Journal of Geoscience and Environment Protection, 2016, 4, 43-53

http://dx.doi.org/10.4236/gep.2016.44007

Drinking Water Quality in the Sagarmatha National Park, Nepal

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Received 7 March 2016; accepted 19 April 2016; published 22 April 2016

Abstract

In 2014 we began the first systematic study of water quality, specifically fecal contamination of drinking water in the Khumbu Valley, Sagarmatha National Park (SNP, Mt. Everest region), Nepal. Our goal was to identify coliform bacteria and *E. coli* in drinking water and groundwater-fed springs to generate a data set that will function as a base for potable water supplies and further monitoring. Sampling occurred in May (pre-monsoon summer) and early November (post-monsoon early winter) 2014. Sample sites were selected based on proximity to villages and primary use as a drinking water source. Overall, the data presented a predictable correlation between fecal contamination and both elevation and increasing population/tourist traffic. Drinking water within the study area met current World Health Organization drinking water standards for the physical properties of temperature (2.8˚C - 13˚C), pH (5.27 - 7.24), conductivity (14.5 - 133 μS) and TDS (7.24 - 65.5 ppm). Samples from the more populated, lower altitude areas had higher levels of *E. coli*. Samples collected and analyzed in May (pre-monsoon summer) had a higher level of *E. coli* and coliform bacteria than samples collected in November (post-monsoon early winter) suggesting a seasonal dependence overlaid on the population signature. Surface water typically had higher *E. coli* values than groundwater-fed springs. Temperature, total dissolved solids and conductivity generally decreased with increasing elevation, whereas pH increased with increasing elevation. There appears to be significant presence of fecal contamination of water sources due to a combination of tourism, elevation and seasons.

Keywords

Fecal Coliform, *E. coli*, Mt. Everest, Drinking Water

1. Introduction

The Sagarmatha National Park (SNP; **Figure 1**) is located in the southeastern part of the Nepali Himalaya on the

How to cite this paper: Nicholson, K., Hayes, E., Neumann, K., Dowling, C. and Sharma, S. (2016) Drinking Water Quality in the Sagarmatha National Park, Nepal. *Journal of Geoscience and Environment Protection*, **4**, 43-53.
http://dx.doi.org/10.4236/gep.2016.44007

Figure 1. Generalized map showing the major rivers, ice fields, major townships and main mountain peaks, including Mt. Everest. Inset map shows the position of the study area within the country of Nepal.

southern slope of Sagarmatha (Mt. Everest). The SNP is in the Solukhumbu district, approximately 140 km due east of Kathmandu and covers 1148 sq km. It ranges between 27˚30'19"N to 27˚06'45"N latitude to 86˚30'53"E to 86˚99'08"E longitude. The elevation of townships and communities in the SNP watersheds varies from 2610 m (Phakding) to over 5000 m at Mt. Everest base camp (EBC). The area experiences a temperate climate characterized by cold winters, warm summers and clear seasonality, with average annual precipitation ranging from 450 mm at EBC to 1800 mm at Lukla township (the town where tourists begin their trekking adventures). Maximum rainfall generally coincides with the Indian Monsoon, between June and September, and there is great variability of temperature, which ranges from 37˚C in summer to −17˚C in winter. The Himalayan Mountains are the source of water for over a billion people and form the main headwaters for major river systems, such as the Ganges, Yangtze and Indus Rivers [1].

The SNP was established in 1976. It was declared a World Natural Heritage Site in 1979, and is the world's highest altitude protected area. The natural beauty and diversity in culture, flora and fauna, and the majesty of Mt. Everest make it a prime destination for adventure loving tourists [2]. Since the first ascent of Everest in 1953, around half a million trekkers have visited the SNP. The annual number of tourists in the Khumbu region was 20 in 1964, and rose to peak number 32,123 in 2009. In addition to international trekkers, a large number of people visit the SNP as porters and guides [3]. Many protected areas, such as the SNP, have promoted tourism development to improve their economic conditions [3] [4]. However, the negative effects of tourism are of significant concern and tourism operations in protected areas need to be carefully planned, managed and monitored to ensure their long-term sustainability [4].

Over the past twenty years, the continuously increasing number of tourists to the SNP is causing increasing anthropogenic pressure with serious environmental consequences to the unique SNP ecosystem [5] [6]. Although the impact is visible primarily along the more popular trekking routes, where non-biodegradable solid wastes (such as water bottles, batteries and more) has resulted in environmental pollution, the effects are also felt in the waterways. Unmanaged or poorly managed solid waste disposal and open defecation have resulted in contamination of the major rivers [5]. Sewage waste is often directly discharged into nearby streams and rivers [7] resulting in considerable degradation of major rivers in the region [5]. Even though the surface water is polluted, it is still used as a potable water supply. However, no studies of local surface water and groundwater and their suitability as reliable water sources have ever been conducted. The SNP is a well suited location to investigate surface and ground water or the effects of tourism on potable water supplies because there is access to moderate and high altitude springs that have and have not been affected by major human populations, which allows for comparative analyses. In addition, the SNP region is generally better studied than other parts of the Himalayan region in terms of geology, glaciology, and anthropology.

In natural systems, microorganisms are widely distributed whereby their diversity and abundances may be used as an indicator for suitable water sources [8]. Although there is a wide range of pathogenic microorganisms that can be transmitted to humans via water contaminated with fecal material (*i.e.* enteropathogenic agents such as salmonellas, shigellas, enteroviruses, and multicellular parasites as well as opportunistic pathogens like *Pseudomonas aeroginosa*, *Klebsiella*, *Vibrio parahaemolyticus* and *Aeromonashydrophila* [9]), the isolation and identification of these organisms is extremely complicated and seldom quantitative [10] [11]. As it is not practical to test water for all these organisms, the measurement of *E. coli* and coliform bacteria (total coliform bacteria and/or fecal coliforms) may be used as an indirect approach based on the assumption that the groups of normal enteric organisms will indicate the level of fecal contamination of the water supply [11]-[15]. The presence of coliform bacteria can be used as an indicator of potential danger to human health, as fecal contamination poses significant health risks. Finally, when combined with other indicators such as the physical characteristics of the water as well as distribution and access to water, the presence of bacteria can be used to help identify the reasons behind the contamination.

The study area begins just outside of the SNP boundary at the township of Lukla and extends through to the township of Deboche along the main trekking route to Mt. Everest base camp. It is mainly confined to the DudhKhosi drainage basin (**Figure 2**). The area is characterized by rugged topography, with altitudes ranging

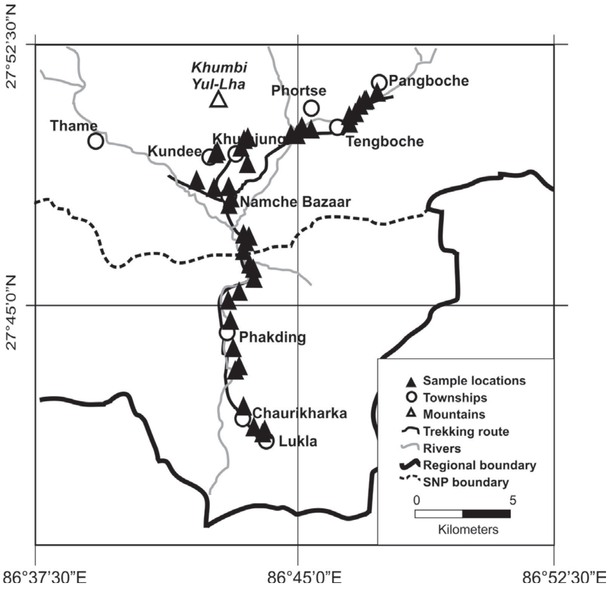


Figure 2. Map of the field study area including the major townships and sample locations (solid triangles). Sample locations correspond to data shown in **Table 1**. The dashed line indicates the park boundary with the SNP to the north and the buffer zone in the south.

Table 1. Data table showing all sample locations from May and October/November 2014.

Date	Sample #	Northing	Easting	Altitude (m)	Source
5/8/14	MAY 1	27.42264	086.43132	2702	spring fed
	MAY 2	27.71835	086.71604	2563	surface water
	MAY 3	27.73057	086.71380	2607	surface water
	MAY 4	27.73230	086.71326	2615	spring fed
5/9/14	MAY 5	27.75193	086.71057	2602	surface water
	MAY 6	n/a	n/a	2650	surface water
	MAY 7	27.75913	086.71003	2700	surface water
	MAY 8	27.76195	086.71467	2700	surface water
	MAY 9	27.76969	086.72402	2800	surface water
	MAY 10	27.78205	086.72275	2810	surface water
	MAY 11	27.78375	086.72253	2843	surface water
	MAY 12	27.78550	086.72172	2850	surface water
5/10/14	MAY 13	27.79960	086.71024	3350	spring fed
	MAY 14	27.80255	086.71085	3440	spring fed
	MAY 14	27.80255	86.71085	3440	spring fed
	MAY 14	27.80255	086.71085	3440	spring fed
	MAY 15	27.81528	86.7179	3440	surface water
	MAY 15	27.81528	086.71790	3440	surface water
	MAY 16	27.80636	086.70947	3440	spring fed
10/31/14	OCT 1	27.78202	086.72281	2810	surface water
	OCT 2	27.78549	086.72177	2843	surface water
	OCT 3	27.79905	086.71065	3370	surface water
11/1/14	NOV 4	27.81167	086.69595	3546	surface water
	NOV 5	27.80806	086.70241	3586	spring fed
	NOV 6	27.80634	086.70947	3512	spring fed
	NOV 7	27.80413	086.71030	3426	surface water
	NOV 8	27.81528	086.71790	3440	spring fed
	NOV 9	27.81528	086.71790	3440	spring fed
	NOV 10	27.80255	086.71085	3440	spring fed
	NOV 11	27.80255	086.71085	3440	spring fed
11/2/14	NOV 12	27.84580	086.77763	3466	surface water
	NOV 13	27.83992	086.77145	3728	spring fed
11/3/14	NOV 14	27.83969	086.77020	3762	spring fed
	NOV 15	27.83662	086.76598	3842	spring fed
	NOV 16	27.83558	086.76459	3864	spring fed
	NOV 17	27.83558	086.76459	3864	spring fed
	NOV 18	27.83511	086.76278	3812	spring fed
	NOV 19	27.83216	086.74734	3852	spring fed

Continued

	NOV 20	27.83233	086.74473	3891	surface water
	NOV 21	27.82983	086.73985	3444	spring fed
	NOV 22	27.82897	086.73801	3482	spring fed
	NOV 23	27.82503	086.73041	3521	spring fed
	NOV 24	27.82569	086.71862	3,660	spring fed
	NOV 25	27.82509	086.71645	3,764	spring fed
	NOV 26	27.82368	086.70473	3870	spring fed
	NOV 27	27.82291	086.70359	3886	spring fed
	NOV 28	27.82082	086.71576	3,891	spring fed
11/5/14	NOV 29	27.77805	086.72196	2815	spring fed
	NOV 30	27.77330	086.72262	2870	spring fed
	NOV 31	27.76991	086.72401	2908	surface water
	NOV 32	27.76742	086.72296	2896	spring fed
	NOV 33	n/a	n/a		surface water
	NOV 34	27.75175	086.71042	2688	spring fed
	NOV 35	27.73960	086.71194	2,610	spring fed
	NOV 36	27.73231	086.71326	2,610	spring fed
	NOV 37	27.68955	086.72945	2,849	spring fed
11/6/14	NOV 38	27.68955	086.72945	2,860	spring fed

"n/a" means that no data was collected.

from of 2610 m at Phakding and 2774 m at Lukla airstrip, to a maximum altitude of 5364 m at Mt Everest base camp (the lowest Mt Everest base camp). Within the study area there are four main villages: Lukla, Namche Bazaar, Khumjung and Chaurikharka. The four villages are located in this lower portion of the SNP that experiences the highest numbers of tourists each year. It is at risk from the conflicting interests between the need for economic growth (based on tourism) and the ability of the current infrastructure to handle issues such as human waste disposal [3]. The goal of this study was to characterize and monitor potable water quality close to and within the SNP using *E. coli* and coliform bacteria as indicators of fecal contamination.

2. Methods

Water samples were collected in May and November 2014 (**Table 1**). Sites were selected based on the availability of the water that the local populations and tourist use as drinking. Sample sites include standpipes (water that is brought via tubing from higher elevations), groundwater-fed springs, creeks, and tributary streams. The major rivers and streams were omitted as they previously have been studied in detail [5].

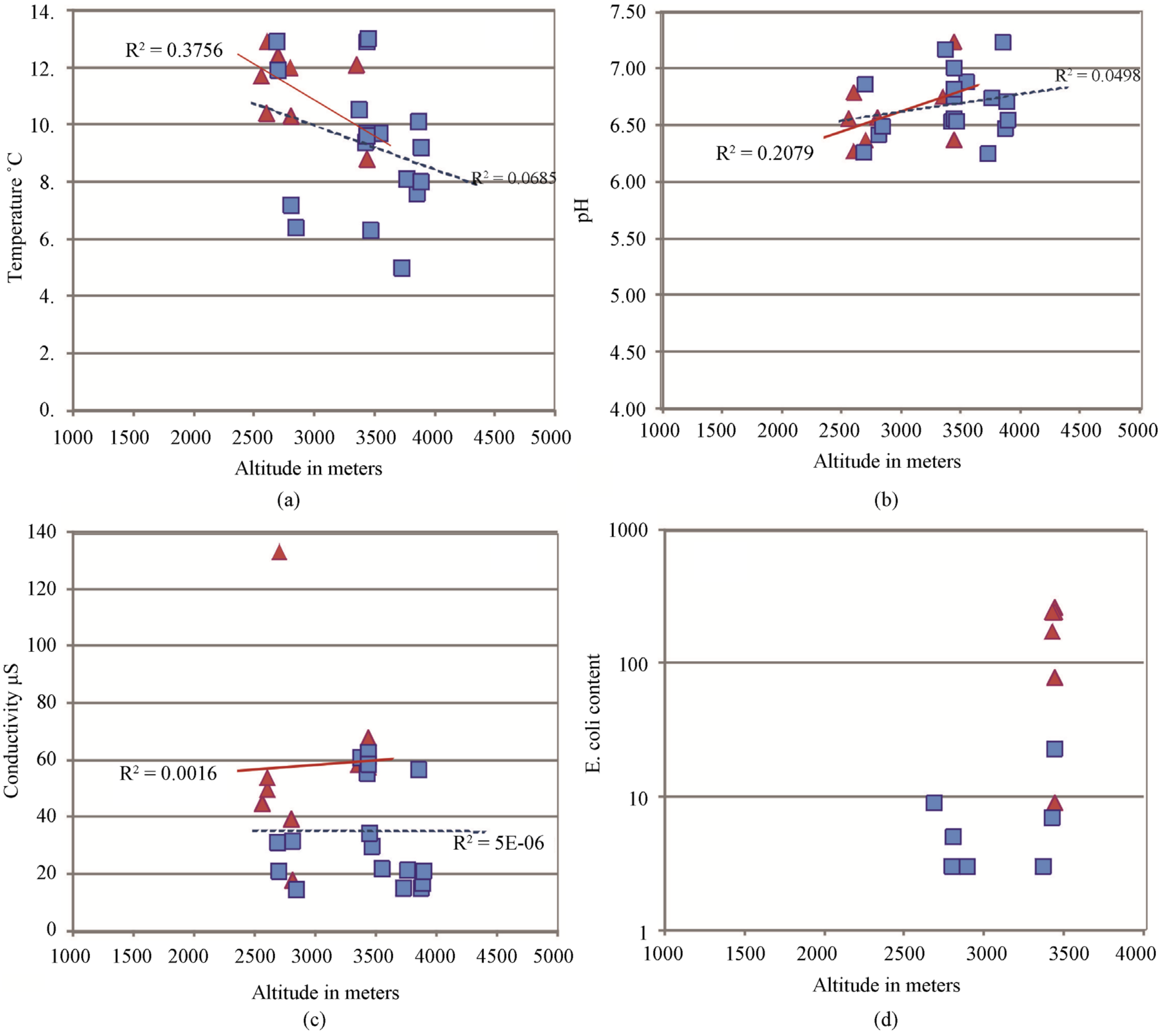
Temperature, pH, conductivity and TDS were measured in the field using a FisherSci Ap85 pH/conductivity meter. Samples taken for bacteria analyses were collected in sterile 100 mL Whirl-pak bags containing a non-nutritive pill with 10 mg sodium thiosulfate and kept at temperatures below 20˚C prior to analyses. Analysis of fecal coliform in surface and drinking water followed the EPA approved method 9222D in Standard Methods [16] by using a standard Hach® portable water test kit. Samples were filtered using a hand vacuum pump to filter sample through sterile 0.45 micron filter, placed into a petri dish treated with Hach® m-ColiBlue24® broth medium and placed in a Hach® portable field incubator at 35˚C ± 0.5˚C for 24 hours. Sample counts were done using a magnifying glass and a 10× geological hand lens where *E. coli* colonies are royal blue and coliform bacteria colonies appear to be crimson red. Two people counted bacteria samples and duplicate samples were run on approximately every tenth sample.

3. Results

Samples were taken from 27 different localities in May and November 2014 (**Figure 2**). Of these samples, 17 were from standpipes or groundwater-fed springs and 10 were from minor creeks or tributaries. Where possible, samples were taken from local drinking water sources.

3.1. Temperature

Temperatures ranged between 2.8˚C and 13˚C with an average of 9.63 (±2.6)˚C (**Figure 3(a)**). The samples collected in May were on average 2.06˚C warmer than the samples collected in November. The samples in May ranged between 7.2˚C and 12.9˚C with an average of 11.04 (±1.5)˚C, whereas the samples collected in November ranged between 2.8˚C and 13˚C with an average of 8.96 (±2.7)˚C. It includes the November sample from Tengboche (lowest temperature recorded of 2.8˚C) that was taken at 8AM when the air temperature was approximately −5˚C. This sample was from shallow, slowly moving water, and the air temperature obviously affected the sample. In general, it was noted in the field that air temperature had little effect on groundwater but could have a major effect on slow moving surface waters. However, with this sample removed the November



(a) (b)

(c) (d)

Figure 3. Bivariate plots showing the relationship between (a) temperature and altitude, (b) pH and altitude, (c) conductivity and altitude and (d) *E. coli* and altitude. Red triangles and corresponding red regression lines: May samples. Blue squares and corresponding dashed blue regression lines: November.

temperature data changes slightly with an increased average temperature of 9.3 (±2.4)˚C. As expected, the temperatures decreased with altitude. With the exception of the Tengboche sample, both sets of our data compare well to Ghimire *et al*. [5] who analyzed 51 sample locations on the four major rivers (DudhKoshi, ImjaKhola, BhoteKoshi, LobucheKhola (**Figure 1**)) within the SNP that showed an average temperatures varying between 8˚C and 13˚C, with an average of 10.7 (±1.5)˚C, over three years.

3.2. pH

The pH values ranged between 5.27 and 7.24 with an average of 6.60 (±0.4) (**Figure 3(b)**). Again the outlying sample is from Tengboche with a pH of 5.27. Excluding the November Tengboche sample, the samples collected in May had a pH range of 6.27 to 7.24 with an average of 6.61 (±0.3), whereas the November samples range from 6.25 to 7.23 with an average of 6.68 (±0.3). The observed pH values for drinking water are within the permissive limit pH (6.5 - 8.5), as prescribed for the drinking water by the World Health Organization (WHO) [17].

3.3. TDS and Conductivity

The range in TDS in the samples is relatively small. The average is 21.27 (±12.4) ppm, with a range between 7.24 ppm and 65.50 ppm. Samples taken in May have a slightly higher average (28.46 ± 15.5 ppm) than the samples collected in November which average 17.86 (±9.3) ppm. In the 2011 WHO [17] guidelines for drinking water, it is suggested that drinking water should contain less than 600 mg/L (which is roughly the same as 600 ppm), hence the drinking water in the SNP falls well within the recommended limit.

Conductivity was measured in the same samples and shows similar trends as TDS. The average value for both sets of data is 43.14 (±25.3) μS. Samples collected in November had lower conductivity with an average of 36.10 (±18.8) μS whereas the samples collected in May had higher values, ranging between 17.87 μS and 133 μS with an average of 57.99 (±31.5) μS (**Figure 3(c)**).

Figure 3 indicates that the samples show a negative correlation between altitude and the physical parameter of temperature, a positive correlation between altitude and pH, and a near neutral correlation between altitude and conductivity.

3.4. *E. coli* and Coliform Bacteria

A total of 41 samples from 27 locations were analyzed for *E. coli* and coliform bacteria (*Escherichia coli* and *Streptococcus faecolies*, respectively). Analyses were conducted proximal to the sampling sites within 20 hours of collection, with a majority conducted within 8 hours after collection. Only five samples were analyzed in May and the remaining 36 analyses conducted in November, which includes repeat sampling of the 5 location analyzed in May. The average high and low air temperatures, respectively, in Namche Bazaar are: 14˚C and 4˚C in May, and 9˚C and 3˚C in November. As anticipated, due to lack of daylight hours and colder weather conditions [18], the bacterial content was higher in May than in November. Only one sample, from the main groundwater-fed stream running through Namche Bazaar, tested positive for colonies of both *E. coli* and coliform bacteria. However, retesting the sample location in November showed only minor *E. coli* colonies (<5) and no coliform bacteria.

The five samples collected and analyzed in May all tested positive for *E. coli* with colony numbers ranging between 5 and 260 (**Figure 3(d)**). Only five out of the 36 November samples tested positive for *E. coli* (with greater than 3 colonies each, **Figure 3(d)**). Two of the samples were from Namche Bazaar: the main stream (groundwater sourced) running through town and the water supply for one of the local cafes. Three other samples tested positive for *E. coli* colonies, and they were collected from lower elevations: a lodge at Chaurikharka, the waterfall at Benkar, and a standpipe in Toktok (elevations between 2680 m and 2900 m). Considering the samples collected in November, there appears to be an inverse correlation between the presence of *E. coli* and altitude, with more *E. coli* detected in lower altitude townships than at higher elevations. This might be a result of several factors including: higher local population, higher numbers of tourists, higher daytime temperatures, and higher levels of surface water in the some springs.

Overall, the groundwater samples (springs and standpipes) contained fewer bacteria than surface water (streams and creeks). Typically, they have lower temperatures than the surface water samples, suggesting that the bacteria content might be related to water temperature. However, springs sampled both in May and November had similar temperatures, such as Namche Bazaar town stream, which had a May temperature of 8.8˚C and a November temperature of 9.4˚C. In May, the Namche Bazaar town stream had significant *E. coli* colonies whereas in November there were very few. There is no correlation between groundwater temperature and bacteria content.

In summary, surface water samples were more likely to contain bacteria than the groundwater samples, and water samples collected in May were more likely to contain *E. coli* than those collected in November. The presence of *E. coli* in the surface and groundwater-fed springs is a concern due to the heavy dependence on these drinking sources for the local communities and tourists.

4. Discussion

This project investigated the quality of drinking water through physical field characteristics of the water and bacteria values in an effort to identify areas most at risk from fecal contaminated water. This study was necessary along the route to Mt Everest base camp (and in the SNP) because of the increasing number of tourists and lack of water and sanitation infrastructure. In the last forty years the number of visitors to the park has increased from fewer than 100 tourists per year to over 30,000 foreign tourists per year (not including their Nepalese guides and porters). As a result, the area is suffering from significant environmental degradation [5] [6].

A recent study by Salerno *et al.* [3] focused on tourist impressions of environmental conditions within the SNP, and their results suggest that visitors to the SNP appear to be satisfied with the current conditions, including water quality, energy use and tourist numbers [3]. Non-biodegradable waste can be seen along the major trekking routes; however, the recent addition of waste collection facilities appears to have helped alleviate this problem. Therefore, tourists do not typically see the disposal and results of biodegradable waste, such as human waste. Salerno *et al.* [3] suggested that there was room for further growth in tourist numbers; however, they also noted that the current environmental conditions would significantly limit growth and further development, and their research suggested that limiting tourist numbers to fewer than 15,000 would mitigate current environmental concerns [3].

Currently unmanaged and/or poorly managed solid waste disposal and open defecation throughout the SNP have resulted in fecal contamination and degradation of the major rivers [5]. In the major townships, it is possible to observe sewage and toilet waste piped into nearby streams and rivers (authors' personal observations; [7]). This study measured coliform bacteria (total coliform bacteria and/or fecal coliforms) as an indirect method to identify contamination by fecal material as fecal contamination poses significant health risks [11]-[15].

The first study of *E. coli* and coliform bacteria in the Sagarmatha National Park was conducted by Ghimire *et al.* [5] between 2008 and 2010. Their study focused entirely on the major rivers within the park, and they concluded that all of the rivers contained *E. coli* and coliform bacteria, although the upper reaches of most rivers did not. Their results summarized the findings from analyses of forty-five water samples that were collected and analyzed at the Central Department of Botany, Tribuvan University (Kathmandu), at Kunde Hospital in Kunde (in 2010) and in a portable laboratory in a hotel in Namche Bazaar. Total coliforms and *E. coli* estimations were done following APHA [19] methods.

A study published by Baghel *et al.* [18] of the Gangetic headwaters, beginning at the Gangotri glacier (Uttarakhand, India) and extending 27 km downstream produced similar results to this study and Ghimire *et al.* [5]. That investigation involved 21 sites that were sampled three times each year: the pre-monsoon summer, the monsoon, and the post-monsoon winter. The authors found that bacterial contamination increased from the upper, higher altitude, portion of the study area to the lower altitude stretches of the river [18] as shown here in the SNP. The results of Baghel *et al.* [18] indicate that the rising development in anthropogenic and socio-cultural activities in the lower stretch was responsible for the increased bacterial contamination. Baghel *et al.* [18] also found that total coliform and thermotolerant coliforms were at a maximum during summer (followed by monsoon and winter), which the researchers attributed to a larger number of pilgrims and trekkers visiting the area during the summer.

Our results are complimentary to those of Baghel *et al.* [18], Sood *et al.* [20] and Ghimirie *et al.* [5] [6]. In general we found that increasing altitude corresponded to decreasing temperature, and increasing pH, TDS, conductivity, and bacteria (**Figure 3**). Almost all of the samples collected, both in May and November, are slightly alkaline and the physical properties for all of the samples fall within the WHO [17] guidelines for safe drinking water. The bacteria content of our samples was higher in the summer (May). November, the post monsoon early winter season, has a reduced number of daylight hours (approximately 11 hours and 5 minutes daylight average), and colder conditions (average daytime highs approximately 9˚C) than the pre-monsoon early summer month of May (approximately 13 hours and 20 minutes daylight, and average daytime highs of approximately 14˚C) [1]. The shorter days and cooler temperatures most likely explain why samples collected in November contained fewer bacteria than the samples analyzed in May (the effects of daylight, or lack thereof, on *E. coli* has long been known [21]). As the samples collected in May contained more *E. coli* than those collected in November, there may be also a relation between *E. coli* and both air temperature and daylight hours in the SNP and surrounding areas.

The largest low-altitude towns (Lukla, Namche Bazaar, Khumjung and Chaurikharka) have the highest density of tourists and the greatest resident populations. Exact population data is difficult to acquire. The Chaurikharka region (including the townships of Lukla and Chaurikharka) has a population of approximately 2200. The population of Namche Bazaar township is ~1600 and the combined populations of Khumjung, Kundee and Tengboche are estimated to be 1800. Our coliform and *E. coli* data indicate that fecal contamination of drinking water is related to population, the number of tourists and temperature/daylight hours. These results show that field-based monitoring of physical parameters is not sufficient to assess water contamination in the region.

The results of this study also show two similar, but distinct, trends in the data based solely on altitude, which suggest that the lower altitude samples may be affected by different processes. The lower portion of the study area, between Lukla and Monjo, experiences higher tourist and local traffic and is located within the SNP buffer zone, not the SNP proper itself. The differences in field parameters and bacterial content between the buffer zone and SNP proper may relate to more humans, livestock and deforestation, in addition to altitude and tourist traffic. The higher altitude samples, between Namche Bazaar and Deboche have larger temperature ranges but overall show similar trends as the lower altitude samples. This area is completely within the SNP boundary so the difference might be the result of less deforestation, lower temperatures and/or less human impact. Alternatively, these differing trends might reflect variations in rock types, proximity to structural geology features (faulting), and/or ratios of glacial melt in the groundwater between the upper and lower reaches of the study area. Further work is needed to assess the cause of the different trends.

Fecal pollution indicators, such as *E. coli* and coliform bacteria, can be used to evaluate the health of aquatic ecosystems and the potential for health effects among individuals within those environments [22]. The presence of such indicator organisms may provide evidence of water-borne problems and direct threats to human and animal health. Our study clearly suggests that there is a significant presence of bacterial indicators of fecal pollution in this study area. This work suggests that groundwater-fed springs may be safer to drink during the cold winter months. However, further work is needed to ascertain the bacteria content of the drinking water during the warmer summer months when bacteria levels are likely to be higher. Importantly, more research is needed to ascertain the ultimate water sources, such as glacial melt, to surface water or the shallow groundwater. The quality and quantity of these sources are likely to change with the current global warming trends and accelerated melting of glacial ice, which could have a significant impact on the potable water in the region. Continued monitoring of microbial contamination in the SNP should be an essential component of the environmental protection strategy in the SNP.

The World Tourism Organization (WTO) states that tourism operations in protected areas need to be carefully managed and monitored to ensure their long-term sustainability. Otherwise, such operations will have negative environmental and cultural consequences, and tourism will contribute to the further deterioration [4]. Although the negative effects of tourism are of significant concern, many protected areas have promoted tourism development to improve their economic conditions, particularly to generate revenue to finance other social and economic development activities and to provide direct income and employment opportunities for the local population [3] [4]. In the SNP there are conflicting interests between the need for economic growth based on tourism and the ability of the current infrastructure to handle issues such as human waste disposal. As such, continued monitoring of water quality, specifically fecal contamination, can be used as a key indicator of the effects of both continued economic growth and climate change.

5. Conclusions

Our study shows that:

1) Drinking water within the SNP region currently meets current WHO [17] drinking water standards for the physical properties of temperature (2.8˚C - 13˚C), pH (5.27 - 7.24), conductivity (14.50 - 133 µS) and TDS (7.24 - 65.5 ppm).

2) Samples collected and analyzed in May (pre-monsoon summer) had a higher level of *E. coli* and coliform bacteria than samples collects in November (post-monsoon early winter) suggesting a seasonal dependence.

3) Samples from surface water sources have higher concentrations of *E. coli* and coliform bacteria than groundwater-fed springs.

4) Samples from lower altitude drinking water sources were higher in *E. coli* and coliform bacteria than samples from higher altitude sources.

5) Field-based measurements of physical parameters, temperature, pH, TDS and conductivity alone are not sufficient to detect or monitor drinking water contamination in the SNP.

Acknowledgements

The authors would like to thank the following people and organizations for their support: Troy Risk Inc. (Indianapolis), Indiana Geologists, Ball State University, AngNorbu Sherpa (Holiday Namche), AngPema Sherpa (Valley View Khumjung) and the Sagarmatha National Park Service.

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