CHAPTER 6

6.0 UV RADIATION AND HUMAN HEALTH

This Chapter presents an analysis of effects of UV-B radiation on human health with special focus on ocular epidemiology. It is based on analyses of literature review from various works and publications on radiation and ocular health as data available from the Department of Ophthalmic Services, Ministry of Health, in Kenya on reported incidences contain a lot of inconsistencies and gaps. This being the case, and for the completeness of this study, it is important to discuss various aspects of the impact of UV-B radiation on eye epidemiology from published literature review and epidemiological studies.

6.1 RADIATION AND HEALTH

Most people spend part of each day under the influence of sunlight. However, as society becomes more urbanized, more time is spent under artificial lamps, which is a far cry from the natural environments of our ancestors. The environment in which we live is commonly surrounded by walls, floors and ceilings covered with colors from artificial light sources designed more for efficiency than for their possible physiological or psychological effects on people as happens in nature. The artificial lighting systems can only simulate twilight levels of illumination—light levels of 200 to 1500 lux in comparison to natural light, which at twilight ranges from 2,800-8,200 lux and at noon up to 100,000 lux (Thorington, 1971). However, the beneficial effects of natural light on human health are many which include the fact that physiological disorders may occur in the human system if the human skin does not receive some exposure to solar radiation for long periods of time. It is also believed that with insufficient light leads to vitamin D deficiency followed by weakened body defenses and an aggravation of chronic diseases.

Radiation affect human health through three major systems whose cells and tissues are commonly exposed to sunlight: the eye, the immune system, and the skin. The cells/tissues exposed in the eye are principally those associated with the cornea, the iris, and the lens;
those of the skin include the outermost layer of the skin, the stratum corneum, and the epidermis; and those of the immune system are the Langerhans (or antigen-presenting) cells that reside in, or migrate through, the epidermis.

![Diagram](image)

**Fig. 6.1.1. Sequences of events in light-induced effects (Longstreth et al., 1998)**

Each of the different types of UV-exposed organs and tissues contains a collection of chemical substances, which are affected differently from exposure to UV-B radiation by molecules (termed chromophores) present in the tissues/cells of these organs. The absorption of photons leads to changes in these molecules and eventually in a biological effect. The organ systems are structured such that some tissues or cells will absorb part of the UV energy before it reaches others (figure 6.1.2). Thus the spectrum of light that first hits the surface of an organ such as the skin is not the same as that reaching tissues or cells located deeper, e.g., in the basal layer of the epidermis. As a result, the wavelength dependence, or action spectrum, of a particular end-point of concern rarely looks exactly like the absorption spectrum of a particular chromophore.

Chromophores absorb light energy, at different wavelengths, with differing efficiencies characteristic of the absorption spectrum and depending on the type of molecule involved. There are absorption spectra for five of the chromophores present in skin and eye tissues that are thought to be important to the biological effects of UV-B in humans and animals. These are DNA, tyrosine and tryptophan (two amino acids that are largely responsible for the UV-B absorbance of proteins), trans-urocanic acid (a molecule present in large amounts in the outermost layer of skin), and melanin (the principal pigment of the skin). The gray area in Fig. 6.1.3 marks that part of the UV-B spectrum, wavelengths under 290 nm, which is not present in terrestrial energy. Thus only those portions of these absorption spectra
appearing in the white area (above 290 nm) are likely to be of any relevance to the effects associated with environmental exposures.

![Action spectra of key UV-associated health effects.](image)

**Fig. 6.1.2: Action spectra of key UV-associated health effects.**

Studies on the potential ocular hazards show that the thresholds for acute photokeratitis (from wavelengths below 400 nm) and cataract (from wavelengths below 325 nm) rise significantly with increasing wavelength, from approximately 10J/cm² at 320nm to over 250J/cm² at 390 nm. The typical UV-B dose experienced on a sunny day while sailing or skiing can be enough to cause keratitis, for which the threshold for 300nm UV-B is 0.03-0.08J/cm². Voke (1999), has done some analysis on protection standards used in various countries. Most standards recommend that the incident UV-A (315nm-400nm) irradiance on the eye should not exceed 1mW/cm² for periods greater than 103 seconds. For exposure times less than 103 seconds, the total radiant exposure should not exceed 1 J/cm² in total. These values for exposure of the eye apply to UV radiation from arcs, gas and vapour discharges and incandescent sources, but not UV lasers or solar radiation.

### 6.2 EFFECT OF SOLAR UV ON HUMAN SKIN

It has been established through various studies that prolonged exposure to ultraviolet radiation (UV) may cause erythema and premature ageing of the skin (Gallagher et. al., 1990;
Hillenkamp, 1985; Lindgren, 1998; Scotto, 1996). The skin response to UV is either acute or chronic effects with the acute effect being that of rapid onset and generally of short duration, as opposed to a chronic effect, which is often of gradual onset and long duration. The acute reactions are sunburn, tanning and vitamin D production. Photo-ageing and skin cancer are reactions produced by prolonged or repeated UV exposure. Sunburn, or erythema, is an acute injury following excessive exposure to solar UV. The redness of the skin which results is, due to an increased blood content of the skin by dilatation of the superficial blood vessels in the dermis, mainly the sub-capillary venules.

Various studies have examined relationship between various factors and erythemal effects. Hawk and Parish (1982), have reported lack of distinction in sunburn susceptibility between sexes and that though erythemal sensitivity may change with age as young children and elderly people are more sensitive. However, other studies of erythemal sensitivity in children and elderly subjects have not confirmed this (Cox et. al., 1990). Heat, humidity and wind have been shown to alter the erythemal sensitivity of mice exposed to artificial UV-B radiation, but the significance of these atmospheric conditions upon the induction of sunburn in humans has not been clearly identified. Studies by Urbach (1969), Diffey et. al. (1979) have shown that about 90% of all basal cell carcinoma and more than half of all squamous cell (SCC) occur on the head and neck (Urbach, 1982). Comparison of the geometry of insolation of the head and neck areas with sites of non-melanoma skin cancers (NMSC) shows close correlation.

Studies have also established some common facts like Caucasians are much more likely to develop NMSC than races with more marked pigmentation have been established. The other include the fact that genetic factors associated with a tendency to develop skin cancer are light eyes, fair complexion, light hair colour, tendency to sunburn and poor ability to tan (Urbach et. al. 1974). Surveys of the incidence of skin cancer carried out in various countries yield ample evidence that a geographical latitude gradient exists (Gordon and Silverstone 1976, Scotto et. al., 1981). Very roughly, the incidence doubles for every 10° decrease in latitude, provided that the population is genetically equally susceptible. Swanbeck and Hillstrom (1971) indicated the existence of power law relationship between incidence and age with an exponent of approximately 4 to 5 indicating that NMSC is essentially a disease of
the elderly, and people who work outdoors are more likely to develop skin cancer than indoor workers. Results from the study by Larko and Swanbeck (1982) in Sweden have shown that outdoor workers are about three times more likely to develop skin cancer than indoor workers.

6.3 INFECTIOUS DISEASES

At ambient environmental levels, animal models have shown that UV radiation reduces the ability of the cell-mediated arm of the immune system to respond adequately to foreign substances, known as antigens (De Fabo and Kripke, 1979). The skin often is the first point of contact with many foreign substances including infectious agents. In these instances, the skin's immune response is the body's first line of defense. Animal studies have shown that when foreign substances (antigens) are given via the skin to UV-treated animals, they induce tolerance rather than inducing a protective response (immunity). The explanation given for this failure appears to be due to an increase in or elicitation of the activity of a class of lymphocytes termed suppressor T-cells (Ts cells).

Studies on effect of UV exposure and vitamin enhancement in the body have also been reported (Mawer, 1980; Stephens et. al., 1982). Serum 25-hydroxyvitamin D₃ (25-OH-D₃) levels in humans are enhanced after short-term UV exposure either from natural sunlight or artificial UV irradiation (Stamp et. al., 1975; Stephens et. al., 1982). Stamp (1975) have shown that serum levels of 25-OH-D₃ continue to rise for several days after exposure to solar irradiation has ceased. Mawer confirmed these findings and also provided data to suggest that there is a rise in serum 25-OH-D₃ following ultraviolet radiation.

The mechanism of acclimatization to prolonged and continued solar exposure in tropical population as well as elevation in serum 25-OH-D₃ levels is associated with increase in levels of the active metabolite 1,25(OH)₂D₃ and increased risk for any pathological conditions. A study by Rajastree et. al. (1999) in India on samples of people involved in various occupation found that Serum levels of 25-OH-D₃ depends on the length of time spent outdoors in the sun and clothing habits and may not reflect body storage pool. The degree of skin pigmentation can modify effective penetration of ultraviolet rays into cutaneous layers.
However, observations on Negroid people repeatedly exposed to ultraviolet radiation suggest that pigmentation has no significant effect on cutaneous synthesis of vitamin D (Stamp, 1975).

6.4 RADIATION AND OCULAR EFFECTS

Though extensive exposure to UV radiation causes erythema and premature ageing of the skin, however, the skin adapts by thickening of the stratum corneum and increased pigmentation (Hyde, 1906; Kripke, 1993, Streilen, 1994). In contrast, the human eye does not have these inherent defense mechanisms with the natural eye defense strategies being the recessed location of the eye in the orbit and partial closing of the eyelids in response to high visible light levels.

These mechanisms are only partially effective and incident UV radiation that is absorbed and accumulated over long periods may cause degenerative effects (Pitts, 1973; 1993; Taylor, 1992; Bergmanson, 1995; Sliney, 2000). However, the artificial methods to lower incident UV that include covering, filtering, and shading by use of sunglasses and headwear that shade the eyes from direct visible and UV insolation do not generally provide complete protection from scattered and temporally incident light.

![Absorption of UV by the eye](image)

Fig. 6.4.1: Absorption of UV by the eye.
The UV-B portion of the spectrum (6.4.2) can damage the cornea, lens and, to a lesser extent, the retina (Pitts et. al., 1989). Endpoints of concern include cataract, photokeratitis, retinal degeneration, arcus senilis and pterygia. The initial response of the eye to exposure to UV-B radiation (280-315 nm) is the condition termed photokeratitis in which the front of the eye, the eyelids and the skin surrounding the eye reddens. This condition is commonly seen in skiers and also is called snow-blindness. The cornea absorbs UV-C and UV-B with a peak effect at 270nm.

UV radiation is also known to cause damage to the retina by causing both functional and morphological damage. Lenses that have been removed after a cataract operation, provide clear evidence of this occurrence. The threshold for damage to the rabbit eye at 300 nm was found to be 0.23 J/m² with a value of 0.36 J/m² for the primate eye at 325 nm (not UV-B).

6.5 UV RADIATION AND EYE CATARACTS

Cataract is the most prevalent form of ocular damage associated with UV exposure, which creates opacities in the lens of the eye that impair vision. Cataracts are estimated to be responsible for more than one-half of all the 17 million cases of blindness in the world and constitute 55% of total blindness in India (Bhaduri and Banerjee, 1996). Corrective surgery
can prevent most cataracts from causing blindness. In developing countries where such operations are not always available, cataracts result in a much higher incidence of blindness than other places. Cataracts represent a significant problem, which is anticipated to grow worse as life expectancy increases in both the developed and the developing countries.

Figure 6.5.1: Eye Cataract

In 1980 almost one-half of the world's 260 million elderly resided in the developed nations, whereas by the year 2000, an estimated two-thirds of the elderly (400 million) will reside in the now developing nations (Maitchouk, 1985). Thus, cataract is expected to grow as a public health problem in the developing countries. It has been estimated that if the development of cataract could be delayed by 10 years, the number of cataract operations could decrease by 45%, considerably reducing the expenditure and burden on the National Blindness Control Programmes in the world's poorer countries (Kupfer, 1984).

The U.S. Environmental Protection Agency estimated that for every 1% decrease in stratospheric ozone, between a 0.3 and 0.6% increase in cataracts is anticipated. The work of Taylor et. al., (1988) has indicated that for every 1% decrease in stratospheric ozone there will be a 1.2% increase in cortical cataracts. Given that nuclear cataracts account for about 30% of all cataracts and that posterior subcapsular cataracts account for about 40% and apparently have approximately the same dose-response relationship as that observed for cortical cataracts, the EPA estimates might need to be revised upward slightly to 0.6-0.8% (Taylor, 1989). Application of this range of estimated increase (0.6-0.8%) in cataracts to the number of cases of cataract blindness estimated for 1985 (Maitchouk, 1985) suggests that if
the same population had lived with the ozone layer reduced by 1%, there would have been between 100,000 and 150,000 additional cases of cataract-induced blindness.

### 6.5.1 Sources and causes of Cataracts

The exact mechanism of the formation of a cataract is still unknown, although its origin is considered to be from multiple factors. Epidemiological studies suggest that some cataracts, particularly cortical and posterior subcapsular cataracts are etiologically related to exposure to solar radiation, specifically UV-B (Hollows and Moran, 1981; Taylor et. al., 1988; Bochow et. al., 1989). Studies by Pitts et. al., (1986) in animals suggest that the active portion of the solar spectrum that induces cataracts lies in the UV-B region. Also, Ultraviolet-A radiation and other causes, such as nutritional deficiency, also may contribute to cataract formation. Even more persuasive, however, is the finding in a recent epidemiologic study of occupationally exposed individuals that the incidence of cortical cataracts appears to be directly related to exposure to UV-B (Taylor et. al., 1988). A doubling of cumulative exposure increased the risk of cortical cataract by a factor of 1.6.

A number of risk factors have been shown to be associated with cataract that include socioeconomic status (SES), illiteracy, marital status, history of diarrhoea, history of diabetes, glaucoma, use of cholinesterase inhibitors, steroids, spironolactone, nifedipine, analgesics, myopia early in life, renal failure, heavy smoking, heavy alcohol consumption, hypertension, low body mass index (BMI), use of cheaper cooking fuel, working in direct sunlight, family history of cataract, occupational exposure, and several biochemical variables. (Lleske and Sperduto, 1983; Hodge, 1995; West and Valmadrid, 1995)

One of the most comprehensive studies to examine the impact of the various causes of cataract in developing countries has been undertaken by Ughade et. al, (1998) in India. The study considered twenty one (21) hypothesised risk factors for cataract namely low SES, illiteracy, marital status, low BMI, history of diabetes, history of diarrhoea, smoking, alcohol consumption, glaucoma, myopia, family history of cataract, hypertension, renal failure, use of drugs like aspirin, nifedipine, steroids, cholinesterase inhibitors, spironolactone, occupational exposure, working in direct sunlight, and use of cheaper cooking fuel.
Low SES has been significantly associated with senile cataract (Chatterjee, 1982; Hiller, 1986; Mohan et al., 1989, Ughade et al., 1998). Socioeconomic variables related to educational achievement are likely explanation for this finding. As with many diseases, low SES, measured by income, education, or occupation, is a risk factor for cataract formation and probably for all subtypes of cataract. (Hodge, 1995)

Severe diarrhoea has been proposed as a major cause to account for the excessive prevalence of cataract in tropical countries. The role of diarrhoea in cataract formation has been confirmed by case-control studies conducted in central and eastern India (Minassian et al., 1984; 1989). Severe dehydration episodes have been reported to be significantly associated with cataracts in a dose-dependent fashion playing and play a significant role in the etiology of cataract (Ughade et al., 1998). However, other authors have failed to support this association. The case-control study in rural India, showed no association nor did the observational study in Bangladesh (Hodge, 1995). The India-US case-control study used confinement to bed for one day as the definition for diarrhoea and also found no association (Mohan et al., 1989).

Diabetes has been identified as a significant predictor of cataract (Ughade et al., 1998). However, the support for diabetes as a risk factor for cataract formation is not very clear. In the Italian-American cataract study found no association between a past history of diabetes and cataract formation (IAGCS, 1991). In the lens opacity case-control study, a modest association for all cataract types except nuclear sclerosis was demonstrated (Hodge, 1995) and in the Indian-America case-control study project, diabetes was one of the listed exclusion criteria (Mohan et al., 1989).

Glaucoma appeared as a powerful risk factor for cataract (Ughade et al., 1998). But the study attributed it to the cholinesterase inhibitors widely used to treat glaucoma that are known to cause cataract. Even without this consideration, lenses of glaucoma patients opacify and it appears that the cataract risk associated with glaucoma is increased by a combination of the disease itself and the treatment applied.
Social lifestyle like cigarette smoking and alcoholism has been associated with a number of
diseases including cataracts. However, two case-control studies have failed to establish
relationship between smoking and cataract, even though patients with a history of smoking
were found to be significantly associated with cataracts (Ughade et. al, 1998). Other cross-
sectional, case-control, and prospective cohort studies have found an association with
smoking history and a dose-response relation as well (Hodge, 1995). The role of alcohol in
cataract formation is much less clearer. Three large case-control studies (Lleske et. al., 1983;
IAGCS, 1991; Vitale et. al., 1993) did not find an association between alcohol consumption
and cataract formation. In this study, history of alcohol consumption was significant in
univariate analysis but not in multivariate analysis.

Studies that included age and sex-adjusted analysis reported a positive association between
blood pressure and cataract (Hiller et. al., 1986; Ughade et. al., 1998)). However, the studies
have indicated that more reliable results can be obtained if information on duration of
hypertension and the history of antihypertensive medications by respondents are included
for conclusive investigation on association between blood pressure levels and cataract
(Ughade et. al, 1998).

It has been reported that cataracts are more common among people using less-expensive
cooking fuels, a group likely to have lower SES. Use of biomass (cowdung, wood, charcoal)
as cooking fuel is prevalent in rural areas and urban slums in most developing countries.
Related socioeconomic variables may also explain the association between type of cooking
fuel used and cataract. However, there are very few studies, which have explored cheap
cooking fuel as a risk factor for cataract (Mohan et. al., 1989).

The relationship between cataract and other factors like nutritional, genetic and body index
have also been investigated. While numerous animal studies have shown that nutritional
deficiencies can lead to cataract formation, the role of nutritional status in human
cataractogenesis is unclear. An earlier study demonstrated that increased body mass index
was associated with a decreased risk of nuclear and mixed types of cataract (Mohan et. al.,
1998). This suggests that better nourished persons may have a lower risk of developing
cataracts. However, previous studies of relationship between nutritional status and cataract have provided no clear patterns. This epidemiologic study also did not identify significant association of BMI and cataract. Family history of cataract has been found to be significant in most studies (Lleske, 1983; IAGCS, 1991) however, the study by Ughade et al. (1998) did not associate cataract with family history of cataract and occupational exposure to radiation.

6.6 RADIATION AND PTERYGIUM

Pterygium is a wing-like growth of conjunctival tissue spreading across the corneo-scleral junction, usually on the medial side, extending onto the cornea. The growth of Pterygium is an atavistic attempt to protect the cornea from UV radiation by our vestigial nictitating membrane. Histologically, the pterygium consists of a core of denatured collagen surrounded by lymphocytes and plasma cells. Its growth has been attributed partially to exposure to the elements, especially to ultraviolet (UV) light (Longstreth et al., 1995, West et al., 1998). Although a pterygium rarely affects vision, it is cosmetically distressing and may require surgery. The efficacy of treatment is reduced by high recurrence rates and significant postoperative complications such as dry eye symptoms, granuloma, and corneal scarring.

Figure 6.6.1: Pterygium

Mild inflammation of pterygia may be quelled with the same or typical corticosteroids and non-steroidal anti-inflammatory agents as pinguecula. Surgical treatment is preferable when the growth invades the visual axis, significant astigmatism induction occurs or for cosmetic purposes. Recurrence rates with older surgical techniques are 50% within four months of excision and up to 100% after one year. Newer methods, including conjunctival auto-
grafting and grafting from laboratory made tissue, are quickly becoming the treatment of choice (IRPA, 1985; McLaren et al., 1997).

Original theories perpetuated the thought that a pterygium was a degenerative change, but more recent findings reveal that it may be proliferative in nature. The discovery by McLaren et al. (1997) of P-53 (a tumour suppressor gene which acts as a transcription factor that activates or represses expression of growth controlling genes) in the epithelium of Pterygium specimens supports this idea. Pterygia are usually bilateral, and asymmetric, occurring on the nasal cornea with greater frequency. The histopathology of pterygia is similar to that of pingueculae except that in pterygia, Bowman’s membrane is destroyed within the corneal component.

There is clear evidence associating chronic UV exposure and Pterygium (Taylor et al., 1989). The incidence of Pterygium is confined to those latitudes between 23°N & 23°S, which receive the most ultra-violet radiation. It occurs in greater frequency in those populations living in tropical areas especially near the equator rather than milder climates. The incidence of pterygia, particularly in regions near the equator, approaches 10% (Panchapakesan, 1998; Hirst, 2000). Epidemiological evidence indicates that UV radiation is a significant risk factor in the development of Pterygium (Mackenzie et al., 1992).

A study of fishermen in Maryland, USA, found a substantially enhanced risk of both pterygium and keratopathy in individuals receiving higher exposures of UV (Taylor, 1989) but pingueculae (conjunctival lesions) were very weakly associated with UV-B exposure (Taylor et al., 1989). However, it is not clear as to which type of UV radiation may contribute most to these conditions, but since any damage depends on the absorption of photons, the energetic UV photons are likely to have a greater effect than UV-A or visible photons, for which the cornea is relatively transparent. On the other hand, solar radiation levels are much greater at the longer wavelengths, and higher levels of solar UV-B also imply higher levels of UV-A and visible light. Analysis of the same data on Maryland fishermen showed that the correlation of pterygium and keratopathy with blue light exposure was just as good as the correlation with UV exposure (Taylor et al., 1992). In a study by Lai and Ho (2001) in Hong Kong, found no difference in prevalence of pterygium on sex between

110
fisherman and control groups. The presence of pterygium among fishermen appeared not to affect vision and visual impairment in fishermen was due mainly to cataracts.

Several other factors have also been suggested including a genetic predisposition, chronic dryness, heat, and irritation. The latter theories are not supported by the fact that pterygia are highly prevalent in Eskimos, surfers, and sailors (Coroneo, 1993). A notable consistent predisposing factor is terrain reflectivity (Coroneo, 1993; Sliney, 2000). An Eskimo and an Australian aborigine are the only documented patients ever blinded by pterygia (Taylor and Hollows, 1978; Fritz, 1997). This supports the UV theory because of increased light entering the eye from above and below from high UV albedo.

6.7 ESTIMATING THE IMPACT OF UV ON OCULAR DISEASES

The amount of UV irradiance reaching the ground is influenced by such factors as aerosol type and concentration levels, cloudiness, solar zenith angle, and topography. To understand the effect of UV-B on the eye, additional information like ground reflectance, the geometric orientation of the head and the shading afforded by the brow, nose, cheek and temple are necessary. The ocular irradiance or dose rate represents the approximate amount of energy per unit time, which is incident on the eye of an individual standing upright looking towards the horizon. In order to compute a dose, and therefore to assess the damage caused, the amount of time an individual is exposed to such a dose rate must be known. The product of these two numbers, the dose rate and the time exposed, result in the ocular dose. The daily or annual dose is moderated by a variety of behavioral aspects such as the amount of time spent outdoors, the particular time of day outdoor exposure occurs, and the ocular protection employed. In ocular studies, information is gathered on the basis of prevalence and incidences. By definition, “Prevalence” is an indication of the total number of people with cataract in a population at a given time, while “incidence” is an indication of the number of new cases occurring over a given period.

The use of incidences as an index for studying cataract studies appears in very minimal cases. Minassian and Mehra (1990) have used this index to report very high incidence of cataract in India to show incidences of blindness rises with age: a steep rise after the age of fifty years.
Harding, (1991) has also used reported incidence of cataract as an index of study and reported that the incidences of extraction increases with age and is prevalent in oriental people than Caucacians. In contrast, there are many studies, which use prevalence as an index of study of cataract. Chaterjee et. al. (1982) has used the prevalence index to study cataract problems in Punjab, India that reported a steep rise in the prevalence of cataract after 40 years of age. The index has also been used for comparison with the Framingham study and revealed that cataract is much more prevalent in Punjab and occurs at least 15 years earlier here than in Massachusetts.

Differences in prevalence have also been reported for geographic locations. Chaterjee et. al. (1973) determined the prevalence of cataract in five different regions of northern India, ranging from dry hot plains to the mountains in the Himalayan region. The study revealed that the overall prevalence was lower in the mountains than in the plains, apparently indicating that people inhabiting the plains develop cataract ten years earlier than those inhabiting the mountains. A similar study conducted in Nepal also showed higher prevalence of cataract in the plains (4.2%) than in the mountains (1.9%).

6.7.1 Modelling UV Ocular effect

One of the major difficulties in epidemiological studies of the impact of radiation on ocular disease has been quantification of the actual exposure to UV from the sun. In addition to intensity of sunlight, the ocular dose depends on other factors such as the amount of time spent outdoors, the condition of the environment, the use of eye protection, and the use of hats (Rosenthal et. al. 1985; Slinley et. al., 1994). Ocular sensitivity versus wavelength and exposure time for UV-induced cataract have been studied experimentally in animals (Bachem, 1956; Pitts, 1973; Ayala et. al., 2000). In pigmented rabbits, Pitts et. al. (1977) determined the threshold dose for UV in the most toxic wavelength region, around 300 nm, to be 1.5 kJ/m² for transient and 5 kJ/m² for permanent lens damage. Deduction from animal data to the human situation is always questionable. However, it is the only option for development of empirically based safety recommendations for avoidance of cataract after exposure to UV.
6.7.2 Maximum Acceptable Dose Estimation Model

Safety limits for avoidance of UV-induced cataract obtained from studies from animal models, have greatly assisted in providing information on the impact of UV on health and hence to develop appropriate public health measures (Dong et. al., 2003). In the past models, safety limits for UV-B induced cataract have been based on a dichotomous dose–response model, assuming that the outcome of UV-B exposure is limited to a binary response: cataract/no cataract (Pitts et. al., 1977). In such studies, cataract was measured qualitatively by slit lamp, with a grading scale (Merriam et. al., 2000). However, it has recently been shown with quantitative measurements of cataract, that UV-B-induced cataract has a continuous dose–response function. For this reason, a new concept, maximum acceptable dose (MAD) for avoidance of UV-B cataract, has been developed for estimation of UV-B toxicity in the lens (Michael, 2000).

Based on the dose–response function, MAD is defined as the dose corresponding to a limit for pathologic forward light-scattering, which is settled arbitrarily based on the frequency distribution of light-scattering in normal unexposed lenses. The limit is defined so that a certain fraction of normal unexposed lenses scatter’s light in the forward direction to an intensity above the limit. The magnitude of the fraction is a parameter that has to be settled and is given as an index to MAD.

The study by Michael et. al. (2000) on a group of rats serves as an illustration how to compute MAD. In the study, the intensity of forward light-scattering (\(y\)), as a function of UV dose received (\(x\)) in all the rats within an age group were fitted to a second-order polynomial omitting the first order term as described by Michael et. al. (2000)

\[
y = a - kx^2
\]

MAD was estimated as outlined in the introduction. The mean and the standard deviation for normal non-exposed control lenses were estimated in each age group from the readings of the intensity of forward light scattering for the contralateral non-exposed lenses. The limit between normal and pathologic light scattering was then calculated from the standardized...
normal distribution setting the risk for wrong classification of a normal lens as pathologic to 2.5%.

\[ y_{\text{lim}} = \mu + 1.96\sigma \]

Finally, the MAD was read on the dose–response function as the dose corresponding to the limit between pathologic and normal light scattering and a value of 0.975 was obtained.

Figure 6.7.2 shows the MAD concept according to Michael et al. (2000) with two functions indicated by the curves on the left and right. The left function represents the frequency distribution for non-exposed control lenses, where the (arrow) indicates the probability for a non-exposed control lenses to be classified as pathologic. The dashed line is the limit between physiological and pathologic light scattering. The right function shows the dose-response function.

### 6.7.3 Correlation Studies

Three different correlation study types have been employed to investigate cataract formation. These studies are the geographical correlation studies, cross-sectional prevalence studies and case-control studies. Geographical correlation studies examine the rates of cataract formation in relation to the ambient levels of UV-B irradiance determined by geographical position (for example, latitude). Cross-sectional studies examine a population or
occupational group, some with cataract, some without, and tie the prevalence of cataract to individual UV-B exposure. Finally, case-control studies use individual cataract cases from hospitals or clinics and other people with good vision who were attending the same hospital and compare UV-B exposure. Two extensive cross-sectional prevalence studies have been performed, the Beaver Dam and the Chesapeake Bay studies (Taylor, 1998). In the Chesapeake Bay study, watermen in the upper quartile of annual UV-B exposure were found to be three times more likely to have a cortical cataract than those in the lowest quartile.

The findings of geographical studies based on place of residence have consistently demonstrated an association between prevalence of cataract and meteorological factors, such as annual hours of sunshine. In the Beaver Dam study, males with greater than 1.01 sun years were 1.4 times more likely (at 95% confidence interval - 1.0 to 1.8 times) to have a cortical cataract than males with less than 1.01 sun years with women, however, exhibited no association in this study. There have also been two case-control studies exhibited, in US and Italy that exhibited less dramatic results. In a Massachusetts study, no association was found between cortical cataract and occupational exposure to sunlight while an Italian study found that those whose occupations involved sunlight exposure were 1.8 times more likely (95% confidence interval - 1.2 to 2.6 times) to have a cortical cataract. Furthermore, those whose leisure time involved sunlight exposure were 1.4 times more likely to have a cortical cataract.

In a study involving 35 geographic location with different climatic conditions during the National Health and Nutrition Survey of 1971-1972 in the USA, found the prevalence of cataract to be higher in those areas with the highest hours of sunlight. Among persons aged between 65 and 74, the prevalence of cataract in areas with over 3000 annual hours of sunlight was approximately 2.7 times that with areas of less than 2400 annual hours of sunlight (95% confidence interval - 1.6 to 4.6). A similar trend was found for those in the aged group of 45 to 64. Another study of Australian aborigines related prevalence of cataract was found to be correlated with hours of sunlight. A cataract prevalence survey of 97 rural villages in Nepal examined how prevalence varied with hours of sunlight and altitude (Brilliant et. al., 1985). The prevalence of cataract in villages with 12 hours of sunlight was 2.5 times that of villages with 7.9 hours of sunlight.
According to the World Health Organization health fact sheet of 2002, more than 161 million people were visually impaired, of whom 124 million people had low vision and 37 million. Worldwide for each blind person, an average of 3.4 people have low vision, with country and regional variation ranging from 2.4 to 5.5. Visual impairment is unequally distributed across age groups. More than 82% of all people who are blind are 50 years of age and older, although they represent only 19% of the world's population. Available studies consistently indicate that in every region of the world, and at all ages, females have a significantly higher risk of being visually impaired than males. Visual impairment is not distributed uniformly throughout the world. More than 90% of the world's visually impaired live in developing countries see figure.

Figure 6.8.1: Global estimate of visual impairment by region (http://www.who.int/mediacentre/factsheets/)

In the economically advanced countries, prevalence of blindness ranges from about 0.05% to 0.2 %, whereas a study by Tabara et. al.(1986) revealed prevalence as high as 10% in Saudi Arabia. Blindness in Kenya is estimated at 0.7%, with cataract contributing 43%, trachoma 19% and glaucoma 9% (Karimurio, 2000).
The major causes of blindness in developing countries include cataract, onchocerciasis, trachoma, keratitis (measles and xerophthalmia), leprosy, glaucoma and trauma as documented by various workers in Africa (Kayembe 1985; Chirambo, 1986; Sangawe, 1988; Whitfield et al., 1990). Cataract is considered as the most important cause of blindness and low vision in Africa constituting over 40% reported cases (Forster, 1989). In the West, the incidence of cataract in people over 50 years is 15%, while in developing countries it is about 40% (Ohrloff, 1989; Fasina and Ajaiyeoba, 2003).

So far, the only available treatment for cataract worldwide is through surgical removal of the lens. Although this method is quite effective, it has its share of risks and limitations with its attendant economic burden for most poor countries. Also, the increasing incidence of cataract has widened the gap between the number of patients requiring surgery and cataract surgeons, thus making it difficult to management problems. For instance, in Nepal, only 35% of cataract patients receive surgery (Brilliant and Brilliant, 1985), while it is not astonishing that even in countries like England cataract patients are wait listed for surgery for a period of 4 years (Wilson, 1987). In India, the scenario is even more depressing with a gigantic backlog of more than 22 million cataract cases (1990 statistics).

The Kenya Ophthalmic Program (KOP) is a governmental agency under the Ministry of Health (MOH), which was started in 1956, and is responsible for all eye health care programmes in the country. It is estimated that about half a million patients are treated annually through the various eye facilities in Kenya. The surgical method recommended by the KOP is that which uses ECCE with PC IOL implant. The table 6.8.1 below shows the comparison between Kenya's cataract surgical rate (CSR) against those of the other countries within the East African region during the year 1999 (Karimurio, 2000). The declared CSR target under "The VISION 2020" is 30,000 per year.
Table 6.8.1: Cataract Surgical Rates in the Region

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (millions)</th>
<th>Cataract operations 1999</th>
<th>CSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>30</td>
<td>12,000</td>
<td>400</td>
</tr>
<tr>
<td>Uganda</td>
<td>20</td>
<td>6,000</td>
<td>300</td>
</tr>
<tr>
<td>Tanzania</td>
<td>30</td>
<td>10,000</td>
<td>333</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>60</td>
<td>18,000</td>
<td>300</td>
</tr>
</tbody>
</table>

6.8.1 Trend Analysis of Pterygium and Cataract in Kenya

The figure 6.8.2 shows the monthly trend of the UV-B irradiance convolved with the cataract spectra compared with the reported incidences of eye cataract and Pterygium in Malindi, Kenya. The plots indicate a positive trend between reported incidences of both eye cataracts and Pterygium for the case of Malindi during most months except for cataract in the month of December. This discrepancy can be attributed to incomplete data collected from some stations, which did not submit full reports for the period in consideration.
Figure 6.8.2: Trend analysis for reported incidence of eye cataract for Malindi

The figure 6.8.3 shows the monthly trend analyses of the irradiance convolved with the eye spectra to the reported incidences of eye cataract and Pterygium for Nairobi. Like in the case of Malindi there exists a positive trend between reported incidences of both eye cataracts and Pterygium for the case of Nairobi with discrepancies attributed to incomplete data as was the case with Malindi. Also, the trend for Nairobi is not as “smooth” as in the case of Malindi as Nairobi has disproportionately more eye healthcare facilities and also acts a referral center for handling cases from other centers. This leads to a situation of double reporting; a case that was reported at the primary healthcare is reported again as another incidence in Nairobi within the same period of time.
Figure 6.8.3: Trend analysis for reported incidence of eye cataract for Nairobi

Even though in both cases of Malindi and Nairobi, there seems to be an indication of positive trend between irradiance level and the selected ocular diseases, this evidence is not conclusive enough to attest positive correlation between exposure to UV-B radiation and prevalence for both cataract and Pterygium. There are other intervening factors other than UV-B, which were previously mentioned in this chapter from various studies that affect both cataracts and pterygium. One weakness that this analysis suffers from is that the reported incidences are confined to access such that areas with more “dense” eye health care facilities reporting higher incidences and thus geographical spread of healthcare facilities is a factor. The inadequacy of health care facilities in Africa is not limited to eye care only but also to other medical facilities.

It is necessary to conduct further studies to model the UV risk for cataract and pterygium as those conducted by West et. al. (1995; 1998; 2005). Other additional information such as population census, data distribution by region, according to sex, age group and occupation, among others, are necessary to adequately analyze the impact of UV-B radiation on ocular
diseases. Even then as it is a common knowledge, long-term time series analysis are invaluable to establish the correlation between exposure and effect as it has been indicated in sections 6.5 and 6.6 that dose accumulation over long period of time is a primary factor especially in the development of cortical cataract.