DESERT PV RESOURCE ANALYSIS BY DETECTING SEASONAL CHANGES AMONG SATELLITE IMAGES

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ABSTRACT: Recently, a Very large scale photovoltaic power generation (VLS-PV) system has been studied in order to resolve the world energy and environment problems. A desert is very suited for VLS-PV system and has very large resource, because a desert has a lot of solar irradiation and a large unused land. However, it is very hard to install PV systems to all area, because a desert has various ground surfaces. Moreover, it is distant to make firsthand observations. Therefore, a remote sensing approach using satellite images was selected for detecting a suitable area easily from very large desert area. The vegetation level was analyzed more accuracy than the previous method by installing the yearly maximum NDVI. A resource of solar photovoltaic generation in Gobi deserts has been evaluated very large.
Keywords: Remote sensing, Satellite image, VLS-PV

1 INTRODUCTION

A Very large scale photovoltaic power generation (VLS-PV) system has been studied in order to resolve the world energy and environment problems in recent years. It's contemplated that a desert is very suited for VLS-PV system and has very large resource, because a desert has a lot of solar irradiation and a large unused land. For example, the resource of VLS-PV system in Gobi desert is as much amount as of world primary energy supply in theory. But, deserts have some area which is very hard for install the PV system. In this paper, it is defined that sand dune, mountain and oasis area were not suitable for PV system installation. Sand dune area is unsuitable for PV system, because it is unstable and PV modules may be covered with sand by sand storm. In addition, PV system should be constructed at the area without oasis, because, it is useful place for not only animals and plants but also human.

To calculate concrete resource of photovoltaic system in deserts is very useful for energy plan and installation plan of VLS-PV system. But, it is almost impossible to conduct a field survey at all area. Therefore, in this study, a remote sensing approach using satellite images was selected for finding a suitable area easily for the VLS-PV system from very large desert area. Sakakibara et al. [1] estimated the potentials of six major world deserts. However, the estimation didn't enough consider the disparity of the images acquisition date.

Purpose of this study is invention of the method which is able to estimate suitable area without dependency on the image acquisition date even if estimation area bestrides many images. Furthermore, the authors made the PV potential map in Gobi desert.

2 SATELITTE IMAGES AND SUBJECT AREA

2.1 Satellite images and subject area

LANDSAT-7 ETM+ (Enhanced Thematic Mapper Plus) images and Normalized Difference Vegetation Index (NDVI) dataset were used for this study. These images are available to download free.

LANDSAT-7 images which are 30m x 30m resolution are released at the website of the Global Land Cover Facility (GLCF)[2]. This database publishes one image per scene which are obtained about year 2000. That is to say, acquisition date and sensor setting of images are different. Therefore, authors converted from raw data by sensors to reflectance. This conversion uniformed images level between images. The expression is released at Landsat7 Science Data Users Handbooks[3]. The pixel values were doubled, because the value of reflection is very small.

The NDVI dataset are released at the website of the Center for Environmental Remote Sensing (CEReS)[4]. It is the Pathfinder global 10-day composite 8 km Global 4-minute Advanced Very High Resolution Radiometer (AVHRR) NDVI data. NDVI is one of the most famous evaluation approach of vegetation level. It is calculated from atmospherically corrected reflectance from the visible red (Red) and near infrared (IR):

$$\frac{(IR - Red)}{(IR + Red)} \qquad (1)$$

At AVHRR, Red is Ch1 in the reflective wavelengths (0.58-0.68 um) and IR is Ch2 in the reflective infrared wavelengths (0.725-1.1 um). One year data consist of 36 (= 3 x 12) 10 day composites data. The authors used five years data from 1995 to 1999.

A subject desert is Gobi desert in China and Mongolia. The desert has many types of land surfaces. The LANDSAT-7 images of 60 scenes were used for the analysis. The subject area is about 152 x 10^4 km^2.

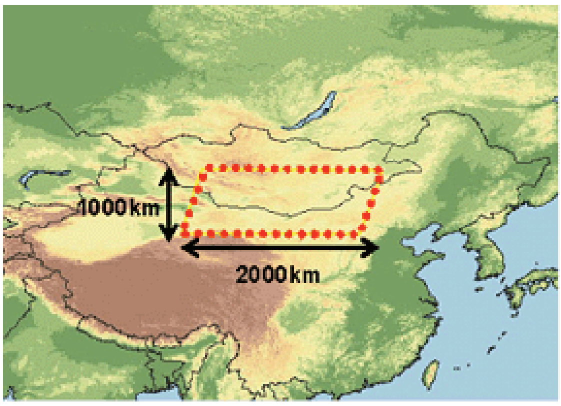


Figure 1: Analysis area in Gobi desert

2.2 Definition of potential area for PV system

Deserts are not all suitable area for installation of PV system. For example, a sand dune is the most unsuitable land, because it is easy to remove and PV modules are covered with sand by heavy sand storms. A precipitous mountains area is not suitable land, too. Moreover, an oasis in deserts does not have to construct PV system, since it is very valuable land in deserts. Therefore, in this paper, authors defined that the most suitable land is stable, flat and little vegetation area as stony desert. In some case, a steppe vegetation land is possible to set up for PV system.

3 ANALYSIS METHOD

An analysis method consists of three layers; ground surface classification by Most Likelihood Classifier (MLC), extraction of edge line, and vegetation analysis. The method provided a detail estimation result by uniforming LANDSAT-7 images level to reflection and detecting seasonal differences among satellite images.

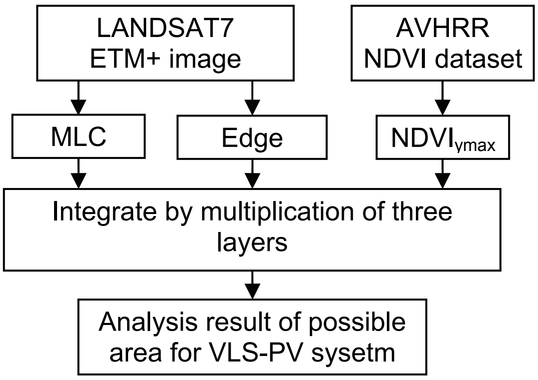


Figure 2: Flow chart of the analysis method

3.1 Classification by MLC

At first, authors classified the ground surface of Gobi desert into major five types by MLC. MLC is one of the most famous classification methods for remote sensing.

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

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

The five classes are shown below. Authors thought that the Stony desert and Steppe classes are able to install PV system. Three bands data of Ch2 of green (0.52-0.60 um), Ch3 of red (0.63-0.69 um) and Ch4 of near infrared (0.76-0.90 um) were chosen as parameters of MLC.

- Stony desert
- Sand dune
- Steppe
- Forest
- Water

Training data of MLC are chosen 10 points of 100 pixels x 100 pixels per class. It is shown in Figure 3. A result of MLC in a test site is shown in Figure 4. The classified area was painted black and others area were painted white. The subject area are around a lake in north with an area of 60 km x 45 km.

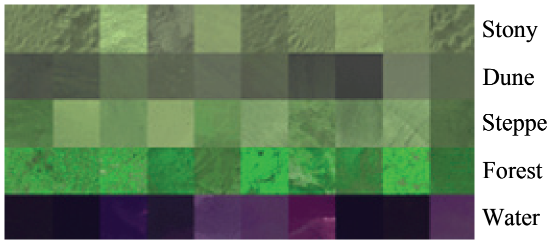
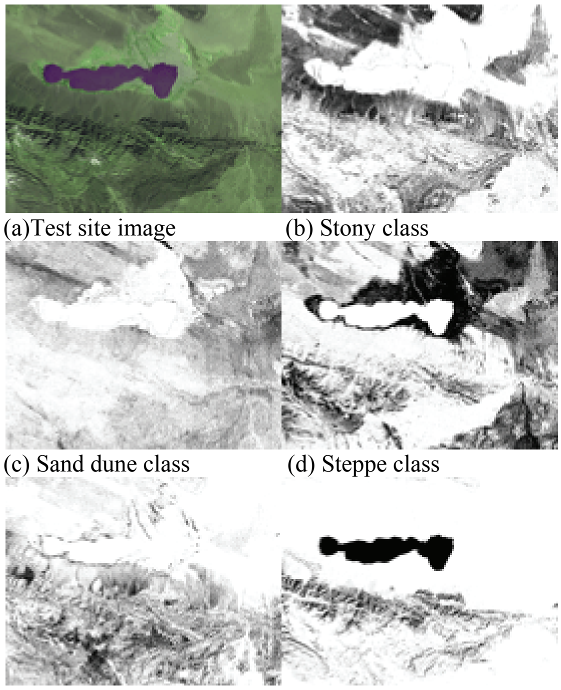


Figure 3: Training data of MLC



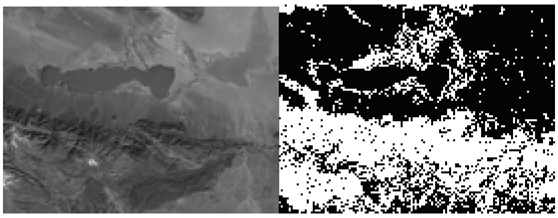
(a)Test site image (b) Stony class
(c) Sand dune class (d) Steppe class
(e) Forest class (f) Water class

Figure 4: Result of MLC at a test site

3.2 Extraction of edge line

The MLC is not able to identify the up and down land. It is able to find the unsuitable areas which are sand dune, mountainous area and flood mark. The up and down of terrain were extracted with the use of Gaussian filter and Laplacian filter for band3. Gaussian filter is used for smoothing of images. It is weighted by distance from the target pixel. Laphlacian filter is used for edge extraction. The window size of these filters is 3 pixels x 3 pixels. The filtering result images were divided to two levels of white and black by a threshold level. The threshold is changed by differential of a ground surface distribution if threshold number is set the number at the percentage to the all number of pixels in one image. Therefore, the authors decided one threshold. In addition, two levels image reduced noise by filtering of dilation and erosion.

A result of edge extraction is shown in Figure 5. The test site is same place of MLC. The rugged area was painted in white. The lower half of the image was extracted as up and down lands. The mountainous area was picked up finely by the effect of dilation and erosion operation. However, this method was extracted too much area. Some flat area by visual observation was estimated as rugged lands. It is most important future problem.



(a) Band2 of a test site (b) Result of edge extraction

Figure 5: Result of edge extraction

3.3 Vegetation analysis

The authors can not know the seasonal difference, since LANDSAT-7 images of GLCF are used only one image per scene. Arid area has very large variation width vegetation change. For example, even if the place was very dry, we can not estimate the ground condition in rainy season. Therefore, the authors used the NDVI dataset. It consists of yearly variation of vegetation. However, the resolution of this dataset is lower than one of LANDSAT-7. Though the original resolution of AVHRR is 1 km, the dataset was processed resampling to 4 minute (about 8 km). It is problem for detail analysis to use different resolution data. However, next two points were emphasized; one is that the vegetation level changes very smoothly, and the other is that it has the detailed yearly seasonal variations. A vegetation level of the point was decided by the yearly maximum NDVI ($NDVI_{ymax}$).

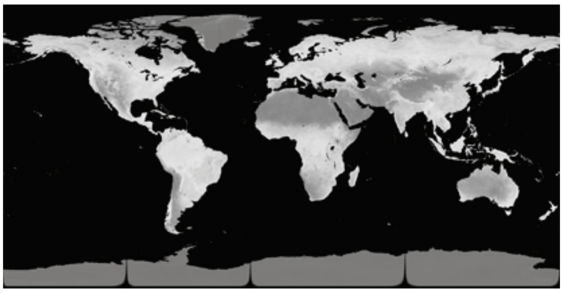


Figure 6: World yearly maximum NDVI

Moreover, yearly change of vegetation is very large in arid and semi-arid area. The relation of NDVI to vegetation level is not defined, because NDVI is affected by not only vegetation but also ground surface. Gamo[5] classified the desertification area by $NDVI_{ymax}$. In this paper, it is defined that area of $NDVI_{ymax} \geq 0.55$ is abundance of vegetation and excluded from possible area. In addition, $NDVI_{ymax}$ was separated by color by 0.1 from 0.05 to 0.55 according to the classification.

4 RESULT AND VALIDATION

4.1 Analysis result

The potential of VLS-PV system installation was estimated by integrating with three layers. For example, the suitable land for PV system is the land which is classified stony class or steppe class by MLC and which is estimated flat land by extraction of edge line and which is presumed arid area. In addition, the authors estimated the potentials by 20 pixels x 20 pixels for VLS-PV system, because a very large area was required for installation of a PV system.

Authors analyzed Gobi desert (1.52 x 10^6 km^2) by these methods. Result was calculated six types of vegetation level. In case of allowing vegetation at the maximum, the area percentage of suitable land was estimated as 47%. Most of estimated area as suitable was very arid desert area which $NDVI_{ymax}$ is less 0.15. It represented that a resource of solar photovoltaic generation in Gobi deserts has been evaluated very large.

Table 1: Standing waves ratio

$NDVI_{ymax}$	~0.15	~0.25	~0.35	~0.45	~0.55	Total
percentage	28.4%	11.9%	4.5%	1.8%	0.7%	47.4%
x10^3 km^2	433	181	69	28	11	721

An estimated result at the test site is shown in Figure 7. High vegetation area of near lake and the mountainous area in the lower half of image were excluded as unbefitting area. However, the resolution of $NDVI_{ymax}$ is much lower than LANDSAT-7 images. The algorithm was not able to respond to rapid changes of vegetation.

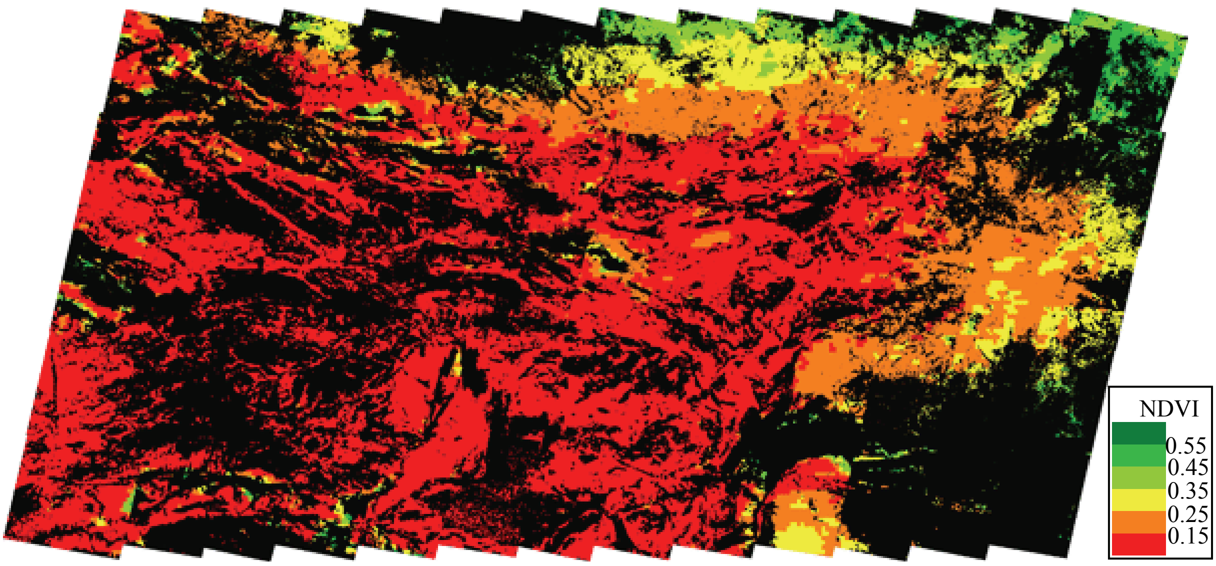


Figure 7: Estimated result in Gobi desert

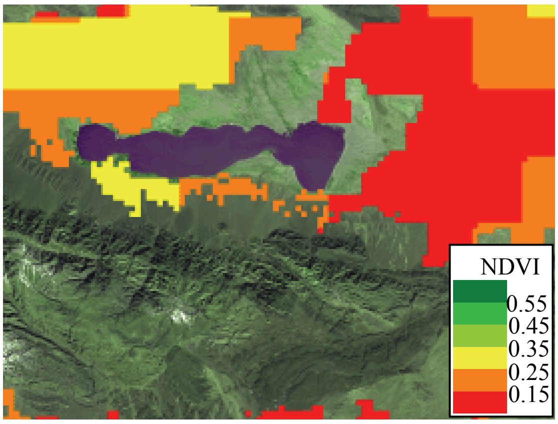


Figure 8: Estimated result in a test site

4.2 Ground truth

Authors verified the accuracy of estimated results by actual ground truth data. Ground truth means accuracy validation or the field investigation for accuracy validation of remote sensing. Ground truth data is obtained by using a GPS receiver and digital camera, when Sakakibara et al. visited at Noyon soum, in Mongolia in 2003 September 7. The precise latitude and longitude were measured every second by GPS receiver. A lot of photographs were taken on the running car or getting out of the car. A GPS-photograph dataset was made by these data. Because some data which is same GPS data were excluded from the database, 46 points in the dataset were available data. In this dataset, each photograph was evaluated as S, A and B rank. The definition of these ranks was shown in Table 2.

Table 2: Standing waves ratio

rank	condition
S	stable and flat surface as far as one can see
A	stable and flat surface, but rugged area in far
B	unbefitting surface. i.e. rugged or forest etc.

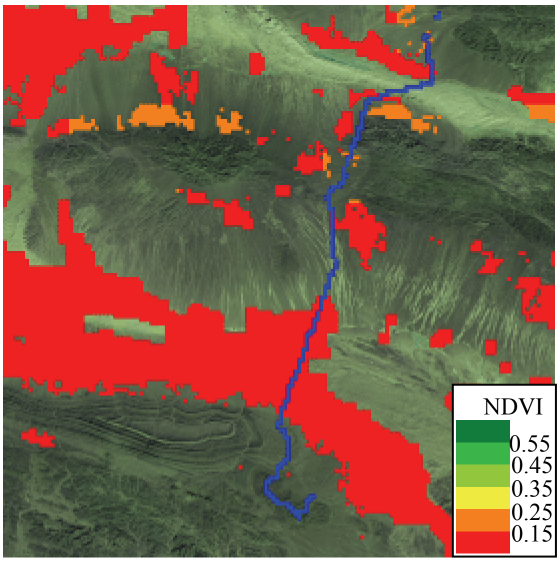


Figure 9: Accuracy validation of estimated result

Figure 9 is lied the GPS data on the estimated result image. The light blue line is the tracking points of GPS data. There are few points of Steppe or Forest lands. The analysis accuracy was 74 %. The mountainous area was certainly eliminated, but the accuracy at the rich vegetation area was not validated because the test area is very arid area. Most of mistake points were rejected by misclassification at extraction of edge line in spite of S or A rank.

The validation result is far from very high accuracy. However, the analysis result has a certain amount of accuracy because the potentials of desert PV were estimated uniformly by detecting seasonal changes among satellite images as shown in Figure 7. Thus, it means that this study can provided with sufficient information for the planning of PV system installations.

5 CONCLUSIONS

The authors identified the potential of PV system in desert by the remote sensing methods. The method is consisted of ground surface classification by MLC (Most Likelihood Classifier) method, vegetation analysis by NDVI dataset and edge extraction by filtering. The algorism was developed by conversion from raw image data to reflection and by adopting the yearly maximum NDVI ($NDVI_{ymax}$). These methods redused difference of image acquisition condition, and detected seasonal differences among satellite images. The algorithm is adopted to many satellite images in Gobi desert. The unique each parameteres of the algorithm were used for all images. Moreover, the accuracy of analysis results was examined by compared with actual ground truth data. It is concluded by the comparative study with the ground truth that the proposed method can provide sufficient information for the planning of PV system installations. Additionally, a resource of solar photovoltaic generation in Gobi deserts has been evaluated huge. However, the following future problems were left. The edge extraction method was extracted too much area as rugged land. In addition, the resolution of $NDVI_{ymax}$ is much lower than LANDSAT-7 images. This algorithm was not able to respond to rapid changes of vegetation. After finding solution of these problems, resources of other deserts and semiarid area will be estimated by this algorithm.

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