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A HEALTH RISK ASSESSMENT OF ULTRAVIOLET RADIATION IN DURBAN

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ABSTRACT

The widely observed depletion of stratospheric ozone and the expected increase in surface ultraviolet radiation receipt has raised much concern about consequent health risks, particularly in the form of erythema (sunburn) and non-melanoma skin cancer. This paper presents the findings of a health risk assessment of surface ultraviolet radiation in Durban. The risk of erythema and non-melanoma skin cancer was estimated for four lifestyle-scenarios, viz. a child, an outdoor worker, an indoor worker and a mixed-mode worker. It was shown that the Hazard Quotient for all scenarios was greater than one, indicative of a risk of erythema. Even an indoor worker who is assumed to spend only one hour per day outdoors during the week is at risk, since the exposure usually occurs when the ultraviolet radiation levels are high. The risk of non-melanoma skin cancer in an outdoor worker is almost twice that of an indoor worker. When compared to an indoor worker of a British population, who receives an annual MED dose of approximately 372 MED units, which is fives times less than that of a South African indoor worker, the risk of non-melanoma skin cancer for an outdoor worker in South Africa is emphasised.

Introduction

Stratospheric ozone plays an important role in influencing the amount of ultraviolet radiation (UV) incident on the earth's surface. The inverse relationship between global stratospheric ozone depletion and increased surface UV is well established in theory and has been confirmed through observations at a number of sites across the world, see for example, Herman *et al.* (1998).

South Africa, situated in the southern subtropical region, has experienced a general downward trend in total column ozone of the order of 2% per decade (Diab *et al.*, 1992; Kalicharran *et al.*, 1993), in common with other locations at these latitudes. It is expected that, as a result of this negative trend in total ozone, the UV flux at the earth's surface has increased, and there are likely to be associated adverse impacts on human and biological systems. These effects are expressed, *inter alia*, as a higher incidence in the occurrence of severe erythema (sunburn), cataracts, non-melanoma skin cancer (NMSC), malignant melanoma skin cancer (MMSC) and suppression of the immune system, within both present and future human populations (Harm, 1980; Diffey, 1991).

NMSC is the result of cumulative UV exposure and as such is one of the chronic effects. It consists of two types of skin cancer, viz. basal cell carcinoma (BCC) and squamous cell carcinoma (SCC) and, although estimated to have a low fatality rate (<1%) (Weinstock, 1995), the lumps or spots on the skin can become unsightly if untreated. MMSC, on the other hand, is a malignant tumour that arises from melanocytes, the pigment producing cells of the skin (Jones and Wigley, 1989). The malignant tumours tend to metastasise or grow in size and ultimately cause death. Certain phenotypic characteristics, such as the presence of blue or green eyes, blonde or red hair, a light complexion and the presence of moles larger than 2 mm in diameter tend to predispose certain individuals to the occurrence of MMSC (Diffey, 1991). Due to the smaller amount of melanin found in the epidermis of fair skinned individuals that would serve to protect the melanocytes found in the basal layer of the epidermis from UV, their risk of MMSC increases.

In the United States, there has been a consistent increase in the incidence and mortality rate of MMSC since 1979 (NRC, 1994). This is partially ascribed to increased solar exposure as a result of altered behaviour patterns, but could also be linked to elevated UV receipt due to increases caused by ozone depletion. It is estimated that for each 1% depletion of stratospheric ozone that there is a 2% change in erythemal UV worldwide (NIH, 1989; McKenzie and Elwood, 1990).

In South Africa, there have been no studies linking the occurrence or risk of skin cancer to the incidence of UV radiation. However, previous work by Duigan *et al.* (1995) has drawn attention to the relatively high levels of ambient UV radiation received at Durban, particularly during summer, and noted that these levels are sufficiently high to raise concern about possible health effects. With this in mind, this study aims to investigate the risk of erythema and NMSC at Durban within a health risk assessment framework. The study is preliminary and is perceived to be the first of its kind to be undertaken in South Africa. A similar study was undertaken by Diffey (1992) in Britain based on the application of a risk calculation using surface UV radiation values. This study uses a health risk assessment model together with risk equations to determine the risk of erythema and NMSC for four lifestyle-scenarios.

Health Risk Assessment framework

Risk assessment is the process of identifying probable negative effects of exposure to a hazardous situation or agent. Within this broad framework, health risk assessment (HRA) is one such model that is used to quantitatively estimate the health risks associated with a particular agent or substance. The HRA model was first applied in the United States in 1983 (NRC, 1994) and has been used extensively to quantify the risk of human exposure to toxicants, in particular SO_2 and NO_2 (NRC, 1994). It has also been applied to the estimation of risks associated with both the acute (short-term) and chronic (long-term) exposure to UV radiation (CSIR, 1999).

The four phases of the HRA framework (NRC, 1994) are:

- Hazard Identification
- Dose-Response Assessment
- Exposure Assessment
- Risk Characterisation, which includes Risk Calculation and Communication

The *hazard identification phase* recognises UV radiation as an environmental hazard that poses a threat to all living systems, particularly human health, when received in excessive amounts.

The *dose-response assessment* presents the relationship between the exposure level or dose, and the severity of the consequences experienced by an individual. The relationship between the UV dose received by an individual and the consequent biological response is complex and includes changes in biophysical and photochemical molecular events, alterations in cellular biochemistry, metabolism and structure (Parrish *et al.*, 1978). An action spectrum or weighting function is used to identify the effectiveness of each wavelength in producing a particular biological response (Diffey, 1991).

The *exposure assessment phase* identifies the exposed or target population that is affected by the hazard as well as their individual UV exposure patterns. The estimation of exposure times for this study is described in the Methodology section.

The final stage, *risk characterisation*, involves the integration of the first three stages and provides a general estimate of the likelihood and nature of the risk posed to the target population. This stage also includes risk communication in which the information determined in the first three stages is mobilised and transformed into relevant and accessible material. This material can then be used to provide the public with an understanding of the risks associated with exposure to UV, thereby raising levels of environmental and public health awareness, with the long-term goal of benefiting and protecting the health of individuals.

Whilst the HRA model has been widely applied in the United States and elsewhere (for example, Beer and Ziolkowski, 1995) and the number of applications in South Africa is on the increase (CSIR, 1999), it is important to be mindful of its shortcomings and inherent uncertainties. The chief criticisms relate to the lack of sufficient scientific data to provide a quantitative assessment of health risks associated with exposure to a particular hazard, and the failure to consider the individual and his/her understanding and interpretation of risk (NRC, 1994).

Data and methodology

Surface UV radiation measurements were made using a Yankee Environmental Systems (YES) UVB-1 pyranometer located on the roof of a building (~ 20 m above ground level) at the University of Natal (Durban). The instrument is situated in a non-shaded location and horizontally orientated manner. The YES is a broadband instrument that measures both integrated UVB and erythemal ultraviolet radiation (EUV) between 280 – 320 nm on a continuous basis. EUV is defined as UV irradiance weighted by the Commission Internationale d'Eclairage (CIE) action spectrum for human erythema (CIE, 1987). The readings are logged at 10-minute intervals and then averaged to provide 1-hour values. UVB data recorded during 1999 were regarded as representative of a typical year in Durban and were used to provide a preliminary estimation of the associated health risks.

The EUV data were converted into Minimal Erythema Dose units (MED), where 1 MED is equivalent to 231 J m^{-2} in accordance with the method used by the South African Weather Services (SAWB, 1999). A MED unit describes the minimum UV dose that results in minimal perceptible redness of the skin (Diffey, 1991). The MED value varies as a function of skin type, ranging from 140 J m^{-2} for skin type I (fair with freckles) to 261 J m^{-2} for skin types IV, V and VI, which include moderate brown to black skins with dark eyes (Duigan, 1995). The MED value of 231 J m^{-2} used in this study is equivalent to a white skin that tans easily (skin types II and III).

The total daily MED dose (DMD) was calculated from the equation below and the subsequent annual MED dose determined.

$$\mathrm{DMD} = \frac{\Sigma\ \mathrm{AEI} \times \mathrm{EXP}}{231} \qquad (1)$$

where DMD is the total daily MED dose, AEI is the average hourly reading of EUV for the hour of exposure (Wm^{-2}) and EXP is exposure duration (seconds)

Four lifestyle-scenarios were selected to determine the exposure duration. Scenario 1 was a child aged 10 years (S1), scenario 2 was an indoor worker (S2), scenario 3 an outdoor worker (S3) and scenario 4 a mixed-mode worker, who worked both outdoors and indoors on any given day (S4). The annual UV exposure patterns of each category were based on intensive interviews with selected individuals who typified each of these categories. The total daily MED dose and annual MED dose were then calculated for each scenario and used to calculate the risk of erythema and NMSC for each scenario.

The risk of non-carcinogenic acute health effects such as erythema was estimated by means of a Hazard Quotient (HQ), which is used to indicate the presence or absence of the effect upon exposure to the hazardous agent or substance i.e. UV (NRC, 1994). The HQ expresses a short-term, readily visible effect and is calculated by dividing the average total daily MED dose (ADD) by the reference exposure level (REL). The REL was taken as 1 MED unit (231 Jm^{-2}). An HQ value of less than one indicates a negligible risk, whereas a value greater than or equal to one indicates some risk, with the risk increasing as HQ increases.

The risk of NMSC was calculated using a power law relationship defined by Diffey (1992) that expresses the cumulative risk in terms of the annual UV dose (in MED units) and age (in years) according to the following equation (Diffey, 1991):

$$\text{Risk (2) (annual UV dose)}^{\beta}\ (\text{age})^{\alpha}$$

where α and β are constants with values of five and two respectively. These values were the same as those used by Diffey (1991). The former is a numerical constant associated with the age dependence of the cumulative UV incidence, while the latter is the biological amplification factor. There is no benchmark value against which the calculated risk may be compared, although, a comparison with other similar studies in terms of annual MED dose was undertaken (Diffey *et al.*, 1992; Goettsch *et al.*, 1995).

This risk equation assumes that individuals receive a constant annual UV dose throughout their lifetime. While it is recognised that this is unlikely to be true since behavioural patterns change with age and circumstance, the equation has been applied in this form in order to gain a first insight into the potential risk of NMSC in Durban.

A slight modification was made and a second risk equation used to estimate the risk of NMSC based on a singular change in UV exposure patterns during an individual's lifetime. The equation according to Diffey (1992) is as follows:

$$\text{Risk (cumulative UV dose at age T)}^{\beta-1} \sum_{t=0}^{T} [\text{annual UV dose at age (T} - \text{t)]}\ t^{\alpha-\beta} \qquad (3)$$

where T is the age (in years) of the individual at the time of study and the cumulative UV dose is computed from the *annual UV dose (in MED units) x age.* For the purposes of this study, the change in UV exposure was assumed to occur at age 18. Hence a distinction was made between the MED dose received as a child (0 – 18 years) and the MED dose received as an adult (19 – 35 years). This division is based on similar work conducted by Diffey (1992).

Seasonal and diurnal trends in surface UV at Durban

A brief overview of the seasonal and diurnal trends in surface UV radiation at Durban provides the context for the study. Figure 1 illustrates the variation of daily integrated surface UV radiation in a typical year. Summer UV radiation levels lie between ~ 150 mW m^{-2} and 180 mW m^{-2}, while values around 30 mW m^{-2} occur during winter. Values are scattered below a well-defined sinusoidal envelope, which represents the maximum clear sky value that can be obtained on any one day according to the seasonal position of the sun. Values below the envelope are reduced according to the extent, height and type of cloud. Although representative of only one year, the pattern is similar to that noted in other papers on UV in Durban (Scourfield *et al.*. 1990; Bodeker and Scourfield, 1998).

EUV values measured by the YES pyranometer were converted into total daily MED units. Typical summer values range between ~ 20 – 30 MED units per day, while minimum values of ~ 1.5 MED units per day and less were recorded during the winter months (not shown). Taking into account that 1 MED unit is defined as the minimum UV dose that results in erythema, it is clear a full day's exposure to UV during summer may result in adverse health consequences. South African Weather Service defines a daily MED dose less than 7 as moderate, between 7 and 14 as high, 14 - 24 as dangerous and >24 as very dangerous (SAWB, 1999). A total of 26 days in January had a MED dose equal to or above 14.

Figure 1: Integrated daily UVB irradiance for Durban 1999.

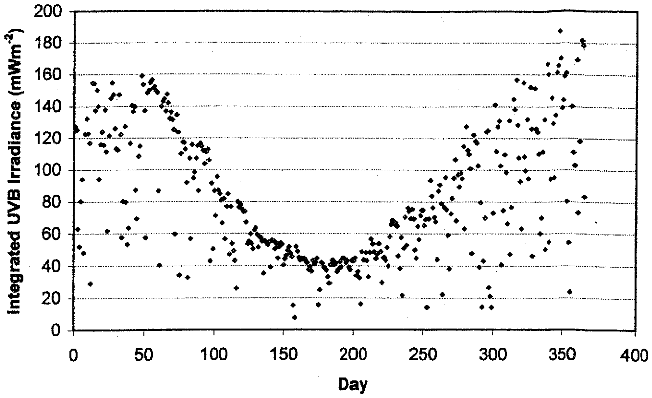
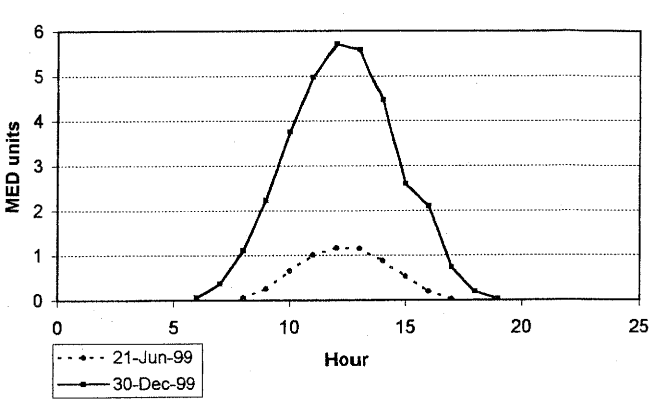


Figure 2: Comparison between the diurnal variation in MED units per hour for 21 June 1999 and 30 December 1999 for Durban.



The diurnal variation in EUV for a typical summer (30 December 1999) and a typical winter day (21 June 1999) is shown in Figure 2. A symmetrical distribution about solar noon is evident, with marked seasonal variations in the hourly MED dose. A maximum hourly value of 5.88 MED units was measured at 12:00 during summer, while winter noon EUV values seldom exceeded 1 MED unit.

Results of the Health Risk Assessment

The application of the health risk assessment model involves four steps, which were outlined in the methodology. The first two steps, viz. hazard identification and dose-response assessment are based on well-documented research and are not repeated here. Discussion will be confined to the exposure assessment and the estimation of the risk.

Table 1: UV exposure times of each lifestyle-scenario

Scenario	Individual	Age (yrs)	UV Exposure Times		Holidays/Annual Leave
			Weekdays	**Weekends**	
S1	Child	10	10:00 - 10:30 12:00 – 13:00 14:00 – 16:00	9:00 - 12:00 13:00 – 15:00	13 Dec – 18 Jan 1 Apr – 13 Apr 1 Jun – 23 Jun 23 Sep – 5 Oct
S2	Indoor worker	35	13:00 – 14:00	10:00 – 15:00	17 Dec – 13 Jan
S3	Outdoor worker	35	7:00 – 11:00 12:00 – 18:00	9:00 - 14:00	2 Aug – 21 Aug
S4	Mixed-mode worker	35	9:00 – 10:00 11:00 – 12:00 14:00 – 16:00	9:00 - 14:00	17 Dec – 13 Jan

Exposure assessment

Human UV exposure varies as a function of ambient EUV levels and individual exposure habits i.e. duration of time spent outdoors. Factors such as the fraction of ambient EUV received by a particular anatomic site, degree of shading, orientation of the body to the direct solar beam and the use of UV protective agents and mechanisms, such as sunscreen and umbrellas, were not taken into consideration in this study. The assumed UV exposure patterns of each lifestyle-scenario based on intensive interviews with typical individuals are presented in Table 1. Public holidays, annual school holidays and annual vacations were taken into account. Maximum exposure periods were assumed in order to determine the worst-case for each lifestyle-scenario. Hence, during vacation periods it was assumed that the exposure period was equivalent to that of the weekend exposure.

The UV exposure periods were used to determine total daily, monthly and annual MED doses for each scenario. Figure 3 illustrates the variation in monthly MED dose for each lifestyle-scenario. Doses are clearly greater during summer than during winter on account of the higher ambient EUV levels. The outdoor worker (S3) consistently received the highest monthly MED dose throughout the year, at times being 67% greater than the indoor worker (S2), who received the lowest monthly MED doses. The monthly MED doses of the child (S1) and the mixed-mode worker (S4) were similar throughout the year, in view of their similar UV exposure patterns.

The annual MED doses are presented in Table 2 and reveal that the outdoor worker receives an annual dose more than double that of an indoor worker. Although an indoor worker is assumed to spend only I hour per day outdoors, the exposure time occurs when ambient EUV levels are high, thereby giving rise to a higher annual UV dose than expected.

Figure 3: Comparison between the monthly MED dose of each lifestyle-scenario for one year. S1 represents a child, S2 an indoor worker, S3 an outdoor worker and S4 a mixed-mode worker.

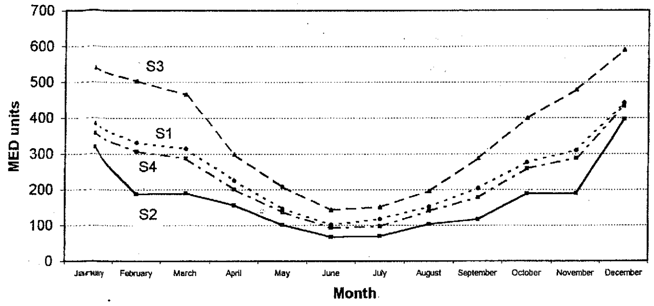


Table 2: Annual MED dose (MED units) of each lifestyle-scenario

Scenario	Individual	Annual MED dose
S1	Child	3011
S2	Indoor worker	2083
S3	Outdoor worker	4261
S4	Mixed-mode worker	2774

Table 3: Hazard quotient for each lifestyle-scenario

Scenario	Individual	ADD	REL	HQ
S1	Child	8.2	1	8
S2	Indoor worker	5.7	1	5
S3	Outdoor worker	11.6	1	11
S4	Mixed-mode worker	7.6	1	7

The values presented in Table 2 reflect maximum EUV doses incident on a horizontal surface or on a horizontal anatomic position such as the top of the head. The amount incident on other anatomic sites varies according to their orientation (Diffey *et al.*, 1977). It is estimated, for example, that the face receives approximately 25% of the EUV incident on a horizontal surface. Comparing the facial doses for the above scenarios, computed according to the factor of 25%, with facial doses of people in the Northern Hemisphere, it is apparent that the values obtained in this study are considerably higher. An indoor worker in the Netherlands received an annual facial dose of 112 MEDs (Goettsch, *et al.*, 1998) compared with 521 MEDs in this study. A study by Diffey (1992) in Britain showed a value of 157 MEDs for a child compared with 753 MEDs in this study. When comparing an indoor worker in South Africa to an indoor worker of a British population, who receives an annual MED dose of approximately 372 MED units (Diffey, 1992), the annual MED dose of a South African indoor worker is fives times larger. The values in Durban are higher, notwithstanding the fact that the other studies used a lower amount of EUV radiation as equivalent to 1 MED unit, viz. 150 Jm^{-2}. Clearly, the greater ambient EUV radiation at the latitude of Durban is largely responsible for this difference.

Risk characterisation

The risk of erythema is indicated by the HQ values, which are presented in Table 3 for each lifestyle-scenario. All the calculated HQs lie above the benchmark value of 1, which is used to distinguish the presence or absence of a risk of erythema. The outdoor worker (S3) has the highest HQ as a result of long periods spent outdoors. It is likely that such workers will experience erythema on any given day, including weekend days, unless protective mechanisms are used. Due to the nature of their work, their risk of erythema is involuntary and with minimal resources available to these generally lower income earners, their vulnerability is increased. Children (S1) have an HQ of 8, indicating a likely risk of erythema on a daily basis. Children and adolescents tend to have more leisure time available to them (Diffey *et al.*, 1996) and may spend this time outdoors, particularly during summer in Durban when weather conditions are favourable. They may be exposed to relatively high ambient EUV levels and this enhances the likelihood of experiencing erythema. Indoor workers (S2), although possessing the lowest HQ, still have a value greater than 1, indicating they too are at risk of developing erythema.

The risk of NMSC is presented in Table 4 for each of the lifestyle-scenarios for both an unaltered and altered lifetime annual MED dose. The risk is greatest for the outdoor worker (S3) in both cases. Their total daily MED doses closely resemble the daily ambient EUV levels, particularly on summer days when ambient EUV levels are relatively high.

A child (S1) has the lowest risk of developing NMSC as a result of a reduced age. However, cumulative UV exposure, particularly during childhood and adolescence, is recognised as being a primary cause in the occurrence of NMSC during adulthood. A relationship between childhood UV

Table 4: Calculated risk for an unaltered and altered lifetime annual MED dose for each lifestyle-scenario

Scenario	Individual	Unaltered lifetime annual UV dose			Altered lifetime annual UV dose		
		Annual MED dose	Age	Risk	Cumulative MED dose	Age (T)	Risk
S1	Child	3011	10	0.009×10^{14}	30110	10	0.009×10^{14}
S2	Indoor worker	2083	35	2.27×10^{14}	89609	35	0.83×10^{14}
S3	Outdoor worker	4261	35	9.53×10^{14}	126635	35	1.54×10^{14}
S4	Mixed-mode worker	2774	35	4.04×10^{14}	101356	35	1.07×10^{14}

exposure and the incidence of NMSC during adulthood has been identified (Lew and Rosenthal, 1988: Diffey *et al.*, 1996: Gies *et al.*, 1998: Moise *et al.*, 1999a: Moise *et al.*, 1999b: O'Riordan *et al.*, 2000: and Kimlin and Parisi, 2000) and a repeated incidence of erythema during childhood may increase this risk. The child's annual MED dose is high and continued UV exposure of this nature during adulthood would increase their risk of NMSC with age. As a consequence of prior UV exposure, particularly when resulting in erythema, the risk of NMSC for a child in Durban may be promoted. The indoor workers (S2) were found to have the lowest risk of NMSC amongst the adult lifestyle-scenarios as a result of their short daily UV exposure periods. However, the timing of their UV exposure may be classified as intense and regular. This type of UV exposure, described as the intermittent exposure hypothesis, has also been identified as a causative factor in the aetiology of NMSC (MacKie and Aitchison, 1982; Sorahan and Grimley, 1985; Conti *et al.*, 1989).

The mixed-mode worker (S4) exhibits a similar risk of NMSC as the indoor worker (S2), except that the risk is enhanced as a result of a greater number of UV exposure periods during the day. This leads to an intermittent UV exposure pattern however, since no time is spent outdoors between 12:00 and 14:00, the risk is reduced.

The risk of NMSC calculated according to a change in lifestyle is evidently lower than that calculated using an unaltered lifetime annual MED dose (Table 4). Even though the annual MED dose of an adult working predominantly indoors or between indoor and outdoor settings is lower than that received by a child, the calculated risk of NMSC is not sufficiently reduced during adulthood to eliminate the risk of contracting NMSC.

Risk communication

Risk communication is the final stage of the health risk assessment and determines the means by which the derived information should be mobilised to inform the public of the health risks associated with UV exposure. It highlights target groups who are most susceptible and provides options for the reduction of the adverse health impacts. This study has focused on light to medium-skinned children, indoor workers, outdoor workers and mixed-mode workers. In the light of the estimated health risks for each of the lifestyle-scenarios, it is recommended that UV exposure be minimised, particularly between the hours of 10:00 and 15:00. Protective devices such as hats, protective clothing and sunscreen should be utilized. However, it is noted that the use of sunscreen, whilst effective in preventing erythema, has not been proven to be effective against skin cancer (Holman *et al.*, 1986; Roy and Gies, 1997).

National campaigns have been adopted by various countries including Australia and the United States of America as a means of communicating the health risks of overexposure to UV to the public (Borland, 1999). An effective UV monitoring network in each country has allowed for public broadcasting of a UV index to assist the public in making decisions to protect their health. A similar initiative has been adopted by the SAWS. It has the potential to gradually influence the South African public's perceptions of the dangers of UV exposure and subsequently offset the risk of NMSC and reduce the burden on health care providers and the country's health budget.

Conclusion

A health risk assessment framework was used to characterise the magnitude of the risk of erythema and NMSC for four lifestyle-scenarios. Ambient EUV levels in Durban ranged between 25 – 35 MED units per day during summer. These are relatively high EUV levels and extended periods of exposure to such levels may result in severe adverse health implications for susceptible individuals.

All of the lifestyle-scenarios had HQ values above 1, indicative of the risk of erythema. The outdoor worker had the highest value, followed by the child. Even indoor workers are at risk of experiencing erythema as their exposure time occurs when ambient EUV levels are high.

The risk of developing NMSC is greatest for an outdoor worker as a result of their extended period of exposure to high EUV levels on a daily basis. This risk is almost double that of an indoor worker.

It is apparent that there is a need for serious consideration of the adverse effects of UV exposure on the inhabitants of Durban and by implication the whole of South Africa. The implementation of a persuasive form of risk communication indicating the dangers of overexposure to UV is required to raise public awareness and alter perceptions in order to reduce the incidence of erythema and NMSC.

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