Solar ultraviolet radiation, skin cancer and photoprotective strategies in South Africa

Caradee Yael Wright*[1, 2], and Mary Norval [3]

[1]. Environment and Health Research Unit, South African Medical Research Council, Pretoria, South Africa,

[2]. Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria, South Africa,

[3]. Biomedical Sciences, University of Edinburgh Medical School, Edinburgh, United Kingdom

*Corresponding author e-mail: Caradee.Wright@mrc.ac.za (Caradee Yael Wright)

ABSTRACT

The most recent data relating to the incidence of, and mortality from, the three commonest forms of skin cancer, namely basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and cutaneous melanoma (CM), in the Black African, Coloured, Asian/Indian and White population groups in South Africa are reviewed. While exposure to solar ultraviolet radiation is the major environmental risk factor for BCC in all four groups, for SSC in the White and Asian/Indian groups, and for CM in the White group, this is unlikely to be the case for most SCCs in the Black African group and for most CMs in the Black African and Asian/Indian groups. Strategies for practical personal photoprotection in South Africa are discussed with particular emphasis on people at heightened risk of skin cancer including the White population group, those with HIV or oculocutaneous albinism, and outdoor workers.

INTRODUCTION

South Africa is located at the southern tip of Africa, spanning latitudes 22.34° S to 34.28° S (Figure 1). The country's narrow coastal plain rises to a large plateau called the Highveld at an altitude of 1200 m. The Highveld is characterized by high atmospheric pressure resulting in cloudless skies which, in combination with the altitude, lead to high levels of ambient solar ultraviolet radiation (UVR). Table 1 illustrates the climatic variation between the four major cities, Cape Town, Durban, Kimberley, Johannesburg and Pretoria in South Africa: latitude, altitude, summer and winter noon UV Index, average daytime summer and winter temperature, and noon solar zenith angle summer solstice (21 December) and winter solstice (21 June). Johannesburg, Pretoria and Kimberley are located on the Highveld while Cape Town and Durban are at the coast.

Figure 1. Map of South Africa showing topography, provincial borders and major cities.

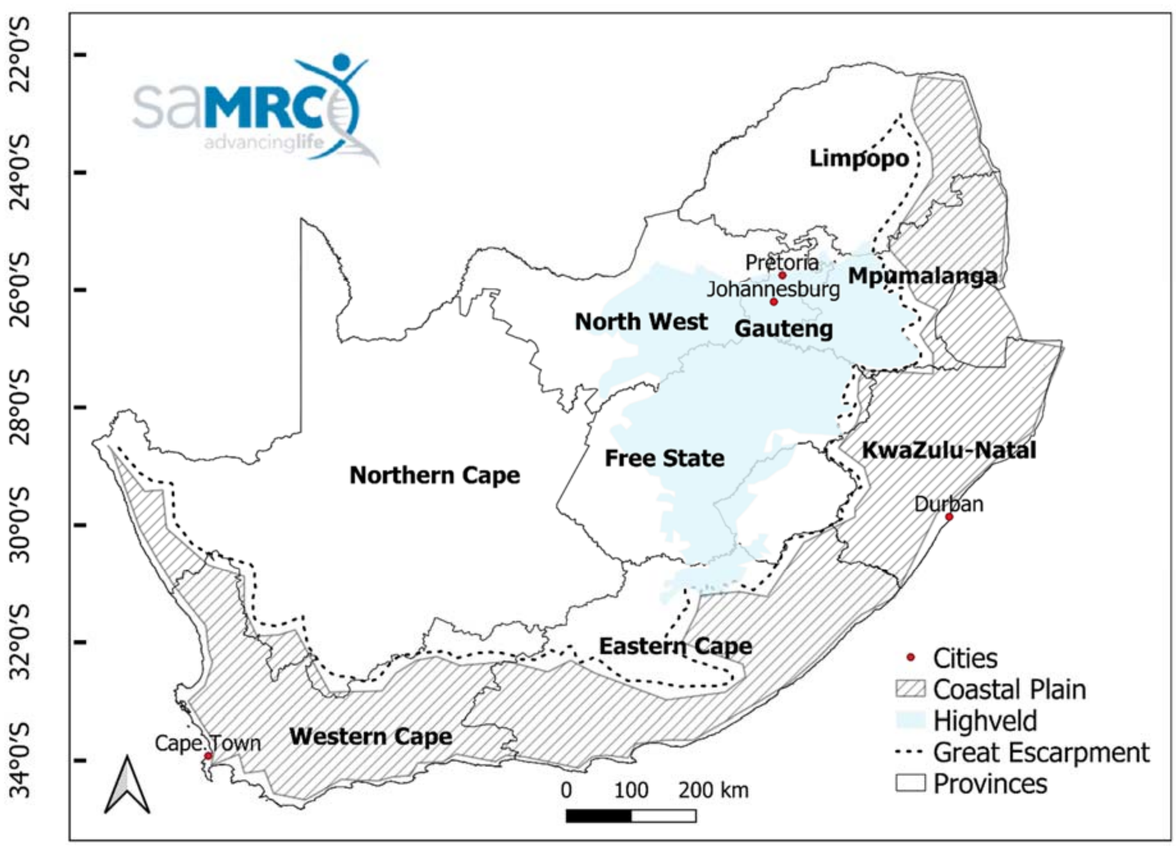

Table 1. Climate statistics for the four largest cities in South Africa (All data were obtained via personal communication with the South African Weather Services).

Characteristic	Cape Town	Durban	Johannesburg	Pretoria	Kimberley
Latitude (°S)	34	29	26	26	29
Altitude (m)	0-300	0-21	1 750	1 340	1 184
Ultraviolet Index at noon (summer)	9-10	10-11	11+	11+	11+
Ultraviolet Index at noon (winter)	4-5	5-6	5-7	4-7	5-6
Average daytime temperature (summer) (°C)	26	29	26	30	31
Average daytime temperature (winter) (°C)	15	21	15	18	19
Solar zenith angle summer solstice at noon (21 Dec) (°)	10.54	6.17	2.46	2.37	5.28
Solar zenith angle winter solstice at noon (21 June) (°)	57.39	53.02	49.3	49.23	52.14

In 2021, South Africa had a population of about 60 million people (Table 2), of whom 51% were female. The population is multi-ethnic comprising four groups, 80.9% Black African, 8.8% Coloured (mixed ancestry of White and Black or Black and Asian population groups), 2.6% Asian/Indian (frequently termed Asian in South Africa) and 7.8% White (1). A socio-demographic profile of South African characteristics is given in Table 2.

Table 2. South African population and health statistics.

Parameter	Figures / statistics	Reference
Population (mid-2021)	60.14 million; 80.9% Black Africa, 8.8% Coloured, 7.8% White, 2.6% Indian/Asian	Stats SA, 2021 (1)
Prevalence of adult HIV (2021)	13.7%	Stats SA, 2021 (1)
Life expectancy at birth (2021)	59.3 years for females, 64.6 years for males	Stats SA, 2021 (1)
Employment rate, ages 15-49 years (2021)	34.9%	Stats SA, 2021 (86)
Number living in poverty (2020)	1 in 5 people	Statistica.com, 2020 (87)
Education attainments (2020)	2.0% no schooling, 6.8% less than primary school, 4.2% primary school, 38.3% some secondary school, 32.5% secondary school, 15.3% tertiary education, 0.8% other	DHET, 2021 (88)

Studies relating to skin cancer in South Africa are reviewed below, including consideration of the incidence of, and deaths from, basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and cutaneous melanoma (CM) in the four population groups, followed by an assessment of the role of solar UVR as a risk factor in each of these groups, and then suggestions for effective photoprotection.

SKIN CANCERS IN SOUTH AFRICA

Information relating to the incidence and mortality of skin cancers in South Africa and risk factors involved is scarce. We first addressed this topic in 2012 (2) when there were even less data available than now. As this issue of Photochemistry and Photobiology celebrates the 50th Anniversary since its inception, it is interesting to note that the earliest paper it published on the topic was in 2013 (3). Reviews encompassing global figures rarely include data from South Africa although some contain results from limited studies in other African countries (4). A literature search of PubMed between 2000 and March 2022 using the terms “South Africa” in combination with “skin cancer” found 351 publications initially which was reduced to 18 of relevance on reading the titles and abstracts. A search using the same terms for articles published between 1990-2014 located only four papers (5). This and the following sections provide an account of these and other papers but starts with an introduction to the most common types of skin cancer that occur globally.

Throughout the world, the keratinocyte cancers (KCs), formerly called the non-melanoma skin cancers (NMSCs), are the most frequent. Their incidence has increased steadily during the past century or so in countries where the majority of the population has fair skin (6). The KCs are divided into basal cell carcinomas (BCCs) and squamous cell carcinomas (SCCs) with the BCCs generally outnumbering the SCCs. As an illustration of this, it was estimated that there were 4 million new cases of BCC and 2.4 million new cases of SCC globally in 2019 (7). The actual figures are likely to be higher as many such skin tumours are underreported. They are rare in children, and BCCs become more frequent in middle age than SCCs, with around equal numbers in old age (8). The KCs are rarely fatal (56,000 deaths globally due to SCCs in 2019, with considerably fewer due to BCCs (7)) but can be disfiguring with diagnostic and treatment procedures incurring significant medical costs. The third most frequently occurring skin tumour is malignant melanoma which is less common than the KCs with 0.3 million new cases estimated globally in 2019 (7). Cutaneous melanomas (CMs) can metastasise and result in death, for example in 63,000 cases worldwide in 2019 (7). Incident rates for the KCs and CMs vary considerably between countries depending on several factors including the ethnic background of the population, latitude and societal circumstances. As examples, the age-standardised incidence rate per 100,000 people for CM in Australasia was estimated as 31.7 in 1990, then 43.4 in 2019, while it was estimated as 1.3 in 1990, then 1.6 in 2019 in Southern Sub-Sahara Africa (7).

There are large differences between skin cancers in those with light skin and those with darker skin which relate to incidence, histological type, body site, stage at presentation and prognosis. A variety of risk factors have been identified which can vary with the skin colour of the individual. However, exposure to solar UVR is recognised as carcinogenic in humans and is critical in promoting skin cancer, especially in those with light skin. Indeed, the World Health Organization International Agency for Research on Cancer attributes 65-90% of all skin cancers to such irradiation (9).

Cumulative life-time exposure is key for SCC, with intermittent intense exposure, particularly in childhood and adolescence for BCC (10,11). For CM, a dual pathway has been proposed, one relying on chronic sun exposure in sun-sensitive people and the other relying on naevi initiated by sun exposure in childhood and then promoted thereafter by intermittent sun exposure (12). As shown in Table 1, the UV Index is high throughout most the year in much of South Africa and this, combined with ambient temperatures which are rarely extreme, plus common outdoor occupational and recreational activities, means that the majority of the population is exposed to considerable levels of solar UVR.

Incidence of and deaths from skin cancers in South Africa

The National Cancer Registry of South Africa was formed in 2008 but reporting was incomplete until the formalisation of the National Health Regulations in 2011. The Registry is based purely on histological diagnosis, thus probably underestimating the true incidence of KCs in particular which are either unreported or treated without the necessity for obtaining and subsequent pathological examination of biopsies. In addition, there is some uncertainty about assigning individuals to a particular population group. The most recent data relating to the number of cases of BCC, cutaneous SCC and CM in the four population groups of South Africa are available for 2019 and are shown in Table 3 (13). In addition, the percentage of all cancers represented by the three cancer types, as reported to the Registry, is indicated in Table 3, as well as the age-standardised incidence rate per 100,000. Various points of interest can be drawn from these figures. First, there is a larger number of KCs in males compared with females overall and this is also found among the White, Coloured and Black population groups. There is not such a large difference between males and females in incidence rates for CM as for BCC and SCC. It is also of note that skin cancers represent approximately 24% of all cancers in females and 34% of all cancers in males in South Africa. These figures rise to 39% in White females and 56% in White males while, in contrast, only 5% of all cancers in Black females and 6% in Black men are skin cancers. As the results depicted in Table 3 indicate, the incidence rates for the three types of skin cancer in the Coloured population lie about midway between the rates in the White and the Black African population. While the incidence of BCCs is higher than the incidence of SCCs in the White, Coloured and Asian population groups, the reverse is seen for the Black African group. The incidence of KCs and CM that develop in the Asian population group is considerably lower than in the White or Coloured groups and is similar to that recorded for the Black African group. In both sexes in all four population groups, the number of cases of BCC, SCC and CM rises with age and this is particularly true for the White population (14).

It is not possible to determine accurately any trends in the incidence figures in South Africa since country-wide data have been collected over a relatively short period of time and are not complete. However limited information indicates that the incidence rates recorded in 2019 for BCC and SCC in females and males in each of the four population groups are similar to the mean annual age-standardised incidence recorded in 2000-2004 (14). There are also similar incidence rates for CM in 2019 as there were in 2000-2004 in males and females in the Asian, Black and Coloured populations. However, a possible increase in CM incidence is noted in the White population from a mean annual incidence rate of 16.5 in 2000-2004 to 18.2 per 100,000 in 2019 in females, and from 20.5 to 22.4 per 100,000 in males. Previously, an increase in the annual incidence rate for CM in White males and females in Cape Town between 1990-1995 and 2001-2003 had been reported (15).

Table 3. The number of cases of basal cell carcinoma (BCC), cutaneous squamous cell carcinoma (SCC) and cutaneous melanoma (CM) diagnosed histologically in 2019 in South Africa. The percentage of all cancers each number represents, and the age standardised (World standard population) incidence rate per 100,000 are also shown. Data from https://www.nicd.ac.za/centres/national-cancer-registry/cancer-statistics/.

Population	BCC: number, (% of all cancer cases), [incidence rate]	SCC: number, (% of all cancer cases), [incidence rate]	CM: number, (% of all cancer cases, [incidence rate]
Female (total population)	6685, (15.2%), [21.9]	2992, (6.8%), [9.4]	1031, (2.4%), [3.4]
Male (total population)	8581, (20.7%), [41.2]	4328, (10.4%), [21.5]	1135, (2.7%), [5.3]
Asian, female	37, (2.8%), [3.5]	27, (2.0%), [2.3]	11, (0.8%), [1.1]
Asian, male	28, (2.7%), [3.2]	26, (2.5%), [2.9]	8, (0.8%), [0.9]
Black female	328, (1.7%), [1.6]	416, (2.2%), [1.9]	170, (0.9%), [0.8]
Black, male	318, (2.3%), [2.4]	419, (3.0%), [2.9]	104, (0.7%), [0.7]
Coloured, female	603, (14.5%), [23.0]	330, (6.9%), [10.8]	116, (2.4%), [3.9]
Coloured, male	879, (18.6%), [43.3]	451, (10.0%), [24.6]	103, (2.2%), [5.0]
White, female	5625, (32.3%), [117.4]	2219, (12.8%), [34.8]	732, (4.2%), [18.2]
White, male	7355, (35.5%), [170.1]	3428, (16.5%), [66.6]	919, (4.4%), [22.4]

Any assessment of the number of deaths due to skin cancer in South Africa in recent years and in the past is difficult to establish due mainly to the lack of a comprehensive population-based death registration system and probable under-reporting. The most recent World Health Organisation (WHO) data for South Africa estimated the age-standardised death rate for skin cancer as 3.72 per 100,000 population in 2018, with the majority assumed to be due to CM (16). This ranks South Africa as the ninth highest of countries in the world with the top ranking being New Zealand at 6.6 skin cancer deaths per 100,000 population. Despite the acknowledged limitations on exact mortality each year in South Africa, a study of CM deaths between 1997 and 2014 demonstrated an increasing trend in age-adjusted mortality rates in males between 2000 and 2005 from 2 to 3 per 100,000, in females between 1997 and 2014 from 0.9 to 1.2 per 100,000, and by 3% in the White population between 1999 and 2014 (17). No trend was apparent in the Black African population.

ROLE OF SOLAR UVR AS A RISK FACTOR FOR SKIN CANCER IN SOUTH AFRICA

There is strong evidence that exposure to solar UVR is the major risk factor for BCC. This is true for all four population groups in South Africa as demonstrated by the majority of the tumours developing on body sites commonly exposed to the sun, such as the face and neck. However, the incidence of BCC is markedly lower in the Black African population than in the White. This illustrates the protection from solar UVR offered by pigmented skin, thought to be due mainly to the high content of cutaneous eumelanin which filters twice as much UVB radiation as the epidermis of white skin, thus providing a natural sun protection factor, calculated as higher than 60 for black African skin (18). The Coloured population with less pigmented skin than in the Black Africans has an incidence rate between those of the Black African and White populations (Table 3).

One recent study illustrates typical findings relating to KCs in South Africa. Histological examination of 700 biopsies from patients with suspected skin cancer attending a dermatology clinic in the public health care system in Western Cape Province found that 68% were malignant with 55% of these diagnosed as BCC and 19% as SCC (19). The face was the commonest location biopsied, followed by the leg. BCC was diagnosed in 90% of the malignant biopsies from White patients, 8% from Coloured patients and 1.6% from Black African patients while SCC was diagnosed in 90% of malignant biopsies from White patients, 7% from Coloured patients and 7% from Black African patients.

With regard to SCC, cumulative exposure to solar UVR is acknowledged as the major environmental risk factor in Caucasians and Asians with the tumours occurring predominantly on sun-exposed body sites like the face and neck. This is unlikely to be the case for Black Africans as the tumours are found approximately eight times more frequently on non-sun exposed body sites than on exposed sites (20). Here the risk factors may be chronic scarring processes, areas of chronic inflammation or ulceration scars from chemical or thermal burns, and skin infected with high-risk human papillomavirus (21). These lesions have a 30% metastatic rate compared with the 2-4% rate in SCCs induced by UVR exposure (22).

The body sites of CM and their subtypes in South Africa indicate that different risk factors are involved in the four population groups. In the White population, the tumours are commonly the superficial spreading subtype occurring on sun-exposed body sites, frequently affecting the trunk in males and the legs in females. Only 3% of CMs are the acral subtype in White patients as reported in several countries (23). In contrast in the Black African population, CMs are rarely located on the head, neck or trunk, and are more likely to be the acral lentigenous subtype affecting the soles of the foot, palms and subungal body sites. Using cases reported to the Cancer Registry in 2005-2013, Tod et al found that, in 878 Black Africans diagnosed with CM on the limbs, 91% were on the lower limb with 74% of these affecting the foot and 65% being acral lentigenous melanomas (24). A recent study of primary cases of acral melanoma in 78 patients presenting at a dermatology clinic in Cape Town between 2010 and 2018 discovered that half had occurred in Black Africans, with the majority of these tumours on the foot, frequently on the heel, and acral lentigenous melanoma was the commonest subtype (25). It is thought probable that the acral subtype in the African Black population is more aggressive that the subtypes found in the White population. In addition, the tumours are frequently diagnosed at an advanced stage of the disease (25), leading to a higher mortality rate than CMs in the White population group. Lodder et al (26) studied 175 cases of CM in Black Africans in Cape Town – all were diagnosed as the acral lentigenous subtype with the majority on the foot, most at the junction between the sole and the dorsal pigmented skin. While 30 of these patients survived for more than three years, 35 died within one year of presentation. Apart from late presentation, other factors may contribute to these deaths such as misdiagnosis, lack of medical insurance cover, a low standard of education, poor living conditions and an inability to recognise the early lesions allied with not knowing the need for prompt treatment (27).

Thus, while exposure to solar UVR constitutes a risk for melanoma in the White population of South Africa, it is of minor importance in the Black African population in which genetic analysis of tumours has revealed different polymorphisms of the MC1R gene with effects on pigmentation and fewer mutation in tumour genes compared with other CM subtypes (28). In the Asian population group, CMs occur predominantly on non-exposed body sites, similar in location to those in the Black African group (29). Other non-UVR related factors have not been extensively investigated as yet but could include an association with naevi on the soles of the feet (30) or previous episodes of trauma especially if shoes are not worn regularly.

Table 4 depicts a summary of the major body sites of and risk factors for skin cancers in the White and Black African population groups of South Africa.

Table 4. Common body sites of, and risk factors for skin cancers in the White and Black African population groups in South Africa.

	White	Black African
Basal cell carcinoma *Risk factors*	head, neck *solar UVR*	head, neck *solar UVR*
Squamous cell carcinoma *Risk factors*	head, neck *solar UVR*	leg and other non-exposed body sites rarely head, neck *chronic scars, chronic inflammation, ulcers, human papillomavirus infection, chronic non-healing wounds*
Cutaneous melanoma *Risk factors*	head, neck, trunk, leg *solar UVR*	soles, palms, nail bed rarely head, neck, trunk *unknown*

One aspect which may affect the incidence of skin cancer relates to the HIV epidemic in South Africa which is the biggest in the world. There were 7.7 million people living with HIV in 2021 and 13.7% prevalence in adults (1). Despite more than 5 million HIV-positive individuals being treated with antiretroviral therapy in 2021, it has proved impossible thus far to substantially reduce the population-level incidence of HIV (31). As HIV adversely affects cell-mediated immunity, as does exposure to UVR (32), it is not a surprise to note that there is a 1.39-fold increase in the risk of BCC and a 1.83-fold increase in the risk of SCC in people living with HIV compared with matched HIV-negative individuals (33).

A further factor involves individuals with oculocutaneous albinism (OCA) who are at very high risk of skin cancer, estimated as one thousand times greater than in the general population (34). OCA consists of a group of congenital developmental disorders in which there is alteration of pigmentation in the skin, eyes and hair, ranging from total loss of melanin to almost normal levels. The number of melanocytes is not altered but defects in the genes in the melanin biosynthetic pathway are present (35), resulting in an inability to synthesise eumelanin (brown/black pigment) or pheomelanin (yellow/orange pigment) or less of these than found normally. The national prevalence of OCA in South Africa has been estimated as 1:3 900 (36). It is higher in some parts of the country, such as in the Venda people living on the South African-Zimbabwean border (37).

The skin cancers in individuals with OCA, induced by exposure to solar UVR, are SCCs most frequently, BCCs less often, and CMs rarely. The tumours occur on the head and neck with a few on the arms and legs although these are not associated with scars or chronic ulcers as is the case in Black Africans without OCA (38,39,40). They commonly develop in the third decade of life and can rapidly metastasise to the cartilage, bone and neck resulting in a lower life expectancy than in individuals without OCA (41). The role of solar UVR in those with OCA in South Africa is further emphasised by the higher rate of skin cancer in such people living in Soweto and Gauteng (26º S latitude, 1600 m altitude) compared with people living in the Eastern Cape (32º S latitude, sea level to 942 m altitude) (42) where the UV Index at most times of the year is lower than further north.

A final group to consider in the context of solar UVR as a risk factor for skin cancer is outdoor workers. Approximately four million people in South Africa have outdoor occupations, such as in forestry, fishing, agriculture, construction and open-pit mining. No reports on this topic relating to South Africa have been published to date. However, two systematic reviews and meta-analyses based on studies in Europe, North America and Australia have demonstrated an increased risk of SCC in those with occupational solar UVR exposure compared with those without such exposure with the odds ratio 1.77 (43) and a 40% increased risk of BCC in outdoor workers compared with indoor workers (44). In addition, in both instances, there was a strong inverse relationship between occupational solar UVR exposure and risk of KC with latitude. In contrast there is little evidence from several studies in a variety of countries, although none in Africa, that there is any association between outdoor work and an increased risk of CM in people of any skin colour (45).

PHOTOPROTECTION STRATEGIES IN SOUTH AFRICA

Although the focus of the Cancer Association of South Africa (CANSA) is on SunSmart Awareness only in the months of December and January, its website provides information about photoprotection and recommends sun protection throughout the year (46). CANSA advises on ways to reduce skin cancer risk including doing a monthly self-check for moles, avoiding being in the sun between 10 am and 3 pm, and staying under shade as much as possible. It also recommends using an effective sunscreen with the CANSA Seal of Recognition logo that indicates the product complies with European Colipa Standards (47). The sunscreen must be applied correctly according to the instructions on the bottle. In addition, it promotes wearing protective clothing and swimsuits, using thickly woven hats with wide brims, and sunglasses with a UV protection rating of UV400. CANSA supports the ultraviolet protection factor (UPF) for clothing that has been checked to meet UPF levels between 20 and 50.

Evidence of personal photoprotection strategies in South Africa is relatively sparse. A search in PubMed using the terms “photoprotection / sun protection” and “South Africa” in the years 2000 to April 2022 found 15 relevant articles which are discussed below.

UV Index

Situated in the mid-latitudes, South Africa can experience UV Index values that exceed 11+ during summer months at midday and this has likely remained relatively constant over the past 20 years despite the thinning of the ozone layer at higher latitudes (48). While some countries provide a forecasted UV Index for the days ahead, this is not the case in South Africa. An attempt to do so was made in the 1990s, but the media stopped reporting it because the value did not change day by day since variables such as cloud cover and rain were not included. About six years ago, the South African Weather Service (SAWS) initiated the development of a forecasted UV Index value that took account of clouds, aerosols and other factors. This exists on the SAWS intranet and is available to forecasters but not to the general public.

International evidence suggests that, while people are aware of the UV Index, there is insufficient evidence to confirm that this leads to the use of sun protection or sun safe behaviours (49). In one study, knowledge of the UV Index among South African students was found to be low (50). No other reports relating to South Africa have been published on this topic.

Shade

Trees can provide effective shade depending on their leaf type and density (51). Built shade, such as gazebos, shade sails and awnings, can also be effective against solar UVR exposure but factors such as design, quality and ease of use are important considerations to ensure efficacy and to reduce exposure to diffuse UVR. Handheld umbrellas are commonly used in South Africa to provide shade and relief from the heat (Figure 2). Umbrellas are not necessarily an effective means of sun protection with one study based in California showing that more than 17% of solar UVR penetrated the umbrella fabric (52). The fabric and size of the umbrella are critical factors with some able to block between 77% and 99% of solar UVR (53) although additional means of sun protection, such as sunscreen, are recommended. In addition, the effectiveness of umbrellas is reduced by diffuse UVR.

Figure 2. Lady in North-West province carrying an umbrella for personal shade (Permission granted by the participant for use of the photograph, which was taken by the author, CYW).

Black Africans in South Africa have reported skin changes, including erythema, when exposed to the sun (54). They make use of sun protection, typically preferring shade from, for example, trees, beach umbrellas, gazebos and built structures, to other sun protection strategies such as sunscreen and clothing (55). No study has assessed whether Black Africans, or individuals from other South African population groups, seek shade specifically to reduce the risk of skin cancer.

Protective clothing and hats

Tightly woven, loose fitting clothing that covers most of the body can provide protection from exposure to solar UVR. Australia, New Zealand, the UK and other countries have standards and

/ or certification trademarks that use a UPF to express how effective a material is at sun protection (56). This is of particular value for parents wanting sun protective full body swimsuits for children, but may not be of value if the garment provides very little body coverage, such as a bikini. Clothing fabrics with the recommended level of 20 to 50 UPF are considered protective (57,58). In South Africa, it is rare to see a UPF swing tag on a garment other than on child swimsuits, wetsuits used for surfing and adult swimwear. A four-year old child's swimsuit (also known as a sunsuit) made of UPF50 material costs about ZAR350 (US$ 22 on 16 May 2022) compared with one made with non-UPF material that costs about ZAR250 (US$ 15) with the price differential of ZAR100 equating to about 10 loaves of bread.

Hats can provide sun protection to the eyes, ears, face and back of the neck depending on the design. A hat with a brim greater than 7.5 cm is considered most sun protective for the face. Bucket hats with a wide brim and legionnaire style hats also provide good protection, but when solar UVR is diffuse or scattered from clouds, additional sun protection is needed. Peak caps provide good protection to the forehead and nose but do not protect the ears and the cheeks.

Limited studies have assessed self-reported hat-wearing in South Africa. Outdoor workers picking nuts and fruit on a farm in Limpopo province in the north of South Africa tended to wear peak caps while 23% never wore a hat (59). Schoolchildren from schools across South Africa reported that they 'sometimes/most of the time/always' wore a cap (74% of 705 child participants) (60).

Sunglasses

Sunglasses can provide good protection to the skin around the eyes as well as the eyes themselves if the frames, size and lenses are appropriate. South Africa does not have a regulation regarding sunglasses, although UV400 lenses are suggested on the CANSA website. One study found that sunglasses were seldom worn by farmworkers in Limpopo province explained by factors including cost, cultural acceptance and possible interference with work activities (59).

Sunscreen

In South Africa, the South African National Standard (SANS) 1557:2019 (61) [SABS, 2019] regulates all aspects of sunscreen products, including ingredients, advertising and labelling, and test methods for determining SPF and UVA, in vivo SPF and 'water resistant' and 'very water resistant' properties. All sunscreen products in South Africa must comply with SANS 1557:2019 requirements including testing. The South African Bureau of Standards leads oversight of the implementation of these standards.

Currently sunscreens with SPFs as high as 50 are available; as are broadband sunscreens protecting against both solar UVA and UVB radiation. Regular sunscreen use has been associated with decreased risks of photoaging (62) and skin cancer (63-66) in particular for SCC (67) and CM (63) but less so for BCC. However, such protection depends on many factors such as the amount of sunscreen applied and frequency of application. It is well known that in most instances sunscreens are applied in thinner layers and less frequently than recommended by the manufacturer's instructions on the bottle and international standards (69).

In South Africa, the cost of sunscreens is considered expensive with 50 ml of a SPF 50 sunscreen costing between ZAR 200 (US$ 13 on 27 April 2022) and ZAR 400 (US$ 25). This may lead to people using the cream sparingly and thus not preventing sunburn (66). While regular sunscreen use may be a cost-effective approach to skin cancer prevention in high-income countries, this may not be the case in low- and middle-income countries (68). The cost of sunscreens is likely to be beyond the means of the majority in South Africa, and there is little public health guidance to promote their use, beside the advice given on the CANSA website. It should be noted that sunscreen is provided free of charge by the South Africa Government for those with OCA.

Only a few reports have examined sunscreen use in South Africa per capita or in each population group. For example, in a study specifically of children with OCA, about one third wore sunscreen (70), while in a larger study of children from all population groups about two-thirds of respondents said they used sunscreen 'sometimes / most of the time / always' (60). A cross-sectional survey among general outpatients at a large central hospital in Durban found that only half of White participants reported regular sunscreen use with even fewer Black African and Indian participants reporting so (71).

Alternative 'sunscreen-type products' are used by some South Africans. These may fulfil a similar function to sunscreen but are unlikely to be specifically chosen for reducing the risk of skin cancer. Some of these traditional products have been tested for their photoprotective properties. For example, clays rich in the mineral kaolinite have a SPF 3 with broad spectrum UV protection (72). The efficacy of ochre used in some parts of South Africa as a topical photoprotection compound is high and habitual application inhibits solar UVR exposure of the skin (73). The use of such products among people with deeply pigmented skin may be to protect against photoaging, to prevent skin on the face from darkening, or be part of cultural practices or rituals rather than to reduce the risk of skin cancer.

Vulnerable groups and raising awareness

Several groups in South Africa are particularly vulnerable to the adverse effects of solar UVR. The first of these is people with OCA. Sun protection use by children with OCA tends to be low (74,75) due to several challenges including peer pressure. In addition, access to free (government-funded), high quality sunscreen with an SPF greater than 15 remains a problem for many due to several factors including the distance involved to reach the primary health care clinics for the collection of the sunscreen (70). Typically hats in addition to sunscreens are recommended for people with OCA, but hats are not always affordable and may not be favoured by children.

Outdoor workers in South Africa are at risk of excess solar UVR exposure. Guards, who protect cars from theft in car parks, make use of long sleeve clothing and hats but do not recognise the need for sunscreen as most have deeply pigmented skin (76). Informal traders working in markets selling traditional medicines and other products try to have portable shade, such as an umbrella or make-shift gazebo while attending to their stand throughout the day (77). It is of importance to recognise that the amount of sky which can be seen from under portable shade influences the solar UVR exposure of those below. Interestingly, one study found that workers based in the Western Cape province had negotiated with their managers to begin work very early in the morning to avoid the hottest time of the day when solar UVR levels are high (78). This approach would be appropriate for other occupational groups such as agricultural, construction and road repair workers. There is a need for sun safety to become part of workplace occupational health and safety protocols in South Africa, as is the case in other countries (79).

Children require protection from solar UVR as early years and adolescence are important life stages when excess sun exposure increases the risk of developing CM and NMSC later in life. This is especially important for children with lightly-pigmented skin, particularly those who do not tan and burn easily on sun exposure. It should be mandatory that schools, especially new schools under construction, provide sun protection such as shade in playgrounds and encourage effective sun behaviour. While some schools in South Africa have policies that promote sunscreen use and the wearing of hats, these policies are not mandatory by law (58). Priority currently is given to pressing health challenges such as malnutrition.

South Africa's sunny, mild climate is conducive to participation in an extensive range of outdoor sports. Surfing, rugby, soccer, golf, cricket and cycling are among many sports practiced professionally and for recreation. Several of these entail extended periods of solar UVR exposure, including at peak UVR hours and with limited shade (80). Marathon runners in Cape Town were found to have low solar UVR exposure levels as a result of the races being held outside peak solar UVR hours (81). To the best of our knowledge, use of photoprotection by athletes in South Africa has not been studied.

Vulnerability to solar UVR requires consideration within the context of climate change. South Africa is expected to experience warming on average double the global increase projected for the end of this century (82). Changes in temperature, especially the number of hot days and the frequency of heatwaves, are anticipated to impact South Africa's population. People may spend more time indoors if it is too hot outdoors, or potentially be outdoors to collect water from rivers, springs and boreholes in areas without indoor taps or outdoor standpipes, a necessity for about 5 million South Africans (83). Clothing practices may change leading to increased exposure of the skin to excess solar UVR. Public healthcare messages about prevention of skin cancer should include threats posed by climate change and appropriate sun safe messaging for personal protection.

Despite the high protection to epidermal DNA afforded by darker pigmentation, especially in the basal epidermis, among Black South Africans (18,84), photoprotection for people with deeply pigmented skin could still be important to reduce pigmentary disorders, photoaging and the risk of BCC (85).

Cost of treating skin cancers in South Africa

The costs of diagnosing and treating skin cancers in South Africa were estimated for 2015 at ZAR 92.5 million (US$ 15.7 million) (68). On average, each confirmed case of CM cost ZAR 4 197 (US$ 712), while each confirmed NMSC cost ZAR 2 767 (US$ 470) (68). This study only considered direct medical figures. Peripheral figures related to skin cancer diagnosis, such as loss of income, administration of disability grants, insurance claims, transport and accommodation of patients living outside the major centres, were not included. Due to the recent COVID-19 epidemic and spiralling inflation, all these costs will likely be significantly higher currently.

Despite KCs having a low rate of major morbidity and mortality, the expenditure on diagnosis and treatment is large. It is important to note that most CMs in South Africa are diagnosed in the private sector (24). Given the associated costs, any increase in the incidence of skin cancers in South Africa is likely to present a significant financial burden for both the private and public sectors.

CONCLUSION

As described above, exposure to solar UVR constitutes the major environmental risk factor for the development of many skin cancers in South Africa. It is particularly relevant for the White population group with respect to BCC, SCC and CM, for the Coloured group to a lesser extent for each of these tumour types, and for the Asian/Indian and Black African groups for BCC. Risk factors for SCC and CM in the Black African group remain largely unknown. Within the population groups, there are people at particular risk of developing skin cancer due to solar UVR exposure including those with OCA or infected by HIV, and those working outdoors or participating in regular recreational activities outside. Policy and legislation changes are needed to ensure appropriate shade is included in the design of school playgrounds. Schools should be required to have a sun protection policy and photoprotection such as using hats and sunscreen encouraged. Timing of school outdoor events need to be considered in light of CANSA's recommendations to avoid high solar UVR exposure. Public health messages regarding sun protection and skin cancer prevention require to be made more prominent, especially for the groups at highest risk of skin cancer.

ACKNOWLEDGMENTS*:* Caradee Y. Wright receives research funding from the South African Government through the South African Medical Research Council. We thank Bianca Wernecke of the South African Medical Research Council for Figure 1.

REFERENCES

1. Statistics South Africa. South African population statistics. Available at http://www.statssa.gov.za/publications/P0302/P03022021.pdf (Accessed 19 May 2022)
2. Wright, C. Y., Norval, M., Summers, B., Davids, L. M., Coetzee, G., and M. Oriowo (2012) Solar ultraviolet radiation exposure and human health in South Africa: finding a balance. *S. Afr. Med. J.* **102**, 665-666. https://doi.org/10.7196/samj.5921
3. Wright, C. Y., Brogniez, C., Ncongwane, K.P., Sivakumar, V., Coetzee, G., Metzger, J.M., Auriol, F., Deroo, C., and B. Sauvage (2013) Sunburn risk among children and outdoor workers in South Africa and Reunion Island coastal sites. *Photochem. Photobiol.* **89**, 1226-1233. https://doi.org/10.1111/php.12123
4. Lomas, A., Leonardi-Bee, J., and F. Bath-Hextall (2012) A systematic review of worldwide incidence of nonmelanoma skin cancer. *Br. J. Dermatol.* **166**,1069-1080. https://doi.org/10.1111/j.1365-2133.2012.10830.x
5. Lucas, R.M., Norval, M. and Wright, C.Y. (2016) Solar ultraviolet radiation in Africa: a systematic review and critical evaluation of the health risks and use of photoprotection. *Photochem. Photobiol. Sci.* **15**, 10. https://doi.org./10.1039/c5pp00419e
6. Lucas, R. M., Yazar, S., Young, A.R., Norval, M., de Gruijl, F. R., Takizawa, Y., Rhodes, L. E., Sinclair, C. A., and R. E. Neale (2019) Human health in relation to exposure to solar ultraviolet radiation under changing stratospheric ozone and climate. *Photochem. Photobiol. Sci.* **18**, 641-680. https://doi.org/10.1039/c8pp90060d
7. Zhang, W., Zeng, W., Jiang, A., He, Z., Shen, X., Dong, X., Feng, J., and H. Lu, (2019) Global, regional and national incidence, mortality and disability-adjusted life-years of skin cancers and trend analysis from 1990 to 2019: An analysis of the Global Burden of Disease Study 2019. *Cancer Med.* **10**, 4905-4922. https://doi.org/10.1002/cam4.4046
8. Pandeya, N., Olsen, C. M., and D. C. Whiteman (2017) The incidence and multiplicity rates of keratinocyte cancers in Australia. *Med. J. Aust.* **207**, 339-343. https://doi.org/10.5694/mja17.00284
9. International Agency for Research on Cancer (2012) IARC Monograph on Evaluation of Carcinogenic Risks to Humans, Volume 100D. Lyon, France. Available

https://publications.iarc.fr/_publications/media/download/2931/d7a4e802483b1374482768a36a7c78e1b33aa1c8.pdf (Accessed 19 May 2022)

10. Olsen, C. M., Wilson, L. F., Green, A. C,, Bain, C. J., Fritschi, L., Neale, R. E., and D. C. Whiteman (2015) Cancers in Australia attributable to exposure to solar ultraviolet radiation and prevented by regular sunscreen use. *Aust. N. Z. J. Public Health*. **39**, 471-6. https://doi.org/ 10.1111/1753-6405.12470
11. Diepgen, T. L., and V. Mahler (2002) The epidemiology of skin cancer. *Br. J. Dermatol*. **146** Suppl 61, 1-6. https://doi.org/10.1046/j.1365-2133.146.s61.2.x
12. Armstrong, B. K., and A. E. Cust (2017) Sun exposure and skin cancer, and the puzzle of cutaneous melanoma: A perspective on Fears et al. Mathematical models of age and ultraviolet effects on the incidence of skin cancer among whites in the United States. *Cancer Epidemiol*. **48**, 147-156. https://doi.org/10.1016/j.canep.2017.04.004.
13. National Cancer Registry. (2022) Cancer Statistics. National Institute for Communicable Diseases. Available at https://www.nicd.ac.za/centres/national-cancer-registry/ (Accessed 19 May 2022)
14. Norval, M., Kellett, P., and C. Y. Wright (2014) The incidence and body site of skin cancers in the population groups of South Africa. *Photodermatol. Photoimmunol. Photomed*. **30**, 262-265. https://doi.org/10.1111/phpp.12106
15. Jessop, S., Stubbings, H., Sayed, R., Duncan-Smith, J., Schneider, J. W., and H. F. Jordaan (2008) Regional clinical registry data show increased incidence of cutaneous melanoma in Cape Town. *S. Afr. Med. J*. **98**, 197-199. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0256-95742008000300019
16. World Life Expectancy com. (2022) World Life Expectancy. Available at www.worldlifeexpectancy.com (Accessed 19 May 2022)
17. Wright, C. Y., Kapwata, T., Singh, E., Green, A. C., Baade, P., Kellett, P., and M. Norval (2019) Trends in Melanoma Mortality in the Population Groups of South Africa. *Dermatol*. **235**, 396-399. https://doi.org/10.1159/000500663
18. Fajuyigbe, D., Lwin, S. M., Diffey, B. L., Baker, R., Tobin, D. J., Sarkany, R. P. E., and A. R. Young (2018) Melanin distribution in human epidermis affords localized

protection against DNA photodamage and concurs with skin cancer incidence difference in extreme phototypes. *FASEB J*. **32**, 3700-3706. https://doi/org/10.1096/fj.201701472R

19. de Wet, J., Steyn, M., Jordaan, H. F., Smith, R., Claasens, S., and W. I. Visser (2020) An Analysis of Biopsies for Suspected Skin Cancer at a Tertiary Care Dermatology Clinic in the Western Cape Province of South Africa. *J. Skin Cancer*. **2020**, 9061532. https://doi.org/10.1155/2020/9061532
20. P. T. Bradford (2009) Skin cancer in skin of color. *Dermatol. Nurs*. **21**, 170-177. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2757062/
21. Bender, A. M., Tang, O., Khanna, R., Ständer, S., Kang, S., and S.G. Kwatra (2020) Racial differences in dermatologic conditions associated with HIV: A cross-sectional study of 4679 patients in an urban tertiary care center. *J. Am. Acad. Dermatol*. **82**, 1117-1123. https://doi.org/10.1016/j.jaad.2019.08.072
22. M. Gohara (2015) Skin cancer: an African perspective. *Br. J. Dermatol*. **173** Suppl 2, 17-21. https://doi.org/10.1111/bjd.13380
23. Bernardes, S. S., Ferreira, I., Elder, D.E., Nobre, A.B., Martínez-Said, H., Adams, D.J., Robles-Espinoza, C. D., and P. A. Possik (2021) More than just acral melanoma: the controversies of defining the disease. *J. Pathol. Clin. Res*. **7**, 531-541. https://doi.org/10.1002/cjp2.233
24. Tod, B. M., Kellett, P. E., Singh, E., Visser, W.I., Lombard, C.J., and C. Y. Wright (2019) The incidence of melanoma in South Africa: An exploratory analysis of National Cancer Registry data from 2005 to 2013 with a specific focus on melanoma in black Africans. *S. Afr. Med. J*. **109**, 246-253. https://doi.org/10.7196/SAMJ.2019.v109i4.13565
25. Tod, B., Visser, W., de Wet, J., Kotze, M., Bowcock, A., Ayele, B., McCaul, M., and J. Schneider (2021) Clinicopathological features and associations in a series of South African acral melanomas. *Pigment. Cell. Melanoma Res*. **34**, 1120-1122. https://doi.org/10.1111/pcmr.13003
26. Lodder, J. V., Simson, W., and P. J. Becker (2010) Malignant melanoma of the skin in black South Africans: a 15-year experience. *S. Afr. J. Surg*. **48**, 76-79. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0038-23612010000300002

27. Zakhem, G. A., Pulavarty, A. N., Lester, J. C., and M. L. Stevenson (2022) Skin Cancer in People of Color: A Systematic Review. *Am. J. Clin. Dermatol*. **23**, 137-151. https://doi.org/10.1007/s40257-021-00662-z
28. Haugh, A. M., Zhang, B., Quan, V. L., Garfield, E. M., Bubley, J. A., Kudalkar, E., Verzi, A. E., Walton, K., VandenBoom, T., Merkel, E. A., Lee, C. Y., Tan, T., Isales, M. C., Kong, B. Y., Wenzel, A. T., Bunick, C. G., Choi, J., Sosman, J., and P. Gerami (2018) Distinct Patterns of Acral Melanoma Based on Site and Relative Sun Exposure. *J. Invest. Dermatol*. **138**, 384-393. https://doi.org/10.1016/j.jid.2017.08.022
29. Bradford, P. T., Goldstein, A.M., McMaster, M. L., and M. A. Tucker (2009) Acral lentiginous melanoma: incidence and survival patterns in the United States, 1986-2005. *Arch. Dermatol*. **145**, 427-434. https://doi.org/10.1001/archdermatol.2008.609
30. Palicka, G.A., and Rhodes, A.R. (2010) Acral Melanocytic Nevi: Prevalence and distribution of gross morphologic features in White and Black adults. *Arch. Dermatol*. **146**, 1085-1094. https://doi.org/10.1001/archdermatol.2010.299"cmelink=1"
31. Bacaër, N., Pretorius, C., and B. Auvert (2010) An age-structured model for the potential impact of generalized access to antiretrovirals on the South African HIV epidemic. *Bull. Math. Biol*. **72**, 2180-98. https://doi.org/10.1007/s11538-010-9535-2
32. Hart, P. H., Norval, M., Byrne, S. N., and L. E. Rhodes (2019) Exposure to Ultraviolet Radiation in the Modulation of Human Diseases. *Annu. Rev. Pathol*. **24**; 55-81. https://doi.org/10.1146/annurev-pathmechdis-012418-012809
33. Dhokotera, T., Bohlius, J., Spoerri, A., Egger, M., Ncayiyana, J., Olago, V., Singh, E., and M. Sengayi (2019) The burden of cancers associated with HIV in the South African public health sector, 2004-2014: a record linkage study. *Infect. Agent. Cancer*. **14**, 12. https://doi.org/10.1186/s13027-019-0228-7
34. Hong, E. S., Zeeb, H., and M. H. Repacholi. Albinism in Africa as a public health issue. *BMC Public Health*. **17**, 212. https://doi.org/10.1186/1471-2458-6-212
35. Ma, E. Z., Zhou, A. E., Hoegler, K. M, and A. Khachemoune (2022) Oculocutaneous albinism: epidemiology, genetics, skin manifestation, and psychosocial issues. Arch. Dermatol. Res. **Feb 25**. https://doi.org/10.1007/s00403-022-02335-1

36. Kromberg, J. G., and T. Jenkins (1982) Prevalence of albinism in the South African negro. *S. Afr. Med. J.* **61**, 383-386. https://journals.co.za/doi/pdf/10.10520/AJA20785135_14335
37. Lund, P. M., Maluleke, T. G., Gaigher, I., and M. J. Gaigher (2007) Oculocutaneous albinism in a rural community of South Africa: a population genetic study. Ann. Hum. Biol. **34**, 493. https://doi.org/10.1080/03014460701401261
38. Yakubu, and O. A. Mabogunje (1993) Skin cancer in African albinos. *Acta. Oncol*. **32**, 621-622. https://doi.org/10.3109/02841869309092440
39. Kiprono, S. K., Chaula, B. M., and H. Beltraminelli (2014) Histological review of skin cancers in African Albinos: a 10-year retrospective review. *BMC Cancer*. **14**, 157. https://doi.org/10.1186/1471-2407-14-157
40. Okafor, O. C., and N. T. Onyishi. (2021) Primary cutaneous malignancies in nonalbino and albino Africans. Int. J. Dermatol. 2021 Feb;60(2):222-228. https://doi.org/10.1111/ijd.15312.
41. A. N. Okoro (1975) Albinism in Nigeria. A clinical and social study. *Br. J. Dermatol*. **92**, 485-492. https://doi.org/10.1111/j.1365-2133.1975.tb03116.x
42. Kromberg, J. G., Castle, D., Zwane, E.M., and T. Jenkins (1989) Albinism and skin cancer in Southern Africa. *Clin. Genet*. **36**, 43-52. https://doi.org/10.1111/j.1399-0004.1989.tb03365.x
43. Schmitt, J., Seidler, A., Diepgen, T. L., and A. Bauer (2011) Occupational ultraviolet light exposure increases the risk for the development of cutaneous squamous cell carcinoma: a systematic review and meta-analysis. *Br. J. Dermatol*. **164**, 291-307. https://doi.org/10.1111/j.1365-2133.2010.10118.x
44. Bauer, A., Diepgen, T. L., and J. Schmitt (2011) Is occupational solar ultraviolet irradiation a relevant risk factor for basal cell carcinoma? A systematic review and meta-analysis of the epidemiological literature. *Br. J. Dermatol*. **165**, 612-625. https://doi.org/10.1111/j.1365-2133.2011.10425.x
45. Wright, C. Y., and M. Norval (2021) Health Risks Associated With Excessive Exposure to Solar Ultraviolet Radiation Among Outdoor Workers in South Africa: An Overview. *Front Public Health*. **9**, 678680. https://doi.org/10.3389/fpubh.2021.678680

46. The Cancer Association of South Africa (2022) Be SunSmart Everywhere. Available at https://cansa.org.za/be-sunsmart/ (Accessed 19 May 2022)
47. COLIPA (2022) The European Trade Association. Available at https://colipa.eu/ (Accessed 18 May 2022)
48. Bernhard, G. H., McKenzie, R.L., Lantz, K., and S. Stierle. (2022) Updated analysis of data from Palmer Station, Antarctica (64° S), and San Diego, California (32° N), confirms large effect of the Antarctic ozone hole on UV radiation. *Photochem. Photobiol. Sci*. **21**, 373-384. https://doi.org/10.1007/s43630-022-00178-3
49. Heckman, C.J., Liang, K., and M. Riley (2019) Awareness, understanding, use, and impact of the UV index: A systematic review of over two decades of international research. *Prev. Med*. **123**, 71-83. https://doi.org/10.1016/j.ypmed.2019.03.004
50. Wright, C. Y., Reeder, A.I., and P. N. Albers (2015) School students' knowledge and understanding of the Global Solar Ultraviolet Index. *S. Afr. Med. J*. **105**, 1024-9. https://doi.org/10.7196/SAMJ.2015.v105i12.10120
51. Downs, N. J., Butler, H. J., Baldwin, L., Parisi, A.V., Amar, A., Vanos, J., and S. Harrison (2019) A site-specific standard for comparing dynamic solar ultraviolet protection characteristics of established tree canopies. *MethodsX*. **6**, 1683-1693. https://doi.org/10.1016/j.mex.2019.07.013
52. Saric-Bosanac, S. S., Clark, A. K., Nguyen, V., Pan, A., Chang, F.Y., Li, C.S., and R.K. Sivamani (2019) Quantification of ultraviolet (UV) radiation in the shade and in direct sunlight. *Dermatol. Online. J*. **25**, 13030. https://doi.org/10.5070/D3257044801
53. McMichael, J. R., Veledar, E., and S. C. Chen (2013) UV radiation protection by handheld umbrellas. *JAMA Dermatol*. **149**, 757-758. https://doi.org/10.1001/jamadermatol.2013.2519
54. Wright, C. Y., Wilkes, M., du Plessis, J.L., and A. I. Reeder (2015) Self-reported skin colour and erythemal sensitivity versus objectively measured constitutive skin colour in an African population with predominantly dark skin. *Photodermatol Photoimmunol Photomed*. **31**, 315-324. https://doi.org/10.1111/phpp.12191
55. Diffey, B.L., Fajuyigbe, D., and C. Y. Wright (2019) Sunburn and sun protection in black skin. *Int. J. Dermatol*. **58**, 1053-1055. https://doi.org/10.1111/ijd.14402

56. Australian Radiation Protection and Nuclear Safety Agency. (2022) Ultraviolet Radiation Services. Available at https://www.arpansa.gov.au/ (Accessed 19 May 2022)
57. Gies, H. P., Roy, C. R. and A. McLennan (1996) Textiles and sun protection. In: Volkmer B, Heller H, eds. Environmental UV-Radiation, Risk of Skin Cancer and Primary Prevention Stuttgart: Gustav Fischer, 213 – 234. . Available at https://scholar.google.com/scholar_lookup?&title=Textiles%20and%20sun%20protection&pages=213-234&publication_year=1996&author=Gies%2CHP&author=Roy%2CCR&author=Mclennan%2CA (Accessed 19 May 2022)
58. C. M. H. Driscoll (2000) Clothing protection factors. Radiological Protection Bulletin Chilton: National Radiological Protection Board, 222. Available at https://scholar.google.com/scholar_lookup?&title=Clothing%20protection%20factors.%20Radiological%20Protection%20Bulletin%2C%20Chilton&publication_year=2000&author=Driscoll%2CCMH (Accessed 19 May 2022)
59. Linde, K., Wright, C. Y., Kapwata, T., and J. L. du Plessis (2021) Low Use of Ocular Sun Protection among Agricultural Workers in South Africa: Need for Further Research. *Photochem Photobiol*. **97**, 453-455. https://doi.org/10.1111/php.13388
60. Wright, C. Y., Reeder, A. I., and P. N. Albers (2016) Knowledge and practice of sun protection in schools in South Africa where no national sun protection programme exists. *Health Educ. Res*. **31**, 247-259. https://doi.org/10.1093/her/cyw005
61. South African Bureau of Standards. South African National Standard SANS 1557:2019 Sunscreen Products. Available at https://ctfa.co.za/wp-content/uploads/2020/06/SANS1557_2019_Ed4.pdf (Accessed 9 July 2022)
62. Iannacone, M. R., Hughes, M.C., and A. C. Green (2014) Effects of sunscreen on skin cancer and photoaging. *Photodermatol Photoimmunol Photomed*. **30**, 55-61. https://doi.org/10.1111/phpp.12109
63. Green, A. C., Williams, G. M., Logan, V., and G. M. Strutton (2011) Reduced melanoma after regular sunscreen use: randomized trial follow-up. *J. Clin. Oncol*. **29**, 257–263. https://doi.org/10.1200/JCO.2010.28.7078
64. Manovich, D., Vogel, R. I., Berwick, M., Weinstock, M.A., Warshaw, E.M., and K. E. Anderson (2011) Melanoma risk in relation to use of sunscreen or other sun protection

methods. *Cancer Epidemiol. Biomarkers Prev.* **20**, 2583-2593. https://doi.org/10.1158/1055-9965

65. Ulrich, C., Jürgensen, J., Degen, A., Hackethal, M., Ulrich, M., Patel, M., Eberle, J., Terhorst, D., Sterry, W. and E. Stockfleth, E (2009) Prevention of non-melanoma skin cancer in organ transplant patients by regular use of a sunscreen: a 24-months, prospective, case–control study. *Br. J. Dermatol*. **161**, 78-84. https://doi.org/10.1111/j.1365-2133.2009.09453.x
66. Neale, R., Williams, G., and A. Green (2002) Application patterns among participants randomized to daily sunscreen use in a skin cancer prevention trial. *Arch. Dermatol*. **138**, 1319-1325. https://doi.org/10.1001/archderm.138.10.1319
67. R.P. Gallagher (2005) Sunscreens in melanoma and skin cancer prevention. *CMAJ*. **173**, 244-245. https://doi.org/10.1503/cmaj.050762
68. Gordon, L. G., Elliott, T. M., Wright. C. Y., Deghaye, N., and W. Visser (2016) Modelling the healthcare costs of skin cancer in South Africa. *BMC Health Serv. Res*. **16**, 113. https://doi.org/10.1186/s12913-016-1364-z
69. B.L. Diffey (1996) Sunscreens, suntans and skin cancer: People do not apply enough sunscreen for protection. *Br. Med. J*. **313**, 942.
70. Lund, P. M. and J. S. Taylor (2008) Lack of adequate sun protection for children with oculocutaneous albinism in South Africa. *BMC Public Health*. **8**, 225–233. https://doi.org/10.1186/1471-2458-8-225
71. Dlova, N.C., Gathers, R. and Tsoka-Gwegweni, J., Hift R.J. (2017) Skin cancer awareness and sunscreen use among outpatients of a South African hospital: need for vigorous public education. *S. Afr. Fam. Prac*. **40**, 132-136. https://doi.org/10.1080/20786190.2018.1426900
72. Dlova, N. C., Nevondo, F. T., Mwangi, E. M., Summers, B., Tsoka-Gwegweni, J., Martincigh, B.S., and D. A. Mulholland (2013) Chemical analysis of in vitro UV-protection characteristics of clays traditionally used for sun protection in South Africa, *Photodermatol. Photoimmunol. Photomed.* **29**, 164–169. https://doi.org/10.1111/phpp.12042
73. Rifkin, R. F., Dayet, L., Queffelec, A., Summers, B., Lategan, M., and F. d'Errico (2015) Evaluating the Photoprotective Effects of Ochre on Human Skin by In Vivo SPF

Assessment: Implications for Human Evolution, Adaptation and Dispersal. *PLoS One*. **10**, e0136090. https://doi.org/10.1371/journal.pone.0136090

74. Lund, P. M. and R. Gaigher (2002) A health intervention programme for children with albinism at a special school in South Africa. *Health Educ. Res*. **17**, 365–372. https://doi.org/10.1093/her/17.3.365
75. Wright, C. Y., Norval, M., and R. W. Hertle (2015) Oculocutaneous albinism in sub-Saharan Africa: adverse sun-associated health effects and photoprotection. *Photochem. Photobiol*. **91**, 27-32. https://doi.org/10.1111/php.12359
76. Nkogatse, M. M., Ramotsehoa, M. C., Eloff, F. C., and C. Y. Wright (2019) Solar Ultraviolet Radiation Exposure and Sun Protection Behaviors and Knowledge Among a High-Risk and Overlooked Group of Outdoor Workers in South Africa. *Photochem. Photobiol*. **95**, 439-445. https://doi.org/10.1111/php.13008
77. Wright, C.Y., Reddy, T., Mathee, A., and R. A. Street (2017) Sun Exposure, Sun-Related Symptoms, and Sun Protection Practices in an African Informal Traditional Medicines Market. *Int. J. Environ. Res. Public Health*. **14**,1142. https://doi.org/10.3390/ijerph14101142
78. Rother, H. A., John, J., Wright, C. Y., Irlam, J., Oosthuizen, M. A. and R. M. Garland (2019) Perceptions of occupational heat, sun exposure and health risk prevention: a qualitative study of forestry workers in South Africa. *Atmosphere*. **11**, 37. https://doi.org/10.3390/atmos11010037
79. M. Wittlich (2022) Criteria for Occupational Health Prevention for Solar UVR Exposed Outdoor Workers-Prevalence, Affected Parties, and Occupational Disease *Front. Public Health*, 9. https://doi.org/10.3389/fpubh.2021.772290
80. Gilaberte, Y., Trullàs, C., Granger, C., and M. de Troya-Martín (2022) Photoprotection in Outdoor Sports: A Review of the Literature and Recommendations to Reduce Risk Among Athletes. *Dermatol. Therapy*. **12**, 329–343. https://doi.org/10.1007/s13555-021-00671-0
81. Nurse, V., Wright C. Y., Allen, M. R. L. and R.L. McKenzie (2015) Solar ultraviolet radiation exposure of South African marathon runners during competition marathon runs and training sessions: a feasibility study. *Photochem. Photobiol.* **91**, 971-979. https://doi.org/10.1111/php.12461

82. Engelbrecht, F., Adegoke, J., Bopape, M. – J., Naidoo, M., Garland, R., Thatcher, M., McGregor, J., Katzfey, J., Werner, M., Ichoku, C., and C. Gatebe (2015) Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environ. Res. Lett.* **10**, 1-16. https://doi.org/10.1088/1748-9326/10/8/085004
83. Statistics South Africa (2022) General household survey 2019. Available at https://www.statssa.gov.za/?page_id=1856&PPN=P0318&SCH=72766 (Accessed 19 May 2022)
84. Fajuyigbe, D., Douki, T., van Dijk, A., Sarkany, R. P. E., and A. R. Young. (2021) Dark cyclobutane pyrimidine dimers are formed in the epidermis of Fitzpatrick skin types I/II and VI in vivo after exposure to solar-simulated radiation. *Pigment. Cell. Melanoma Res*. **34**, 575-584. https://doi/org/10.1111/pcmr.12956
85. Tsai, J., and A. L. Chien (2022) Photoprotection for Skin of Color. *Am. J. Clin. Dermatol*. **23**, 195-205. https://doi.org/10.1007/s40257-021-00670-z
86. Stats SA. (2021) Quarterly Labour Force Survey (QLFS) – Q3:2021. Available at https://www.statssa.gov.za/?p=14957#:~:text=The%20official%20unemployment%20rate%20was,2021%20to%2014%2C3%20million (Accessed 10 July 2022)
87. Statistics.com (2020) Number of people living in extreme poverty in South Africa from 2016 to 2025. Available at https://www.statista.com/statistics/1263290/number-of-people-living-in-extreme-poverty-in-south-africa/#:~:text=As%20of%202020%2C%20around%2016.31,increase%20in%20the%20coming%20years (Accessed 10 July 2022)
88. DHET. (2021) The Highest level of education attainment in South Africa. Available at https://www.dhet.gov.za/Planning%20Monitoring%20and%20Evaluation%20Coordination/Fact%20Sheet%20on%20the%20Highest%20Level%20of%20Education%20Attainment%20in%20South%20Africa%20-%20March%202021.pdf (Accessed 10 July 2022)