RESULTS OF PV RESOURCE SURVEY FOR WORLD 6 DESERTS BY A MODIFIED REMOTE SENSING APPROACH

Koichiro Sakakibara, Masakazu Ito and Kosuke Kurokawa
Tokyo University of Agriculture and Technology, 2-24-16 Naka-cho, Koganei, Tokyo 184-8588, JAPAN
Phone:+81-42-388-7445, FAX: +81-42-385-7445, E-mail: sanbara@cc.tuat.ac.jp

ABSTRACT

Recently, very large-scale photovoltaic generation (VLS-PV) system has been studied in order to resolve the world energy problems. From a point that the desert has a strong solar irradiation and a large unused land, the desert is so much the better for VLS-PV system. This study has defined conditions for suitable land for installing VLS-PV as part of a project of VLS-PV system. Basic requirements for the land selection are considered that surface must be flat, rigid and covered with small stone. This work has indicated a detail classification algorithm to find a suitable area by using remote sensing approach. The six world deserts have been researched. In addition, a part of the estimated results have been modified and evaluated by actual ground truth operation. It is concluded that the six major world deserts have a large potential of a resource for VLS-PV system and the proposed method can provide sufficient information for the planning of VLS-PV system installations.

INTRODUCTION

The healthy global environment is changing tremendously. The energy demand in the world is continuing to increase with the economic growth in the world, and the increase in population. In addition, various environmental problems, such as global warming, desertification, and acid-rain issue will also increase in connection with it. On the basis of such background, large-scale photovoltaic generation system (VLS-PV system) has been treated as an important solution. And VLS-PV system can provide a source of megawatt-class electricity. In order to solve the energy problems, a planning of large-scale PV system installed in a desert has been studied. Irradiation in a desert is very strong, it is a suitable land area for large-scale PV system. Therefore former project has been thought that play an important role in a future energy source. However very unstable areas like a sand dune, water basin, and mountain are not suitable for installation of PV system. The area which is suitable for PV system is not a sand desert but a rock desert. The rock desert consists of flat, arid and covered with small stone. Consequently, estimation for suitable land is needed. In this work, the six major world deserts have been researched and evaluated. Authors investigated these deserts by analyzing satellite images taken by JERS-1 and LANDSAT-7. The Gobi desert has been investigated by high resolution JERS-1 image and middle resolution LANDSAT-7 image. All the other deserts have been investigated by only LANDSAT-7. In addition, Authors developed the method of selecting the land where a VLS-PV system can be installed. And the potential of a resource for VLS-PV system is presented.

SUBJECT AREA AND REMOTE SENSING

Subject deserts have been located in the Gobi, Sahara, Negev, Sonora, Thar, and Great Sandy desert (six major world deserts). It is necessary to investigate in detail because these deserts have many types of land surface. These deserts are composed of not only stone area but also sand dune, water basin and mountain area. Additionally, the features of land surface are different by every desert. In specially, the categories of soil differ according to the location. Forest zone and removing area such as a sand dune zone is not most suitable zone, it is the priority matter of this study. Authors decided to analyze the JERS-1 image and LANDSAT-7 image. Although the JERS-1 image is known as high resolution satellite, it is difficult to get an all images of these deserts. For only Gobi desert, it was possible to get a JERS-1 image, therefore, the Gobi desert has been investigated with both the images of JERS-1 and LANDSAT-7. All the other deserts have been investigated with the image from LANDSAT-7. Incidentally, the great amount of images give an advantage on LANDSAT-7 image.

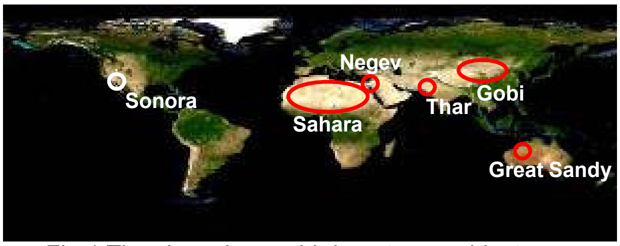


Fig.1 The six major world deserts as subject area

Table.1 Main Characteristics of satellite images

	JERS-1	LANDSAT-7
Analyzed image	Band 1,2,3	Band 2,3,4
Resolution	18.3m×24.2m	30.0m×30.0m
Swath Width	75km	180km
Subject desert	Gobi	Gobi, Sahara, Negev, Sonora, Thar, Great Sandy

VEGETATION INDEX

At first, a Modified Soil Adjusted Vegetation Index (MSAVI) is calculated in order to investigate the vegetation level. MSAVI was analyzed by using reflectance values from two channels (NIR:860nm, RED:672nm). The MSAVI comprises the density and the quantity of vegetation. In more depth, when the vegetation covers in low density, normally the soil reflectance increases in both the red and infrared channels. To describe more adequately this soil-vegetation system, other indices are proposed. To minimize the effect of bare soil, the Modified Soil Adjusted Vegetation Index was developed by Qi et al [2]. The authors extracted various images as training data based on results which were previously investigated in detail by Michael et al[3]. According to these training dataset, the three types of suitable vegetation level were decided. These suitable vegetation levels are shown in Fig.2. The vegetation levels are divided into six patterns, and the three types of suitable vegetation levels are decided as superior steppe line, inferior steppe line and desert line. The six major world deserts were classified by these threshold values.

However, there is a necessary care to be taken and problems encountered on applying MSAVI. The problems lie in seasonal changes in MSAVI by the difference in date of satellite images. In order to correct the defect, it is estimated that the seasonal changes in MSAVI based on Global 4-minute Advanced Very High Resolution Radiometer-Normalized Difference Vegetation Index(AVHRR-NDVI) Dataset. This dataset was already developed by the Center for Environmental Remote Sensing (CEReS). Based on this dataset, the seasonal changes in vegetation level are analyzed. This method is adapted to LANDSAT-7 image. The method which was adapted to JERS-1 was already developed in our previous paper[4]. Each seasonal change in vegetation level is shown in Fig.3. Although these vegetation lines are different, if we focus on desert line and inferior steppe line, these two threshold lines are not nearly fluctuations. Therefore, the superior steppe threshold line is only adapted as seasonal change in vegetation level.

$$MSAVI = \frac{2NIR + 1 - \sqrt{(2NIR+1)^2 - 8(NIR - RED)}}{2} \qquad (1)$$

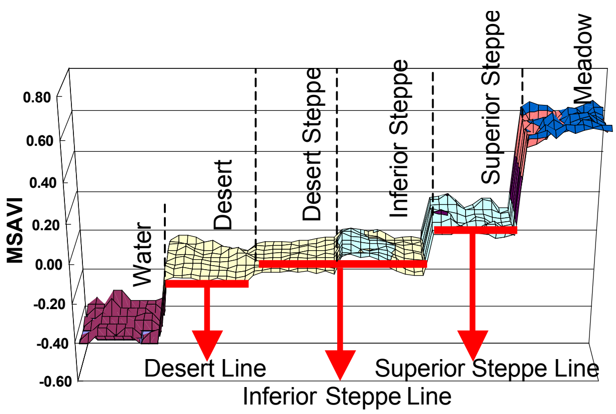


Fig.2 Suitable vegetation levels for VLS-PV system

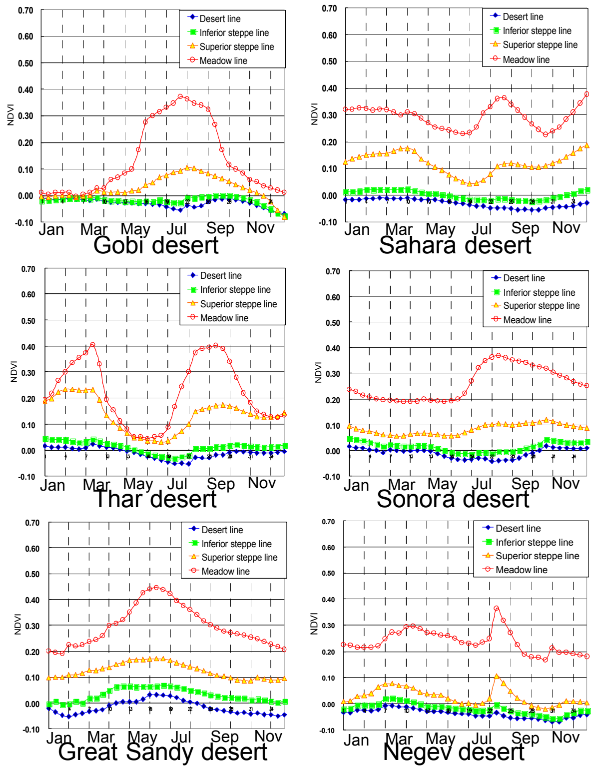


Fig.3 Each seasonal change in vegetation level

CLASSIFICATION OF THE SIX WORLD DESERTS

Secondly, the surfaces of the six major world deserts are classified into five patterns from satellite image according to Visual Evaluation Standard (VES) of Natural Color. The Natural Color image is a composed image with blue and red filters applied on in two visible bands and a green filter on in a near-infrared band. Forests and grasslands displayed in bright green and city areas, in magenta. It is different from actual color. At this point, five patterns are shown below.

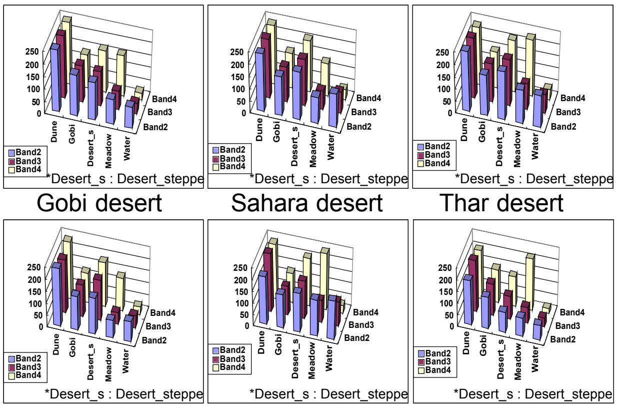
1 : Rock desert
2 : Dune　　　　　　4 : Meadow
3 : Desert steppe or steppe　　5 : Water

Authors classified surface of the six major world deserts into five patterns with the use of Maximum Likelihood Classifier (MLC). MLC is known as a classification technique.

$$L(x,c) = \frac{1}{(2\pi)^{K/2} \left|{}_cV\right|^{1/2}} \exp\left\{-\frac{1}{2} d^2{}_M(x,c)\right\} \qquad (2)$$

C : classification class
L(x,c) : likelihood
$d^2_M(x,c)$: Maharanobis distance
$_cV$: covariance matrix

Parameters of MLC are set up as reflection level of band2, band3 and band4 (Fig.4). These deserts classification by MLC played an importable role in excepting areas such as water basin and meadow. This classification provided an available area to analyze. This paper presents only parameters of the LANDSAT-7 image. The parameters of the JERS-1 have been already decided in our previous paper[4].



Gobi desert Sahara desert Thar desert

Sonora desert Great Sandy desert Negev desert

Fig.4 Parameters of MLC

EXTRACTION OF EDGE LINE BY FILTERING

Suitable areas for PV system installation must be a flat surface. Up and down hills are extracted with the use of Gaussian filter and Laplacian filter for band3. Up and down hills include a valley and trace of flood. In addition, the processed image was divided into white and black color by threshold level and morphology filter. The Morphology filter includes dilation and erosion. Threshold value is decided by the number of pixels from either end of histogram for processed images. Authors set the number of pixels at 6 percent of the all number of pixels. Edges exist in the area shown white as in Fig.5, and the area shown black indicates flat areas. And, Morphology filter is useful in solving above misclassification problem that is caused by relief shading. However, several problems arise along with these methods. Process of dilatation paints the circumference of the neighborhood where the edge line is extracted, but enlarges noise together. Process of constriction reduces noise, but reduces important information of ground level. This algorithm depends in good part on ground resolution, and the authors estimate that the ground resolution is higher, the more fine edge line can be extracted. The ground resolution that authors applied is approximately 30.0m. If this algorithm is applied to higher resolution images, it is considered that appreciation accuracy of up and down hills is improved dramatically. These generalizations must be evaluated with caution, lengthy and careful consider should be given to these countermeasures.

Band3 image Edge lines image Result of Dune

Fig.5 The results of edge lines extraction

A RESOURCE EVALUATION OF PV SYSTEM

According to these processes, estimation of the PV system installation for suitable land was evaluated by integrating with three processed images, i.e. the image which was presumed as suitable land by MSAVI, the image which was presumed as not suitable land by MLC, and the image which was suitable land by edge lines extraction. In this paper, the estimation results of LANDSAT-7 were only presented because the quantity of result was very large and it was necessary to present a latest result of LANDSAT-7. The area percentage of suitable land for JERS-1 image have been already estimated as 40 percent in our previous paper[4].

Authors have indicated three different analyzed results by three types of vegetation level. The area percentage of suitable land for each desert was shown in Table.2. From these results, in the each desert, suitable areas were scattered. The surface geometry of each desert was uneven. In particular, there were a large number of sand dune in the Sahara desert, and there were a large number of small stone covered area in the Gobi desert. It is able to forecast that PV system installation for suitable land is very large and have big potential possibilities of electric power generation.

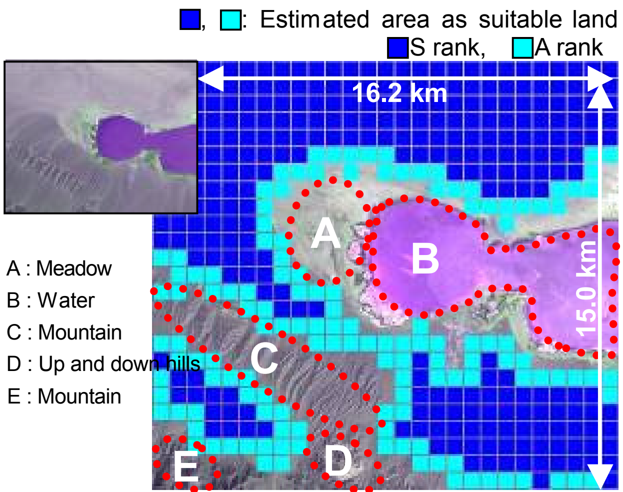


Fig.6 Estimated result in Sahara desert

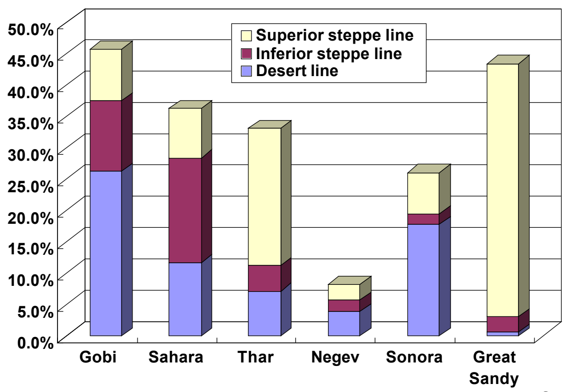


Fig.7 Estimated area percentage as suitable land for VLS-PV system by LANDSAT-7

Table.2 A resource potential of six major world deserts

	Desert line *1	Inferior steppe line *2	Superior steppe line *3	Total area (*1+*2+*3)	Total $10^3 \times km^2$
Gobi	26.3%	11.3%	8.2%	45.8%	595.4
Sahara	11.7%	16.8%	7.8%	36.3%	3121.8
Thar	7.2%	4.1%	21.8%	33.1%	66.2
Negev	3.9%	1.8%	2.5%	8.2%	0.1
Sonora	17.8%	1.6%	6.6%	26.1%	80.9
Great Sandy	0.6%	2.5%	40.4%	43.5%	174.0

ACTUAL GROUND TRUTH

Authors examined the accuracy of estimated results by actual ground truth. Ground truth operation compares estimated result with actual field examination by using a GPS receiver. Fig.8 shows the result of actual ground truth. This site is located in Tunisia. Line displays track of ground truth, and white points display actual field photograph as in Fig.8. Actually, the precise latitude and longitude were measured every second by GPS receiver. These photographs were taken on the run. Authors made a GPS-photograph dataset by using a measured data. In this dataset, each photograph was evaluated as S, A and B rank. At this point, "S, A and B rank" as standard of evaluation was shown below.

S rank --- Most suitable ground condition by reason of stable surface geometry.

A rank --- Although surface geometry is S rank, the up and down hills is visible to the eye well ahead.

B rank --- Most unbefitting ground surface by reason of rugged surface geometry

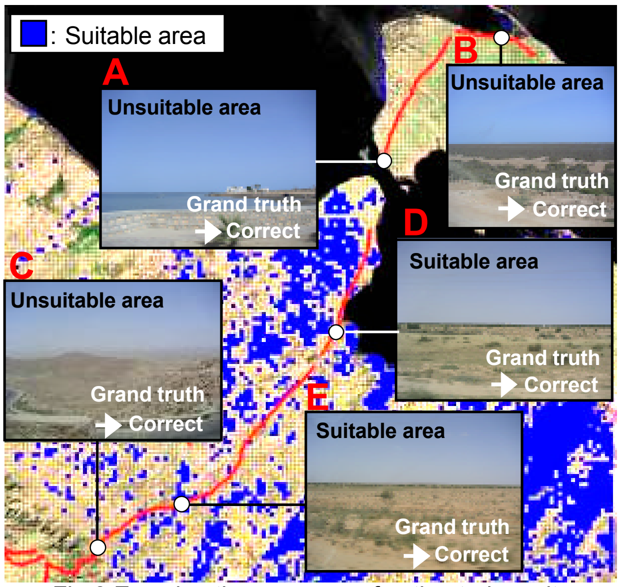


Fig.8 Examine the accuracy of estimated results

And, actual ground truth operation was done as in Fig.8. Actually, photograph number "D" evaluated as "S rank" indicated suitable area which was estimated by classification algorithm. Number "C" evaluated as "B rank" also indicated Unsuitable area. Therefore, sufficient results were obtained. However, although ground condition is evaluated as "S lank" in the actual field photograph, a point that is evaluated as unbefitting ground surface also existed. This is attributed to the fact that threshold level for extraction of suitable ground condition is tightly configured. If the threshold level for extraction of suitable ground condition is configured loosely, unbefitting ground surface is extracted as suitable ground condition. Moreover, the seasonal changes of NDVI made it difficult. Under such circumstances, it would appear that presumed accuracy drop to a lower value. From these point, it would appear that tighten threshold level is better than loose threshold level. Anyhow, it is necessary to investigate in detail. And additional ground truth is expected to develop an accuracy of estimation by increasing a number of GPS-photograph dataset.

CONCLUSION

The authors demonstrated an efficacy of technique for investigating the suitable area of PV system installations by using remote sensing. The six major world deserts have been investigated and evaluated in detail. The authors have developed an algorism by using a vegetation index, Maximum Likelihood Classifier method and edge line extraction method. These methods were adapted to the six world deserts. Each parameter of these algorism were decided every deserts. And, authors examined the accuracy of estimated results by actual ground truth. It is concluded that the proposed method can provide sufficient information for the planning of PV system installations. Additionally, a resource of solar photovoltaic generation system in these deserts has been evaluated as huge potential. However, the following points are left as future problems. One difficulty with this method is decision of the parameters by the deserts. In order to correct the defect, it is necessary to do actual ground truth moreover. Hereby, it is possible to make it better the accuracy of estimation algorism. The investigation on estimation of world deserts is summarized above and it is evident that more work using different approaches is necessary. At the end, the author would like to express his sincere gratitude to Mr. Amar, who provided related data.

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