EXPLORING THE WATER RESOURCE SYSTEM AND THE MULTI-FUNCTIONALITY OF DRINKING WATER QUALITY OF THE SAGARMATHA NATIONAL PARK, NEPAL

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BY

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ABSTRACT

THESIS: EXPLORING THE WATER RESOURCE SYSTEM AND THE MULTI-FUNCTIONALITY OF DRINKING WATER QUALITY OF THE SAGARMATHA NATIONAL PARK, NEPAL

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The Sagarmatha National Park (SNP), Nepal is regarded as one of the most beautiful mountain tourism sites in the world. Tourism provides the majority of the capital for the SNP, however, the protected mountain region has experienced negative effects for those capital gains. Corruption and governance issues related to the tourism industry in Nepal have resulted in conflicts regarding environmental cooperation, skewed caste systems, and poor management of natural resources. The basic human rights of the residents and the well being of tourists of the SNP are being infringed upon, as access to clean drinking water is being compromised. This thesis explores the multi-functionality of drinking water as it relates to basic human rights, governance, and environmental policy in the Sagarmatha National Park.

Identifying common drinking water contaminants by assessing the overall drinking water quality in the SNP was the main objective of this study. The second objective of this study was to establish a water quality data set which can be used to create a comprehensive map of water quality for the Sagarmatha National Park region for future studies. The final objective of this study was to review the current environmental policy standards in the SNP, comparing them to international water quality standards and identifying any improvements to policy based on the

research conducted. Understanding the current governance of the SNP and the effects of tourism on the region was important in fulfilling this objective. The outcomes of these three objectives are necessary for providing essential accurate water quality information to the residents of the SNP and the scientific community.

A survey of drinking water sources in the SNP was completed to assess bacterial contamination and its association with tourism. Analysis of fecal coliforms in surface and drinking water sources followed standard U.S. Environmental Protection Agency (EPA) and World Health Organization (WHO) approved methods. Temperature, pH, conductivity, and total dissolved solids (TDS) were measured in the field on the basis of general drinking water quality standards.

Overall, the data we collected presented a predictable correlation between fecal contamination and both decreasing elevation and increasing population/tourist traffic. Drinking water within the study area meets current WHO drinking water standards for temperature (2.8°C - 13°C), pH (5.27 - 7.24), conductivity (17.87 µS - 133 µS) and TDS (7.24 ppm - 65.5 ppm). A total 41 samples were collected for this study: 5 were collected and analyzed for bacteria in May and all tested positive for *E. coli*; 5 of the 36 samples collected and analyzed in November also tested positive for *E. coli*. Samples collected and analyzed in May (pre-monsoon summer) had a higher concentration of *E. coli* and coliform bacteria than samples collected in November (post-monsoon early winter) suggesting a seasonal dependence. Samples from the more populated, lower altitude, areas had higher levels of *E. coli* as well. Physical parameters measured in the field, temperature, pH, TDS and conductivity, decreased with increasing elevation, and proved poor indicators of water contamination.

The data presented in this thesis clearly indicate a significant presence of bacterial indicators of fecal pollution in the surface waters of the Sagarmatha National Park, Nepal. The proper balance of tourism and natural resource management strategies must be a priority as increasing tourist numbers and the influence of climate change will result in poorer drinking water conditions in the SNP.

1. INTRODUCTION

As the backbone of Nepal, the Himalayan Mountain range provides the country's most abundant natural resource: water. Despite water being an abundant natural resource, millions of Nepalese are without access to clean drinking water. Nepal is a nation depending on an income derived from trade and tourism services; 48.7% of the national GDP of Nepal is attributed to the service sector (CIA 2014). Thousands of people travel to Nepal every year, looking to summit Mt. Everest and utilizing the abundant trail systems, and these visitors indirectly contribute to a rising waste management problem. Upon arriving to this culturally rich country, it is apparent there is a need for improved resource management. The country of Nepal produces 2,000 tonnes of solid waste across its 58 municipalities every day, yet it lacks an efficient system to manage that waste (Newar 2013). In Kathmandu Valley garbage chokes the main rivers restricting flow and creating a breeding ground of parasites and disease (Ashbolt 2004; Prasai et al. 2007). Improper disposal of human waste creates an additional and more severe risk of contamination to the Nepali water supplies (WECS 2004; EPA 2009; WHO 2011). Water quality in Nepal varies from the lowland regions to the highlands; however, poor waste management contributes to the detriment of water sources across the country.

This thesis concentrated on drinking water sources in the Sagarmatha (Mt. Everest) National Park. Water sources in the Sagarmatha National Park (SNP) have lower levels of contamination than those in the Kathmandu Valley and the Terai region, however, there is still a harmful amount of fecal pollution; the presence of fecal coliforms, such as Escherichia coli (*E. coli*), encourage pathogenic diseases. Poor sanitation and the lack of sewage and treatment infrastructures create a subsequent problem for the 5,869 people inhabiting the SNP and the thousands of visiting tourists traveling there year round (Ghimire et. al 2013).

Many studies have been done on water quality within the Kathmandu Valley (Sharma et al. 2004; Prasai et al. 2007; Warner 2007), but little research has been done on the water contamination within the SNP. This study is the first qualitative analysis of drinking water sources in the Sagarmatha National Park. The goal of this research was to collect and analyze drinking water samples along the upward Mt. Everest Base Camp trekking route in order to complete a total water quality assessment for the region. Physical parameters analyses, bacterial analyses of *E. coli* and total coliforms, and ion chromatography analyses were completed in order to define contamination parameters.

1.1 The Drinking Water Crisis

In January 2015, the World Economic Forum announced the global water crisis as the #1 global risk (*Figure 1*) based on impact to society (WEF 2015). Higher water temperatures and glacial melting, results of climate change, are only going to exacerbate the problems associated

Figure 1- World Economic Forum 2015 Global Risk Report- Notice water crisis is the number one societal risk based on impact to society. (WEF 2015)

with water quality/quantity issues (Solheim et al. 2010). More than one-third of Earth's accessible renewable fresh water, which is used for agricultural, industrial, and domestic purposes, is being chemically polluted by geogenic sources and natural chemicals such as nitrogen and phosphorous species (Schwarzenbach et al. 2010). Environmental contamination of drinking water sources can spread infectious diseases like cholera, typhoid, hepatitis, dysentery, worms etc. (WECS 2004; EPA 2009; WHO 2011). Harmful anthropogenic materials such as heavy metals, pesticides, and bacterial contaminants increase the deterioration of drinking water quality (WHO 2011). An estimated 80% of all diseases and over one-third of deaths in developing countries are caused by the consumption of contaminated water (Lloyd and Bartram 1991).

Around the world people are facing a crisis due to water pollution and the lack of water and sanitation resources. In Nepal, due to an increasing population, unsanitary disposal of wastes, and poor sanitation practices, many of the water sources are being polluted (Shakya 2009; Ghimire et al. 2010; WaterAid 2011). Open defecation, improper disposal of human wastes, and agricultural practices in most of the rural villages have increased the level of microbiological contamination in the water from streams, springs, and groundwater sources. Water quality problems caused by physical and chemical parameters have large impacts on public health when the concentrations are high. In 2005, Nepal had the lowest coverage rates for improved sanitation of any sub-region within the Asia and Pacific region (ADB 2006). The immediate necessity is to assess water quality, health impacts, and sustainability of the drinking water systems of Nepal.

1.2 Objectives

Identifying common drinking water contaminants by assessing the overall drinking water quality in the SNP was the first objective of this study. Collecting and analyzing known and possible drinking water sources along the main trekking route to Mt. Everest Base Camp (EBC) was the first step in accomplishing this objective. Following protocol and standards implemented by the EPA and the WHO was important for maintaining legitimacy in both the sampling and analysis of drinking water sources. The second objective of this study was to establish a water quality data set which can be used to create a comprehensive map of water quality for the Sagarmatha National Park region for future studies. This map should include water quality data in reference to site characteristics, altitude, differing climatic situations, population, and contamination levels. The final objective of this study was to review the current governance and environmental policy standards in Nepal, comparing them to international water quality standards and identifying the most effective improvements to policy based on the research conducted. These three objectives are necessary for providing essential accurate water quality information to the residents of the SNP and the scientific community, which has never before been accessible.

1.3 Location

Figure 2- Satallite imagery map of Nepal with relation to India and China

This study is located in the Sagarmatha National Park and its defined buffer zone (SNP or SNPBZ) within the Himalayan region of Nepal. Every aspect of Nepal, its economy, history, resources and culture are intrinsically tied to the Himalayan Mountains. The Himalayan Mountain Range was formed as a result of a continental collision of the Indian Plate with the Eurasian Plate about 50 million years ago (Searle et al. 2003). Nepal remains an active seismic zone characterized by frequent earthquakes, occasionally devastating the densely populated metropolitan areas such as the capital city of Kathmandu (e.g. April 2015). Nepal's landscape is divided into three sections based on elevation: The Himalayan region (4,877- 8, 848 m), the middle hilly region (600-4877 m), and the Terai region (100-300 m) (Mayhew et al. 2012). The Terai region of Nepal consists of the flat, lowland plains, whereas the middle hilly region is where the majority of Nepal's major cities are located, including the capital city of Kathmandu. The Himalayan region displays Nepal's highest altitudes including Mt. Everest (Sagarmatha), the highest mountain peak in the world, located within the SNP. Mountain ecosystems, such as found in the SNP, are among the most fragile in the world and are under severe threat from climate change, globalization, urbanization, and other anthropogenic pressures (Ning et al. 2013). Rapid urbanization in developing regions places further stress on inadequate water supplies and sanitation (Ashbolt 2004). Rapid urbanization in Nepal is complimented by the large influx of tourists which travel to the Himalaya annually.

Figure 3- Location map of Sagarmatha National Park and buffer zone

The SNP is located in the southeastern part of the Nepali Himalaya on the southern slope of Mt. Everest (*Figure 3*). The SNP is approximately 140 km due east of Kathmandu, characterized by rugged topography, and covers 1,148 km^2 ranging in altitude from 2,845 m in Jorsalle to 8,848 m at the peak of Mt. Everest (Ghimire et al. 2013). Precipitation inputs to the SNP are highest in the summer monsoon season (June–September), accumulating 75–85 % of the annual precipitation (McDowell et al. 2013; Sharma et al. 2005). Precipitation also occurs during the winter months (January–March) due to the orographic forcing of mid-latitude westerlies (Lang and Barros 2004). Although local precipitation patterns vary with elevation and topography, the region as a whole is considered to have relatively high annual precipitation inputs of 500–2,500 mm, depending on elevation (Salerno et al. 2008; Thapa and Shakya 2008).

Conditions in Nepal are likely to modify as a response to climate change; USAID ranked Nepal as the 14th country in the world for vulnerability to climate change (Taylor 2014). The current trends in climate change will increase pressure on biodiversity, land use, forest health and quality, and water resources. Climate change has already begun affecting monsoon pat-

Figure 4a- Woman washing clothes in a community water source (also used for drinking water purposes). **Figure 4b**- Drinking water piped from above along the trekking path which receives a large amount of human and animal traffic. (Photo credit: Emily Hayes)

terns, water availability and quantity, the occurrence of droughts and floods, and changes in water tables and freshwater storage in glaciers (Taylor 2014).

Drinking water in the SNP is supplied by the southward flowing surface waters, and especially, spring waters. Three main rivers flow through the region from north to south: Dudh Koshi, Bhote Koshi, and Imja Khola. Dudh Koshi originates from the Ngozumpa glacier, Imja Khola from the Khumbu glacier, and Bhote Koshi originates in Tibet and meets the Dudh Koshi below the market town of Namche Bazaar (Ghimire et al. 2013). There are several tributaries in the region feeding these three main rivers; however, river water is not regularly used for human consumption. Throughout the region, water for household uses (e.g., drinking water, cooking, personal hygiene) is piped from nearby streams and springs to community access points from which residents collect water (McDowell et al. 2013); in 2011, 88.8% of household water sources were tapped or piped in this manner (CBS 2011). According to the Khumbu Local Adaption Plan of Action, a combination of changing precipitation patterns, the drying up of springs, and new tourism imposed water demands for flush toilets and showers are quickly depleting freshwater supplies in villages along the main trekking routes in the SNP (USAID 2014).

1.4 Background

1.4.1 *Water Contaminants*

Environmental contamination of drinking water can spread infectious diseases such as cholera, typhoid, hepatitis, dysentery, worms etc. (WECS 2004; EPA 2009; WHO 2011). An estimated 80% of all diseases and over one-third of deaths in developing countries are caused by the consumption of contaminated water (Lloyd et al. 1991). The World Health Organization recognizes health-based targets as an essential component of the drinking water safety framework; these targets provide a basis for the application of the guidelines to all types of drinking water supplies (WHO 2011). According to the drinking water safety framework, contaminants such as pathogenic microorganisms may cause adverse health effects from a single instance of exposure (WHO 2011). The Environmental Protection Agency has implemented a set of Primary Drinking Water Regulations (PDWR) to legally enforce standards for public water systems within the United States. Drinking Water Standards employed by the WHO and the EPA are not legally recognized in Nepal but should be considered for reference as they are the leading regulatory standards in protecting public health in the United States and around the globe. No water quality monitoring is completed on a systematic basis in Nepal due to the lack of a monitoring network (Sharma et al. 2005). The EPA Standards for drinking water along with the WHO Guidelines for Drinking Water Quality are used as points of reference for this study as a basis for water quality parameters. These regulations aim to monitor drinking water supplies and reduce the levels of contaminants such as: microorganisms, disinfectants, disinfectant byproducts, inorganic chemicals, organic chemicals, and radionuclides (EPA 2015). Along with the list of contaminants, the EPA states Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs) which define the amount of contaminants allowable in public drinking water sources in the United States. Among the contaminants listed in the PDWR are pathogenic disease causing organisms such as total coliforms and *Escherichia coli* (*E. coli*). McLellan et al. (2001) stated that contamination by fecal pollution is a serious public health concern. Due to the difficulty of monitoring for pathogens directly, indicator organisms such as E. coli may be more efficient fecal pollution verifiers (McLellen et al. 2001; Farnleitner et al. 2010; Sati et al. 2011). *E. coli* bacteria are defined by the Centers for Disease Control and Prevention (CDC) as bacteria normally living in the intestines of mammals; *E. coli* are normally harmless and play a part in a healthy human intestinal tract (CDC 2014). Fecal coliforms and *E. coli* are often analyzed to indicate that water may be contaminated by human or animal wastes (EPA 2015). Pathogens in these wastes can cause short term effects such as diarrhea, cramps, nausea, headaches, or other symptoms and pose a special health risk for infants, young children, and people with severely compromised immune systems (CDC 2014).

Commonly known waterborne pathogens are of concern in developing nations such as Nepal. Environment, water, food, and poor hygiene are all important factors in the fecal to oral transfer route of infectious pathogens (WHO 2003). Ashbolt (2004) states that by 2001 the World Health Organization (WHO) had recorded a total of 1,415 species of infectious pathogenic organisms. Typical *E. coli* strains are a leading cause of infantile diarrhea in developing countries. According to Ansari et al. (2012) it is estimated that 25% of child mortalities are associated with diarrheal disease. Ansari et al. (2012) explains that diarrheal disease remains one of the largest health problems in many parts of the world. The disease is often mild, but the symptoms can be very severe for young children and the elderly. Diarrheal disease occupied the second place among the diseases in Nepal (Ansari et al. 2012). Sharma et al. (2004) conducted a study of 533 schoolchildren in the northeastern part of the Kathmandu Valley, Nepal. Fecal samples were taken from children 1-19 years of age in clean, dry, screw capped, and properly labeled plastic containers. Of the 533 school children, 355 (66.6%) had some kind of parasitic infection (Sharma et. al 2004). Of all the parasites and bacteria tested, *E. coli* was detected as the most common protozoa pathogen (Sharma et al. 2004). Another study of school children, at the Khumjung School located within the SNP, revealed that poor waste management resulted in 37% of students suffering from either a protozoan or helminthic parasitic infection (Lachapelle 1998). The localized presence of bacteria and parasites in schoolchildren justifies the necessity of research regarding water resources and waste management in the SNP.

Drinking water sources in the SNP may also be at risk of chemical contamination. Potential sources of chemical contamination in the Himalaya include introduced agricultural fertilizers and cold trapping of persistent organic pollutants (POPs) in snow and glaciers (Loewen et al. 2005; Gong et al. 2010; Ghimire et al. 2013). Loewen et al. (2005) explains cold trapping as an effect that happens as volatilized POPs are transported through the atmosphere, condense in colder regions, and get trapped in ice and snow deposits. Ghimire et al. (2013) analyzed the physical and chemical characteristics of water samples in the SNP to identify sources of pollution linked to human waste and use of agricultural fertilizers. The results of the study showed an increasing trend of chemical contamination over the three-year sampling period (Ghimire et al. 2013). This increase in chemical pollutants suggests an increase in the use of fertilizers which will degrade the surface water sources of the SNP.

The EPA (2015) defines POPs as "intentionally produced chemicals currently or once used in agriculture, disease control, manufacturing, or industrial processes". Examples of persistent organic pollutants include PCBs, which have mainly industrial uses and DDT, which is still used to control mosquitoes that carry malaria in some parts of the world (EPA 2015). The Nepal Himalaya is situated between China and India, the two most populous countries in the world. Due to their high population density, it is known that these two countries create high emissions of air pollutants and high usage of pesticides such as DDT (Loewen et al. 2005). In 1989, India banned the use of DDT for agricultural purposes, but continues to use between 5,000 and 10,000 kg/year for malaria control (Santillo et al. 1997; Loewen et al. 2005). According to the EPA, DDT can take more than 15 years to break down in the environment and is known to cause harmful effects such as damage to the liver, nervous, and reproductive systems and is a probable human carcinogen (EPA 2011). People who inhabit the Himalaya and surrounding areas generally rely on snowmelt and glacially fed rivers and streams for drinking water purposes. During warmer months, semi-volatile POPs that are trapped in glaciers and snow are released into the surface waters via meltwater transportation; this remobilization of POPs can contaminate drinking water sources for thousands (Loewen et al. 2005). Loewen et al. (2005) focused on collecting and analyzing soil samples for evidence of POPs. The results of that study revealed that a lake in the Solu Khumbu, at 5,067m, presented trends of cold trapping effects of pollutants. As malaria is not an issue in the high altitudes of the SNP, finding positive levels of POPs in Khumbu water sources suggests pollution by cold trapping of these chemicals and transportation through meltwater.

1.4.2 *Similar Studies*

Similar studies have been completed for other high altitude tourist destinations regarding drinking water quality; these studies are useful comparisons for this thesis as there have been few drinking water surveys completed in the SNP. Warner (2002) conducted research in the Annapurna Conservation Area (ACA) in the Western Himalayas of Nepal. The ACA mirrors the SNP in terms of tourism influence, ecology, climate, and socioeconomic parameters. Twenty-six different water sources were sampled and analyzed in the ACA along the main tourist trekking route. Most of the samples were taken from springs which were then piped down to the town's drinking water distribution system. The results of this study revealed that 94% of the samples were contaminated with total coliform bacteria and 72% were contaminated by *E. coli* bacteria, both of which are indicators of sewage contamination (Warner 2002). Warner continued research in 2007, focusing on the drinking water quality in Kathmandu Valley (Warner et al. 2007).

Although other water surveys have been completed for the main rivers and streams of the region (Manfredi et al. 2010; Ghimire et al. 2013), this is the first survey of its kind to focus exclusively on the drinking water sources within the townships of the Sagarmatha National

Park (SNP). Manfredi et al. (2010) completed a comprehensive water quality survey of the SNPBZ. The survey included collecting 104 surface water samples from streams, rivers, and the Gokya, Imja, and Pyramid Inferior Lakes (Manfredi et al. 2010). The samples were analyzed for physical parameters (temperature, pH, conductivity, and total dissolved solids), nutrients such as nitrogen and phosphorus, and microbiological parameters of total and fecal coliforms (Manfredi et al. 2010). Manfredi et al. found that nutrient levels for nitrogen were within the WHO and Nepali drinking water guidelines, however some river samples had phosphorus level which exceed the USEPA standards. Fecal coliform contamination was found in water sources that were obtained near Namche Bazaar's waste dumping site; this result was one of 6 sampling points in the SNPBZ that had elevated levels of fecal coliform bacteria (Manfredi et al. 2010).

Ghimire et al. (2013) conducted a survey similar to that of Manfredi et al. (2010) in which 135 surface water samples from the main rivers and tributaries in the SNPBZ were analyzed for microbiological parameters of *E. coli* and *Streptococcus faecolies*. Ghimire et al. (2013) revealed positive concentrations of bacterial contamination (both *E. coli* and *Streptococcus faecolies*) in the analyzed surface water sources. The presence of fecal coliforms in surface waters supports a continuing trend of bacterial indicator pollution of drinking water in the SNPBZ.

Kedrowski (2012) conducted a study in which he sampled from 6 water sources in the Upper Khumbu region that includes Mt. Everest Base Camp. The samples were treated with a coliform indicator and used the most probable number method to quantify amounts of *E. coli* bacteria. All the samples analyzed contained amounts of *E. coli* bacteria (Kedrowski 2012). This study expands the known bacterial contamination to the higher altitude regions in the Khumbu and supports a correlation between water contamination and increasing tourism numbers. Goodwin et al. (2012) conducted a study similar to Kedrowski (2012) in Denali National Park, Alaska. The study focused on the transport of human waste along the Kahiltna Glacier system to answer whether fecal pathogens were present on the glacial surface, within the glacial ice itself, or downstream in the Kahiltna River (Goodwin et al. 2012). Over the period of 15 months several field surveys were conducted in which snow, ice, and water samples were taken along the Kahiltna Glacier; 65 samples were analyzed for mammalian fecal indicators of total coliforms, *E. coli*, and fecal enterococci to determine the presence and persistence of fecal contamination (Goodwin et al. 2012). Results of the study revealed contamination levels increased from pre-climbing season to post-season in both snow and water samples; fecal contamination was greater on ice and snow surfaces and minimal in water samples taken from the Kahiltna River (Goodwin et al. 2012). Goodwin et al. (2012) suggests that pathogenic bacterium of human waste is persistent in glacial environments and may pose increased risks to human health as global temperatures increase glacial melting.

Posch et al. (2015) collected water samples from springs and fountains in Namche Bazaar and Khumjung as part of a waste management assessment of the SNP. The study analyzed water sources that were used for drinking water purposes as part of an all encompassing survey of waste management in the SNP. Results of the study show that several springs and streams had high concentrations of nitrates (NO_3) and phosphates (PO_4) especially in the SNP buffer zone where these chemicals are often used as fertilizers (Posch et al. 2015).

2. MATERIALS AND METHODS

Research Note: High-altitude field work can be complicated and difficult; this research study is no exception to that statement. Field work completed in May was halted by illnesses preventing our group from continuing past the town of Namche Bazaar; this resulted in a smaller set of data than intended at the conception of this project. Bacterial analysis was completed on only five water samples in May as a result of this interruption. As a result of colder conditions in November, re-sampling many locations was not possible, as some springs were no longer flowing.

2.1 Sampling

Figure 5a- Sample taken in Whirlpak bag in front of water source for drinking and washing clothes.(Photo credit: Emily Hayes) **Figure 5b**- Analyzing water samples in the field for physical parameters using a FisherSci Ap85 portable meter. (Photo credit: Kirsten Nicholson)

A quality assurance project plan was created to insure the accuracy of the field measurements taken. Data was carefully processed in order to accurately assess contamination levels of the drinking water. Temperature, pH, conductivity and total dissolved solids (TDS) were measured in the field using standard Hach® surface water testing kit and FischerSci Ap85 pH/conductivity meter 13-636-AP85 (*Figure 4b*). Measurements were taken after waiting at least 5 minutes for the meter to stabilize to insure accurate readings for temperature and pH.

Measurements for temperature, pH, conductivity, and TDS were obtained by rinsing a Nalgene bottle twice with the source water before taking the measurements. Samples taken for bacterial analysis were collected in sterile Hach® Whirl-pak bags and stored at temperatures below 20°C prior to analysis. All samples taken in Whirl-pak bags were labeled with the corresponding

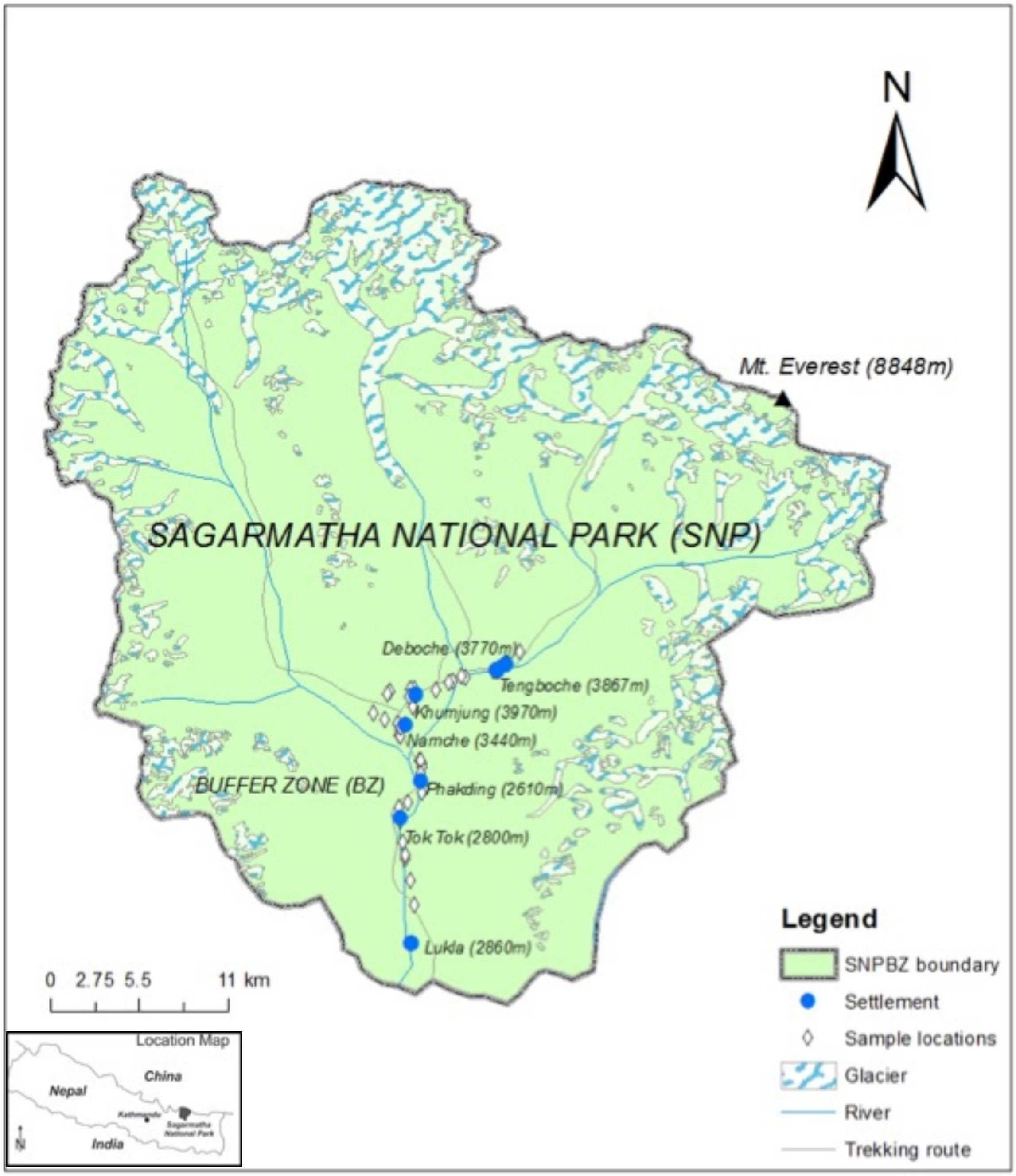

Figure 6- Sample location map of Sagarmatha National Park and Buffer Zone (SNPBZ).

date, sample name (EBC- Everest Base Camp) and number (example: EBC08Oct14-21) (*Figure 4a)*. Samples were taken from flowing water sources only and were collected mid-flow to reduce sediment levels in samples.

Sampling began on May 5, 2014 at an altitude of 2,702 meters above sea level. Sixteen water sources were sampled over the next three days and analyzed for physical parameters such as pH, temperature, conductivity, and total dissolved solids (TDS). Five out of the 16 samples were chemically analyzed for ammonia-nitrogen, orthophosphate, and nitrate-nitrogen. After the required 24-hour incubation period in Namche Bazaar, 5 out of the 16 samples were analyzed for bacterial contamination (not necessarily the same samples which were chemically analyzed). This three-day sampling period was the initial trial for all equipment and analysis methods in the field. The second sampling trip began on October 31, 2014. Nine days in the field produced 37 samples which were analyzed for both physical parameters and bacterial contamination. Samples were collected at the lowest elevation of 2,602 meters at the Ghatte Khola (river) and at the highest elevation of 3,891 meters at the school in Khumjung (spring-fed standpipe). Sampling both before and after the annual monsoon season was important in developing any seasonal climatic contributions to drinking water contamination within the Sagarmatha National Park.

2.2 Physical Parameters

Testing the physical and chemical parameters of the water is necessary in determining the acceptability of water for drinking purposes. The *WHO International Standards for Drinking-Water* (WHO 1958) identify certain chemical substances affecting the potability of water. Criteria such as pH range, total dissolved solids, turbidity, and heavy metal concentrations are important in assessing the potability of water. These limiting concentrations are only indicative of contamination and can be disregarded in specific instances (WHO 1958).

CHEMICAL AND PHYSICAL REQUIREMENTS

	Permissible	*Excessive*
Total solids	500 mg/l	1500 mg/l
Colour	5 units *	50 units *
Turbidity	5 units **	25 units **
Taste	unobjectionable	—
Odour	unobjectionable	—
Iron (Fe)	0.3 mg/l	1.0 mg/l
Manganese (Mn)	0.1 mg/l	0.5 mg/l
Copper (Cu)	1.0 mg/l	1.5 mg/l
Zinc (Zn)	5.0 mg/l	15 mg/l
Calcium (Ca)	75 mg/l	200 mg/l
Magnesium (Mg)	50 mg/l	150 mg/l
Sulfate (SO_4)	200 mg/l	400 mg/l
Chloride (Cl)	200 mg/l	600 mg/l
pH range	7.0-8.5	Less than 6.5 or greater than 9.2
Magnesium + sodium sulfate	500 mg/l	1000 mg/l
Phenolic substances (as phenol)	0.001 mg/l	0.002 mg/l

Figure 7- List of chemical and physical requirements for the acceptibility of water for drinnking purposed. (World Health Organization 1958)

Groundwater in Nepal is at risk from contamination of sewage-sourced pathogenic bacteria, pesticides, nitrates, and industrial effluents (Sharma et. al 2005). The United States Environmental Protection Agency (EPA) lists these elements as Primary Drinking water contaminants and has set a standard of Maximum Contaminant Levels (MCLs) which if exceeded, deem the water source as unsuitable for human consumption (EPA 2009). The bacterial contamination of the drinking water for the SNP has been addressed in this study, however, the issue of non-bacterial contamination must be explored in the future to completely assess the quality of the water sources as it relates to agricultural pesticides.

2.3 Bacterial Analysis

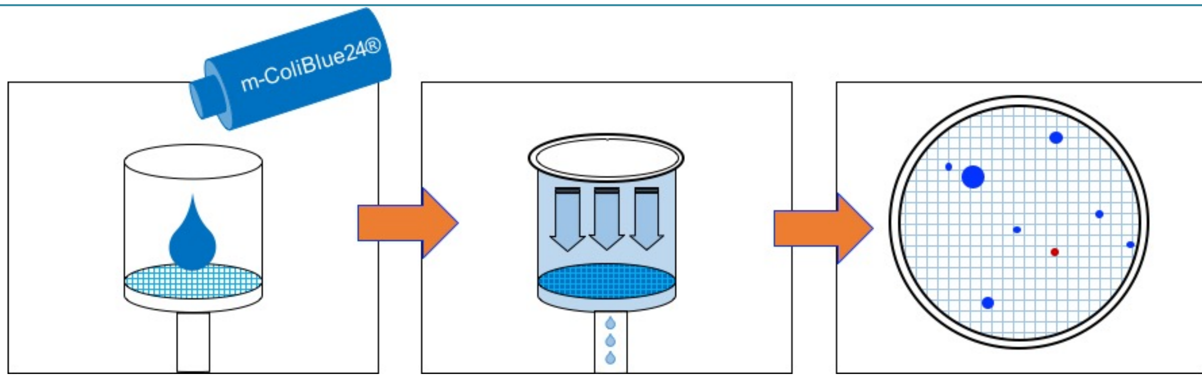

Figure 8- Membrane Filtration method for bacterial analysis of drinking water

Standard fecal indicator bacteria (SFIB) have been evaluated as applicable analysis methods to address mammalian fecal contamination of alpine mountainous water supplies (Edberg et al. 2000; Farnleitner et al. 2010) Analysis of fecal coliform in surface and drinking water follows the EPA approved method 9222D in Standard Methods (APHA 1998). Bacterial analysis was conducted by using the membrane filtration method (*Figure 7*). Water samples were collected in sterile 100 mL Whirl-pak bags containing a 10 mg sodium thiosulfate non-nutritive pill and labeled with the sample number. Fecal coliforms are the indicator of choice for revealing mammalian fecal contamination in water sources (Edburg et al. 2000, Farnleitner et al. 2010; Amoruso 2011). *E. coli* and coliform bacteria were analyzed using a standard Hach® portable water test kit; *E. coli* is the most abundant representative of fecal coliforms, therefore, the best candidate for analysis (Amoruso 2011). Samples were filtered through sterile .45 micron filters using a hand vacuum pump. Each filter was previously treated with coliform-indicating Hach® m-ColiBlue24® broth medium in order to visually identify *E. coli* and coliform bacterial colonies.

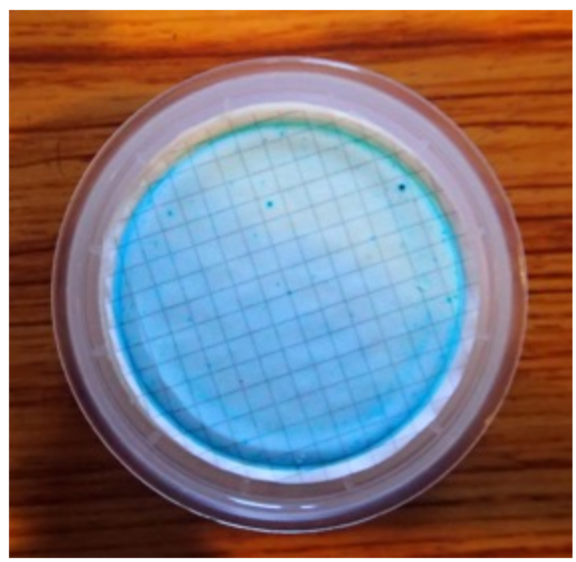

Figure 9- *E. coli* coliform bacteria colonies indicated by royal blue colored spots on the .45 micron filter. (Photo credit: Kirsten Nicholson)

After pre-treating the filters and pumping the sample through, all samples were placed in a Hach® portable field incubator at 35°C ± 0.5°C for 24 hours. After the 24-hour period, royal blue *E. coli* colonies and crimson red coliform colonies were counted using a magnifying glass and 10x geological hand lens. Each sample was analyzed by more than one person in order to preserve accuracy of the data. All data was recorded in a field notebook, a master electronic data file, and backed up on multiple locations.

3. DATA AND RESULTS

Samples were collected during the months of May and November from known drinking water sources at 27 different locations. Sample locations were chosen based on parameters such as proximity to settlements, function of source, accessibility, and apparent water flow. Some sample locations from May were resampled during November in order to determine a seasonal correlation.

Date	Sample #	Source	Northing	Easting	Altitude (m)	*E. coli* colonies	pH	Temp (°C)	Conductivity (µS)
5/8/14	EBC08MAY14-1	flowing standpipe	27.42264	86.43132	2702	n/a	6.37	12.4	133
	EBC08MAY14-02	surface water	27.71835	86.71604	2563	n/a	6.56	11.7	44.8
	EBC08MAY14-03	surface water	27.73057	86.7138	2607	n/a	6.79	12.9	49.7
	EBC08May14-04	flowing stand pipe	27.7323	86.71326	2615	n/a			
5/9/14	EBC09MAY14-05	surface water	27.75193	86.71057	2602	n/a	6.27	10.4	53.8
	EBC09MAY14-06	surface water	n/a	n/a	2650	n/a			
	EBC09MAY14-07	surface water	27.75913	86.71003	2700	n/a			
	EBC09MAY14-08	surface water	27.76195	86.71467	2700	n/a			
	EBC09MAY14-09	surface water	27.76969	86.72402	2800	n/a	6.57	12	39.3
	EBC09MAY14-10	surface water	27.78205	86.72275	2810	n/a	6.47	10.3	17.87
	EBC09MAY14-11	surface water	27.78375	86.72253	2843	n/a			
	EBC09MAY14-12	surface water	27.7855	86.72172	2850	n/a			
5/10/14	EBC10MAY14-13	spring fed faucet	27.7996	86.71024	3350	n/a	6.75	12.1	58.3
	EBC10MAY14-14A	spring fed faucet	27.80255	86.71085	3440	5			
	EBC10MAY14-14B	spring fed	27.80255	86.71085	3440	261	6.37	8.8	67.6
	EBC10MAY14-15	spring fed stream	27.81528	86.7179	3440	241	7.24	8.8	57.5
	EBC10MAY14-16	spring fed	27.80636	86.70947	3440	78			
10/31/14	EBCOct14-01	surface water	27.78202	86.72281	2810	5	6.42	7.2	31.7
	EBCOct14-02	surface water	27.78549	86.72177	2843	0	6.49	6.4	14.5
	EBCOct14-03	surface water	27.79905	86.71065	3370	3	7.17	10.5	60.7
11/1/14	EBCOct14-04	surface water	27.81167	86.69595	3546	n/a	6.88	9.7	21.8
	EBCOct14-05	spring fed	27.80806	86.70241	3586	n/a			
	EBCOct14-06	spring fed	27.80634	86.70947	3512	0			
	EBCOct14-07	spring-fed stream	27.80413	86.7103	3426	7	6.53	9.4	55.4
	EBCOct14-08	Namche Coffee Shop tap	27.81528	86.71790	3440	23			
	EBCOct14-09	Holiday Namche kitchen tap	27.81528	86.71790	3440	0	6.56	12.9	61.1
	EBCOct14-10	spring fed	27.80255	86.71085	3440	0	6.75	9.7	62.7
	EBCOct14-11	spring fed	27.80255	86.71085	3440	0	6.82	9.6	58.6
11/2/14	EBCOct14-12	surface water	27.8458	86.77763	3466	n/a	6.54	6.3	29.7
	EBCOct14-13	spring fed	27.83992	86.77145	3728	n/a	6.25	5	15.25
11/3/14	EBCOct14-14	spring fed	27.83969	86.7702	3762	n/a			
	EBCOct14-15	spring fed	27.83662	86.76598	3842	0	5.27	2.8	57
	EBCOct14-16	spring fed	27.83558	86.76459	3864	0			
	EBCOct14-17	spring fed	27.83558	86.76459	3864	0			
	EBCOct14-18	spring fed	27.83511	86.76278	3812	0			
	EBCOct14-19	spring fed	27.83216	86.74734	3852	0	7.23	7.6	56.6
	EBCOct14-20	surface water	27.83233	86.74473	3891	n/a			
	EBCOct14-21	spring fed	27.82983	86.73985	3444	n/a	7.01	13	34.4
	EBCOct14-22	spring fed	27.82897	86.73801	3482	0			
	EBCOct14-23	kitchen tap	27.82503	86.73041	3521	0			
	EBCOct14-24	kitchen tap	27.82569	86.71862	3660	0			
	EBCOct14-25	spring fed	27.82509	86.71645	3764	0	6.74	8.1	21.3
	EBCOct14-26	spring fed	27.82368	86.70473	3870	0	6.47	10.1	15.17
	EBCOct14-27	spring fed	27.82291	86.70359	3886	0	6.71	8	16.64
	EBCOct14-28	spring fed	27.82082	86.71576	3891	0	6.55	9.2	21.2
11/5/14	EBCOct14-29	kitchen tap	27.77805	86.72196	2815	0			
	EBCOct14-30	spring fed	27.7733	86.72262	2870	0			
	EBCOct14-31	surface water	27.76991	86.72401	2908	1			
	EBCOct14-32	spring fed	27.76742	86.72296	2896	3			
	EBCOct14-33	surface water	n/a	n/a	n/a	3	6.86	11.9	21
	EBCOct14-34	spring fed	27.75175	86.71042	2688	9	6.26	12.9	31.2
	EBCOct14-35	kitchen tap	27.7396	86.71194	2610	0			
	EBCOct14-36	spring fed	27.73231	86.71326	2610	1			
	EBCOct14-37	bathroom tap	n/a	n/a	2849	n/a			
11/6/14	EBCOct14-38	kitchen tap	n/a	n/a	2860	0			

Table 1- May 2014 and November 2014 data

3.1 Physical Parameters Results

Drinking water sources within the Sagarmatha National Park presented physical properties of temperature (2.8°C – 13°C), pH (5.27 - 7.24), conductivity (17.87 µS - 133 µS) and TDS (7.24 ppm - 65.5 ppm); all samples meet current WHO (2011) drinking water standards for physical parameters. Water samples also met aesthetic acceptability standards for drinking water potability (WHO 2011). Physical parameters such as pH, temperature, total dissolved solids and conductivity aid in determining the acceptability of drinking water but are not directly indicators of water contamination; the WHO Guidelines for Drinking Water Quality explains that the temperature of the drinking water source does not have specific acceptability limits, however, warmer temperatures will increase chances for microbial growth, taste, odor, and color (WHO 2011). Fecal coliform presence proved to be the most accurate indicator of contamination in this study.

3.1.1 *pH*

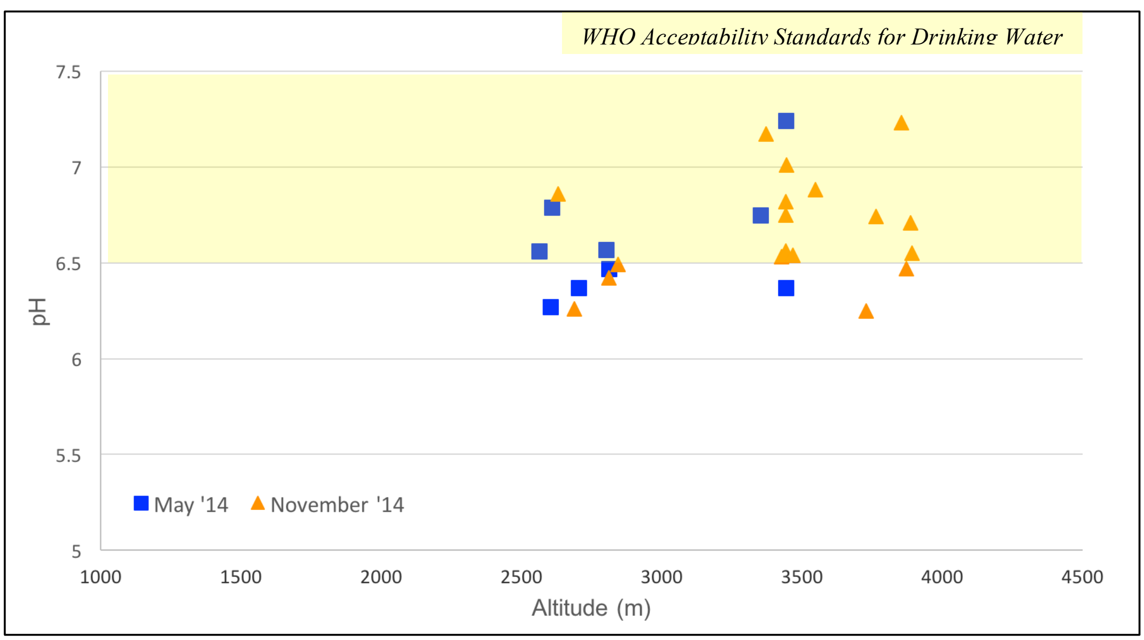

Figure 10- pH values plotted with reference to altitude of sample location; Samples taken in May 2014 are identified by the black squares and grey triangles are identifying samples taken in November 2014

The pH values ranged between 5.27 and 7.24 with an average of 6.60. The observed pH values for drinking water are mostly within the permissive limit pH (6.5 - 8.5), as prescribed for the drinking water by the World Health Organization WHO (2011). One sample was taken around sunrise from a still pool in Tengboche and is the only outlier with a pH of 5.27. *Figure 10* shows the results of pH analyses, omitting the outlying 5.27 sample. The samples collected in May had a pH range of 6.27 to 7.24 with an average of 6.61, whereas, the November samples range from 6.25 to 7.23 with an average of 6.68. Overall, the majority of samples (omitting the outlier) remained within the acceptable range for pH and did not affect drinking water quality.

3.1.2 *Temperature*

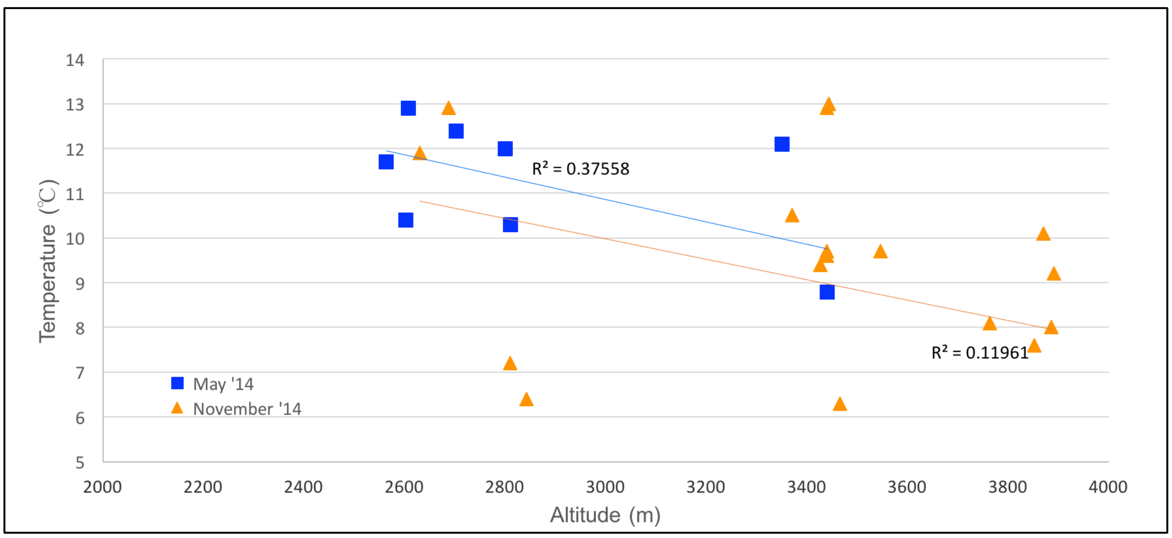

Figure 10- Temperature values plotted in reference to altitude of sample location. The black squares indicate samples taken in May 2014; November 2014 samples are indicated by grey triangles

Temperatures values ranged between 2.8 ºC and 13 ºC with an average of 9.63 ºC. The samples collected in May were on average 2.06 ºC warmer than the samples collected in November. The samples collected in May ranged between 7.2 ºC and 12.9 ºC with an average of 11.04 ºC, whereas, the samples collected in November ranged between 2.8 ºC and 13 ºC with an average of 8.96 ºC. The lowest temperature recorded (2.8 ºC) was taken in November from Tengboche.

This sample is the same sample collected from a shallow collection pond downhill from the Tengboche Monastery that presented our outlying pH value. The air temperature was approximately -5 ºC and most likely affected the temperature of the sample collected. As expected, the

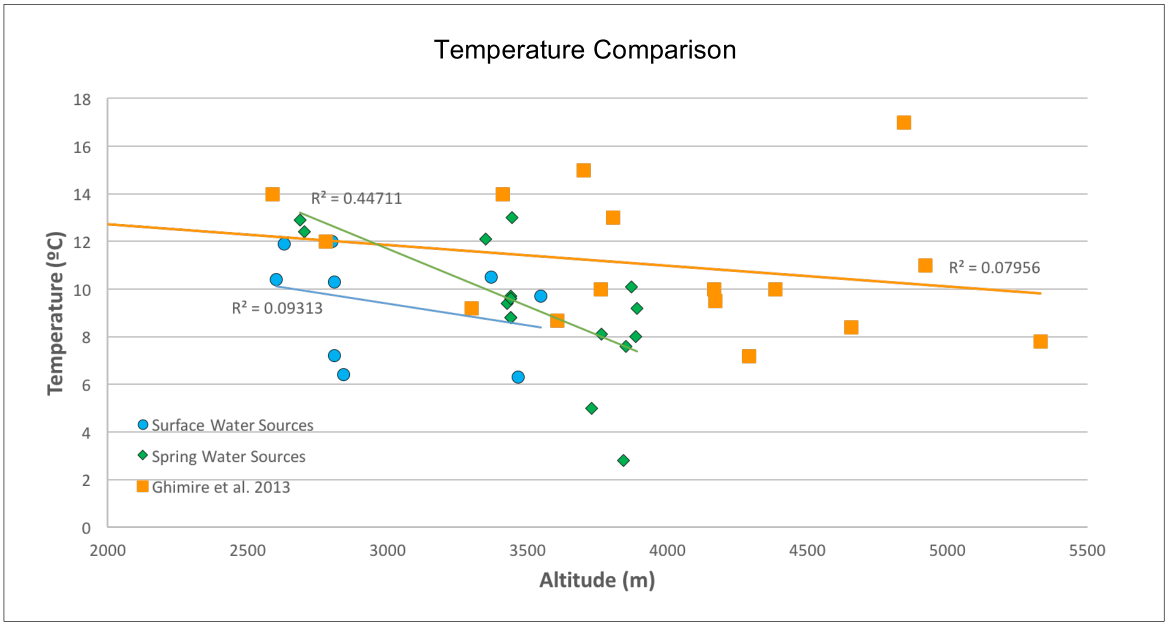

Figure 11- Temperature trend from this study plotted along temperature measurments of Ghimire et al. (2013). Both data sets reveal deacreasing temperatrue trends with an increase in altitude.

temperatures decreased with altitude.

When comparing the results of this study (*Figure 11*), separated by source, with that of Ghimire et al. (2013) we can see distinct temperature profile similarities in the surface water trends. It is also clear that the temperature profile for the spring sourced water samples is distinctly separate from the surface water trends. The R^2 values for both trends also show that the spring water sources are more statistically dependable than the surface water sources.

3.1.3 *Conductivity/TDS*

The range in TDS in the samples is relatively small; the TDS measurement for all samples range between 7.24 ppm and 65.50 ppm with an average TDS measurement of 21.27 ppm.

Samples taken in May have a slightly higher average (28.46 ppm) than the average of the samples collected in November (17.86 ppm). The WHO guidelines for drinking water (2011) suggest that drinking water should contain less than 600 ppm TDS; the drinking water analyzed in this study remained within that recommended limit. When analyzing for conductivity, the average value for both sets of data is 43.14 µS. Samples collected in November had lower con-

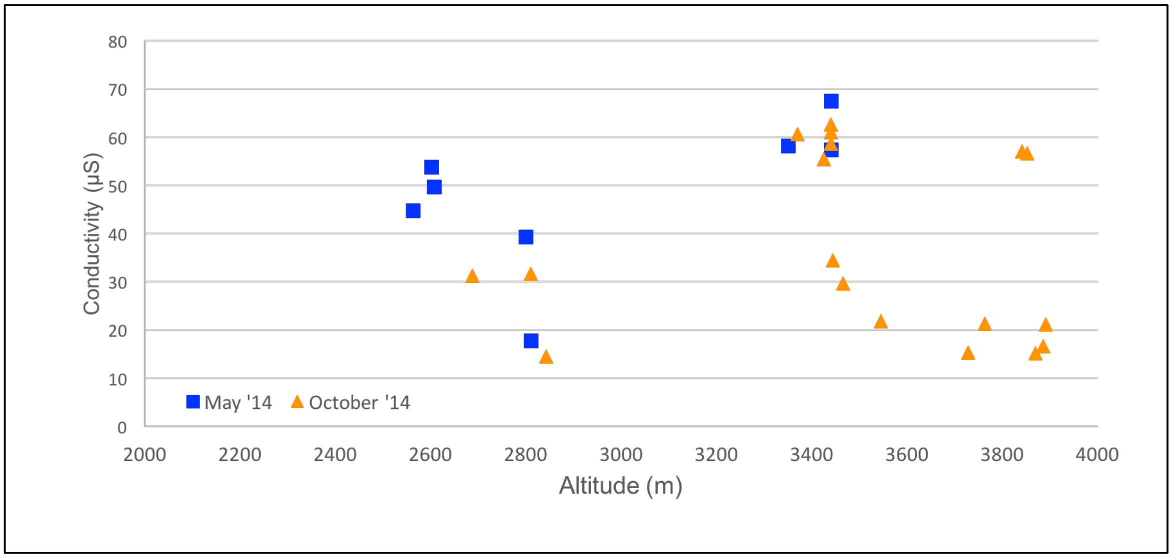

Figure 12- Conductivity readings of water samples plotted in reference to altitude. The black squares indicate samples taken in May 2014; November 2014 samples are indicated by grey triangles

ductivity with an average of 36.10 µ whereas the samples collected in May had higher values, ranging between 17.87 µS and 133 µS with an average of 57.99 µS.

3.1.4 *Physical Parameters Comparison by Source*

The data displayed in *Figure* 13 shows the results of all four physical parameter analyses separated by spring and surface water sources. Distinct trends can be seen between surface water sourced samples and those supplied by spring water sources. Spring water sources had on overall decreasing trend with an increase in altitude for the physical parameters of temperature, conductivity, and TDS. Both surface and spring water sourced drinking waters displayed an increase in pH with an increase in altitude. The data also shows distinct lower altitude (below 3000 m) and higher altitude (3400 m-4000 m) trends for all physical parameters data.

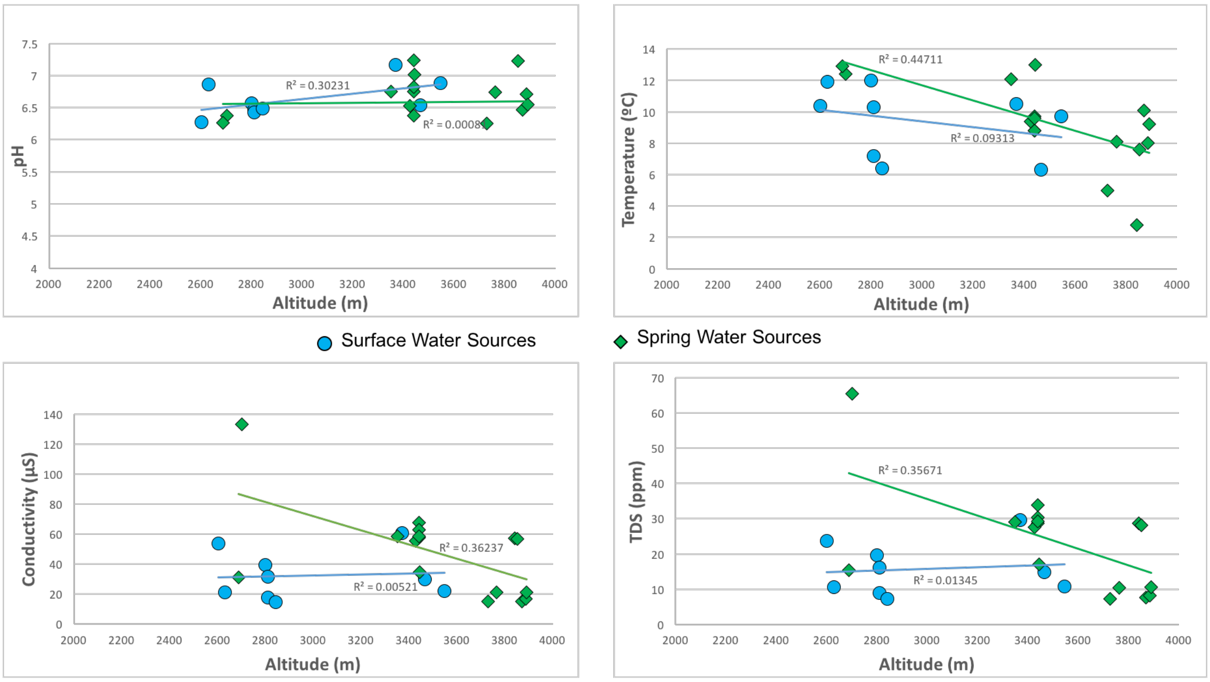

Figure 13- Physical parameters data separated by source. Blue circles indicate surface water sourced drinking water samples; green diamonds indicate spring water sourced drinking water samples

3.2 *Bacterial Analysis Results*

The samples analyzed for bacterial contamination in November 2014 had fewer counts of coliform bacteria and *E. coli* colonies than the samples from May 2014; this suggests a seasonal dependence between amount of rainfall and bacterial contamination. During the dryer season in May, more bacteria were detected in the water than in November, which is subsequent to the monsoon season.

In November, the coffee shop in Namche Bazaar had the highest concentration of *E. coli* colonies in their water at 24 colonies/100mL of sample. Having a high concentration of bacterial contamination in a public café is dangerous to the health of its patrons; water samples known to have contamination from *E. coli* bacteria, may also be vulnerable to other species of waterborne pathogens and parasites.

VDC	Population of VDC / # of Households	Township/Location	Altitude	# of E. Coli Colonies/ 100mL	Households/Teahouses
Chaurikharka	3709 / 968	Tok Tok	2688	9	32
		Benkar	2720	3	41
		Monjo	2810	5	42
		Jorsalle	2896	3	30
Namche	1540 / 480	Namche Bazaar Checkpoint	3370	3	238
		Namche Bazaar Stream Fed Spring (on route to Thame)	3426	7	238
		Namche Coffee Shop	3440	23	238
		Namche Bazaar Water Supply (spout A)	3440	5	238
		Namche Bazaar Water Supply (spout B)	3440	261	238
		Namche Bazaar Stream	3440	241	238
		Namche Bazaar NW Spring	3440	78	238

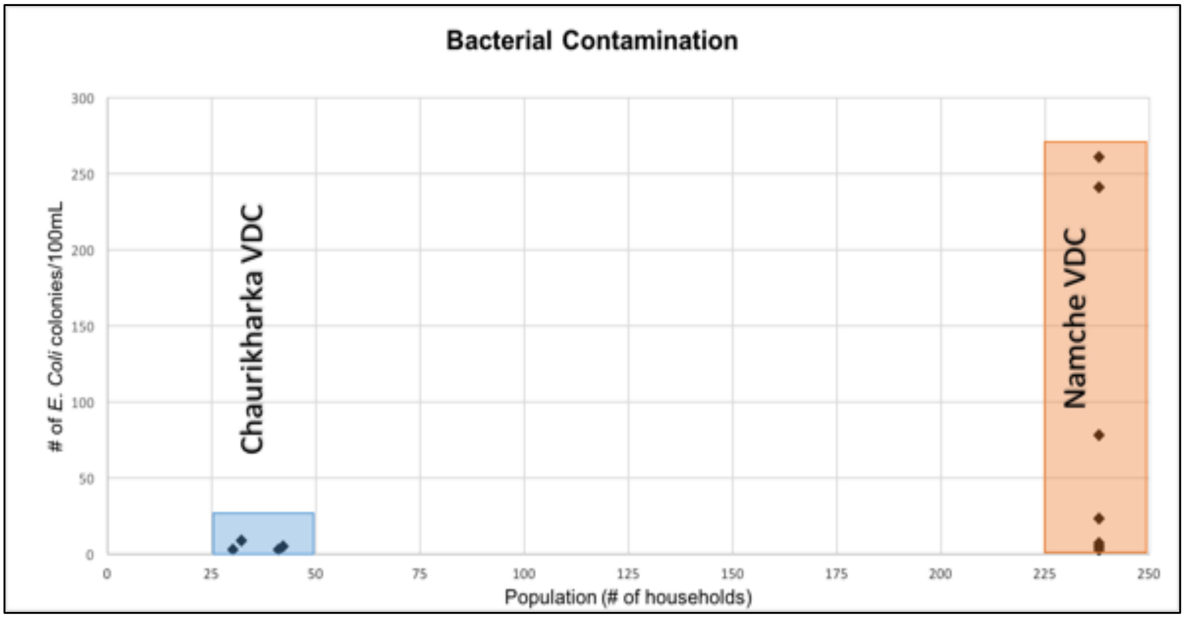

Figure 14 and Table 2- Bacterial contamination plotted with regards to population in number of households. The blue section depicts the lower altitude samples collected in the Chaurikharka VDC; the orange colored section corresponds to samples taken within the Namche VDC

All but seven of the samples collected in November revealed zero colonies of bacteria; however, according to the MCL for *E. coli* and total coliforms, any presence of *E. coli* deteriorates the quality of drinking water. A sample taken from the Thado Koshi revealed 3-5 *E. coli* colonies; this sample complements the findings of Ghimire et al. (2013) which assessed bacterial contamination of the major rivers in the SNP. Sood et al. (2008) completed an assessment of bacterial indicators for the water pollution status of the Gangetic river system in Uttarakhand, India. The study revealed that total coliforms counts were relatively higher during the rainy season than in summer and winter, also suggesting that precipitation and discharge may impact the extent of microbial pollution (Sood et al. 2008). This research revealed a predictable correlation between bacterial contamination and population.

The results of Kedrowski (2012) confirm bacterial contamination of surface waters at higher altitudes near Gorak Shep (5150 m) and Everest Base Camp (EBC), sites that were not sampled in this study. As seen in *Figure 15,* all nine samples analyzed by Kedrowski (2012) were positive for *E. coli* indicator bacteria. Whereas concentrations of *E. coli* and total coliforms taken at Gorak Shep/EBC were not as high as samples collected at lower altitudes, the limit-exceeding presence of indicator bacteria continuing along the tourist trekking route is

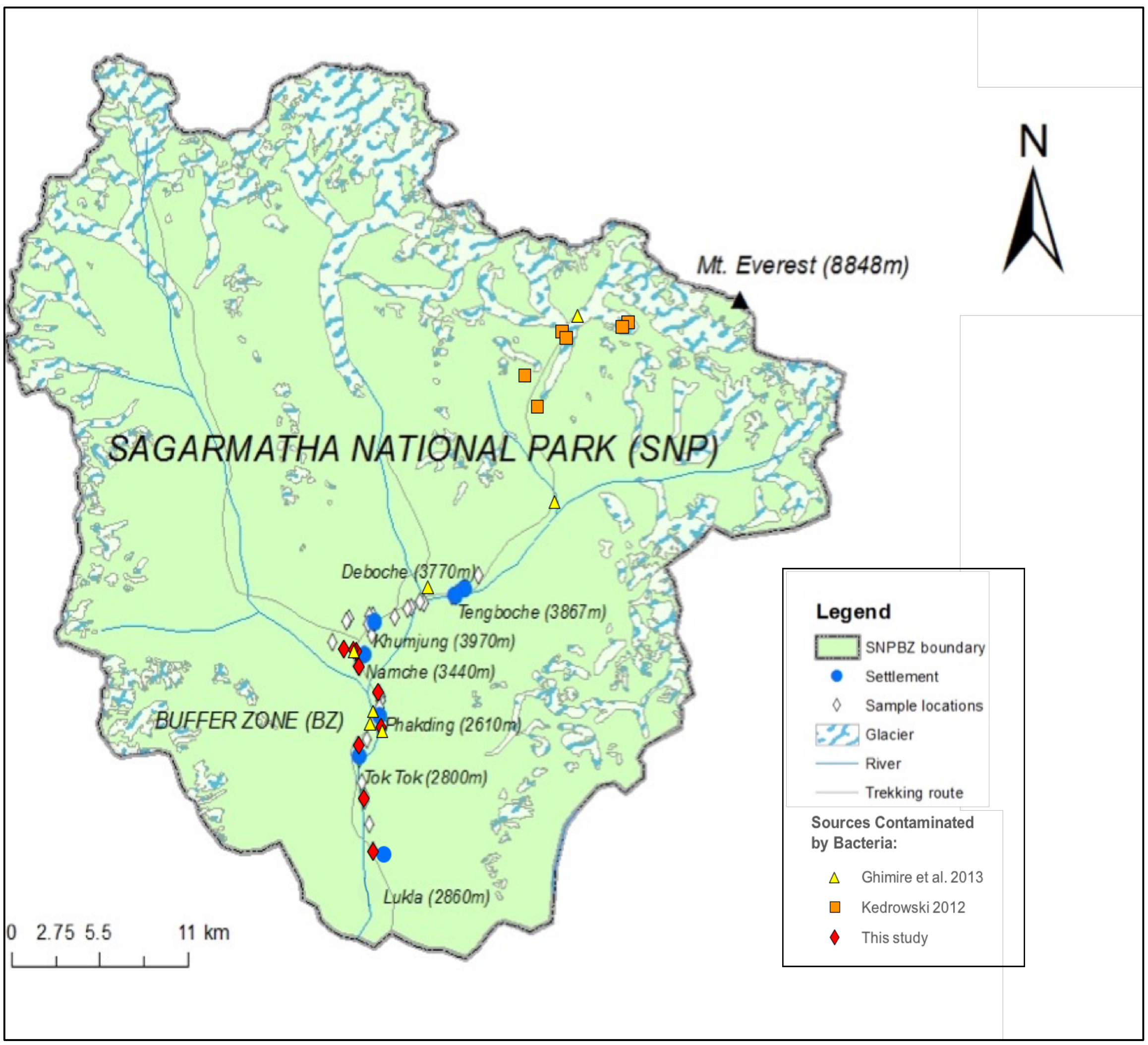

Figure 15- Map of SNP comparing bacterial data from this study (shown in red diamonds) with that of Ghimire et al. 2013 (yellow triangles) as well as, Kedrowski 2012 (orange squares). Each symbol indicates location where water sample had positive concentrations of *E. coli* bacteria.

important to note as human fecal pollution would be the only source for indicator bacteria at those locations. The samples which tested positively for total coliforms and *E. coli* bacterial contamination were taken from sources in more populated townships, such as Namche Bazaar and Lukla. Samples taken from the main spring-fed stream in Namche Bazaar were positive for *E. coli*. Locals used this stream for washing clothing and dishes; burning garbage piles were located near this water body.

4. GOVERNANCE AND POLICY

Nepal is a country in a state of post-conflict political unrest. A decade-long armed conflict (1996-2006), the forging of a new democratic constitution (2015), and the impact of devastating natural disasters have resulted in conflicts regarding environmental distress, a skewed governance distribution amongst caste systems, and poor management of natural resources (Matthew and Upreti 2007; UNDP 2010). International media commentators have described post-conflict Nepal as a “no war, no peace” society (Hoffman 2011; Mahato 2011). The “no war, no peace” theoretical framework proposed by Roger Mac Ginty argues that post-conflict societies are frequently plagued by “chronic poverty and under development, continuing violence, and deeply dysfunctional inter-group relations” (Mac Ginty 2010). In Nepal, there is a well established relationship between natural resource scarcity, demographic pressure, and armed conflict (Upreti 2009). On November 1, 2015 “The Constitution of the Kingdom of Nepal, 2015” was published for public viewing, outlining and enacting the fundamental laws of the newly federal republic. Any progress Nepal has made in regards to environmental resource management and natural human rights remains threatened by conflict brought on by the enactment of this controversial constitution. The current political conflict in Nepal may lead to the consequences explained by Mac Ginty; this would result in reverting to a previously desolate state.

4.1 Governance of the Sagarmatha National Park

The National Parks and Wildlife Conservation Act (NPWCA) of 1973 governs administration of Nepal's national parks and wildlife reserves. According to the NPWCA of 1973, a national park is defined as "an area reserved for the protection, management and use of wildlife, vegetation, and landscape, along with the natural environment" (NPWCA 1973). In 1973, after consulting with several foreign scientists, Nepal established the Royal Chitwan National Park in the central Terai region as the nation's first national park. The Sagarmatha National Park was established in the Himalaya Mountains three years later along with several other parks located in the Terai region. The NPWCA of 1973 was the first initiative to restrict activities such as hunting, mining, logging, grazing, building construction, and stream diversion in order to preserve conditions of Nepal's national parks (Keiter 1995).

The Sagarmatha National Park in Nepal is one of the highest mountain protected areas in the world. The region, locally known as Khumbu, extends over 1148 km^2 and is home to around 6000 people, mostly of the Sherpa ethnic group (Daconto and Sherpa 2010). The Sherpa are the traditional inhabitants of the region, having migrated from Tibet nearly 500 years ago; as the largest ethnic group in the Khumbu, the Sherpa make up nearly 90% of the population (Byers 2005; Tamang 2011). The International Union for Conservation of Nature and Natural Resources (IUCN) distinguishes the Sherpa ethnic group as a people that are fully recognizant toward their role as caretakers of the Khumbu (Borrini-Feyerabend et al. 2013). Spoon (2012) conducted a population census in 2006 which revealed that there were approximately 3000-4000 Sherpa household members spread across 576 households; approximately 2800 of these residents lived in the area for more than three months annually; a census implemented by UNEP's World Conservation Monitoring Centre estimated a population of 3500 Sherpa people in 2004 (UNEP 2011). The SNP is managed by the Sagarmatha National Park Authority of the Department of National Parks & Wildlife Conservation, however, many of the resident Sherpa have legal titles to houses, agricultural land, and summer grazing lands and participate in co-management of the SNP (Jefferies 1984; Brower 1991). The Nepalese government had originally assumed full responsibility for the administration of its protected areas; however, conservation policy and management have more recently been driven by non-governmental organizations (Keiter 1995). Since transitioning from from a monarchy to a federal republic, Nepal has implemented buffer zones (BZ) around existing protective areas to enhance the conservation of parks such as the SNP (Keiter 1995). The Buffer Zone system is a governance model based on the Nepalese community forestry movement initiated in the 1970s (Campbell 2005).

Even throughout periods of political distress, Nepal has maintained a commitment to nature conservation. The Sherpa people have been practicing effective and efficient traditions in nature conservation for several centuries (Basnet 1992). A dramatic increase in the number of annual visitors over the past 40 years has benefited the local economy in the SNP while simultaneously worsening the degradation of the region's vulnerable ecology and cultural traditions. The livelihoods of the local communities and sustainable biodiversity are impacted by global, regional, national and local level conservation policies (Sherpa 2013). The adoption of western management methods initially failed to address the actual environmental problems, and undermined existing indigenous resource management practices directed by the Sherpa people (Brower 1991). The first Park Management Plan in the SNP strengthened governmental control over local resources at the expense of traditional resource management (Daconto and Sherpa 2010). Successful management of the SNP must include the Sherpa people as priority consultants.

The Sherpa represent a unique case where the indigenous people are encouraged to follow their lifestyle, culture, and religious heritage with protection from the disrupting impacts of development. The local Sherpa have retained a considerable amount of control over the Khumbu tourism industry, because teahouses within the SNP and SNPBZ are predominantly Sherpa-owned (Spoon 2012). Establishment of protected areas has historically disregarded the indigenous population; there are few cases where the indigenous peoples retain as much economic control as the Sherpa have (Dowie 2009). The management of national parks has been modified to incorporate conservation with the increasing demands of tourism and mountaineering; this modification includes a shared governance among state, private organizations, and indigenous peoples (WCMC 2011).

4.2 Influence of Mountain Tourism

National and international efforts to conserve biodiversity in mountainous regions have resulted in an impressive network of national parks and protected areas, and the visitor interest that accompanies such designations. Tourism started influencing Nepal's economy when the nation opened its borders in 1951; the main economical influence of tourism in the SNP has been the switch from a traditional subsidence system to the contingent supplementary cash income (Posch 2013). Trekking and sightseeing activities quickly gained popularity in SNP by the 1960s (Spoon 2012). These mountainous developing regions are characterized by inaccessibility, poor development, remote locations, compromised natural resources, poverty, and highly skewed distribution of wealth and property (Nepal 2002). Tourism in the SNP has become an important and expanding industry which provides one of the nation's principal sources of foreign currency. In 1985, 65% of all families in the SNP derived their income from trekking and these lodge owners are the most financially capable sub-population in the SNP (McDowell et al. 2013; Stevens 1993). Spoon (2012) explains that tourism integration has been beneficial to those with a higher economic status, whereas, others experience financial insecurity in low-level tourism positions. Ecotourism and cultural tourism are emerging as means for many of the world's indigenous peoples to integrate into the global market economy. Keiter (1995) explains that while tourism has been beneficial to the economy of the Nepal, due to rapidly increasing tourist population, mountain tourism also contributes to the severe stress on Nepal's land and forest resources. Research indicates that alpine ecosystems (4,000–5,200 m) within the Imja and Gokyo valleys have been noticeably degraded since the 1960s as a result of poor controls on the tourism industry in the SNPBZ (WCMC 2011). There is general agreement that properly planned ecotourism can change the fortunes of people and places in remote and less developed regions such as mountains, however, it is difficult to find successful examples of ecotourism in other mountainous protected areas (Nepal 2002). Any discussion of mountain ecotourism faces two problems: the lack of consensus among scientists as to the precise definition of ecotourism and the lack of research on mountain ecotourism. Nepal (2002) defines mountain eco-tourism in the present context as follows:

> "Tourism that does not degrade the natural and cultural environment of mountain regions, provides economic, environmental, and social benefits to mountain communities (local residents), and offers a high-quality experience for visitors."

Benefits for local people, support for conservation, low-scale development, low visitor volume, and educational experience, are all criteria which suggest that many mountain tourism destinations may not qualify as ecotourism venues as defined above (Nepal 2002). The challenge in the SNP is related to devising an effective conservation policy that protects its natural heritage without sacrificing any human rights or cultural attributes (Keiter 1995).

4.3 Global Development and Monitoring Initiatives

4.3.1 *Millennium Development Goals*

At the beginning of the new millennium, world leaders gathered at the United Nations to create a development framework intended to combat all aspects of poverty around the globe. For the past decade, the Millennium Development Goals (MDGs) have encouraged the commitment of the world community to work together to reduce global poverty (ADB 2006). The MDGs were developed to offer a way of understanding what must be done to reduce poverty. The Millennium Development Goals and the policies and strategies of many organizations like ADB, UNDP, UNESCAP, and WHO address the challenge of water resource management and water supply. The 10-year Millennium Development Goals are listed as follows (UN 2015):

Goal 1: Eradicate Extreme Poverty and Hunger

Goal 2: Achieve Universal Primary Education

Goal 3: Promote Gender Equality and Empower Women

Goal 4: Reduce Child Mortality

Goal 5: Improve Maternal Health

Goal 6: Combat HIV/AIDS, Malaria and Other Diseases

Goal 7: Ensure Environmental Sustainability

Goal 8: Develop a Global Partnership for Development

Presented by the U.N. in 2005, MDG Target 7.C calls for "the proportion of people without sustainable access to safe drinking water and improved sanitation to decrease by half by the year 2015" (ADB 2006). This initiative prioritizes the multi-functionality of water as a means to impact overall poverty and contribute to significant socioeconomic and environmental improvement. According to the Asian Development Bank (2006), Target 7.C is defined by indicators for both safe drinking water and improved sanitation; a country must meet both of these standards to qualify for achieving the entire Target 7.C. The UN MDG Task Force report defines the following four core areas that reflect the key limitations that determine the success of change (ADB 2006):

- Policy, legal, and regulatory reform is an essential pre-condition for sustainable and effective change in Asia and the Pacific. Governments are the central actors because they are responsible for defining the framework within which water supply and sanitation provision takes place.
- Planning and technology choices must ensure that the national legal and policy framework is put into practice. Governments need to ensure that the planning systems surrounding their programs, including programs supported by donors, reflect the policy priorities.
- Financing mechanisms, including supportive investment environments (especially ones that encourage small private sector investments) and effective cost recovery mechanisms are approaches that will address major challenges in many places.
- Institutional reform is needed to build capacity, introduce more appropriate management systems, and bring more effective coordination among government agencies.

The Asia and Pacific region play a pivotal role in the MDG commitment as this region is home to the majority of the world's poor (ADB 2006). In 2005, South and Southwest Asia had the lowest coverage levels for improved sanitation than any other sub-region within the Asia and Pacific region. In comparison, the sanitation coverage level of South and Southwest Asia was the same as Sub-Saharan Africa. Nepal had lower coverage rates than others in its sub-region and did not show the appropriate rates needed to meet Target 7.C (ADB 2006). Data suggested Nepal showing reversing trends in both safe drinking water and improved sanitation, which threatened its chance of meeting the Target 7.C water supply indicator; between 2000 and 2002, Nepal's rate of increase for total coverage fell from 4% to less than 1% (ADB 2006). The civil conflict beginning in the mid-1990s also threatened Nepal's progress by physically restricting access to many parts of the country (ADB 2006).

4.3.2 *Joint Monitoring Programme*

The World Health Organization and UNICEF joined forces in 2005 to produce a Joint Monitoring Programme (JMP) for water supply and sanitation in order to act as the official UN mechanism to monitor progress towards the MDG target for drinking water and sanitation (WHO-UNICEF 2012). Various research methods were used to acquire the data for the Joint Monitoring Programme. A total of 230 datasets were accessed across the globe and 12 of these datasets were utilized to monitor the Southern Asia region (WHO 2013). Progress of the JMP is determined by increasing numbers of people using services, reducing inequalities, increasing service levels, driving progress in schools and health centres as well as households and achieving sustainable, universal coverage (WHO 2013). The following four targets were created by experts in the field of drinking water and sanitation as developmental milestones for progress (WHO 2013):

- Target 1: By 2025, no one practices open defecation and inequalities in the practice of open defecation have been progressively eliminated.
- Target 2: By 2030, everyone uses a basic drinking water supply and hand washing facilities when at home, all schools and health centres provide all users with basic

drinking-water supply and adequate sanitation, hand washing facilities and menstrual hygiene facilities and inequalities in access to each of these services have been progressively eliminated.

- Target 3: By 2040, everyone uses adequate sanitation when at home, the proportion of the population not using an intermediate drinking-water supply service at home has been reduced by half, the excreta from at least half of schools, health centres and households with adequate sanitation are safely managed and inequalities in access to each of these services have been progressively reduced.
- Target 4: All drinking-water supply, sanitation and hygiene services are delivered in a progressively affordable, accountable and financially and environmentally sustainable manner.

These progressive targets are globally focused on outcome and reflect a direct implementation of the human rights to water and sanitation. The JMP targets seek to increase the number of people utilizing water and sanitation resources, practicing basic hygiene skills, and improve levels of service (WHO 2013).

4.3.3 *Millennium Development Goals Results*

As the 10-year development period comes to an end, the data was analyzed and presented in the Millennium Development Goals Report 2015. The MDG report utilizes data from the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation to assess progress and define progress goals for 2015.The data and analysis presented in this report prove that, with targeted interventions, sound strategies, adequate resources and political will, even the poorest countries can make dramatic and unprecedented progress (UN 2015). Globally, 1.9

billion people have gained access to piped drinking water since 1990 (UN 2015). According to the Progress on Sanitation and Drinking Water (2014), Nepal's coverage rates for improved sanitation have increased by 19%, but have failed stay on track for the country's Millennium Development Goals (WHO-UNICEF 2015). Open defecation rates for Nepal have decreased by 56% over the ten-year period ranking Nepal as the 2nd most improved country in the category (WHO-UNICEF 2015).

5. DISCUSSION

Mountain regions in developing countries are characterized by high biological and cultural diversity. During the past few decades there has been a dramatic increase in the number of visitors in the SNP, the world's highest national park. The Sagarmatha National Park is an economically and environmentally vulnerable region that depends greatly on the success of the tourism industry. The challenge in the SNP, and other similar sites, is in devising effective conservation policies that protect natural heritage without sacrificing cultural attributes or economic advances from the tourism industry (Manfredi et al. 2010). The SNP has historically been a positive example of an Indigenous Community Conserved Area (ICCA) and future governance and policy changes must continue to build on this successful framework. The main objectives of future management plans should ensure the protection of the park's wildlife, water, and soil resources, whereas, simultaneously safeguarding the interests of the Sherpa residents and other residents within the SNPBZ. This thesis aims to increase awareness and response of a massive failure to provide a basic human right to the residents and tourists inhabiting the SNPBZ.

Drinking water issues in the SNPBZ stem back to the five basic contributors shown in *Figure 14*. The low economic status of the people in the SNP hinders efforts to improve current drinking water systems and regulations. The locals simply do not have enough capital to implement physical upgrades and installation of community drinking water storage and treatment systems. The tourism industry in the SNPBZ is affected by the drinking water quality issues that originate from a poverty status. Tourism in the area may decrease if residents and visitors are denied the right to clean, affordable drinking water. If the tourism industry is negatively affected, that

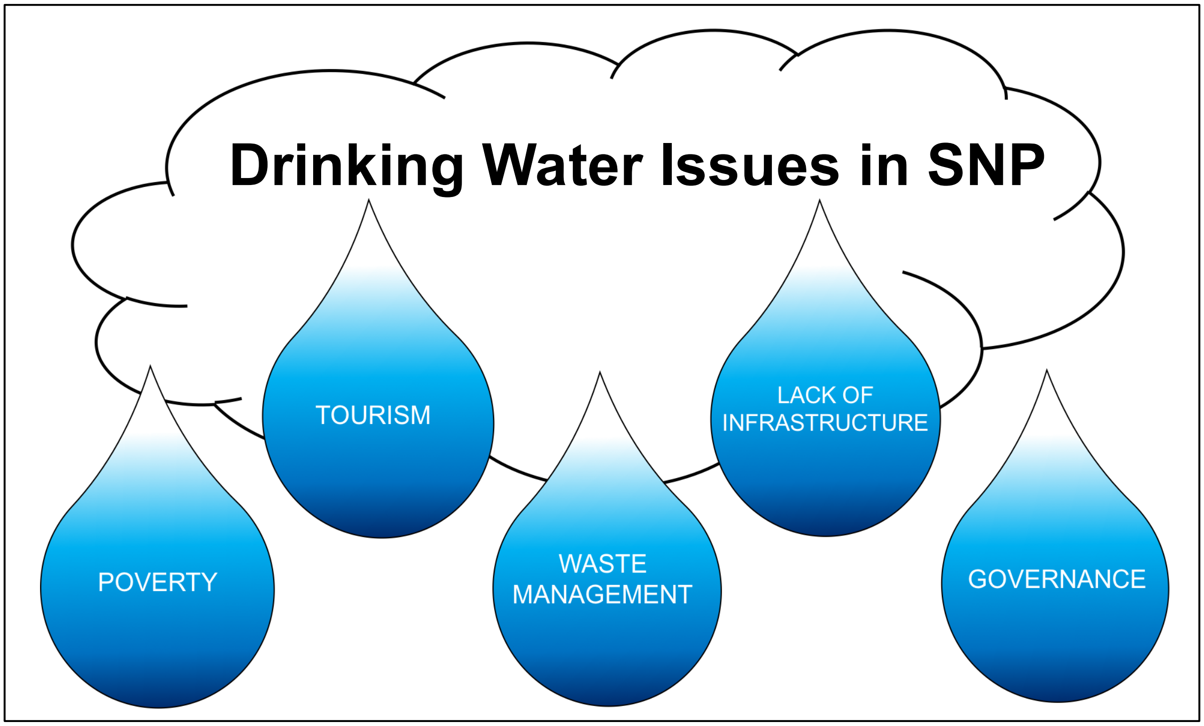

Figure 14- Five main contributors to drinking water issues in the Sagarmatha National Park

will in turn affect the economic status of the local residents and business owners as tourism is the main industry in the SNPBZ. Drinking water quality issues in the SNP are also dependent on the current waste management practices in place. As tourist numbers continue to increase, the current human waste management practices will only worsen the conditions of drinking water in the SNPBZ; the current practices (e.g. open defecation, unlined pit toilets, dumping of human waste, etc) in the SNPBZ are already failing to address current amounts of tourism-produced wastes and are predicted to degrade the natural environment even further if not enhanced in the future. The key to improving waste management practices and drinking water quality is to first address the lack of adequate infrastructure. In order for these conditions to improve, proper infrastructure must be established to correctly treat and store drinking water, as well as waste, according to worldwide health standards. All of the previous contributions to drinking water issues in the SNPBZ are intrinsically tied to the park's governance and the out of date environmental policies and standards. It is understandable that improvements in infrastructure and waste management haven't been completed due to the confused governance of land, resources, and people in the SNPBZ, however, this situation is not sustainable.

The results of this study suggest that drinking water contamination by bacteria is attributed to human influence and a seasonal dependence. Drinking water supplies which were sampled and analyzed for bacterial parameters in both May and November displayed a seasonal dependence of contamination. The analysis revealed that maximum concentrations of bacterial contamination were found in highly populated tourist-friendly townships such as Lukla and Namche Bazaar, suggesting that contamination is intrinsically tied to the tourist population in the SNP. The locations of maximum contamination were also located at the lower altitudes visited in this study. This research provided two distinct trends regarding the relationship of altitude and bacterial contamination. The lower altitude trend, located in the SNPBZ suggests tourist traffic and non-point pollution plays a major role in bacterial contamination. The SNPBZ invites tourists with its highly accessible, low-mountain ecosystem; trekking in this region is less extensive, therefore, more inviting to those not looking to summit mountain peaks. The weather in the SNPBZ is also more temperate and humid than the majority of the SNP. The boundary to the SNP begins just before reaching Namche Bazaar; the EBC trekking route quickly gains in altitude upon entering the SNP. Excluding the samples taken in the highly-populated market town of Namche Bazaar, the majority of samples from the SNP had lower concentrations of bacterial contamination. This result may be tied to a decrease in tourist population and a change to a more deciduous, alpine ecosystem. The samples taken at higher altitudes had an expectedly different temperature profile, but stayed true to other parameter trends.

There is an obvious need for effective water quality monitoring and surveillance programs to ensure safe and sustainable water supply systems within the SNPBZ. Local and global monitoring programs have been successful tools and will continue to be useful for long-term development assessment. Treatment of water in rural supply systems to improve the water quality may not be economically feasible or manageable, therefore, alternative solutions must be taken into account. In-depth research is required to determine appropriate and sustainable options; these options must consider the socio-economic and traditional values of the local Sherpa population.

The results of this study and others (Kedrowski 2012; Ghimire 2013; Posch 2013) support the caustic relationship between increasing tourist numbers and drinking water contamination. Nepal (2003) explains that renowned tourist stops like Namche Bazaar and the Tengboche Monastery have been particularly affected by the human waste issue. Drinking water quality of the Sagarmatha National Park is notably affected by the large tourist traffic introduced to the vulnerable mountain ecosystem. This study found that water sources in densely populated areas were the most heavily affected by fecal waste pollution; by observation and literature review, it can be noted that other types of wastes (garbage, medical, chemical, etc.) also accumulated in these populous hubs (Posch et al. 2015). All forms of waste are intrinsically linked to the tourist population in the SNPBZ. The township of Namche Bazaar presented the most anthropogenic influence on drinking water resources among all of the other townships visited in this study; the reason for this increased anthropogenic pressure in Namche is a multi-faceted issue. Namche Bazaar is the main market town of the Sagarmatha region and holds a weekly market every Saturday; residents of the SNPBZ travel from below and above to Namche every week creating high traffic of locals and livestock, as well as tourists. Tourist also spend more time in Namche Bazaar to acclimatize; this process involves staying for two or three nights. While Namche experiences the most concentrated anthropogenic pressure, the townships within the buffer zone also experience a high level of human influence. Subsistence farming is a common practice in the buffer zone, whereas, it is prohibited within the proper SNP. Over the past 60 years there has been rapid deforestation within the buffer zone (Nepal 2003; Posch 2013). Both of these practices increase surface area of the drainage basins and can impact surface water contamination with increased runoff.

This study has established that proper waste management practices, as well as an adaptation towards eco-tourism, are necessary for promoting mountain development and conservation in the SNPBZ. Successful development of eco-tourism would require long-term development plans and policies which would include the following key variables: sustainability criteria, diversity, governance reforms, gender equality, economic integration, and peace and security (Nepal 2002; Posch 2013). Tourism has become an important and expanding industry for Nepal (and provides one of the nation's principal sources of foreign currency), however, it also adds to the severe stress that Nepal's rapidly growing population has placed on its natural resources. Historically, mountains in developing countries are negatively influenced by high population growth rates, inaccessibility, governance issues, and high stresses on natural resources (Nepal 2002); the SNPBZ is hindered by these issues but remains a promising eco-tourist location based on its high biological and cultural diversity, affordability, natural splendor, and willingness to adapt to positive change.

Major research work is required in both the technical and social aspects of water supply and sanitation and should focus on affordable, environmentally friendly, and socially acceptable solutions. Community based need identifications are required, as well as detailed assessments of the existing practices, in order to achieve the goal of quality drinking water at the community level. An overall attitude of environmental consciousness will be required to change waste disposal practices. Posch et al. (2013) described this attitude as the “strongest and most significant factor for predicting waste behaviour in the SNPBZ”. Personal experiences with the local residents of the SNPBZ revealed an open-mindedness and willingness to adapt to more environmentally conscious waste disposal practices, however, unstable or undefined governance of waste management would hinder progress.

This study confirmed a presence of fecal coliforms, indicators of sewage pollution, in the drinking water sources of the Sagarmatha National Park. The aggressive anthropogenic pressure tourism places on the SNP must be addressed in order to evolve into an eco-tourist hub. This confirmation identifies a need for economically viable and beneficial upgrades in waste systems infrastructure. The local economy of the SNP cannot financially support such upgrades, therefore, will need to rely on tourist input to cover renovation costs. This can be achieved in many ways including (but not limited to) support from microloan programs, charging tourists to use upgraded facilities, and applying additional charges onto boarding fees at teahouses. Composting toilets are an exciting and viable option that have proven to be beneficial in developing areas, with the proper maintenance (Anand and Apul 2011). Maintenance of such facilities would create local jobs within township communities and result in increased local economy. Further research into effective ecological waste management practices is necessary to define proper management protocol.

The multi-functionality of water resources affects every aspect of the livelihoods of the residents and tourists in the SNP. Water is Nepal's most important natural and human resource. Water scarcity and pollution are inherent human rights issues and initiate conflict through governmental oppression, inter-caste divergence, and the degradation of the human condition. The importance of drinking water quality in the SNP is defined by the impact it creates physiologically, socio-economically, politically, educationally, and interpersonally.

6. CONCLUSION

This study examined drinking water quality as a multi-faceted issue that is directly associated with socio-economic factors, tourism, and the governance of developing protected sites. The following are the major conclusions identified in this study:

- Changes in governance have historically sparked conflict in Nepal and the enactment of the 2015 Constitution is no exception.
- Global development goals and international policies are useful tools for determining the status and progress of poverty indicators such as improved sanitation and drinking water sources.
- Bacterial contamination by anthropogenic waste is a pertinent source of drinking water pollution in the SNPBZ.
- Largely populated areas, such as major townships like Lulka and Namche Bazaar, exhibit greater bacterial contamination than less populated areas; in the same respect, more “tourist friendly” townships within the SNPBZ are at greater risk for bacterial contamination, based on population density.
- Analysis of drinking water sources in the SNPBZ revealed a seasonal/temperature dependence regarding bacterial contamination, whereas, greater concentrations of bacteria were discovered during the month of May when it was warmer and had higher amounts of precipitation.
- Global warming trends are likely to increase bacterial contamination as an increase in surface water input is eminent.

- Future regulations and policies on tourism and waste management practices in the SNP must directly involve the Sherpa people and be created with the goal of improving the permanent local economy.

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