AMERICAN JOURNAL OF EPIDEMIOLOGY
Vol. 118, No. 2

Printed in U.S.A.

ASSOCIATIONS AMONG CATARACT PREVALENCE, SUNLIGHT HOURS, AND ALTITUDE IN THE HIMALAYAS[1]

LAWRENCE B. BRILLIANT,[2,4] NICOLE C. GRASSET,[3] RAM PRASAD POKHREL,[3] ALBERT KOLSTAD,[3] JAMES M. LEPKOWSKI,[5] GIRIJA E. BRILLIANT,[2,4] WILLIAM N. HAWKS[6] AND R. PARARAJASEGARAM[7]

Brilliant, L. B. (School of Public Health, U. of Michigan, Ann Arbor, MI 48109), N. C. Grasset, R. P. Pokhrel, A. Kolstad, J. M. Lepkowski, G. E. Brilliant, W. N. Hawks and R. Pararajasegaram. Associations among cataract prevalence, sunlight hours, and altitude in the Himalayas. *Am J Epidemiol* 1983;118:250-64.

The relationship between cataract prevalence, altitude, and sunlight hours was investigated in a large national probability sample survey of 105 sites in the Himalayan kingdom of Nepal, December 1980 through April 1981. Cataract of senile or unknown etiology was diagnosed by ophthalmologists in 873 of 30,565 full-time life-long residents of survey sites. Simultaneously, the altitude of sites was measured using a standard mountain altimeter. Seasonally adjusted average daily duration of sunlight exposure for each site was calculated by a method which took into account latitude and obstructions along the skyline. Age- and sex-standardized cataract prevalence was 2.7 times higher in sites at an altitude of 185 meters or less than in sites over 1000 meters. Cataract prevalence was negatively correlated with altitude ($r = -0.533$, $p < 0.0001$). However, a positive correlation between cataract prevalence and sunlight was observed ($r = 0.563$, $p < 0.0001$). Sites with an average of 12 hours of sunlight exposure had 3.8 times as much cataract as sites with an average of only seven

---

[1] From the Nepal Blindness Survey, an undertaking of the World Health Organization Prevention of Blindness Programme; the Ministry of Health, His Majesty's Government of Nepal; the Seva Foundation; and the University of Michigan.

[2] Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, MI 48109. (Reprint requests to Dr. Lawrence Brilliant).

[3] World Health Organization - His Majesty's Government of Nepal Blindness Prevention and Control Programme, World Health Organization, Kathmandu, Nepal.

[4] Seva Foundation, Chelsea, MI.

[5] Survey Research Center, Institute for Social Research, University of Michigan, Ann Arbor, MI.

[6] Department of Ophthalmology. Medical School, University of Michigan, Ann Arbor, MI.

[7] Prevention of Blindness Programme, World Health Organization Regional Office for Southeast Asia, New Delhi, India.

Presented at the Symposium on Eye Disease Epidemiology, sponsored by the National Eye Institute, NIH, Bethesda, MD, June 1982.

Agencies supporting work: Drs. Lawrence Briliant, Lepkowski and Hawks were World Health Organization (WHO) consultants on leave from the University of Michigan when this survey was carried out. Dr. Lepkowski's work in Nepal was supported by the Centers for Disease Control. Dr. Kolstad was WHO Medical Officer on leave from the University of Oslo Department of Ophthalmology when this study was carried out. Drs. Grasset and Pokhrel are co-managers of the WHO-Government of Nepal Prevention of Blindness Project. Dr. Girija Brilliant was supported by a fellowship from the American Foundation for the Blind. The Nepal Blindness Survey was supported by generous grants from the Government of the Netherlands and the Seva Foundation.

The authors thank the following ophthalmologists who carried out eye examinations and provided clinical expertise: Drs. S. K. Khatri, R. K. Koirala, K. Konyama, I. C. Biswas, O. K. Malla and B. K. Malla, as well as the many field workers who participated in the Nepal Blindness Survey; Drs. Roy Milton, Daniel Seigel, James Koopman and Hugh Taylor for valuable advice; J. Kuo-Dick, B. Mitchell, Dr. G. P. Pokhrel, S. R. Shrestha and V. Dhakwa for assistance with data management. The authors especially thank Timothy Gilbert, landscape architect, who suggested the method of calculation of sunlight hours used in this study.

hours of exposure. Sunlight was blocked from reaching certain high altitude sites by tall neighboring mountains.

health surveys; ophthalmology; ultraviolet rays

Cataract has proven difficult to study in part because of its long period of latency, its apparent relationship to the process of aging, and its multiple etiologies. While it is known anecdotally that certain exposures have caused individual cases of cataract, the cause or causes of the vast majority of cataract cases remain unknown.

Reports have appeared in the literature of cataract appearing in humans after nuclear accidents and atomic bomb irradiation (1), exposure to cyclotrons and radium therapy (2), infrared radiation (3), whole-body irradiation (4), radar and microwaves (5), laser beams (6), heat from occupational exposure to glass-blower's torches and blast furnaces (7), x-rays (8), electric shock (9), and ultraviolet light (10). In addition, prenatal infection with rubella is known to cause congenital cataract (11), and a "sunflower cataract" has been found to be associated with Wilson's disease (12). Individual risk factors which have been associated with excess cataract in India include age, nutritional status, short height and low weight, widowed status, low education, and use of rocksalt in cooking (13). Several attempts have been made to understand cataractogenesis in the light of an underlying nutritional process (14) or an underlying systemic factor (15). Some scientists have tried to present unifying theories of cataractogenesis based on a better understanding of aging (16, 17).

Despite these many attempts to elucidate the cause of cataract, the vast majority of cataracts are still grouped into a "senile cataract" category, "a diagnosis of exclusion" for which the etiology remains unknown (18).

One well-known hypothesis in ophthalmology since 1926 is the hypothesis of Duke-Elder (19) that "the fundamental cause of cataract in all its forms may be traced to the incidence of radiant energy directly on the lens itself."

There are several reports from geographic and population studies associating cataracts with naturally occurring radiant energy either as sunlight or as ultraviolet radiation. Zigman et al. (20) studied the extracted cataractous lens of humans in three geographic locations (Manila, Philippines; Tampa, Florida; and Rochester, New York) and found that a particular type of cataract, the brown or "brunescent" cataract, was more common in areas where ultraviolet components of sunlight are more intense. Hiller et al. (21) found a higher cataract-to-control ratio for persons aged 65 or over in locations with longer duration of sunlight.

In Australia, Taylor (22) reported a positive relationship with ultraviolet light, latitude, and average hours of sunlight. No relationship with maximum temperature, evaporation rate, relative humidity, global radiation for January, or annual rainfall was found. Hollows and Moran (23) report further information from Australia showing a positive correlation between the prevalence of cataract and levels of climatic ultraviolet radiation.

Ultraviolet radiation is known to be more intense at higher elevations. Several investigators have studied the relationship between cataract and altitude. In the Andes, Goldsmith et al. (24) found a higher than expected prevalence of cataract among the Aymara Indians living above 3000 meters. Vines (25) found a higher prevalence of cataract in the highlands of New Guinea than at lower altitudes. Seung Wen-shi (26) examined 1468 Tibetan farmers and found cataract prevalence rates which were three times higher at 4000 meters (43.6 per cent) than at 2000 meters (13.7 per cent) in the over 40-year age group.

The single finding which did not support this positive association between cataract and altitude is that of Chatterjee (27), who found a lower prevalence of cataract in the Himalayan ranges than in the plains of the Punjab in India. He speculated that altitude actually had a protective effect due to racial or environmental factors. Chatterjee's findings have been cited as part of the evidence against ultraviolet light as a major cause of senile cataract.

If ultraviolet radiation is more intense at higher elevations, then it at first seems unlikely that there should be less cataract in the mountains of the Himalayas, where presumably more intense ultraviolet radiation is to be found than in the plains of Punjab. In reviewing Chatterjee's findings, several writers including Taylor (22) have suggested confounding variables which could explain this paradox. Taylor suggested that Chatterjee's findings might be explained by genetic differences, mineral content of water, socioeconomic variables, cloud cover pattern, or even yogurt consumption.

The literature on cataract and altitude contains contradictions. In the Andes, the highlands of New Guinea, and the Tibetan Himalayas, there are indications that cataract prevalence increases with increasing altitude. On the other hand, Chatterjee's Punjab study showed a negative correlation between cataract prevalence and altitude. In the present report, findings are presented from a study of cataract, altitude, and sunlight in the Himalayas of Nepal. This study suggests that the earlier apparently contradictory findings may actually be consistent with each other and support Duke-Elder's hypothesis (19) on the relationship between cataract and radiant energy.

Materials and Methods

Nepal is a mountainous Hindu kingdom of approximately 14.5 million people residing in an area of 140,798 square kilometers. It is roughly rectangular in shape, situated between India and the Tibetan region of China. The Himalayan ranges in the north blend into the Indo-Gangetic plains in the south, creating four distinct climatic zones: the mountains, the midhills, the plains (called the terai), and the valleys, including the Kathmandu valley (28).

The majority of Nepalese live in the mid-hills (53 per cent) and the terai (37 per cent). The mid-hills have a temperate climate with warm rainy summers and winters ranging from moderately cool to cold. The terai has a climate that is hot and, during the monsoon from June to October, quite humid. The March–June temperatures in the terai range from 25–35 C. The complex arrangements of the mountain ridges (generally oriented in a north-south arrangement) result in rather extreme local variations in exposure to sunlight and climate.

In addition to its unique geography, Nepal contains over 50 major languages and 75 ethnic groups with different diets and customs. Population density varies from less than 250 persons per square kilometer in the mountains to over 2000 persons per square kilometer in the plains.

The Nepal Blindness Programme is a joint undertaking of His Majesty's Government of Nepal and the World Health Organization. The first phase of the Programme was the Nepal Blindness Survey, a national survey of blindness and blinding conditions designed to gather information needed to plan, implement, and evaluate the programme.

The survey employed a two-stage area probability sample of 105 areal clusters containing an expected 70 to 80 households (approximately 400 to 450 persons) each. The sample consisted of all usual residents of the households contained in the geographic units identified as survey sites. The sample selection utilized geographic stratification to disperse the sample as much as possible across Nepal's 75 districts, although it did not attempt to assure a separate selection in each district.

Survey operations at a site were conducted in two stages, enumeration and examination. The enumeration stage included direct measurements for altitude, terrain, skyline, and certain other environmental characteristics. Household level interviews were then conducted on a house by house basis. After all usual residents of a household had been enumerated, an interview was conducted with available household residents concerning household characteristics such as religion, migration history, sources of water, health care utilization practices, and housing unit characteristics.

Altitude was measured in each site using standard mountain altimeters, calibrated for known altitude and barometric pressures at Kathmandu airport. When helicopter transportation was used, altitude readings were cross-checked with helicopter altimeter readings and topographic survey data.

Sunlight hours were measured in 87 rural sites using a method described by Mazria and Winitzky (29). The duration of sunlight reaching a point on the surface of the earth on a particular day is dependent on latitude, season, obstructions due to the skyline, and cloud cover. Knowing only latitude and the obstructions due to the skyline, it is possible to calculate the "seasonally-adjusted" average daily hours of sunlight by subtracting the number of hours the sun is blocked by the obstructing skyline from the expected number of hours for that latitude, and dividing by 365 days. Using a compass and simple surveyors' instruments, survey teams plotted the "skylines" of the 87 rural sites and calculated the times of rising and setting sun for each month, determining a seasonally-adjusted daily average for each site.

The unusual topography of Nepal creates convolutions of mountainous obstructions to the arc of the sun during different seasons. In the absence of mountainous obstructions at 28° northern latitude, villages may receive an average of 12 hours of sunlight each day, not taking cloud cover into consideration. However, at the same latitude but at higher elevations, there may be neighboring taller mountains which block out the sun's rays and shorten the day's sunlight for a given site. In the 87 rural sites or villages where "skylines" were plotted, the average hours of sunlight ranged from 6.6 to nearly 12 hours per day. In the absence of reliable data on cloud cover, the measurements derived from this method should be considered "maximum" or "potential" hours of sunlight exposure for a village and its residents.

An examination team, consisting of an ophthalmologist, a medical officer, and an ophthalmic assistant, arrived in the site after sunlight measurements and enumeration had been completed. The eye examinations were offered at one or more central locations in the site for all enumerated persons. The full description of examination methods is reported elsewhere (30). Visual acuity was measured under natural lighting conditions by the ophthalmic assistant using a two-sided letter E optotype card at a distance of six meters. If the visual acuity was less than 6/18, a pinhole correction was applied and improvements noted.

Each ophthalmologist then examined the study subjects in a darkened room using a standard (i.e., uniform for all survey examinations) focused battery-powered light source and 2.5× head-mounted loupe. The anterior segment of the eye was examined and findings on the lids, conjunctiva, cornea, and lens were recorded. If the visual acuity was less than $^6/_{18}$, and the loss of visual acuity could not be explained by refractive error or by anterior segment findings, the pupil was dilated using 10 per cent phenylephrine, and the lens and posterior segment was examined using an ophthalmoscope. Slit lamp biomicroscopes were not available due to severe space and weight restrictions on transportation and the lack of electrical facilities in most villages. A clinical evaluation of the anatomical cause of visual impairment and the etiology of any ocular disorders was recorded on the eye examination form. Each ophthalmologist carried a written manual which specified procedures for examination and diagnosis. All findings were recorded on a standard ophthalmic examination record which had been pre-tested on about 3000 subjects in Nepal over a two-year period of field testing preceding the field work of the survey.

Ophthalmologists recorded their impression of cataract cause by a history of age of onset (congenital), intercurrent or concurrent disease (inflammatory or infectious), accidents (traumatic), degenerative (senile), or cause unknown. Senile cataract was often a diagnosis made by exclusion of other causes.

The persons included as cataract cases in this study are persons diagnosed by an ophthalmologist to have lenticular opacities in either or both eyes (incipient, immature, or mature cataracts) or persons who have had such cataract(s) removed and are presently aphakic or have after-cataract membranes. Also included are persons who had dislocated cataractous lens due to couching, a traditional method for dislodging lenticular opacities from the visual axis. Several cataract cases diagnosed in the survey were excluded from the case definition in this study because, in the opinion of an ophthalmologist, their cataracts were caused by trauma, congenital disease, or were secondary to other known inflammatory or infectious processes. The cataract cases remaining are considered to be of senile or undetermined etiology.

It is possible to attempt to define a population in such a way as to minimize the heterogeneity of sunlight exposure to make place-level sunlight exposure estimates more meaningful. Individual exposure to sunlight is dependent on many additional factors besides the hours of sunlight reaching someone's home village. These factors include occupation, habits and customs, and travel history. At present there is no simple way to measure person-hours of sunlight exposure on an individual basis, such as the total numbers of hours spent in the sun during a lifetime. A community level measure of sunlight exposure would be more useful if each community consisted of a stable homogeneous population rather than a population heterogenous for migration and occupational exposure.

In rural Nepal, where some communities are isolated due to the terrain, many people may spend virtually their entire lives in one village, never leaving except for occasional festivals and marriages. Although there has been an increasing number of permanent migrants to the plains from the hills and mountains, as well as traditional seasonal migration from high to low altitudes in some occupations like porters and shepherds, it is possible to exclude persons who are not full-time life-long residents of a given site. In the survey, each family was interviewed about its migration history, both seasonal and permanent. Figure 1 shows the results of stratification by these migration measures to obtain a relatively homogenous study population of full-time life-long residents in the 97 rural sites in the survey. A total of 30,565 full-time life-long residents were identified who have

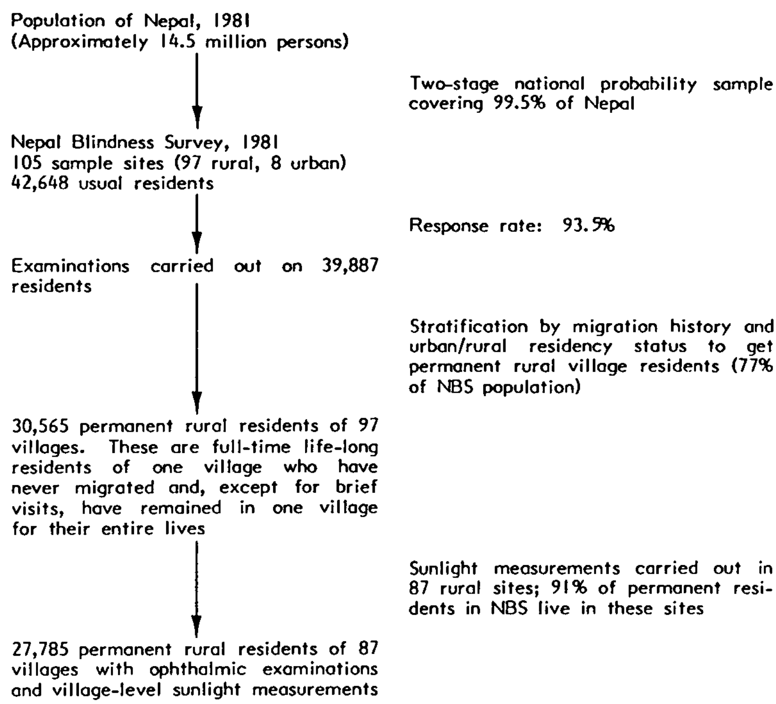

FIGURE 1. Definition of study population, Nepal Blindness Survey (NBS), 1981.

lived in a relatively constant solar environment for virtually their entire lives. Of these, village-level sunlight measurements were available on 27,785 (91 per cent).

RESULTS

The rural villages included in this study ranged from 26° to 29° northern latitude and from 80° to 88° longitude. Altitudes ranged from near sea level (100 meters) to 2272 meters (mean = 900 meters, standard deviation = 631 meters). The seasonally-adjusted average sunlight (ignoring cloud cover) ranged from 6.6 to 12 hours per day (mean = 10.3 hours, standard deviation = 1.5 hours).

Figure 2 shows the relationship between altitude and sunlight in the 87 rural sites or villages in the study. (Sunlight was not measured in 10 of the 97 rural sites in the survey. Data concerning sunlight are shown only for those 87 sites with sunlight measurements, while other findings are presented for all 97 rural sites.) A negative correlation occurs between altitude and sunlight ($r = -0.685$, $p < 0.0001$). Inspection of the scattergram suggests that there are mainly two groups of sites: a cluster of sites representing the unobstructed plains villages and the remaining sites from the hills. The plains sites are near sea level and receive nearly the full 12 hours of sunlight. The pattern for the other sites is more difficult to interpret, and there may be nothing more than random variation in the sunlight pattern in the hills.

Out of 30,565 full-time life-long rural residents in the 97 rural sites of the survey, 873 (2.9 per cent) were found to have some degree of cataract. Cataract prevalence varied by site, altitude, and sunlight; the strongest relationship between survey variables and cataract was with age and sex. Table 1 shows the age-

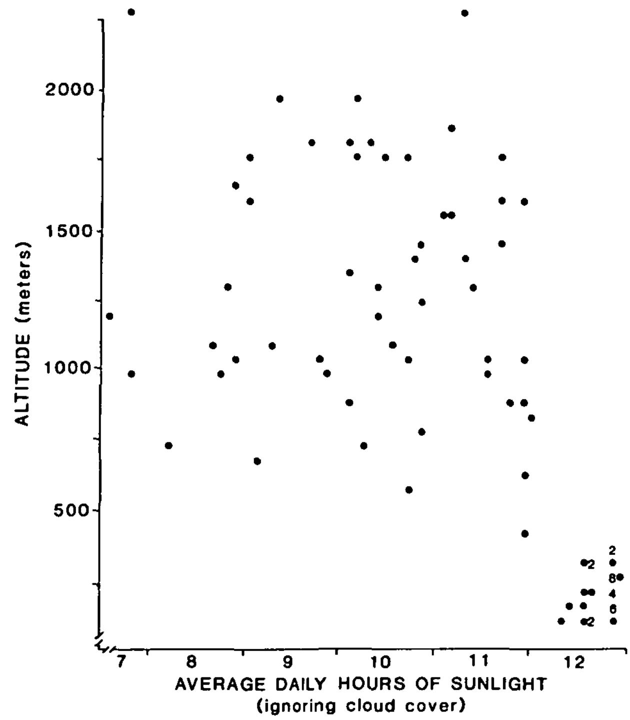

FIGURE 2. Average daily sunlight hours by altitude (in meters) for 87 rural villages for which sunlight data were gathered, Nepal Blindness Survey, 1981; r = −0.685, $p < 0.0001$.

sex distribution of cataract cases of senile or undetermined etiology for permanent rural residents of Nepal. These data are also shown graphically in figure 3. Cataract prevalence rises continuously with age, actually tripling between the 55 to 59 and the 70 to 74 age group. At every age, women have a higher prevalence of cataract than men. The overall cataract prevalence for women is 3.4 per cent compared with 2.4 per cent for men; the prevalence risk ratio (i.e., the ratio of the prevalence for women to men) is 1.4 ($p < 0.001$).

Because of the strong relationships with both age and sex and the changing patterns with respect to terrain, site-specific cataract prevalence rates have been age-and-sex-standardized to the 1981 national age-sex distribution in the Nepal Blindness Survey. Figure 4 shows the large difference in age- and sex-standardized cataract prevalence rates between the plains (4.3 per cent) and the hills (1.8 per cent) and mountains (1.9 per cent). These results agree with the essentially dichotomous clustering of sites with respect to sunlight exposure, which is high in the plains and low but variable in the hills and mountains. These site level age- and sex-standardized cataract prevalence rates are negatively correlated with altitude ($r = -0.533$, $p < 0.0001$; see figure 5).

The number of people examined and those found with cataract for five altitude categories are shown in table 2. The cataract prevalence (unadjusted) ranges from 1.8–1.9 per cent in the hills above 350 meters to 4.3–4.8 per cent in the plains. There is no systematic variation with incremental changes in altitude in the hills. The major difference, as reported by Chatterjee (27), is a significant ($p < 0.001$) difference between the plains and the hills (odds ratio = 2.7).

Cataract prevalence by average daily

TABLE 1

Age-sex distribution of cataract of senile or undetermined etiology for full-time life-long residents of 97 rural villages, Nepal Blindness Survey, 1981

Age (years)	No. of persons examined	Cataract cases	Prevalence per 100
	Males		
0–29	10,007	7	0.07
30–34	815	2	0.25
35–39	822	8	0.97
40–44	634	9	1.42
45–49	660	18	2.73
50–54	573	35	6.11
55–59	431	42	9.74
60–64	367	53	14.44
65–69	256	54	21.09
70–74	195	63	32.31
75+	138	58	42.03
Total males	14,898	349	2.34
	Females		
0–29	10,271	7	0.07
30–34	952	2	0.21
35–39	879	9	1.02
40–44	865	19	2.20
45–49	654	29	4.43
50–54	645	62	9.61
55–59	369	46	12.47
60–64	446	111	24.89
65–69	248	91	36.69
70–74	171	82	47.95
75+	117	65	55.55
Total females	15,617	523	3.35
Both males and females	30,515	872	2.86
Missing data	50	1	
Total	30,565	873	2.86

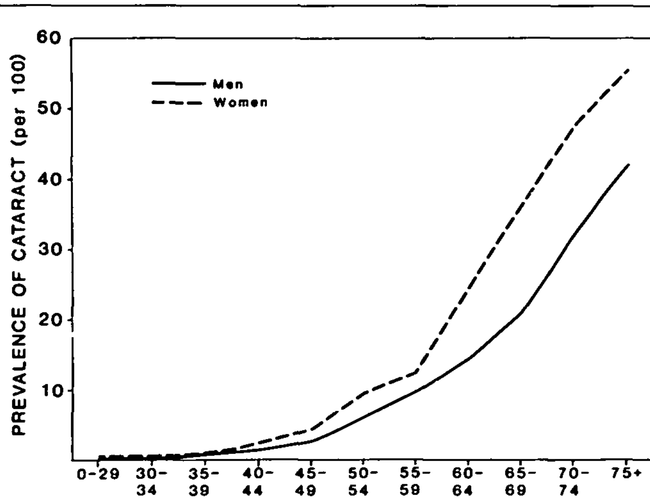

FIGURE 3. Age-sex distribution of cataract of senile or undetermined etiology, full-time life-long residents of 97 rural villages, Nepal Blindness Survey, 1981.

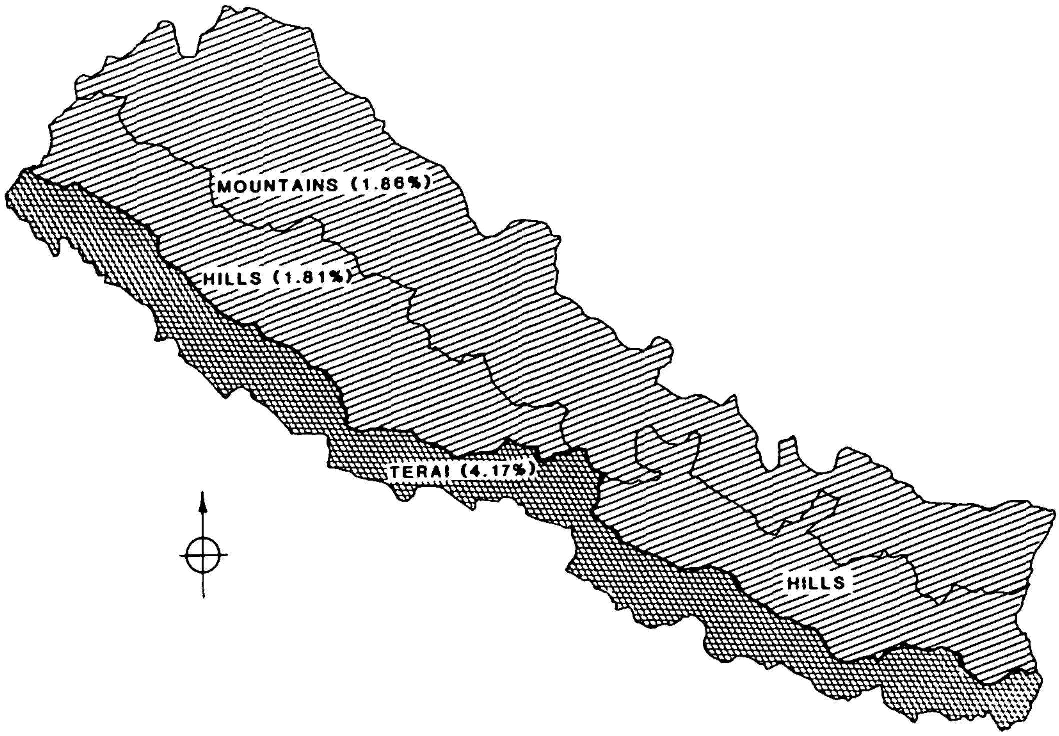

FIGURE 4. Age- and sex-standardized prevalence rates of cataract of senile or undetermined etiology, full-time life-long residents of 97 rural villages, by terrain, Nepal Blindness Survey, 1981.

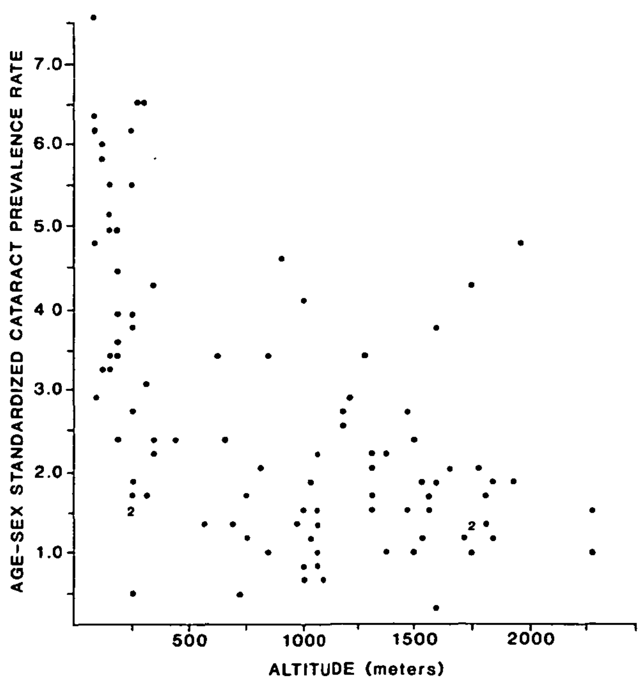

FIGURE 5. Age- and sex-standardized cataract prevalence rates by altitude (in meters) for 97 rural villages, Nepal Blindness Survey, 1981; $r = -0.533$, $p < 0.0001$.

TABLE 2

Cataract prevalence by altitude for full-time life-long residents of 97 rural villages, Nepal Blindness Survey, 1981

Altitude (meters)	Village sites	No. of persons examined	Cataract cases	Cataract prevalence (per 100)	Odds† ratio
1501–2272	22	6583	121	1.84	1.0
1001–1500	22	7139	134	1.88	1.0
351–1000	17	5681	103	1.81	1.0
186–350	19	4414	191	4.33	2.4***
≤185	17	6718	324	4.82	2.7***
All altitudes	97	30,535	873	2.86	
Missing data	0	30	0		
Total	97	30,565	873	2.86	

*** $p < 0.001$.

† The odds that a cataract case lived at a given altitude as compared with the odds that the case lived at the highest altitude level (1501–2272 meters).

hours of sunlight rounded to the nearest hour is shown in table 3. The relationship is not monotonic, although the odds ratio is 3.8 between the highest and lowest categories ($p < 0.001$). When sunlight hours are divided into three exposure groups of similar size populations (table 4), the odds ratio between high and low exposure is 2.6. However, these arbitrary categorizations may obscure trends within categories; moreover, they do not take into account differences in the age structure of populations living in the hills and plains.

The site-specific age- and sex-standardized cataract prevalence rates are positively correlated with sunlight (figure 6). In view of the negative correlation between age- and sex-standardized cataract prevalence and altitude demonstrated in figure 5, there is a relationship between

TABLE 3

Cataract prevalence by average daily sunlight hours for full-time life-long residents of 97 rural villages, Nepal Blindness Survey, 1981

Average daily hours of sunlight	Sites	No. of persons examined	Cataract cases	Prevalence (per 100)	Odds† ratio
7	4	1,034	13	1.26	1.0
8	10	2,695	54	2.00	1.6
9	12	3,507	66	1.88	1.5
10	15	5,845	85	1.45	1.2
11	14	4,418	136	3.08	2.5*
12	32	10,286	476	4.63	3.8***
Subtotal	87	27,785	830	2.99	
Missing data	10	2,780	43		
Total	97	30,565	873	2.86	

* $p < 0.01$.

*** $p < 0.001$.

† The odds that a cataract case was exposed to a given average daily sunlight level compared with the odds that the case was exposed to the minimum average daily sunlight exposure (7 hours).

TABLE 4

Cataract prevalence by average daily sunlight hours (collapsed categories) for full-time life-long residents of 97 rural villages, Nepal Blindness Survey, 1981

Average daily hours of sunlight	Village sites	No. of persons examined	Cataract cases	Prevalence (per 100)	Odds† ratio
Low (7–9 hours)	26	7,236	133	1.84	1.0
Medium (10–11 hours)	29	10,263	221	2.15	1.2
High (12 hours)	32	10,286	476	4.63	2.6**
Subtotal	87	27,785	830	2.99	
Missing data	10	2,780	43		
Total	97	30,565	873	2.86	

** $p < 0.005$.

† The odds that a cataract case was exposed to a given level of daily sunlight compared with the odds that the case was exposed to the lowest daily sunlight level (7–9 hours).

sunlight and altitude which may explain the differences between Chatterjee's findings and others.

Figure 7 shows the relationship between cataract prevalence and average daily sunlight hours, stratified for birth cohort. In this analysis, contributions of both age and sunlight can be seen. Cataract prevalence increases with greater sunlight exposure, particularly in cohorts

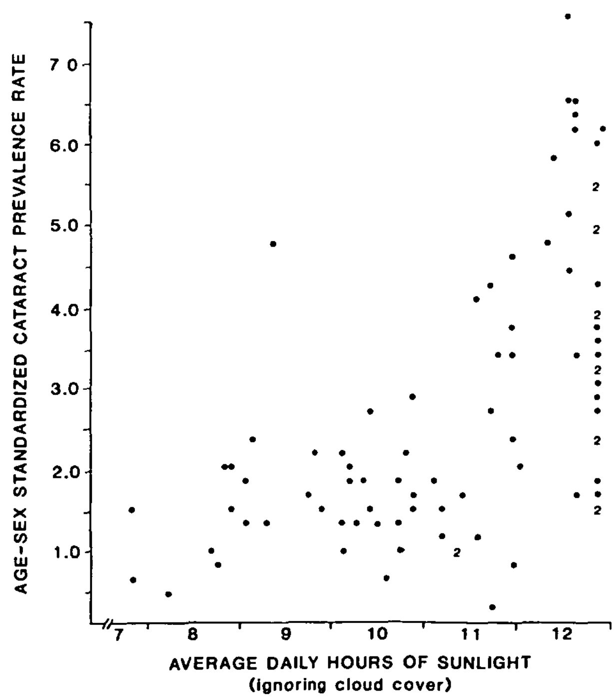

FIGURE 6. Age- and sex-standardized cataract prevalence rates by average daily hours of sunlight (ignoring cloud cover) in 87 rural villages, Nepal Blindness Survey, 1981; $r = 0.563$, $p < 0.0001$.

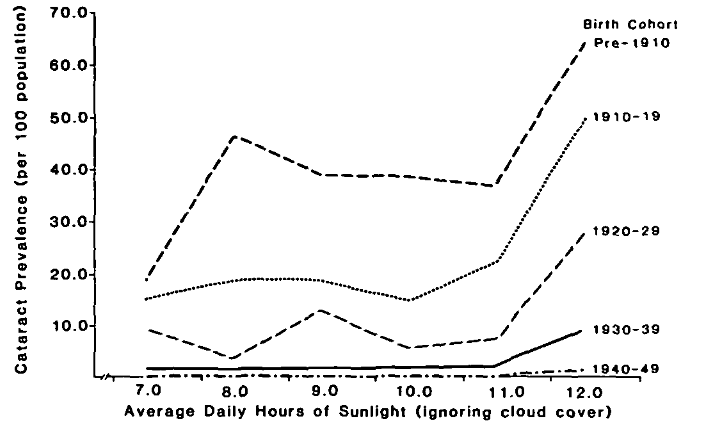

FIGURE 7. Prevalence of cataract of senile or undetermined etiology by average daily hours of sunlight and birth cohort for full-time life-long residents of 87 rural villages, Nepal Blindness Survey, 1981.

born before 1920. Older cohorts have a higher prevalence of cataract than younger cohorts at all sunlight exposure levels.

Linear and logarithmic models were fit to the data and results of the linear model fitting are shown in figure 8. Each model accounted for a high percentage of variation ($R^2 = 0.864, p < 0.001$ for the linear model and $R^2 = 0.855$, $p < 0.001$ for the logarithmic model). As seen in figure 8, there is a suggestion of increasing dose-response with age. The data suggest that increasing age and longer daily sunlight exposure are each associated with increased cataract prevalence.

DISCUSSION

The Nepal Blindness Survey sample was designed to yield population estimates. Because we have stratified the population to get a study population more homogeneous for sunlight exposure (i.e., full-time life-long residents of rural sites), the data presented here are not the same as weighted national prevalence rates which will be reported elsewhere.

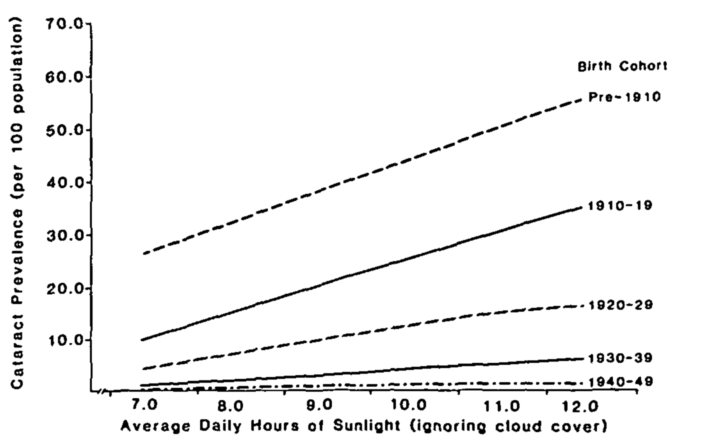

FIGURE 8. Prevalence of cataract of senile or undetermined etiology by average daily hours of sunlight and birth cohort for full-time life-long residents of 87 rural villages, Nepal Blindness Survey, 1981 (linear model).

Study findings suggest that altitude and sunlight may be confounding, not only in the case of the Himalayas but also in other studies in which associations between cataract and altitude have been found (24–27). It is possible that at the elevations where cataract has been studied in the Andes, the Highlands of New Guinea, and on the Tibetan plateau, persons living at higher elevations reside above the obstructions of neighboring mountains and therefore are exposed to the higher intensity of ultraviolet light at higher elevations. The situation in the foothills of the Himalayas, specifically in the southern part of the Himalayas common to Punjab and Nepal, appears to be a rare exception to the rule that the higher one goes the more radiant energy one receives.

The data from the Punjab have been used as an argument against the "sunlight hypothesis." The present study confirms the inverse relationship between cataract and altitude reported from the Punjab; however, we do not agree with its interpretation as an argument against sunlight as a possible cataractogenic agent. It appears that the "protective effect" of living in the hills of Punjab and Nepal is the protective effect due to the shading of the sun provided by neighboring mountains. Not enough is known about the specific environment of the study sites in Tibet to know if the Tibetan study conforms to this pattern. However, Tibet and Nepal, in general, have different patterns of mountainous obstruction to the sun. Even in Nepal, the negative correlation between altitude and sunlight does not hold up at elevations above 2000 meters where there are fewer neighboring obstructions. The Tibetan study was carried out at 2000 to 4000 meters and was likely in the area of both high altitudes and unobstructed sunlight exposure.

Just as sunlight may be confounding for altitude, certain components of sunlight such as ultraviolet radiation may ultimately be found to be the underlying agents of interest. In the case of the Himalayas, there are at least four variables operative with respect to ultraviolet light.

First, there is the effect of altitude on climatic ultraviolet radiation. Gates (31) has calculated that the spectral flux of solar radiation is greater at higher altitudes than at lower altitudes. At 2000 meters, the ultraviolet flux may be 60 per cent greater than at 1000 meters. For the same duration of sunlight much more ultraviolet exposure is experienced at high altitudes than at sea level.

The second variable is duration of sunlight. The regression of sunlight hours on altitude suggests that at 2000 meters, the average village in this study would receive about 8.5 hours of sunlight compared with nearly 12 hours of sunlight at sea level. This reduction of nearly 30 per cent in sunlight hours partially offsets the gain in ultraviolet radiation associated with increasing altitude. This may explain in part why the relationship between sunlight hours and cataract prevalence is clearer when viewed dichotomously (e.g., hills versus terai) than as a linear function of altitude, or even among hill sites at differing levels of estimated sunlight.

The third variable is latitude. The higher peaks of the Himalayas are directly north of the plains, further from the equator. The role of latitude has not been analyzed in this report. Unlike the case of Australia or the United States, both of which are large countries spanning many degrees of latitude, Nepal spans less than 4° of latitude from plains to mountains. Latitude is not likely to play a very important role in Nepal compared with altitude and skyline.

Finally, the effect of cloud cover has not been explored. Cloud cover is not homogeneously distributed in Nepal. There are fewer clouds over the unobstructed plains, while more clouds accumulate over the hills and mountains. If this was consistently true, it would decrease sunlight in the hills more than in the plains and would widen the gap between radiant energy reaching hill villages and plains villages.

The association between cataract and sex is intriguing. In the over 30 age group, Chatterjee et al. (13), found a slightly higher cataract prevalence in women (16.9 per cent) than in men (13.7 per cent) in the Punjab. Although of marginal significance ($p = 0.07$), the authors felt that the actual difference may have been diluted by a lower male response rate. In the Nepal Blindness Survey, response rates were over 90 per cent for both sexes. According to Nepalese observers, women spend more time in the sun than men doing agricultural work. If this anecdotal observation were consistently correct, we would expect to find higher prevalence of cataract for women than men at each village exposure level. Figure 9 shows that this is the case, which may lend additional support to the sunlight hypothesis. It would be interesting to see if women have higher prevalence rates than men when both age and village exposure level are the same. There are other confounding variables as well. Diet, nutrition, life-expectancy, literacy, and general health differ a great deal between

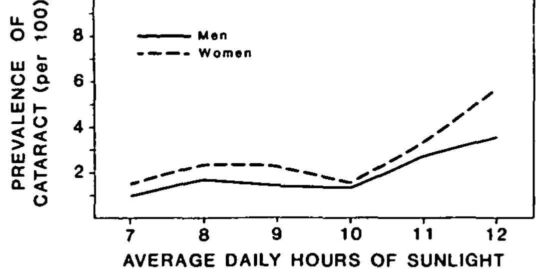

FIGURE 9. Prevalence of cataract of senile or undetermined etiology by average daily hours of sunlight and sex for full-time life-long residents of 87 rural villages, Nepal Blindness Survey, 1981.

men and women in Nepal. These are all variables which should be examined in additional studies and through multivariate analyses beyond the scope of the present study.

The estimation of a "dose" of naturally occurring radiant energy is extremely difficult. The separation of the aging process from estimates of cumulative exposure is likely to be one of the most complex issues faced in the study of cataractogenesis. The approach presented in figures 7 and 8 is a simple examination of cataract prevalence by daily sunlight exposure stratified by birth cohort. While this method lacks the quantification of multivariate techniques, the data do indicate that both age and level of sunlight exposure are associated with increased cataract prevalence. We have presented 10-year cohorts for simplicity; the results of five-year cohorts were similar.

The Nepal Blindness Survey protocol called for ophthalmologists to dilate pupils only when necessary to help make a diagnosis of cause of visual impairment. This was done because to dilate all pupils of all normal people (nearly 75,000 normal eyes) might have reduced response rates and would have been logistically prohibitive. Small peripheral opacities causing no visual impairment were likely less often diagnosed. This should be taken into consideration when comparing the prevalence of cataract from Nepal with studies in which all subjects have their pupils dilated and are given a slit lamp examination regardless of visual acuity status. The effect of the Nepal Blindness Survey method is to underestimate the true extent of early cataract, particularly peripheral opacities. The measurement of the extent of cataract blindness was not affected. Because the procedures which followed were uniform and because of high levels of interobserver agreement (32), it is expected that no biases were introduced into etiologic studies or risk factor analyses by this method.

The major limitation of this study is the generic limitation of all cross-sectional studies. While cross-sectional associations between cataract prevalence and various risk factors are hypothesis-generating, longitudinal studies are needed to measure cataract incidence and confirm relationships to various exposure levels.

REFERENCES

1. Nefzger MD, Miller RJ, Fujino T. Eye findings in atomic bomb survivors of Hiroshima and Nagasaki: 1963-1964. Am J Epidemiol 1969;89: 129-38.
2. Notter G, Walstam R, Wokholm L. Radiation induced cataracts after radium therapy in children. Acta Radial (Diagn) Stockholm 1966; 254:87-92.
3. Zaret M, Snyder W, Birenbaum L. Cataract after exposure to non-ionizing radiant energy. Am J Ophthalmol 1976;60:632-7.
4. Mole R. Radiation effects in man: current views and prospects. Health Phys 1971;20:485-90.
5. Kurz G, Einaugler R. Cataract secondary to microwave radiation. Am J Ophthalmol 1968;66: 866-9.
6. Leobowitz H, Luzzio A. Laser-induced cataract. Arch Ophthalmol 1970;83:608-12.
7. Wallace J, Sweetnam P, Warner C, et al. An epidemiological study of lens opacities among steel workers. Br J Industr Med 1971;28: 265-71.
8. Worgul B, Merriam G. The lens epithelium and radiation cataracts. Radiat Res 1980;84:115-21.
9. Kazdan M. Electric cataract: a report of two cases. Can J Ophthalmol 1969;4:104-5.
10. Lerman S. Human ultraviolet radiation cataracts. Ophthalmic Res 1980;12:303-14.
11. Kipps A, Sevel D, McIntyre A. Rubella infection and other factors associated with congenital cataracts in Cape Town. S Afr Med J 1979;55:245-7.
12. Cairns J, Williams H, Walshe J. "Sunflower cataract" in Wilson's disease. Br Med J 1969;3:95-6.
13. Chatterjee A, Milton RC, Thyle S. Prevalence and aetiology of cataract in Punjab. Br J Ophthalmol 1982; 66:35-42.
14. Bunce G. Nutrition and cataract. Nutr Rev 1979;37:337-43.
15. Testa M, Fiore C, Bocci N, et al. Senile cataract: serum factors producing irreversible precipitation of a lens protein. Exp Eye Res 1969;8:461-6.
16. Bellows J, Bellows D. Aging and senile cataracts: an integrated theory. Ann Ophthalmol 1975;7:157-60.
17. Van Heyningen E. What happens to the human lens in cataract. Sci Am 1975;223:70-9.
18. National Eye Institute. The Framingham eye study monograph. Part I. Bethesda, MD: National Eye Institute, 1979.
19. Duke-Elder WS. The pathological action of light upon the eye. Part II. Action upon the lens: theory of the genesis of cataract. Lancet 1;1926:1188-91.
20. Zigman S, Dadiles A, Torczysnki A. Sunlight and human cataracts. Invest Ophthalmol Vis Sci 1979;18:462-7.
21. Hiller R, Giacometti L, Yuen K. Sunlight and cataract: an epidemiologic investigation. Am J Epidemiol 1977;105:450-9.
22. Taylor H. The environment and the lens. Br J Ophthalmol 1980;64:303-10.
23. Hollows F, Moran D. Cataract—the ultraviolet risk factor. Lancet; 1981;2:1249-50.
24. Goldsmith R, Rothhammer F, Schull W. The multinational Andean genetic and health program. III. Ophthalmic disease and disability among the Aymara. Bull Pan Am Health Organ 1980;13:58-65.
25. Vines AP. An epidemiological sample survey of the highlands, mainland and island regions of the territory of Papua and New Guinea. Port Moresby, New Giunea: Government Printer, 1967.
26. Seung Wen-shi. A survey of senile cataracts among high altitude living Tibetans in Changdu district, Tibet. Chinese Journal of Ophthalmology 1979;15:100-4.
27. Chatterjee A. Cataract in Punjab. In: Symposium on the human lens in relation to cataract. CIBA Foundation Symposium 19. Amsterdam: Associated Scientific Publishers, 1973:265-79.
28. Atkinson ET. Geology of the Himalayas. New Delhi: Cosmo Publications, 1980.
29. Mazria E, Winitzky D. Solar guide and calculator, Eugene, OR: Environmental Research, University of Oregon, 1976.
30. Brilliant LB, Lepkowski JM, Grasset NC, et al. Report of the Nepal Blindness Survey. Kathmandu, Nepal: World Health Organization - Government of Nepal Blindness Prevention Project, 1983 (in press).
31. Gates DM. Spectral distribution of solar radiation at the earth's surface. Science 1966;151: 523-9.
32. Brilliant LB, Lepkowski JM, Musch D. Reliability of ophthalmic diagnoses in an epidemiologic survey. Am J Epidemiol 1983;118:265-79.