Sensitivity of High-altitude Sickness and Death with Meteorological Variables: A Case Study of Khumbu Everest Region in Nepal

Tirtha Raj Adhikari[1*] & Dhiraj Pradhananga[2]
[1] Central Department of Hydrology and Meteorology, Tribhuvan University, Kirtipur, Nepal
[2] Department of Meteorology, Tri-Chandra Multiple Campus, Kathmandu, Nepal
**Correspondence: tirtha43@gmail.com*
https://doi.org/10.3126/jtha.v4i1.46310

Abstract

Many people travel to high altitudes for different purposes, mainly for trekking and expeditions. They may experience high altitude sickness and harsh weather conditions. Therefore, information on weather conditions before any travel is crucial for safety. Altitude sickness normally starts from the elevation above 3500 m. This study explores inter relationships between meteorological parameters and altitude sickness in the Khumbu Everest region and provides information about meteorological conditions during the high deaths. Percentiles and index basis criteria were used to evaluate sensitivity of death cases to meteorological variables. Atmospheric pressure, wind speed and minimum temperature recorded at the nighttime were more sensitive to deaths by high altitude sickness compared to precipitation, maximum temperature, wind speed, relative humidity, and sunshine duration.

Keywords: *High altitude sickness, sensitivity, percentile and index, Everest Khumbu*

Introduction

Tourism is one of the largest industries in Nepal. It is a source of foreign currency and revenue to Nepal [MoCTCA, 2020- Appendix (III)]. Possessing eight out of the ten highest mountains in the world, Nepal is a hot spot destination for mountaineers, rock climbers and people seeking adventure. It is famous for its snow-capped mountains, abundant flora and fauna, exciting trekking routes, and rich cultural and religious diversity. Therefore, it has a great potential to become a top destination for tourists. Travelling to high-altitude regions and mountainous areas is increasingly popular to the people, tourists, and researchers. Mount Everest Khumbu area is attraction to many people for skiing, hiking, snowshoeing, climbing, and research. The area has many types of flora and fauna, including national bird. Mountain goats are common in the area. Most people start trek from Lukla (2846 m) and head towards Everest Base Camp (5,364 m). They pass through, Ghat, Phorest, Namche Bazar (3440 m), Khumjung, Kunde, Pangboche, Tanboche, Dingboche, Lubuche, and Kalapathar. These are high altitude areas. Therefore, many people suffer from high altitude sickness in this area. This paper presents the recent data on altitudinal sickness and deaths in Khumbu area and their relationships with meteorological parameters using sensitivity and percentile analyses.

Objectives

The main objective of this paper is to identify the conditions of meteorological parameters to people;s death by altitude sickness in the Everest Khumbu region of Nepal. The specific objectives are:

- identify the number of deaths by altitude sickness.

- relation between the altitude sickness and meteorology parameters during the sickness events.
- to determine the sensitivity and percentile of meteorological parameters during high number of death events due to altitude sickness.

Study area

The altitudinal gradient of the Khumbu area ranges from 3393 m to top of Mt. Everest 8848.86 m (Figure 1). The Khumbu area has been divided into temporary snow cover land, permanent snow cover, glacierized and snow free areas. In the Khumbu Everest region, the meteorological parameters are quite similar with the nearest surrounding areas of the Dingboche, Lubuche and Gokyo Valley. All these areas are found alpine climates, whereas the Dingboche valley found the meteorological station, which was established by Department of Hydrology and Meteorology (DHM), Government of Nepal in 1988. The meteorological station is located at Longitude 86056'40''E and Latitude 27053'40''N, this is the nearest station which can be representing the meteorological conditions of Chukung Ri, Amphu Gyabien Island peak, Lhotse Peak with Khumnu Everest region also found the alpine climates. In this area having an alpine climate with snow falls over the high mountains in winter and rain in summer (Adhikari & Devkota, 2016).

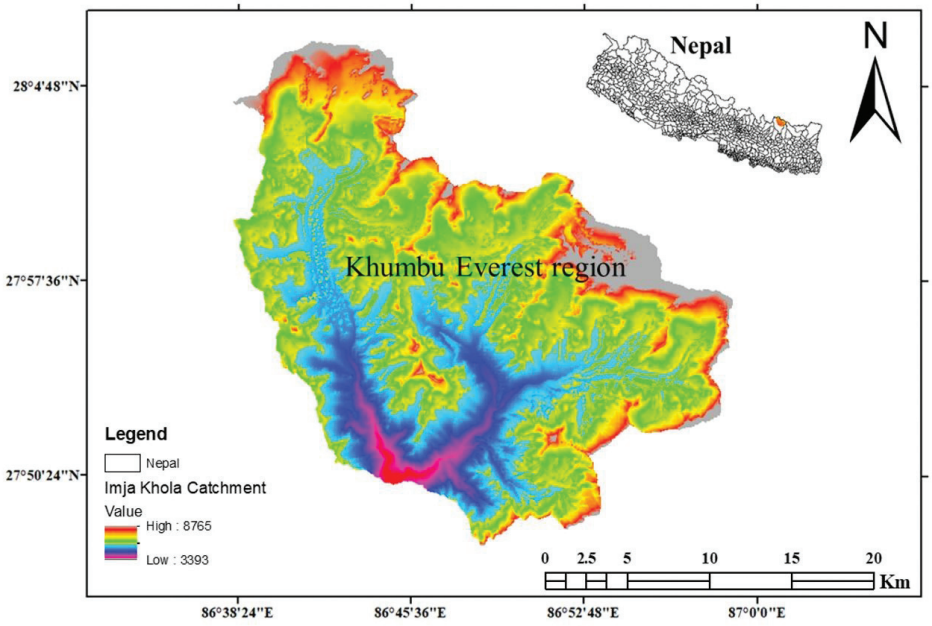


Figure 1: *Khumbu Everest region study area.*

Data collection

Meteorological (observed and satellite) data: The observed monthly meteorological data (precipitation, maximum and minimum wind speed and temperature, relative humidity, and sunshine duration) at Dingboche (4300 m amsl) in Khumbu Everest region from 1988 to 2008 were collected from the Department of Hydrology and Meteorology (DHM), Government of Nepal. This station representing alpine climate is nearby the Khumbu Everest

region (Table 1). The maximum and minimum ranges of meteorological variables are presented in Table 1. Monthly maximum and minimum air temperature were 10.5°C in August and -5.3°C in February respectively. During the day and night-time air pressure and minimum air temperature and wind speed etc. of weather are associated with increased morbidity and mortality compared with an intermediate, comfortable temperature range (Kilbourne, 1998). To analyze the altitude sickness of death cases and satellite data from the same area from 2017 to 2019, snow/rain, air and surface temperatures, atmospheric pressure data were collected (Appendix II). The time series area average, satellite data from Giovanni (Bounding Box: 27.1 to 28.5 and 84. 5 to 87.05) reference No.5 and (ALOS) Digital Elevation Model (DEM) reference No.7 with a ground resolution of 12.5 m were collected.

Table 1: Monthly average of meteorological parameters of Dingboche (DHM) Station (1988-2008)

Month	Precipitation mm	Relative humidity %	Sun shine hour	Max. wind m/s	Min. wind m/s	Maximum temp. °C	Minimum temp. °C
Jan	5.8	25.1	5.5	5.3	4.4	3.1	-4.7
Feb	6.9	30.0	5.5	5.2	4.1	3.8	-5.3
Mar	17.3	37.1	6.0	6.0	4.7	3.9	-4.0
Apr	8.5	35.7	7.0	6.3	4.8	6.9	0.2
May	22.6	43.8	6.0	5.1	4.2	7.3	3.8
Jun	42.6	53.0	2.0	5.2	4.5	9.8	6.5
Jul	91.8	51.7	3.0	4.4	4.3	9.9	7.2
Aug	133.0	50.0	3.0	4.3	4.3	10.5	6.6
Sep	64.0	55.3	3.0	4.4	4.4	9.3	5.1
Oct	6.9	45.9	5.5	4.4	4.2	7.2	1.7
Nov	3.8	27.2	6.5	4.4	4.4	10.0	-1.4
Dec	2.2	24.9	6.0	5.1	3.1	8.2	-0.2

Incident Data: The altitude sickness death data were collected from Ministry of Home Affairs (MoHA), Government of Nepal, from Nepal Disaster Risk Reduction Portal (2022). May typically has higher number of travelers in this area due to the warm temperature; this is also the month when more people get altitude sickness. The number of deaths case by altitude sickness of this month (May) in the Khumbu Everest region detail data are depicted in Table 2.

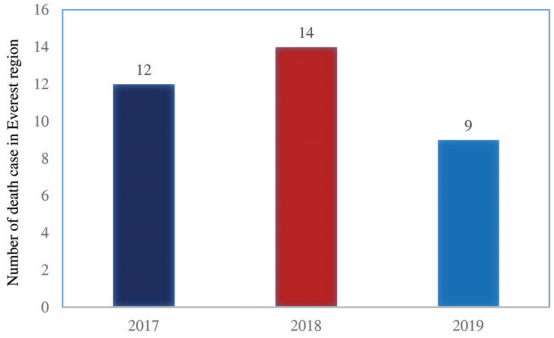
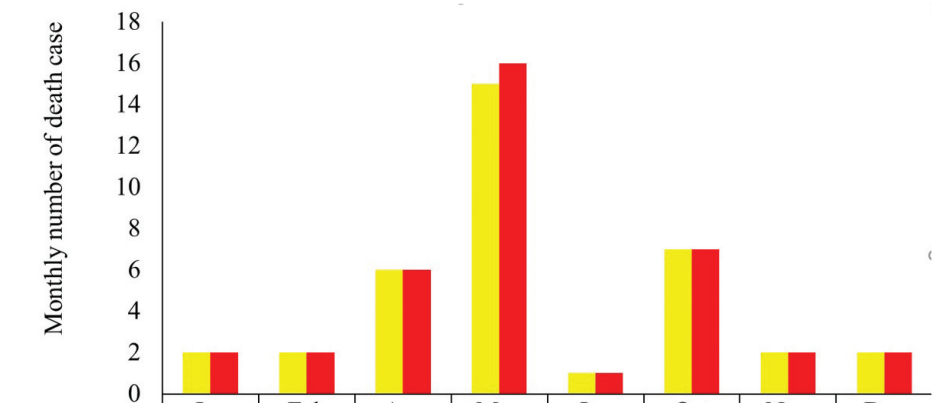


Figure 2: *Annual (2017 to 2019) death cases of 2010, the Khumbu (2018), Everest region (2010)*



	Jan	Feb	Apr	May	Jun	Oct	Nov	Dec
No of Days	2	2	6	15	1	7	2	2
No.of Death	2	2	6	16	1	7	2	2

Figure 3: *Three years monthly yellow is number of days and read is number of death case*

Results and discussion

The number of highest incident deaths in one day cases in the month of May (2017 to 2019) by altitude sickness in the Khumbu Everest region is presented in Table 2. On the event day the atmospheric pressure was highly increased in both day and nighttime on 18th May 2018 and two people died in Khumbu Everest region in one day Appendix (II). The day surface temperature and wind speed were significantly decreased from the day before. Similarly, the precipitation was very light during the event day in the Khumbu Everest area. The six meteorological variables from the Giovanni satellite product final version were plotted in Figure 4. The atmospheric pressure, air temperature and windspeed were more sensitivity among the other meteorological parameters in the month of May. But wind speed and sunshine duration are significantly decreased from observed meteorological data, during the same period of May at the Dingboche station (1988 to 2008), those graphical plots are presented in the Figure 5.

Table 2: Three-year incident cases of altitude sickness

VDC/ Municipality (Ward No.)	Incident Date	Month	Cause of incident	Death Male	Death Female	Death Unknown	Total Death	Affected Family	Source	Remarks
Khumbu Pasang Lhamu-4	5/6/2017	5	High Altitude	2	0	0	2	2	Nepal Police	Min Bdr. Sherchan
Khumbu Pasang Lhamu-4	5/11/2017	5	High Altitude	1	0	0	1	1	Nepal Police	Phiroj Amat
Khumbu Pasang Lhamu-4	5/20/2017	5	High Altitude	0	0	0	1	1	Nepal Police	Parkmun Spok
Khumbu Pasang Lhamu-4	5/26/2017	5	High Altitude	0	1	0	1	1	Nepal Police	Amy Wong Kum Ling
Khumbu Pasang Lhamu-4	5/1/2018	5	High Altitude	1	0	0	1	1	Nepal Police	Lawrene Scott
Khumbu Pasang Lhamu-4	5/6/2018	5	High Altitude	1	0	0	1	1	Nepal Police	Kuga Takahiro
Khumbu Pasang Lhamu-4	5/14/2018	5	High Altitude	1	0	0	1	1	DAO Solukhumbu	Lam Aoon Uhwa Christoper
Khumbu Pasang Lhamu-4	5/17/2018	5	High Altitude	1	0	0	1	1	Nepal Police	Rustem Amirov

Mahakulung Rural Municipality-1	5/19/2018	5	High Altitude	1	0	0	1	1	Nepal Police	Dilli Prasad Poudel
Mahakulung Rural Municipality-1	5/20/2018	5	High Altitude	1	0	0	1	1	Nepal Police	Pemarinji Sherpa
Mahakulung Rural Municipality-1	5/21/2018	5	High Altitude	1	0	0	1	1	Nepal Police	Gjeorugi Pethov
Mahakulung Rural Municipality-1	5/16/2019	5	High Altitude	1	0	0	1	1	Nepal Police	Ravi
Mahakulung Rural Municipality-1	5/17/2019	5	High Altitude	1	0	0	1	1	Nepal Police	Tomov Ivan Yuriev
Mahakulung Rural Municipality-1	5/23/2019	5	High Altitude	0	1	0	1	1	Nepal Police	Kalpana Dash
Mahakulung Rural Municipality-1	5/24/2019	5	High Altitude	1	0	0	1	1	Nepal Police	Dhurba Bista

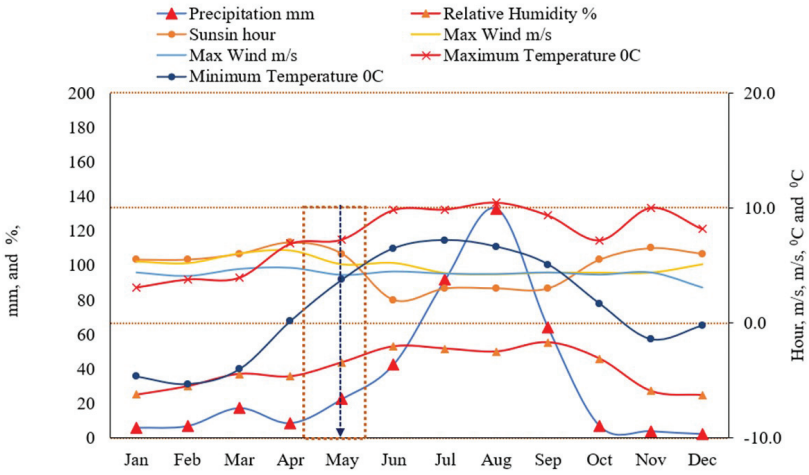


Figure 4: *Sickness effect by meteorological parameters of May 2018 events in the Khumbu Everest Region in Nepal.*

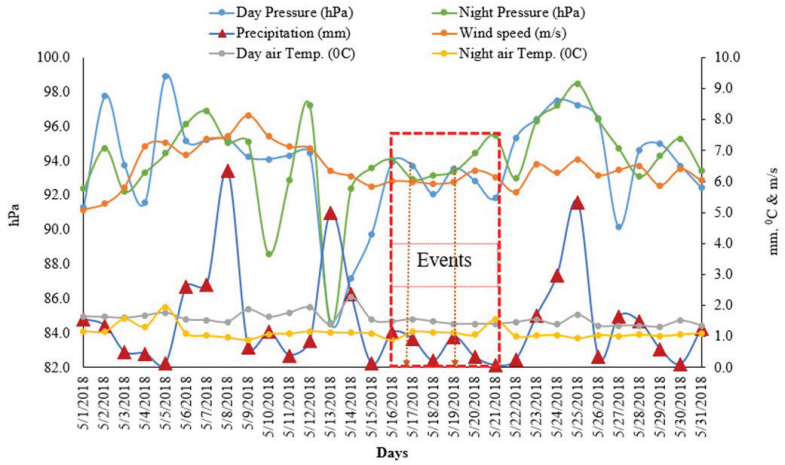


Figure 5: *Observed meteorological parameters from 1998 to 2008 Dingboche station.*

Sensitivity and percentile: Six meteorological parameters were used in the analysis of sensitivity and percentiles from the three years daily data (2017–2019). The three parameters: Night-time atmospheric pressure, air temperature, and wind speed were in high percentile on 17th May and 18th May and there were not any case in that region, but on 19th and 20th both days had death cases. The percentile and sensitivity were collocated by using the statistics, percentiles, and index methods (Agarawal, 2000). The nighttime air temperature from 17th May to 20th May, relatively constant and day-nighttime atmospheric pressure is frequently increase but the daytime air temperature was decreasing (17th to 20th, 2018) of first, third and fourth column. The effect of meteorological parameters of day-nighttime pressure, nighttime air temperature and wind speed were high percentile and more sensitivity presented in Table 3.

Table 3: Sensitivity and percentiles of the meteorological parameters

Meteorological Parameters	17/5/2018	18/5/2019	19/5/2020	20/5/2020
Number of deaths	1	0	1	1
% of sensitivity/ night air pressure (hPa)	70.0%	66.6%	0.0%	0.0%
	93.0	93.2	93.4	94.4
% of sensitivity / day air pressure (hPa)	0.0%	0.0%	0.0%	43.3%
	93.7	92.1	93.5	92.9
% of sensitivity/ day air temperature (°C)	0.0%	60.0%	0.0%	0.0%
	1.6	1.5	1.4	1.4
% of sensitivity/ night air temperature (°C)	70.0%	66.6%	53.3%	0.0%
	1.1	1.1	1.1	1.1
% of sensitivity/ wind speed (m/s)	80.0%	0.0%	0.0%	0.0%
	6.0	5.9	6.0	6.4
% of sensitivity/ precipitation (mm)	0.0%	0.0%	0.0%	0.0%
	0.9	0.2	1.0	0.3

Conclusion

Deaths due to altitude sickness were reported in the months of Jan, Feb, Apr, May, Jun, Oct, Nov and Dec during 2017 to 2018. Number of deaths by altitude sickness in May 2018 was the highest. The day night-time air pressure and minimum air temperature and wind speed were more sensitive to the death events compared to the other meteorological parameters.

Limitation

- This study has considered only three years data. We recommend using a long-term data for a detail study.
- All kind of trekkers, tourists, and researchers should make themselves familiar with the past weather information before a trek to the high-altitude areas.
- All types of trekkers should be aware of atmospheric pressure, minimum air temperature and wind speed during the night.

Acknowledgement

The authors are grateful to Ministry of Culture, Tourism and Civil Aviation, Nepal, Mountain Academy to support this research and Department Hydrology and Meteorology (DHM), Government of Nepal for providing the essential meteorological data of Khumbu Everest Region at Dingboche station.

References

Adhikari T. R., P. Devkota L. (2016) *Climate Change and Hydrological Responses in Himalayan Basins, Nepal*. In: Singh R., Schickhoff U., Mal S. (eds) Climate Change, Glacier Response, and Vegetation Dynamics in the Himalaya. PP 9 – 13, Springer, Cham. https://doi.org/10.1007/978-3-319-28977-9_4 .

Agarawal B. L. (2000). *Basic Statistics.* third Edition, Publish by K.K. Gupta for New Age International (P) Limited 4835/24 Ansari Road Daryaganj, New Delhi, PP 55-57.

GoN. (2022). 'Nepal Disaster Risk Reduction Portal (2022); http://drrportal.gov.np.

DHM. (2022). http://dhm.gov.np/meteorological-station

Government of Nepal, Ministry of Energy, Water Resources and Irrigation, accessed on 30 March 2022.

MoCTCA. (2020). Statics Report (2020); https://www.ceicdata.com/en/indicator/nepal/tourism-revenue https://giovanni.gsfc.nasa.gov/giovanni/#service=TmAvMp&starttime=2018-12-01T00:00:00Z&endtime=2018-12-30T23:59:59Z&shape=state_dept_countries/shp_167&

https://asf.alaska.edu/data-sets/sar-data-sets/alos-palsar/alos-palsar-how-to-cite/

Kilbourne, E. M. (1998), Illness due to thermal extremes. In Maxcy-Rosenau-Last Public Health and Preventive Medicine, ed. RB Wallace, pp. 607–17. Stanford, CT: Appleton & Lange. 14th ed.

Appendix (I), Three years monthly death case Khumbu Everest region

Incident Date	Year	Month	Death	No of Days
1/17/2017	2017	1	1	
1/29/2017	2017	1	1	
2/6/2017	2017	2	1	
5/6/2017	2017	5	1	
5/11/2017	2017	5	1	
5/20/2017	2017	5	0	
5/26/2017	2017	5	1	
6/30/2017	2017	6	1	
10/2/2017	2017	10	1	
10/12/2017	2017	10	1	
10/21/2017	2017	10	1	
12/5/2017	2017	12	1	11
2/25/2018	2018	2	1	
4/1/2018	2018	4	1	
4/9/2018	2018	4	1	
5/1/2018	2018	5	1	
5/6/2018	2018	5	1	
5/14/2018	2018	5	1	
5/17/2018	2018	5	1	
5/19/2018	2018	5	1	3
5/20/2018	2018	5	1	
5/21/2018	2018	5	1	
10/4/2018	2018	10	1	
10/20/2018	2018	10	1	
10/22/2018	2018	10	1	
11/28/2018	2018	11	1	14
4/4/2019	2019	4	1	
4/7/2019	2019	4	1	
4/23/2019	2019	4	1	
4/29/2019	2019	4	1	
5/16/2019	2019	5	1	
5/17/2019	2019	5	1	
5/23/2019	2019	5	1	
5/24/2019	2019	5	1	
11/10/2019	2019	11	1	9
Total	232	38		

Appendix (II) Satellite Meteorological data May 2018 during death case

Date	Precipitation (mm)	Wind Speed (m/s)	Day Air Temp. (°C)	Night Air Temp (°C)	Day Pressure (hPa)	Night Pressure (hPa)
5/1/2018	1.6	5.1	1.6	1.2	91.3	92.4
5/2/2018	1.3	5.3	1.6	1.2	97.8	94.8
5/3/2018	0.5	5.8	1.6	1.6	93.8	92.3
5/4/2018	0.4	7.1	1.7	1.3	91.6	93.3
5/5/2018	0.1	7.2	1.8	1.9	98.9	94.4
5/6/2018	2.6	6.9	1.5	1.1	95.1	96.2
5/7/2018	2.7	7.4	1.5	1.0	95.2	96.9
5/8/2018	6.3	7.5	1.5	1.0	95.3	95.1
5/9/2018	0.6	8.1	1.9	0.9	94.2	95.1
5/10/2018	1.2	7.5	1.6	1.1	94.1	88.6
5/11/2018	0.4	7.1	1.8	1.1	94.3	92.9
5/12/2018	0.9	7.1	1.9	1.2	94.4	97.2
5/13/2018	5.0	6.4	1.4	1.1	84.6	84.5
5/14/2018	2.4	6.2	2.3	1.1	87.2	92.4
5/15/2018	0.1	5.8	1.5	1.1	89.7	93.6
5/16/2018	1.1	6.0	1.5	0.9	93.9	94.1
5/17/2018	0.9	6.0	1.6	1.1	93.7	93.0
5/18/2018	0.2	5.9	1.5	1.1	92.1	93.2
5/19/2018	1.0	6.0	1.4	1.1	93.5	93.4
5/20/2018	0.3	6.4	1.4	1.1	92.9	94.4
5/21/2018	0.1	6.2	1.4	1.5	91.8	95.5
5/22/2018	0.2	5.7	1.5	1.0	95.3	93.0
5/23/2018	1.7	6.5	1.5	1.0	96.4	96.3
5/24/2018	3.0	6.3	1.4	1.0	97.5	97.2
5/25/2018	5.3	6.7	1.7	0.9	97.3	98.5
5/26/2018	0.4	6.2	1.3	1.0	96.5	96.4
5/27/2018	1.7	6.4	1.3	1.0	90.1	94.8
5/28/2018	1.5	6.5	1.4	1.1	94.6	93.1
5/29/2018	0.6	5.9	1.3	1.0	95.0	94.3
5/30/2018	0.1	6.4	1.5	1.1	93.7	95.3
5/31/2018	1.2	6.0	1.4	1.1	92.4	93.4

Appendix (III) Foreign currency and revenue Fact Sheet 2020

Fact Sheet

Indicators	1762019	2020	% Change
Tourist Arrivals by Major Five Airlines			
Rank 1	Nepal Airlines	Nepal Airlines	
Rank 2	Qatar Airways	Qatar Airways	
Rank 3	Fly Dubai	Himalaya Airlines	
Rank 4	Air India	Fly Dubai	
Rank 5	Air Arabia	Air Arabia	
Mountaineering Expedition			
Total Team	1921	153	-92.0
Total Person	8202	447	-94.0
Royalty to Government (Rs. '000)	568269	149790	-71.6
Total Earning (US$ '000)	724337	217007	-70.0
Average Expenses Per Visitor Per Day (US$)	48	65	35.4
Tourism Related Enterprises			
Hotel (Star)	138	142	2.9
Hotel (Non-star)	1151	1171	1.7
Beds (Total)	43999	45850	4.2
Travel Agencies	3680	3743	1.7
Trekking Agencies	2764	2797	1.2
Tourist Guide	4200	4241	1.0
Trekking Guide	17625	17766	0.8