A study on the creation of a UV distribution map using high-resolution satellite images and behavior change

Teppei Ishiuchi (Faculty of Project Design, Miyagi University, ishiuchit@myu.ac.jp, Japan)

高分解能衛星画像を用いた紫外線分布図の作成および行動変容に関する研究

石内 鉄平（宮城大学 事業構想学群）

要約

地球規模で起こる環境問題の一つとして、オゾン層が減少することによる有害な紫外線の増加、それに伴う皮膚ガンや白内障の増加といった生態系への影響が懸念されている。世界保健機構（WHO）でも前述の問題は危険視されており、日本では環境省）や国立環境研究所のほか、気象庁が紫外線に対する取組みを行っている。特に、気象庁では2005年5月以降、UVインデックス指標を用いた紫外線予測分布図を作成してインターネットによる情報提供を開始したが、提供されている紫外線予測分布図は約20 km四方の大雑把なメッシュによる表示であり、ローカルな地域に着目した場合、その地域における詳細な紫外線量は十分に把握できていないのが現状である。そこで本研究では、土地被覆ごとの紫外線反射率を計測するとともに、樹木や構造物といった直射日光を遮る空間構成要素を加味した地上到達紫外線量の割合を算出する式を提案した。加えて、この算出式と高分解能衛星画像を併用することで、気象庁が提供する紫外線予測分布図と比較してより詳細な地上到達紫外線マップの作成方法を提案した。また、地域住民を対象としたアンケート調査を実施した結果、回答者の約8割が紫外線に関心を持っていることがわかった。さらに、回答者の約6割は本研究で作成された詳細な紫外線マップを評価しており、普段の行動パタンを変えるために最も利用される可能性を見出した。

Key words

ultraviolet radiation, outdoor space, land cover, questionnaire survey, behavior change

1. Introduction

Environmental problems that are occurring on a global scale include an increasing amount of harmful ultraviolet (UV) radiation reaching the ground due to depletion of the ozone layer, raising concerns about the effects on ecosystems and increased incidence of skin cancer and cataracts (Japan Fluorocarbon, 2001). The World Health Organization (WHO) released the Global solar UV index: A practical guide in March 2023 and sees it as dangerous (World Health Organization, 2002). The Ministry of the Environment of Japan (Ministry of the Environment, 2020), Japan's National Institute for Environmental Studies (National Institute, 2000), and the Japan Meteorological Agency (JMA) are working on measures to counteract the effects of UV radiation. In May 2005, the Japan Meteorological Agency started to provide information on the UV index via the internet by creating maps of forecasted UV radiation distribution (a UV Index Forecast). However, the data is provided in a course mesh with horizontal resolution 20 km that lacks local details. Figure 1 shows a UV prediction distribution map provided by the Japan Meteorological Agency (Japan Meteorological, 2021).

In existing research, there is a paper that measured the amount of ultraviolet rays on an inclined surface and a vertical surface against ultraviolet rays in an outdoor space (Tomisaka, 2000). Furthermore, studies on the relationship between the amount of solar radiation and the number of ultraviolet rays, and the effects of ultraviolet rays on the body and weather classification have been reported (Tarumi & Shin, 2004). In addition, although there are research cases that discuss the difference in the amount of ultraviolet rays focusing on outdoor spaces, the survey points are limited to observations at each point in the space in front of the station, seaside, parks and green areas (Ishiuchi, Koyanagi, & Kuwahra, 2012).

Furthermore, although there are examples of mapping ultraviolet radiation on the earth's surface using satellite images, they cover a wide area and do not target the local amount of ultravio-

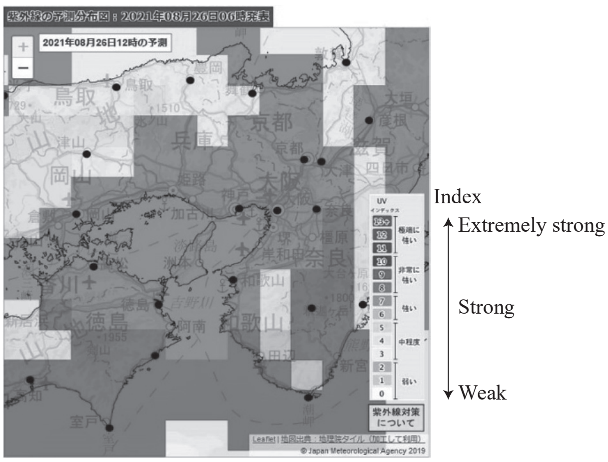


Figure 1: UV prediction distribution map provided by the Japan Meteorological Agency (Published on August 26, 2021)

let radiation on the earth's surface (Lubin & Jensen, 1997).

Therefore, this study focuses on structural elements such as the reflectance of the ground surface, arrangement of trees and structures, and land cover conditions. Simultaneous multi-point observation using a simple UV measurement device was carried out on the premises of Akashi Institute of Technology and public spaces such as the coast and squares in Akashi City. The purpose of this study is to quantitatively understand the difference in the amount of ultraviolet rays received by humans due to the difference in the reflectance of the ground surface, divided into the reflection from the land cover and the direct radiation from the sky. As a result, this study aims to create a more detailed UV distribution map compared to the UV index forecast by the Japan Meteorological Agency.

2. Creating a formula for calculating the amount of UV rays

2.1 Understanding UV reflectance due to differences in land cover

In general, ultraviolet rays are classified by the Japan Meteorological Agency into A region (UV-A; wavelength 315-400 nm), B region (UV-B; wavelength 280-315 nm), and the degree of influence of ultraviolet rays. And, the degree of influence of ultraviolet rays on the human body differs depending on the wavelength. UV-C is absorbed by the atmospheric layer and does not reach the surface of the earth. Most of the UV-B, which is harmful to the skin and eyes, is absorbed by atmospheric layers (such as ozone), but some of it reaches the surface of the earth and causes sunburn and skin cancer. UV-A is not as harmful as UV-B, but there are concerns about the health effects of long-term exposure. It is mainly UV-B that causes health hazards such as skin cancer and cataracts, but from existing research, the correlation coefficient (R) of the daily cumulative amount of UV-A and UV-B is 0.966 ($R^2 = 0.934$, $n = 359$), indicating a very close relationship (Ueno & Matsumoto, 2009).

The readings obtained from a UV radiation sensor constantly fluctuate in response to any slight movement or sensor tilt. If an observer performs an observation while holding the sensor in their hands, the numerical value will be unstable, and the observer will also act as an obstacle that blocks the sunlight, also affecting the readings. Using an observation stand that can anchor the upper and lower sensors horizontally is needed to obtain reliable results. However, since no such observation stands are commercially available, the author of this paper decided to make an original stand. When creating an observation stand, the sensor should be attached as low as possible so as to be minimally affected by the diffuse reflection of UV light from the ground. The requirements for creating a sensor are that the sensor should be attached such that no shadow from the stand falls on the sensor area. The sensors should be attached at the top and bottom and held in a vertical position. After taking these requirements into consideration, this study made an observation stand using a desk lamp.

Table 1: Type of UV observation equipment

UV intensity meter	UVX Radiometer (Digital) 
Sensor	Radiometer senser UVX-36 365 nm
Measurement range	0-200 mW/cm^2
UV measurement wavelength	365 nm (UV-A)

In this study, two UV measuring instruments are used for one point to measure the UV reflectance of each land cover. Table 1 shows an overview of the UV observation equipment.

And, Table 2 shows an overview of the survey. In order to calculate the UV reflectance for each land cover, sand beaches, station squares, and city parks, assuming that these are spaces that people frequently use in their daily lives, were surveyed.

Table 2: Survey overview

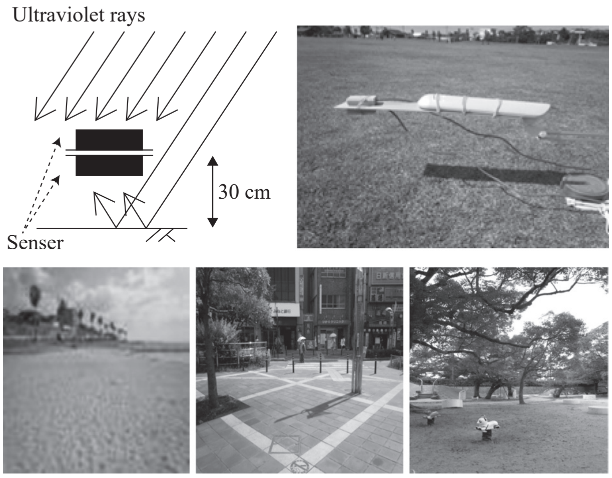
Date of survey	August 27, 2013
Observation time	9:00-16-00
Observation point	5 points in Akashi City, Hyogo Prefecture (the beach, station square, city park)
Weather condition	Highest temperature 31.5 °C Lowest temperature 26.1 °C
Number of observations	Simultaneous observation at 5 points A total of 45 data with 5 observations every hour
Observation method	Sensor position: 30 cm above the ground One direction sensor: upward/downward

Figure 2 shows an image of the observation and the scenery of the survey point. In addition, five typical land cover patterns in the above space are sand, concrete, asphalt, soil, and turf. The reflectance calculation formula obtained by measuring the UV reflectance for each land cover is shown in (1), and the calculated results are shown in Figure 3.

UV radiation reflectance (%)

$$= \frac{\text{Ultraviolet dose from downward sensor observations}}{\text{Ultraviolet dose from upward sensor observations}} \times 100 \qquad (1)$$

From the above, it was found that the reflectance of sand is about 11.9 %, followed by concrete, soil, and asphalt, and the lowest reflectance of turf is about 2.2 %.



Sandy beach Station square City park

Figure 2: The images of the observation and the scenery of the survey points

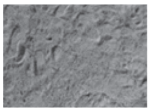
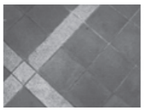
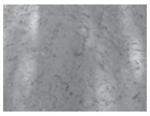
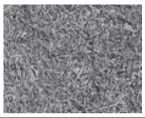
Land cover	Sand	Concrete	Asphalt
Photo image			
Reflectance	11.9 %	6.6 %	5.6 %
Land cover	Soil	Turf	
Photo image			
Reflectance	6.3 %	2.2 %	

Figure 3: UV reflectance per land cover

2.2 Reduction rate of UV dose due to presence of features

According to existing research, when the ultraviolet intensity of multiple points is observed simultaneously with the sensor of an ultraviolet observation device facing upward, differences in ultraviolet intensity occur between the blue sky and the shade caused by tall trees (Watanabe & Ishii, 2017). Also, the instrument used to calculate the UV reflectance (UVX Radiometer) does not have a logger function. However, existing studies have shown that there is a high correlation between the amount of solar radiation and the amount of ultraviolet rays UV-A and UV-B.

Table 3: Type of insolation observation equipment

	Tracing Radiation and Canopy Architecture (TRAC)
	Optical measurement recorder
	Uses optical sensor with 400-700 nm wavelength band
	Built-in 512 kByte data recording memory
	Automatic continuous recording of 32 data per second

Therefore, in this research, a solar radiation measurement device (TRAC) equipped with a logger function to measure the amount of ultraviolet rays reaching the ground when there is a feature that blocks the sunlight was used. Table 3 shows an overview of the solar radiation measurement equipment used in the survey.

Figure 4 shows a graph of the amount of solar radiation at the observation point along with photographs of the observation points in the open sky, roadside trees, and forest zone (inside a park). Table 4 shows the solar arrival rate beside various obstacles when open sky is set to 1.

2.3 Proposal of UV dose calculation formula

This study takes into consideration the difference in solar reflectance due to the presence or absence of features and the difference in solar reflectance due to land cover. The study proposes a formula for calculating the amount of ultraviolet rays that focuses on the difference in spatial configuration. Figure 5 shows an image diagram of each space configuration and the formula for calculating the amount of ultraviolet rays.

This time, the amount of ultraviolet rays, when the land cover is assumed to be turf, is calculated. From Figure 3, the UV reflectance of turf is 2.2 %.

(1) Open sky condition:
$100 \times 1.00 + (100 \times 0.022) = 102.2$

(2) Roadside tree:
$100 \times 0.32 + (32 \times 0.022) = 32.7$

(3) Forest zone (trees):
$100 \times 0.21 + (21 \times 0.022) = 21.5$

Table 4: Sunlight arrival rate due to differences in obstacles

		Amount of solar radiation (μmol/s・m^2)	Number of observed data	Solar radiation arrival rate with and without shade
				shadows cast by features/ open sky condition
Open sky condition		995.0	–	1.00
Shadow status	Roadside trees	318.4	736	0.32
	Forest zone	209.0	2976	0.21
	Buildings	268.7	1696	0.27

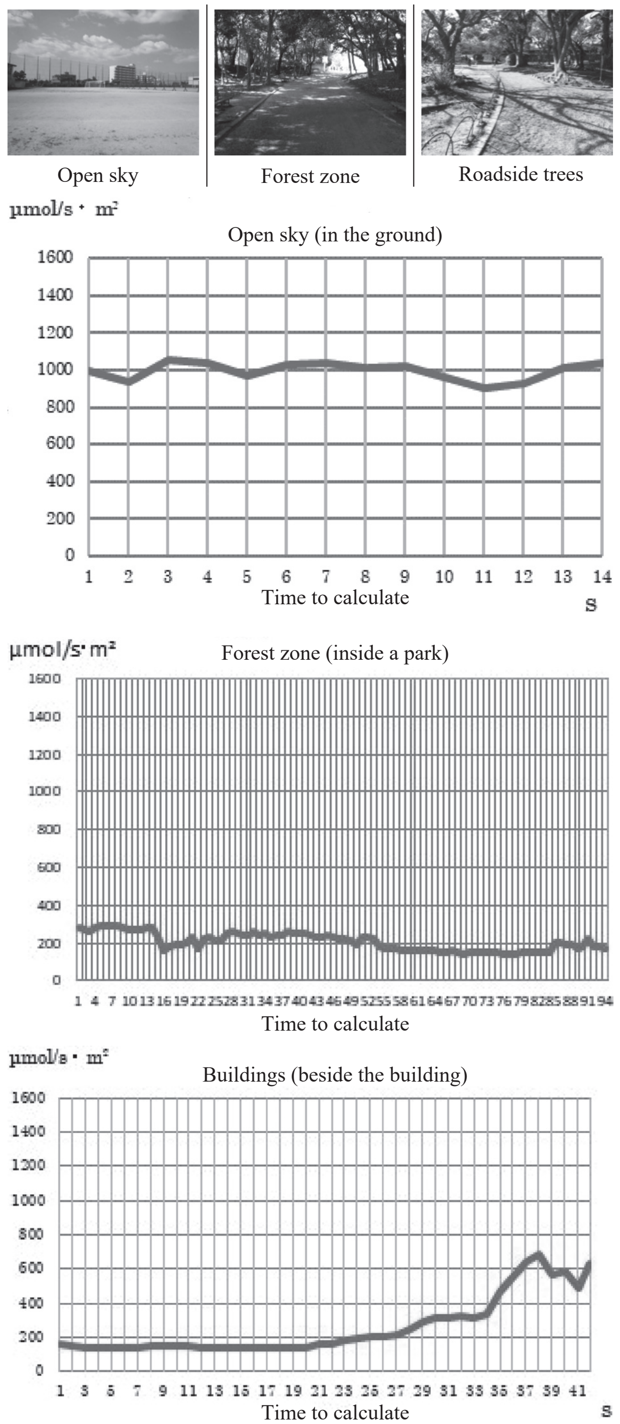


Figure 4: Amount of solar radiation at the observation point

(4) Buildings (beside the building)
100 × 0.27 + (27 × 0.022) = 27.6

Table 5 shows the UV dose obtained from the formula in Figure 5 using the five land covers (Figure 3) treated in this study and the combination pattern of the spatial configuration shown in Table 4. As a result, it was found that there is a large difference in the amount of ultraviolet rays that people are exposed to in open sky conditions and in places where shadows are generated by some features.

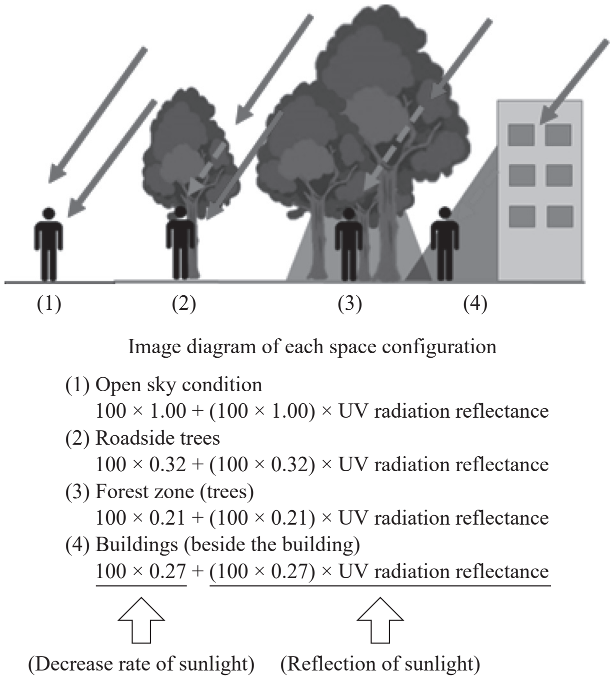


Figure 5: Ultraviolet ray amount calculation formula

Table 5: UV dose considering direct and reflected light

Upper air condition	Land cover	Amount of UV radiation
Open sky (sports ground)	Sand	111.9
	Concrete	106.6
	Soil	106.3
	Asphalt	105.6
	Turf	102.2
Roadside trees	Sand	35.8
	Concrete	34.1
	Soil	34.0
	Asphalt	33.8
	Turf	32.7
Buildings (beside the building)	Sand	30.2
	Concrete	28.8
	Soil	28.7
	Asphalt	28.5
	Turf	27.6
Forest zone (trees)	Sand	23.5
	Concrete	22.4
	Soil	22.3
	Asphalt	22.2
	Turf	21.5

3. Proposal of detailed UV distribution maps using satellite images

3.1 Creation of land cover classification maps using satellite images

This study performed supervised classification for the purpose of creating a land cover classification map using satellite images of GeoEye-1, a high-resolution satellite, in order to create detailed UV distributions. Supervised classification is a classification method that selects land cover that can be confirmed from satellite images as a training sample, conducts field checks, and then color-codes the portions with the same wavelength as the wavelength in the selected sample. In addition, ponds and roofs are similarly selected as samples because they need to be excluded later from the image in order to create an ultraviolet distribution map.

Table 6 shows an overview of the satellite images used in this study. And, Figure 6 shows the true color image of GeoEye-1 and the result of land cover classification.

Table 6: Overview of the satellite images

Satellite image capturing area		Akashi City, Hyogo Prefecture
Satellite		GeoEye-1 (11 bit)
Shooting date		March 19, 2010
Ground resolution（GSD）		0.41 m (50 cm)
Wavelength range band）	Blue	450-510 nm
	Green	510-580 nm
	Red	655-690 nm
	Near infrared	780-920 nm
Analysis software		ArcGIS Special Analyst

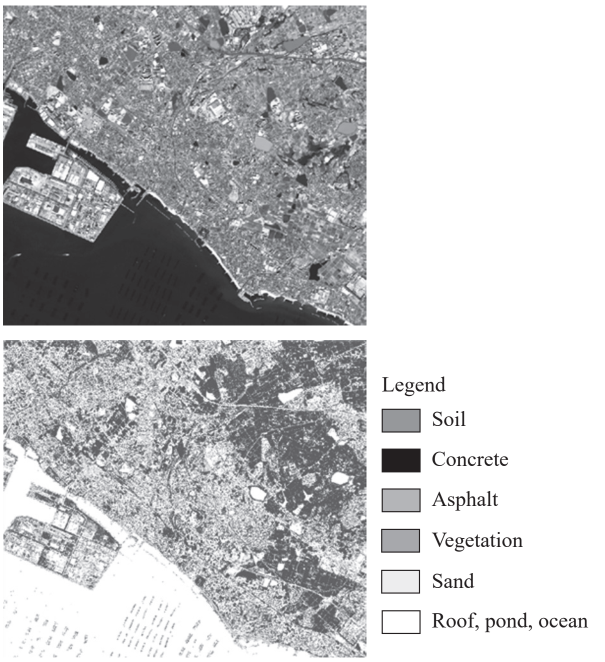


Figure 6: True color image of GeoEye-1 and the result of land cover classification

3.2 Method of locating trees and turf

Land cover classification using satellite images can classify vegetation, however it is difficult to distinguish between tall

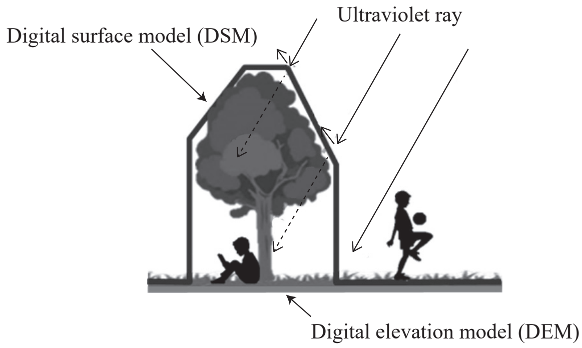


Figure 7: Digital surface model and digital elevation model

trees and turf. In this study, height information of features that block sunlight is very important, and discrimination between trees and grass is essential. Therefore, this research uses a digital surface model and a digital elevation model to distinguish between trees and lawns. Figure 7 shows a conceptual diagram of the digital surface model and the digital elevation model.

Figure 8 shows the survey area for the land cover classification map shown in Figure 6. And, Figure 9 shows the digital surface model (DSM) and digital elevation model (DEM) of the survey area.

The creation of a digital surface model utilizes the principle that the human eye can see objects in three dimensions. By preparing images obtained by observing an object from different positions and arranging the stereo images by reproducing the position and inclination of the center of projection at the time of observation, a stereoscopic image can be obtained at the points where they intersect each other. A three-dimensional model is created from the overlapping photographic images taken, making it possible to grasp the shape of trees and buildings. On the other hand, a digital elevation model is a ground surface model created by filtering the height of buildings and trees to remove the heights of ordinary maps. By performing a raster operation that takes the difference between the digital surface model and

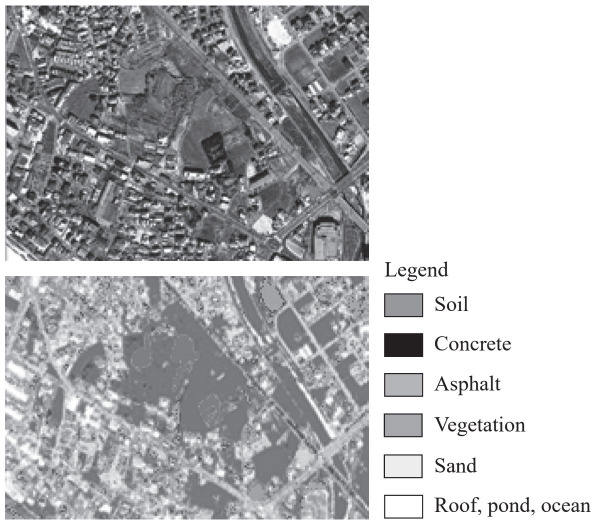
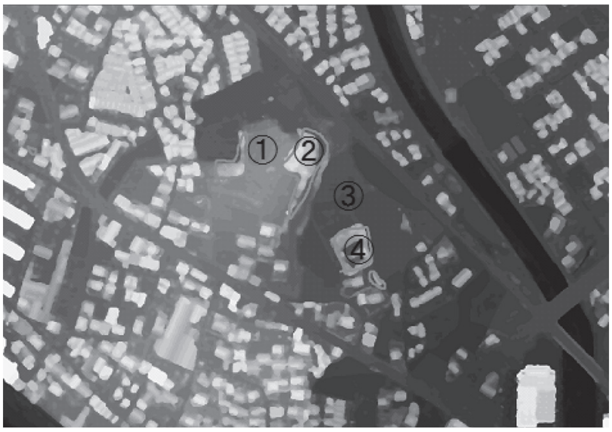
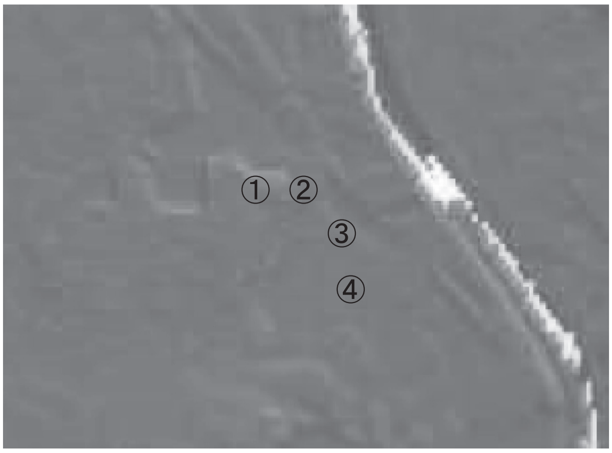


Figure 8: The survey area for the land cover classification map



Digital surface model (DSM)



Digital elevation model (DEM)

Figure 9: Digital surface model and digital elevation model

the digital elevation model, it is possible to distinguish between fields and trees even in the vegetation, and to consider shadows caused by trees.

As a result of this study, it was confirmed that the amount of solar radiation reaching the ground was reduced by approximately 79% compared to open sky conditions in areas with many trees in the park. Therefore, this study extracts the tree part from the vegetation area and classifies it as tree shade from the land cover classification result of the satellite image. According to existing literature, tall trees are defined as having a height of 3m or more, so in this study, areas where the difference between DSM and DEM is 3m or more are extracted as areas with dense trees.

Therefore, an area where “DSM-DEM ≧ 3 m” extract. Next, attention is paid to ① to ④ in Figure 9 as an example. ① to ④ in Figure 9 are all classified as vegetation from Figure 8. However, the results of calculating the “DSM-DEM” for ① to ④ are shown below.

① 11.0 m – 10.5 m = 0.5 m
② 14.4 m – 10.5 m = 3.6 m
③ 6.5 m – 6.0 m = 0.5 m
④ 12.4 m – 6.0 m = 6.4 m

From the above, it was confirmed that it is possible to extract the presence or absence of trees by adding height data even if it is vegetation in the land using a classification map. Figure 10 shows the results. In Figure 10, as shown in Table 5, the open-sky spots where the amount of exposure to UV rays is significantly higher than others are shown in red color (the original image is in color, however, in this paper the image is black and white). In addition, when compared with Figure 8, vegetation areas where the difference between DSM and DEM is 3 m or more are shaded by trees, and part of the red color remains green, which is the original land cover classification map. This study proposed a method of creating a map of the amount of ultraviolet rays reaching the ground using high-resolution satellite images through the above process.

Figure 10: Ground-reaching ultraviolet ray map with height information of features

4. Evaluation of detailed UV distribution map by questionnaire survey

4.1 Questionnaire survey overview

This study conducted a questionnaire survey of citizens in a city for the purpose of surveying citizens’ awareness of ultraviolet rays and evaluating the detailed ultraviolet distribution map that was created. The survey items consisted mainly of respondents’ attributes, their interest in UV rays, and their evaluation of detailed UV distribution maps. Table 7 shows an overview of the survey.

4.2 Questionnaire survey results and considerations

Table 8 shows the gender of the respondents, and Table 9 shows the age of the respondents. From Table 9, it can be seen that this study received responses from people of all ages. Table 10 shows the degree of conscious about UV hazards, and Table 11 shows the degree of recognition of the UV forecast distribution map provided by the Japan Meteorological Agency.

From Table 10, it can be seen that about 80 % of people are conscious of UV rays, but from Table 11, this study shows that the awareness of the UV prediction distribution map published by the Japan Meteorological Agency is very low.

Table 7: Overview of survey

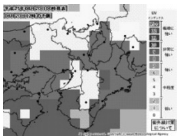
Date of survey	October 23 and 24, 2015	
Observation time	10:00-16:00	
Observation area	Outdoor space in Akashi City, Hyogo Prefecture	
Number of response	101 people	
Survey item	Gender, age groups	
	Degree of concern about UV hazards	
	Frequency of UV protection	
	Popularity of the Japan Meteorological Agency's UV information distribution map	
	Availability of more detailed UV map	
	How to use more detailed UV maps	

Table 8: Gender of respondents

	Number of respondents
Male	38
Female	63
Total	101

Table 9: Age groups

Age groups	Number of respondents	
10's	11	10.9 %
20's	13	12.9 %
30's	23	22.8 %
40's	14	13.9 %
50's	6	5.9 %
60's	11	10.9 %
70's	19	18.8 %
80's and above	4	4.0 %
Total	101	100.0 %

Table 10: Degree of conscious about UV hazards

	Number of respondents	Shares
Very conscious	29	28.7 %
Somewhat conscious	52	51.5 %
Neither	11	10.9 %
Not very conscious	6	5.9 %
Not conscious at all	3	3.0 %
Total	101	100.0 %

Table 12 shows the frequency of UV protection in daily life. From Table 12, it was found that the percentage of people who take measures against ultraviolet rays daily is high. This result seems to be related to the results of people's awareness of ultraviolet rays shown in Table 10.

Table 11: Recognition of UV forecast distribution map

	Number of respondents	Shares
Known	19	18.8 %
Unknown	82	81.2 %
Total	101	100.0 %

Table 12: Frequency of normal UV protection

	Number of respondents	Shares
Always taking measures	25	24.8 %
Sometimes deal with	41	40.6 %
Neither	5	5.0 %
Hardly dealt with	15	14.9 %
Not dealt with at all	15	14.9 %
Total	101	100.0 %

Table 13 shows the results of responses from 66 persons who answered that they always take measures against ultraviolet rays and sometimes take measures against ultraviolet rays in Table 12. In addition, Table 13 shows the result of enabling multiple selection. Table 13 shows that most of the people who take measures against UV rays in their daily life apply sunscreen cream, followed by those who wear hats. However, it was confirmed that the fewest people change their route to their destination.

Table 13: UV protection method

	Number of respondents	Shares ($N = 66$)
Use sunscreen cream	28	42.4 %
Wear a hat	27	40.9 %
Take advantage of the shade	23	34.8 %
Avoid going out during the day	18	27.3 %
Use a parasol	14	21.2 %
Put on sunglasses	12	18.2 %
Change route to destination	2	3.0 %
Others	1	1.5 %

And, Table 14 shows whether they are used when a detailed UV distribution map is provided. Therefore, based on the results of whether to use the detailed UV distribution shown in Table 14, Table 15 shows the possibilities of whether people might

Table 14: Availability of detailed UV distribution map

	Number of respondents	Shares
There is recognition	59	58.4 %
No recognition	42	41.6 %
Total	101	100.0 %

Table 15: Possibility of changing route selection using detailed UV distribution map

	Respondents who want to use		Respondents who do not wish to use		Total	
Always change behavior	4	6.8 %	1	2.4 %	5	5.0 %
Change behavior from time to time	26	44.1 %	8	19.0 %	34	33.7 %
Neither	9	15.3 %	5	11.9 %	14	13.9 %
Doesn't change behavior much	10	16.9 %	9	21.4 %	19	18.8 %
Never change behavior	10	16.9 %	19	45.2 %	29	28.7 %
Total of respondents	59	100.0 %	42	100.0 %	101	100.0 %

want to use it for route selection. From Table 15, it was found that about half of the respondents who wish to use the detailed UV distribution are thinking about using it for route selection.

5. Conclusion

This study grasped the amount of ultraviolet rays reaching the ground, which varies depending on the open sky, the presence or absence of trees and buildings, and calculated the ultraviolet reflectance for each land cover. In addition, the locations of trees and buildings were identified from the land cover classification map using satellite images and the difference between DSM and DEM. As a result of this research, a method for producing a detailed UV map reaching the ground was proposed.

And, by investigating attitudes towards UV radiation from a questionnaire survey, this study found that there were about 80% of respondents who were concerned about UV radiation, and that these respondents were using various methods to cut UV radiation in their daily lives. In addition, they found that the most promising use for a detailed UV map, if it is available, is the possibility of using it primarily to select routes to destinations.

As a future subject of this study, the amount of ultraviolet rays varies depending on the season and time of day, so the degree of danger of ultraviolet rays also changes accordingly. Therefore, since the shade changes, it is necessary to create an ultraviolet distribution map that can deal with these changes.

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