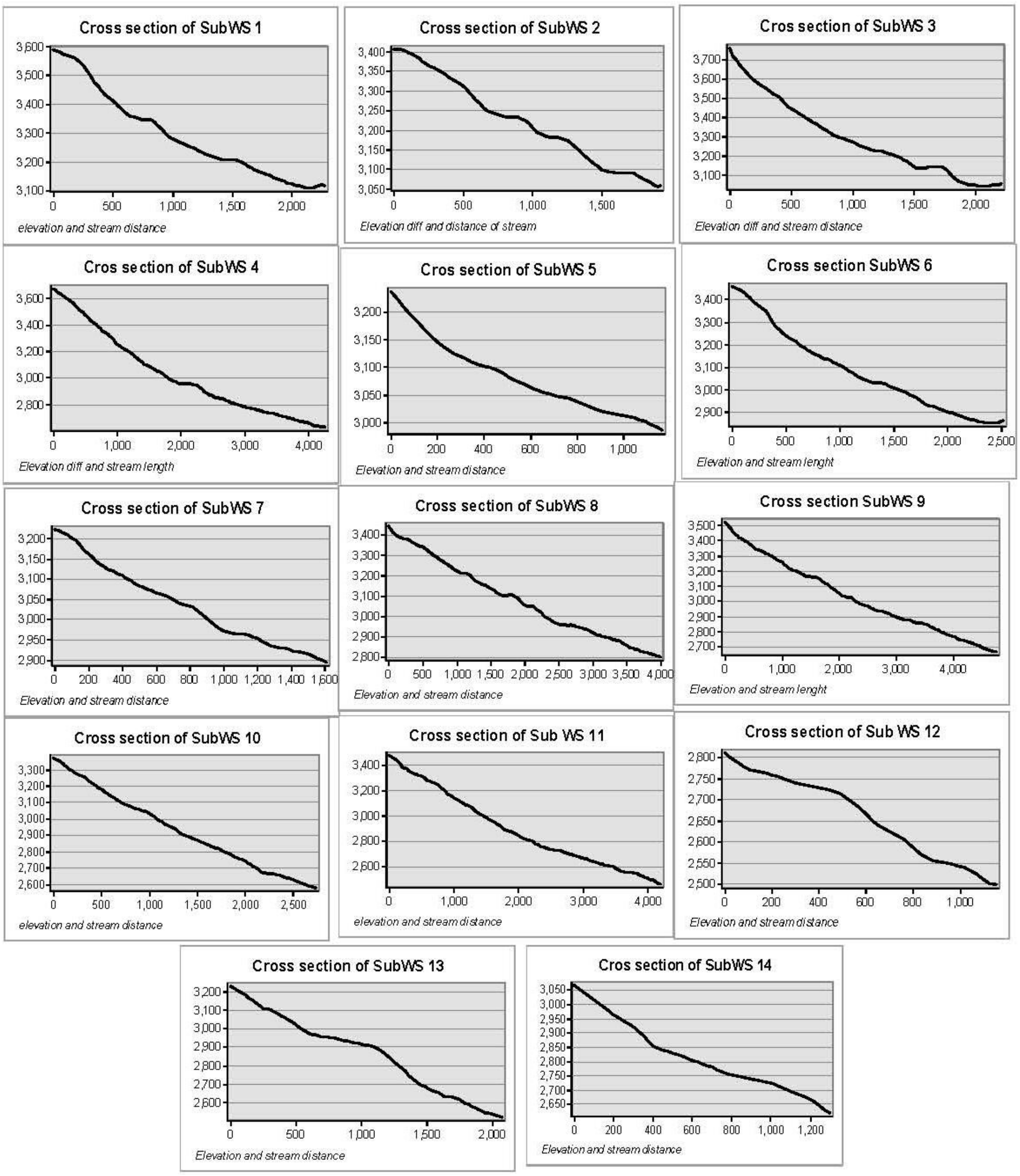
Appendix 1 Stream cross-section of all the sub-watersheds



Appendix 2 Soil Bulk Density

Sample code	Core sample Wet wt			Core samples Dry wt			Mass/Volume	bulk density (Dry wt/Mass)				
	A	B	C	A	B	C	(Pi*r2*h)cm3	A	B	C	Avg BD (kg/cm3)	g/cm3
Ss1 (DL-S1)	0.121	0.135	0.139	0.098	0.113	0.125	98.17	0.000998268	0.00115164	0.00127301	0.001141	1.140878
Ss2 (DL-S2)	0.13	0.132	0.14	0.108	0.11	0.124	98.17	0.00110013 2	0.00112050 5	0.00126311 5	0.001161	1.161251
Ss3 (DL-S3)	0.133	0.136	0.14	0.112	0.115	0.113	98.17	0.00114087 8	0.00117143 7	0.00115106 4	0.001154	1.15446
Ss4 (DL-S4)	0.125	0.127	0.128	0.103	0.109	0.107	98.17	0.0010492	0.00111031 9	0.00108994 6	0.001083	1.083155
Ss5 (OC-S1)	0.13	0.132	0.133	0.11	0.112	0.114	98.17	0.00112050 5	0.00114087 8	0.00116125 1	0.001141	1.140878
Ss6 (OC-S2)	0.129	0.13	0.132	0.107	0.121	0.11	98.17	0.00108994 6	0.00123255 6	0.00112050 5	0.001148	1.147669
Ss7 (OC-S3)	0.171	0.172	0.175	0.159	0.161	0.163	98.17	0.00161963 9	0.00164001 2	0.00166038 5	0.00164	1.640012
Ss8 (OC-S4)	0.138	0.139	0.136	0.121	0.125	0.12	98.17	0.0012325	0.0012733	0.0012223	0.0012	1.2427

								56	01	69	43	42
Ss9 (OC- S5)	0.1 33	0.1 5	0.1 56	0.1 1	0.1 15	0.1 19	98.17	0.001 1205 05	0.001 1714 37	0.001 2121 83	0.0 011 68	1.1 680 42
Ss10 (OC-S6)	0.1 36	0.1 37	0.1 36	0.1 14	0.1 15	0.1 15	98.17	0.001 1612 51	0.001 1714 37	0.001 1714 37	0.0 011 68	1.1 680 42
Ss11 (OC-S7)	0.1 39	0.1 4	0.1 41	0.1 21	0.1 23	0.1 24	98.17	0.001 2325 56	0.001 2529 29	0.001 2631 15	0.0 012 5	1.2 495 33
Ss12 (OC-S8)	0.1 27	0.1 29	0.1 3	0.1 06	0.1 09	0.1 1	98.17	0.001 0797 6	0.001 1103 19	0.001 1205 05	0.0 011 04	1.1 035 28
Ss13 (OC-S9)	0.1 25	0.1 27	0.1 26	0.1 03	0.1 04	0.1 06	98.17	0.001 0492	0.001 0593 87	0.001 0797 6	0.0 010 63	1.0 627 82
Ss14 (DL-S3)	0.1 28	0.1 29	0.1 31	0.0 99	0.1 11	0.1 21	98.17	0.001 0084 55	0.001 1306 92	0.001 2325 56	0.0 011 24	1.1 239 01
Ss15 (DL-S4)	0.1 27	0.1 29	0.1 31	0.1 09	0.1 07	0.1 09	98.17	0.001 1103 19	0.001 0899 46	0.001 1103 19	0.0 011 04	1.1 035 28
Ss16 (DL-S5)	0.1 35	0.1 36	0.1 38	0.1 07	0.1 08	0.1 1	98.17	0.001 0899 46	0.001 1001 32	0.001 1205 05	0.0 011 04	1.1 035 28
Ss17 (OC-S10)	0.1 35	0.1 44	0.1 36	0.1 13	0.1 21	0.1 15	98.17	0.001 1510 64	0.001 2325 56	0.001 1714 37	0.0 011 85	1.1 850 19
Ss18 (DL-S6)	0.1 32	0.1 51	0.1 47	0.1 09	0.1 22	0.1 16	98.17	0.001 1103 19	0.001 2427 42	0.001 1816 24	0.0 011 78	1.1 782 28
Ss19 (DL-S7)	0.1 38	0.1 42	0.1 51	0.1 22	0.1 25	0.1 29	98.17	0.001 2427 42	0.001 2733 01	0.001 3140 47	0.0 012 77	1.2 766 97
Ss20	0.1	0.1	0.1	0.0	0.1	0.1	98.17	0.001	0.001	0.001	0.0	1.0

(DL-S8)	22	24	31	99	02	13		008455	039014	151064	01066	66178
Ss21 (DL-S9)	0.126	0.16	0.161	0.101	0.106	0.124	98.17	0.001028828	0.00107976	0.001263115	0.001124	1.123901
Ss22 (DL-s10	0.15	0.152	0.162	0.118	0.119	0.127	98.17	0.001201997	0.001212183	0.001293674	0.001236	1.235951
Ss23 (OC-S11)	0.142	0.141	0.154	0.127	0.127	0.139	98.17	0.001293674	0.001293674	0.001415911	0.001334	1.33442
Ss24 (OC-S12)	0.147	0.146	0.143	0.129	0.133	0.135	98.17	0.001314047	0.001354793	0.001375166	0.001348	1.348002
Ss25 (DL-11)	0.138	0.138	0.149	0.122	0.123	0.132	98.17	0.001242742	0.001252929	0.001344606	0.00128	1.280092
Ss26 (DL-12)	0.163	0.156	0.159	0.137	0.131	0.133	98.17	0.001395538	0.00133442	0.001354793	0.001362	1.361584
Ss27 (OC13)	0.183	0.205	0.18	0.149	0.179	0.155	98.17	0.001517775	0.001823368	0.001578894	0.00164	1.640012

Appendix 3 Soil infiltration rate

SL. No	Sample	Soil type	Infiltration rate mm/hr
1	SS1	Sandy clay loam	66
2	SS2	Sandy clay loam	62
3	SS3	Sandy clay loam	63.7
4	SS4	Sandy Loam	76
5	SS5	Sandy Loam	75.6

6	SS6	Sandy Loam	74.3
7	SS7	Sandy Loam	75.8
8	SS8	Sandy clay loam	63.5
9	SS9	Sandy Loam	77
10	SS10	Sandy Loam	74.9
11	SS11	Sandy Loam	75.9
12	SS12	Sandy Loam	77
13	SS13	Sandy Loam	73.5
14	SS14	Sandy Loam	78.1
15	SS15	Sandy Loam	74.2
16	SS16	Sandy clay loam	66.8
17	SS17	Sandy clay loam	63.3
18	SS18	Clay loam	56.7
19	SS19	Clay Loam	59
20	SS20	Sandy Loam	77.9
21	SS21	Sandy Loam	74.6
22	SS22	Sandy Loam	76.8
23	SS23	Sandy clay loam	68.8
24	SS24	Sandy Loam	79
25	SS25	Clay loam	60
26	SS26	Sandy clay loam	69
27	SS27	Sandy clay loam	67.30
28	FS-1	Sandy Loam	80
29	FS-2	Clay loam	43
30	FS-3	Sandy clay loam	64.5

Appendix 4 Soil erodibility (K factor) regarding texture from Grain size diagram and Percentage of OM

(Texture class)	Erodibility (% of OM)

	0.5 %	2%	4%
1. ทราย (Sand)	0.005	0.03	0.02
2. ทรายละเอียด (Fine sand)	0.16	0.14	0.10
3. ทรายละเอียดมาก (Vary fine sand)	0.42	0.36	0.28
4. ทรายร่วน (Loamy sand)	0.12	0.10	0.08
5. ทรายละเอียดร่วน (Loamy fine sand)	0.24	0.20	0.16
6. ทรายละเอียดร่วนมาก (Vary loamy fine sand)	0.44	0.38	0.30
7. ร่วนปนทราย (Sandy loam)	0.27	0.24	0.19
8. ร่วนปนทรายละเอียด (Fine sandy loam)	0.35	0.30	0.24
9. ร่วนปนทรายละเอียดมาก (Vary fine sandy loam)	0.47	0.41	0.33
10. ร่วน (Loam)	0.38	0.34	0.29
11. ร่วนปนทรายแป้ง (Silt loam)	0.48	0.42	0.33
12. ทรายแป้ง (Silt)	0.60	0.52	0.42
13. ร่วนเหนียวปนทราย (Sandy clay loam)	0.27	0.25	0.21
14. ร่วนปนเหนียว (Clay loam)	0.28	0.25	0.21
15. เหนียวปนทรายแป้ง (Silty clay)	0.37	0.32	0.26
16. เหนียวปนทราย (Sandy clay)	0.14	0.13	0.12
17. ร่วนเหนียวปนทรายแป้ง (Silty clay loam)	0.25	0.23	0.19
18. เหนียว (Clay)	0.13 – 0.29		

ที่มา : ARS-USDA and ORD-EPA (1975)

Appendix 5 C-Factor depending on plant cover

Types of land use and plant types **Type of plant cover**	C - **factor**	Types of land use and plant types **Type of plant cover**	C - **factor**
Desert (Paddy fallow)	0.100	Mulberry Garden Croton Plant Papaya Garden Plant	0.600

		Mixed Vegetable Grape Pepper (Agro-forest)	
Rice fields: rice fields, rainforests (Paddy field)	0.280	Olive Passion Fruit (passion fruit + hug plum)	0.600
Agro-integrated agriculture (Mixed cropping)	0.225	(Fallow area)	0.020
Wheat, barley, rye (Upland rice)	0.280	(rice, farm-corn) Rotational cropping (Upland rice and maize)	0.250
Field crops, field crops, mixed crops, other crops	0.340	(shifting cultivation)	0.250
Pineapple, Aloe Vera Sisal (upland crop)	0.380	Circulating opium vegetable (Vegetables rotated with opium)	0.250
Black beans, red beans, sesame seeds, opium (Peanut crop)	0.386	(Fallow for Rotational upland rice)	0.250
(Green bean)	0.390	พื้นที่ทิ้งร้างจากการทำไร่หมุนเวียน (Fallow area)	0.250
อ้อย (Cane field)	0.400	ทุ่งหญ้าเลี้ยงสัตว์ (Grazing land)	0.100
ถั่วลิสง (peanut)	0.406	ป่าดิบชื้นและป่าไม้ผลัดใบอื่น ๆ (Evergreen mixed with dipterocarp forest)	0.001
ถั่วเหลือง (soybean)	0.421	ป่าดิบเขา (Hill evergreen forest)	0.003
ฝ้าย + ไร่ร้าง (cotton+abandoned field)	0.500	Dry evergreen forest, pine forest	0.019
ข้าวโพด (maize)	0.502	Deciduous forest (dipterocarp forest, Pa Daeng, Pa Phae)	0.020

มันสำปะหลัง ปอแกว ปอกระเจา ปอสา ปอป่าน พืชเส้นใย (Fiber crop)	0.600	Rainforest, deciduous forest, deciduous forest	0.040
มันฝรั่ง มันเทศ แตงโม ขิง กะหล่ำปลี มะเขือเทศ พริก (Vegetables)	0.600	Deciduous forest	0.250
กัญชา กระเจี๊ยบ (agro forestry)	0.600	Forest plantation (pine, rubber, eucalyptus, teak, neem)	0.088
Millet millet	0.650	Forest Park (Son Pradipat, Krathin, Pradu So)	0.088
Sunflower field rice	0.700	Forest plantation (greasy, queen tiger, wild gooseberry, apple forest)	0.088
ละหุ่ง (castro-oil)	0.790	วนเกษตร (agro forestry)	0.088
Teak neem	0.088	นาร้างเขตชลประทาน (abandoned paddy field, irrigation area)	0.088
ไม้ยืนต้น ไม้ยืนต้นผสมยางพารา ยูคาลิบตัส สนประดิพัทธ์ (perennial plant)	0.150	นาดำ นาหว่าน เขตชลประทาน Paddy field, irrigation area)	0.100
ปาล์มน้ำมัน (oil palm)	0.300	ไม้ผลผสม เขตชลประทาน (mixed orchard, irrigation area)	0.280
ระกำ สละ	0.020	กล้วย เขตชลประทาน (banana in irrigation area)	0.100
จามจุรี (rain tree)	0.088	Banana, Longan, Jack Kranton, Mangosteen, Langsad, Longkong (mixed orchard)	0.150
Mixed fruit bamboo tea, fruit orchard, rambutan, lychee, mango	0.150	สตรอเบอรี่ และรัสเบอรี่ (strawberry, raspberry)	0.270

(mixed orchard)			
Coffee, Nun, Trotters, Orange, Jujube, Annona, Guava, Lemon (mixed orchard)	0.300	อ้อย เขตชลประทาน (sugar cane, irrigation area)	0.400
Winter fruit tree (temperate fruit)	0.300	มันสำปะหลัง เขตชลประทาน (cassava, irrigation area)	0.600
ไม้ดอก (flowering plant)	0.386	ทุ่งหญ้า สนามกอล์ฟ เขตชลประทาน (grassland, golf court, irrigation area)	0.015
Cashew nut, cashew nut	0.400	ทุ่งหญ้าสลับ ไม้พุ่ม ไม้เตี้ย (grassland, shrub)	0.048
ไผ่ (bamboo)	0.020	เหมืองแร่เก่า (old mine)	0.800
ป่าละเมาะ (grove)	0.048	พื้นที่ไม่ใช้ประโยชน์อื่น ๆ (other land use)	0.800
ทุ่งหญ้าผสมป่าละเมาะ (mixed grassland and grove)	0.032		

ที่มา: กรมพัฒนาที่ดิน (2543)

Source : Land Development Department (1990)

Appendix 6 Erodibility level of Thailand

level	**Soil erosion(Ton/rai/yr)**
น้อยมาก (Very slight)	0.01 – 1
น้อย (Slight)	1.01 - 5.00
ปานกลาง (Moderate)	5.01 - 20.00
รุนแรง (Severe)	20.01 - 100.00
รุนแรงมาก (Very severe)	100.01 - 966.65

Source : Land development department (1981)

Appendix 7 Core sample recording format

Sample code	Core samples	Wet weight	Dry weight
Ss1 (DL-S1)	A		
	B		
	C		
Ss2 (DL-SL2)	A		
	B		
	C		

Appendix 8 Soil analysis report

Sample code	Repication	Name of the farmer	Landuse	pH		%OM		P		K		Total N		soil texture						
				pH	Mean	%OM	Mean	(mg P/kg)	Mean	(mg/kg)	Mean	%	Mean	% Clay	Mean	% Silt	Mean	% Sand	Mean	Soil texture
SS1	1	Jamyang Lhamo		4.44	4.48	5.60	5.60	37.55	38.05	241	196	0.35	0.40	21	21	20	22	59	57	Sandy Clay
	2			4.51		5.60		38.5		151		0.46		21		24		55		

	SS8		SS7		SS6		SS5		SS4		SS3		SS2
2	1	2	1	2	1	2	1	2	1	2	1	2	1
	Hemraj		Birkha Bdr Gurung		Birkha Bdr Gurung		Birkha Bdr Gurung		Jamyan g Lhamo		Jamyang Lhamo		Jamyang Lhamo
5.48	5.51	5.19	5.18	5.83	5.83	5.65	5.25	4.97	4.99	5.47	5.45	5.51	5.48
	5.50		5.19		5.83		5.45		4.98		5.46		5.50
11.21	11.21	14.34	14.34	12.33	12.10	11.43	11.88	14.57	14.79	2.69	2.69	10.3	10.31
	11.21		14.34		12.21		11.65		14.68		2.69		10.31
78.56	64.73	55.41	53.39	35.34	37.06	110.64	100.07	70.11	59.16	72.2	56.47	38.5	35.91
	71.64		54.40		36.20		105.36		64.63		64.34		37.23
227	206	120	96	144	125	177	189	38	67	163	166	429	409
	217		108		135		183		53		164		419
0.05	0.05	0.21	0.23	0.30	0.25	0.16	0.28	0.40	0.32	0.16	0.14	0.11	0.09
	0.05		0.22		0.27		0.22		0.36		0.15		0.10
21	21	11	13	15	17	15	15	19	19	21	21	27	27
	21		12		16		15		19		21		27
20	20	18	12	16	16	20	18	22	20	20	22	30	24
	20		15		16		19		21		21		27
59	59	71	75	69	67	65	67	59	61	59	57	43	49
	59		73		68		66		60		58		46
	Sandy Clay		Sandy loam		Sandy loam		Sandy loam		Sandy		Sandy Clay		Sandy Clay

	SS16		SS15		SS14		SS13		SS12		SS11		SS10		SS9
2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
	Santa Bhadur Gurung		Santa Bhadur Gurung		Santa Bhadur Gurung		Sangay Duba		Sangay Duba		Birkha Bdr Gurung		Hemraj		Hemraj
5.88	5.88	5.43	5.44	5.56	5.57	5.66	5.60	5.53	5.47	5.32	5.38	5.46	5.59	5.30	5.42
	5.88		5.44		5.57		5.63		5.50		5.35		5.53		5.36
12.1	12.55	9.41	9.41	10.98	10.98	10.31	10.53	13.2	13.67	11.6	11.88	9.86	9.64	11.21	11.21
	12.33		9.41		10.98		10.42		13.45		11.77		9.75		11.21
102.	107.04	75.6	65.78	65.21	88.36	43.45	86.63	96.8	90.08	136.	136.09	141.	108.00	121.6	121.68
	104.64		70.73		76.78		65.04		93.45		136.09		124.93		121.68
530	528	349	370	344	337	194	191	604	617	472	648	507	542	169	153
	529		359		340		193		610		560		525		161
0.16	0.18	0.12	0.25	0.18	0.14	0.09	0.09	0.32	0.33	0.30	0.26	0.30	0.28	0.14	0.07
	0.17		0.18		0.16		0.09		0.32		0.28		0.29		0.11
23	23	15	15	15	15	15	17	15	15	13	13	13	15	15	15
	23		15		15		16		15		13		14		15
18	18	16	18	16	16	12	10	14	16	14	14	18	16	18	16
	18		17		16		11		15		14		17		17
59	59	69	67	69	69	73	73	71	69	73	73	69	69	67	69
	59		68		69		73		70		73		69		68
	Sandy Clay		Sandy		Sandy		Sandy		Sandy		Sandy loam		Sandy		Sandy

SS24		SS23		SS22		SS21		SS20		SS19		SS18		SS17
1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
Tshering Yangchen		Tshering Yangchen		Pasang Om		Phurba		Kencho Lham		Kencho Lham		Kencho Lham		Kencho Lham
6.47	6.03	6.05	5.40	5.62	5.51	5.57	5.	5.88	6.03	5.99	5.14	5.06	5.23	5.22
6.54		6.04		5.51		5.54		5.86		6.01		5.10		5.23
9.86	8.96	9.41	10.53	11.65	13.67	14.34	12	11.88	10.09	9.86	8.52	8.29	8.74	8.74
9.97		9.19		11.09		14.01		12.33		9.97		8.40		8.74
29.57	77.31	77.31	68.38	61.65	87.97	59.92	90	89.70	91.33	82.69	44.8	53.01	87.78	78.56
37.52		77.31		65.02		73.95		89.89		87.01		48.93		83.17
589	447	416	264	275	287	294	32	319	874	849	171	310	87	227
610		431		270		290		319		861		240		157
0.26	0.35	0.32	0.18	0.18	0.30	0.26	0.	0.12	0.18	0.12	0.07	0.09	0.09	0.12
0.28		0.33		0.18		0.28		0.10		0.15		0.08		0.11
15	21	19	17	17	11	11	17	19	29	29	31	35	27	25
16		20		17		11		18		29		33		26
16	22	24	18	18	10	14	18	16	28	26	34	34	26	26
16		23		18		12		17		27		34		26
69	57	57	65	65	79	75	65	65	43	45	35	31	47	49
68		57		65		77		65		44		33		48
Sandy loam		Sandy Clay		Sandy		Sandy		Sandy		Caly loam		Caly loam		Sandy Clay

	F3/1		F2/1		F1/1		SS27		SS26		SS25	
2	1	2	1	2	1	2	1	2	1	2	1	2
	Forest soil		Forest soil		Forest soil		Pema Tobgay		Rinchey		Rinchey	
5.71	5.77	5.46	5.44	5.42	5.41	6.35	6.31	5.52	5.54	5.83	5.78	6.61
	5.74		5.45		5.42		6.33		5.53		5.81	
8.74	8.74	6.95	6.95	15.24	15.24	9.19	9.64	9.19	8.52	8.74	8.52	10.09
	8.74		6.95		15.24		9.41		8.85		8.63	
10.6	8.73	30.92	8.15	15.21	13.05	24.10	26.60	123.61	134.17	103.4	105.36	45.47
	9.67		19.54		14.13		25.35		128.89		104.40	
154	136	201	181	229	218	370	358	369	365	485	593	631
	145		191		223		364		367		539	
0.26	0.28	0.19	0.18	0.46	0.42	0.21	0.19	0.09	0.11	0.09	0.11	0.30
	0.27		0.18		0.44		0.20		0.10		0.10	
21	21	33	33	11	11	27	27	29	29	29	29	17
	21		33		11		27		29		29	
20	20	26	26	16	16	24	24	24	24	26	26	16
	20		26		16		24		24		26	
59	59	41	41	73	73	49	49	47	47	45	45	67
	59		41		73		49		47		45	
	Sandy Clay		Caly loam		Sandy		Sandy Clay		Sandy Clay		Caly	

Appendix 9 Soil infiltration data collection form

Site location:	Soil type:	date:

Reading on clok			Time difference min	Cumulative time min	Water level		Infiltration mm	Infiltration rate mm/min	Infiltration rate mm/hr	Cumulative infiltration mm
Hr	Min	Sec			Before filling	After filling				

Appendix 10 Compiled Infiltration Rate

Sample	Soil type	Infiltration rate mm/hr
SS1	Sandy clay Loam	66
SS2	Sandy clay Loam	62
SS3	Sandy clay Loam	63.7
SS4	Sandy Loam	76
SS5	Sandy Loam	75.6
SS6	Sandy Loam	74.3

Sample	Soil type	Infiltration rate mm/hr
SS7	Sandy Loam	75.8
SS8	Sandy clay loam	63.5
SS9	Sandy Loam	77
SS10	Sandy Loam	74.9
SS11	Sandy Loam	75.9
SS12	Sandy Loam	77
SS13	Sandy Loam	73.5
SS14	Sandy Loam	78.1
SS15	Sandy Loam	74.2
SS16	Sandy clay loam	66.8
SS17	Sandy clay loam	63.3
SS18	Clay loam	56.7
SS19	Clay loam	59
SS20	Sandy Loam	77.9
SS21	SandyLoam	74.6
SS22	Sandy Loam	76.8
SS23	Sandy clay loam	68.8
SS24	Sandy Loam	79
SS25	Clay loam	60
SS26	Sandy clay loam	69
SS27	Sandy clay loam	67.30
FS-1	Sandy Loam	80
FS-2	Clay Loam	43
FS-3	Sandy clay loam	64.5

Appendix 11 Mean Annual Precipitation

Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Station
PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	type
27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	Lat
89.7	89.7	89.7	89.7	89.7	89.7	89.7	89.7	89.7	89.7	Long
2310	2310	2310	2310	2310	2310	2310	2310	2310	2310	Altitude
2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Year
15.8	1	0	0.2	14.8	6.9	2.6	7.6	4	2.6	Jan
0	0	1.3	27.3	11.7	24.4	0	9.2	0	0.8	Feb
17.7	0	15.1	4.2	9	17.3	20.4	23.8	42.2	60.5	Mar
15.1	27	6.6	5.9	36.1	39	9.7	79	23.5	45.4	April
27.5	146.6	56.2	14.2	21.6	76.6	90.9	27	61.8	84.6	May
132.9	18.8	129.4	136.7	55.5	111.6	151.2	99.9	26.8	88.2	June
152.3	80.9	183.7	99.9	225.6	85.9	168.2	197.2	252.3	162.6	July
115.1	127.3	91.4	124.7	78.7	128.2	101.7	80.6	73.1	93.3	August
68.6	46.1	66.3	111.6	99.7	24	120.8	80.7	154.4	56	Sept
46.7	108.5	34.2	25	12	95.2	0	7.8	72.7	11.9	Oct
0	1.2	0	1.9	0	0	0	0.2	0.8	0.8	Nov
1.6	4.2	0	0	0	0	6.8	0	0	0	Dec
593.3	561.6	584.2	551.6	564.7	609.1	672.3	613	711.6	606.7	Total

Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha	Simtokha
PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP	PRECIP
27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4
89.7	89.7	89.7	89.7	89.7	89.7	89.7	89.7	89.7	89.7	89.7
2310	2310	2310	2310	2310	2310	2310	2310	2310	2310	2310
1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0	0	0	2.4	0	31.3	27.1	21.5	0.8	0	0
19.5	8.2	0	3.8	0	4.5	31	6.5	18.8	0	35.9
57	48.1	21.8	14.4	0	32.8	9.4	6.4	11.9	15.8	14.1
39.7	13.7	28.6	22.8	91.3	20.4	27.5	30	28.6	41.1	14.6
3.8	37.6	56.5	63	100.6	32.3	22.1	38	12.9	56	29.2
161.4	54.4	139.2	85.2	132.3	129.6	159.4	116.2	37.8	24.6	46.1
153	209.5	290.5	197.3	129.1	253.7	168.1	114.6	67.4	147.4	82.9
214.4	152.2	130.6	53	150.6	189.2	162.3	142.5	124.9	122.7	79.9
45.4	54.6	85.9	8.5	111.3	121.4	74.9	18.8	36.9	70.8	90.2
12.9	8	106.6	11.8	55.9	17.3	92.9	48.3	115.9	19.1	18.6
0	1	1.8	0	5.6	1.9	0	0	0	10	0.8
0	0	0	0	1.8	5	6.5	0	0	2.1	0
707.1	587.3	861.5	462.2	778.5	839.4	781.2	542.8	455.9	509.6	412.3

													ion				MAP	**619.33**

Data source: Ministry of Economic Affairs Bhutan

Appendix 12 Sample details

Sample code	Coordinates		Altitude	Remarks
	Northing	Easting		
Ss1 (DL-S1)	27° 28' 36.2"	089° 41' 46.6"	3005	Ap Draba's land (the dry land in converted to apple orchard
Ss2 (DL-S2)	27° 28' 35.0"	089° 41' 46.1"	3002	-do-
Ss3 (DL-S3)	27° 28' 57.3"	"089° 41'81.6"	2991	-do-
Ss4 (DL-S4)	27° 28' 33.0"	089° 41'47.1"	2986	-do-
Ss5 (OC-S1)	27° 28' 29.7"	098° 41'49.5"	2961	Late Lyonpo Dawa's land, caretakers work in the field
Ss6 (OC-S2)	27° 28'27.1"	089° 41'48.0"	2961	Caretakers are unaware of land size Nursery beds made against the contour, along the slope
Ss7 (OC-S3)	27°28'41.6"	089° 41'70.2"	2951	Land periphery surrounded by Yushinia spp (invasive bamboo)
Ss8 (OC-S4)	27° 28'22.9"	089° 41'57.2"	2911	Homraj's land
Ss9 (OC-S5)	27° 28'31.0"	089° 41'89.5"	2889	Orchard terraced properly

Ss10 (OC-S6)	27° 28'17.3"	089° 42'01.1"	2867	
Ss11 (OC-S7)	27° 28'21.1"	089° 41'97.6"	2856	Lt. Lyonpo Dawa's orchard
Ss12 (OC-S8)	27° 28'13.4"	089° 42'03.0"	2841	Apple orchard
Ss13 (OC-S9)	27° 28'10.8"	089° 42 04.2"	2831	
Ss14 (DL-S3)	27° 28'09.4"	089° 42'04.0"	2828	Land belonging to Tshering Wangchu leased in by Mr. Santa Bhadhur. It's a dry land category but converted to the orchard
Ss15 (DL-S4)	27° 28'08.4"	089° 42'05.6"	2821	
Ss16 (DL-S5)	27° 28'08.8"	089° 42' 16.6"	2780	
Ss17 (OC-S10)	27° 28'01.5"	089° 42'03.9"	2489	Kencho Lham's land
Ss18 (DL-S6)	27° 27'59.0"	089° 42'04.1"	2503	Steep land
Ss19 (DL-S7)	27° 27'59.5"	089° 42'05.8"	2814	Steep slope
Ss20 (DL-S8)	27° 28'00.0"	089° 42'18.7"	2802	Mild slope
Ss21 (DL-S9)	27o 28'04.0"	089o 42'04.8"	2818	Ap Phurba's land (50 decimal)
Ss22 (DL-s10	27° 28'03.3"	089° 42'05.1"	2824	Aum Pasang's land (50 decimal)
Ss23 (OC-	27°	089° 42'24.5"	2832	Dema's land (hard soil

S11)	28’18.4”			
Ss24 (OC-S12)	27° 28’09.5”	089° 42’10.9”	2840	Hard soil, steep slope, fodder grass as an undercover
Ss25 (DL-11)	27° 27’92.8”	089° 42’65.5”	2770	Rinchey’s land
Ss26 (DL-12)	27° 27’89.5”	089° 42’62.7”	2760	Terraces are seen
Ss27 (OC13)	27° 27’71.8”	89° 42’15.4”	2808	Aum Gyeltshen’s land, Steep slope, terrace not properly done

Appendix 13 Water sample details

			Parameters										
			1	2	3	4	5	6	7	8			
Sample ID	N	E	Water	Water pH	Total Dissolved solutes	Dissolved Oxygen (mg/L)	Oxygen Saturation (%)	Electro conductivity (	Salinity (%)	Transparency	Elevation(m)	Time	Remarks
Water S1	27o28'16	89o42'02	5.6	7.27	15.79	8.42	94.3	33.8	0.01	4	2862	2:30PM	
Water S2	27o28'04	89o42'09	5.5	6.2	21.36	8.55	95.4	45.6	0.02	3	2700	3:00PM	
Water S3	27o37'36.4	89o42'39.5	5.1	7.44	43.2	8.46	92.4	91.6	0.04	2	00:00	3:45 PM	Below the

Water S4	27o28'72.5	89o	5.3	7.1	11.61	8.43	94.5	27.3	0.01	4	3055	9.30 am	above

CURRICULUM VITAE

NAME	Kinzang Namgay
DATE OF BIRTH	08 December 1978
EDUCATION	Bachelors of Science (Forestry): July 2010- June 2014 Hemwati Nandan Bahuguna Garhwal University (Central University) Srinagar (Garhwal), Dehradun, Uttarakhand India. Diploma in Forestry: July 1997- July 2000 College of Natural Resources, Lobesa, Thimphu, Bhutan Indian Certificate of Secondary Education Examination: 1997 Mongar Higher Secondary School, Mongar, Bhutan Publication: Gender and Equity: A Challenge in Community Forestry 2006, it is cited in 9 research papers International conference and conference proceedings: Assessment of Upstream Farming Intensification and its Impact on Soil: Yusipang and Hongtso Watershed Case. Presented at Bangkok organized by Environmental Engineering Association of Thailand, Bangkok (EEAT)
WORK EXPERIENCE	Forestry Officer, 01/2015 to current Royal Government of Bhutan - Thimphu Forest Division • Planning and implementation of REDD+ activities, one being BCCAP program (Bhutan Climate Change Adaptation Program). It promotes the agroforestry program

at the local and national level in partnership with local communities and government respectively

- Environmental Impact Assessment and Social Impact Assessment in all the developmental Projects
- Valuation of Environmental Services to promote payment for Environmental Services
- Promote local participation in Forest and environment conservation works
- Beautification of Urban areas and strategic locations with assorted native plant species
- Identify critical watershed areas and their management. Conservation of drinking water sources
- Implementation of Wildlife Conservation programs
- Inspection and curbing of illegal wildlife poaching
- Planning and implementation of soil conservation and land management programs
- Implement Forest Management Plans and prepare Operational Plans in collaboration with the Forest Resources Management Division.
- Liaise with Wildlife Conservation Division, Forest Resource Management Division, Social Forestry Extension Division, and Forest Protection Enforcement Division, prepare management plans for biological corridors including Forest Management Units.
- Management and conservation of biological corridors
- Service delivery in line with Government to Community policy such as processing rural timber, commercial timber, permit for Wood Forest Products, forestry clearance for various developmental activities,
- Provide support for Community Based Natural

Resources Management in collaboration with District Forestry Sector

- Human-wildlife conflict management
- Forest protection against fire and advocate forest values and services to the local community
- Forest protection and surveillance against diseases, pests, illegal felling, and illegal transaction

Forestry Extension Agent, 01/8/2001 to 31/7/2010
Royal Government of Bhutan - Punakha and Wangduephodrang Districts

- Planned and implemented various community forestry and private forestry programs in a rural community to enhance rural livelihood through the sale of forest products
- Helped identify local environmental issues and fix solutions through the consultative workshop
- Planned and implemented various flora and fauna conservation activities
- Local environment conservation and monitoring works
- Provided decentralized forestry services to the rural population
- Efficient natural resource sharing among the local communities by addressing equity issues
- Promote and enhance the use of Non-wood forest products to uplift the rural livelihood
- Planned and implemented afforestation and reforestation works in a degraded and barren land

Deputy Forest Ranger, 01/8/2000 to 31/7/2001

Royal Government of Bhutan - Wanguephodrang Forest Division, Punakha Range

- Managed natural resources in collaboration with local people
- Planned and implemented forest and environment protection measures in selected areas in partnership with local stakeholders
- Planned and implemented watershed management activities
- Planned and implemented afforestation works in marginal and wastelands

Accomplishments:

- Recipient of Royal Civil Service award from His Majesty the King of Bhutan in 2013
- Recipient of Outstanding Extension Agent Award in 2006 for promoting local peoples' participation in natural resources management in partnership with government
- Recipient of the appreciation from Chief Forestry Officer for successfully accomplishing local forest and environment protection works
- Recipient of various appreciations from the University for achieving excellence in academic and attendance