Original Paper

Differences in NDVI and iTVDI Among Various Land Cover Types in Kanto region, Japan

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ABSTRACT

The differences in the improved Temperature Vegetation Dryness Index (iTVDI) and the Normalized Difference Vegetation Index (NDVI) between eleven land cover types in northwestern part of the Kanto region of Japan were analyzed using Landsat5 TM data and a vegetation map. The results showed that there were significant differences in iTVDI and NDVI values among the land cover types. The NDVI values were highest in the forest regions including evergreen forest, deciduous forest and mixed forest, while the iTVDI values were relatively lower in comparison to other land cover types, except for water. The iTVDI values of the grassland, cropland and orchard were higher while their NDVI values were not very low. And the iTVDI value of the paddy field was much higher than that of the water. In order to identify the reason, these land cover types were further classified into two classes respectively, the paddy field was classified into water-covered and not water-covered, and the other land cover types were classified into the full-covered and partial-covered. Consequently, the iTVDI values of the water-covered region of the paddy field and the well-vegetated region of the other three types were reduced. These results suggest that different land cover types cause the differences of iTVDI values and NDVI values due to the different fraction of vegetation cover and transpiration rates.

Key words : iTVDI, land cover type, NDVI, transpiration

1. Introduction

Vegetation is a very important part of the terrestrial ecosystem, and its growth and reproduction are crucially dependent on their physical environment. Meanwhile, the vegetation condition and dynamic changes reflect the environmental state and existing problems, such as air pollution and drought (Omasa et al., 2002; Omasa et al., 2005; Jones and Vaughan, 2010; Wan et al., 2014). Therefore, vegetation monitoring and investigation are essential.

In recent decades, remote sensing techniques have been generally used in these field thanks to its lower cost and time-saving advantages. Moreover, plenty of vegetation indices have been developed and applied in extensive studies about vegetation monitoring and environmental investigation (Tucker, 1979; Huete, 1988; Kogan, 1995; Motohka et al., 2010), among which the NDVI (Normalized Difference Vegetation Index, Rouse et al., 1973) is a very common one. It reflects plant biomass such as the chlorophyll content or Leaf Area Index (LAI). However, it was reported that there are some limitations in its application such as a delayed response to the rainfall and little influence from significant precipitation events to the NDVI in the later growing season in arid or semi-arid region (Rundquist and Harrington, 2000; Wang et al., 2001; Rahimzadeh-Bajgiran et al., 2008, 2009). Afterwards, the land surface temperature (Ts), which can indicate energy partitioning at the surface, was taken into account and combined with the vegetation indices to make a

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Ts/vegetation index space for monitoring of vegetation condition to avoid the aforesaid problems. The TVDI (Temperature Vegetation Dryness Index, Sandholt et al., 2002) was just developed on the basis of Ts/NDVI space, however it was not suitable for a heterogeneous area, as the air temperature was assumed to be a constant. The improved TVDI was developed (Rahimzadeh-Bajgiran, et al., 2012) on the basis of the TVDI, by replacing the Ts with Ts minus Ta (air temperature). And it is relative to the transpiration rate and would respond to the water stress.

The iTVDI has also been used in some researches in Japan. Ishimura et al. (2011) found the iTVDI was suitable for detection of Japanese beech forest decline caused by air pollution and water deficit. Naito et al. (2012) compared the difference between NDVI and iTVDI among vegetation cover types in Lake Mashu located in Hokkaido, Japan and showed that the different vegetation cover types could cause significant differences in iTVDI values.

However, the differences in iTVDI and NDVI among land cover types have not been studied yet. And the following points could be suggested: the influence of land cover types on the values of the iTVDI and NDVI; and if there are significant differences in iTVDI and NDVI among land cover types?

In this study, for the first time, the differences in NDVI and iTVDI between various land cover types in Kanto region of Japan were evaluated quantitatively.

2. Materials and methods

2.1 Study area

The study area covered northwestern part of the Kanto region of Japan (Fig. 1, 36.03–36.71 ºN, 137.97–139.57 ºE), where there are various kinds of vegetation species and the elevation of this area ranges from 0 to about 3000 meters.

2.2 Remote sensing data

The Landsat Thematic Mapper (TM) image, acquired on the 28th of May 1993, was used. Firstly, it was converted from DN (Digital Number) to reflectance using FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction model in ENVI software. The band 4 (near infrared band: 0.76–0.90 μm) and band 3 (red band:

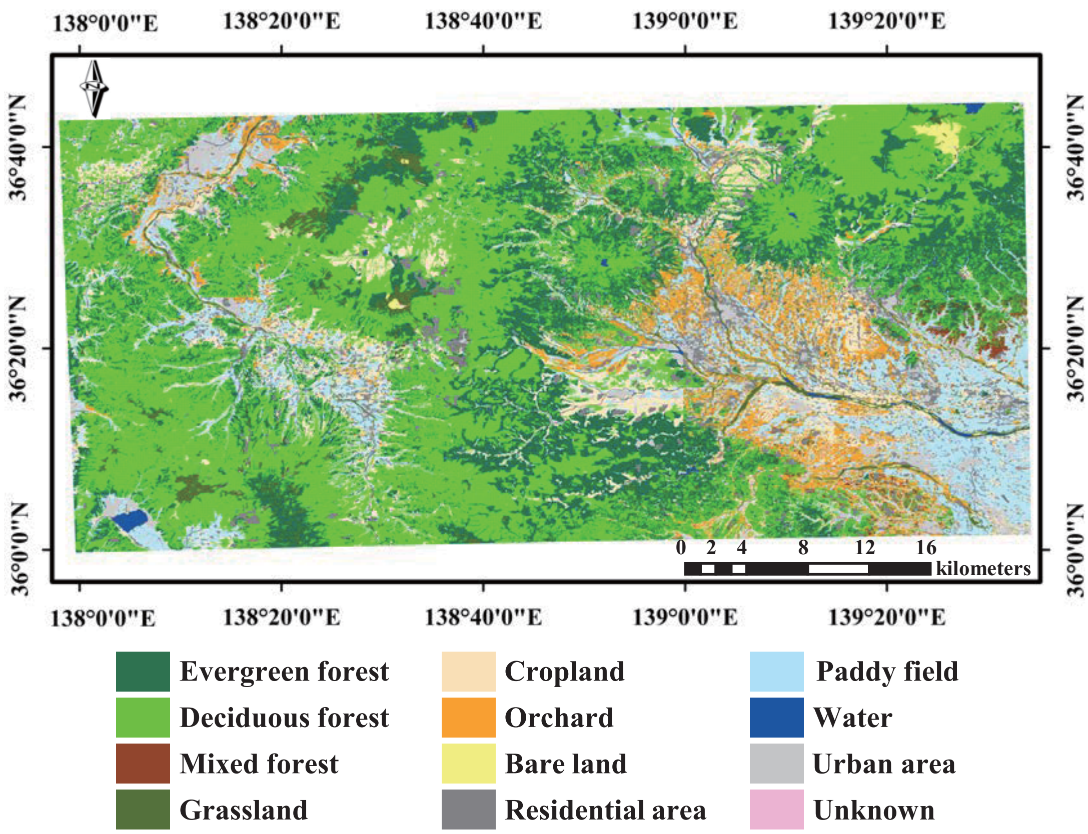

Fig. 1. The land cover classification map.

0.63−0.69 μm) with a spatial resolution of 30m, were then used to calculate the NDVI, and band 6 (thermal infrared band: 10.40−12.50 μm) with a spatial resolution of 120 m, was used to retrieve the land surface temperature.

2.3 Vegetation map

The vegetation map provided by the Biodiversity Center of Japan was used to make the land cover classification map by reclassifying it into 12 kinds of land cover types. The forest was classified into evergreen, deciduous and mixed forests. The residential area, of which over 30% are covered by vegetation, is also differentiated from the urban area. The other kinds of land cover also include grassland, orchard, cropland, bare land, paddy field, water, and unknown which will not be discussed here. Each land cover type is made up of a mass of pixels, among them bare land contains the minimum pixel numbers of 57,849, and deciduous forest contains the maximum pixel numbers of 4,544,235. The land cover classification map is shown in Fig. 1.

2.4 Meteorological data

Air temperature data measured at 10:00 A.M. on the 28th of May 1993 and the elevation data from 84 meteorological stations surrounding the study area were collected to interpolate the air temperature of the whole region using the inverse distance weighted method. To calculate the air temperature of a given pixel, the nearest 6 stations were used, as in this case the Root Mean Square Error (RMSE) was the lowest. Also the Digital Elevation Model (DEM) data (Fig. 2(A)) supplied by ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) was used to calibrate the air temperature. Considering the topography of the study area, the environmental lapse rate was defined as 0.55 ℃/100 m (Yoshino, 1986). Fig. 2(B) presents the interpolated Ta map after the DEM calibration.

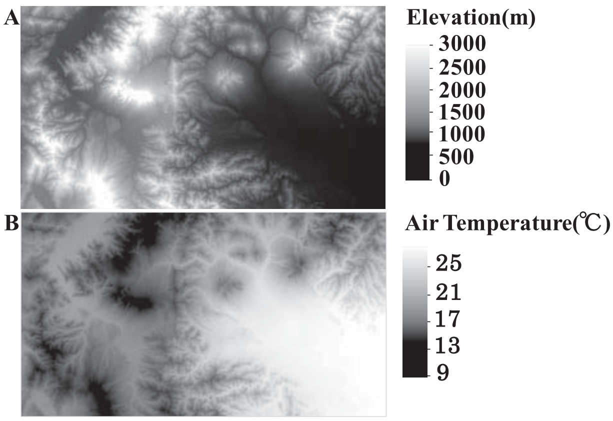

Fig. 2. The DEM of the study area (A) and the interpolated Ta map after a DEM calibration (B).

2.5 Masking

The pixels in the Ts-Ta map, with Ts-Ta values lower than −5 ℃ were used to build a mask to eliminate the pixels covered by thick clouds.

2.6 Methods

2.6.1 NDVI

The NDVI is the most common vegetation index of which the value ranges from −1 to 1, reflecting the vegetation amount and chlorophyll content. It is calculated using Eq. (1)

$$\mathrm{NDVI} = \frac{\mathrm{NIR}-\mathrm{R}}{\mathrm{NIR}+\mathrm{R}} \tag{1}$$

where NIR is the reflectance value of the near infrared band and R is the reflectance value of the red band.

2.6.2 iTVDI

The iTVDI was developed for water stress detection, and performed well in evapotranspiration estimation and water stress determination in the semi-arid region of Iran (Rahimzadeh-Bajgiran et al., 2012). It also has a good relationship with the mortality rate of the beech forest in the Tanzawa mountain in Japan (Ishimura et al., 2011). The iTVDI is calculated using Eq. (2) and schematically shown in Fig. 3.

$$\mathrm{iTVDI} = \frac{(\mathrm{Ts\text{-}Ta})_{obs} - (\mathrm{Ts\text{-}Ta})_{min}}{(\mathrm{Ts\text{-}Ta})_{max} - (\mathrm{Ts\text{-}Ta})_{min}} = \frac{\mathrm{BC}}{\mathrm{AB}} \tag{2}$$

where $(\mathrm{Ts\text{-}Ta})_{obs}$ is the difference between observed surface temperature and air temperature calibrated using DEM. $(\mathrm{Ts\text{-}Ta})_{max}$ and $(\mathrm{Ts\text{-}Ta})_{min}$ are the maximum and minimum differences between Ts and Ta for the same NDVI value in the trapezoidal shape of Ts-Ta vs. NDVI (Fig. 3), respectively. Here the mean value of (Ts-Ta) + S.D. × 2 was defined as the dry edge and (Ts-Ta) − S.D. × 2 was defined as the wet edge. The iTVDI value ranges from 0 to 1, and the iTVDI values of the pixels above the dry edge would result in higher than 1 and the pixels nether the wet edge would lower than 0, hence they were set to 1 and 0 respectively. The higher the iTVDI value is, the less transpiration it means and vice versa.

3. Results and discussion

Spatial variations of the NDVI and iTVDI are presented in Fig. 4. From an overall perspective, it is shown that the NDVI of forest regions (Fig. 1) were higher in comparison to the other land cover types and in the mountainous area (Fig. 2(A)), the NDVI values of eastern part were higher than western part. On the other hand, the iTVDI in the forest region were relatively low, and those in the other regions were higher.

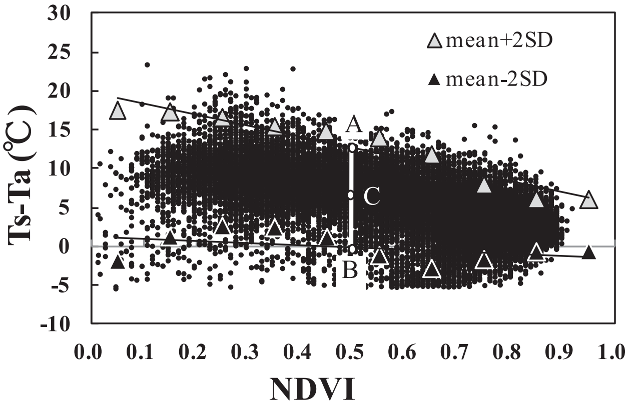

Fig. 3. The trapezoidal shape of Ts-Ta and NDVI to derive the iTVDI. The upper line indicates the dry edge, and the lower one indicates the wet edge. The iTVDI at point C is equal to BC/AB.

The mean values of NDVI and iTVDI for each of the land cover types and S.D. are shown in Fig. 5. Although the standard deviation of both iTVDI and NDVI for each land cover type was high, the standard error ranged from 0.0001 of deciduous forest to 0.0011 of bare land for iTVDI and from 0.0001 of deciduous forest to 0.001 of bare land for NDVI. The mean values of iTVDI in evergreen forest, deciduous forest and mixed forest regions were comparatively low with values of 0.37, 0.42, and 0.43, respectively. The mean values of NDVI, however, were higher, with value of 0.76, 0.75 and 0.72, respectively. The mean values of iTVDI for grassland, cropland, orchard, were as high as 0.59, 0.64, and 0.66. Especially, the paddy field, of which the iTVDI value was expected to be as low as water body, had a high iTVDI value of 0.55, while that of the water was 0.26. In the case of the residential area and the urban area, the mean values of iTVDI were 0.62 and 0.58, respectively, and the mean values of NDVI were 0.45 and 0.35. The mean value of iTVDI and NDVI of the bare land were 0.50 and 0.46, and the mean value of iTVDI of water was 0.26. According to the Tukey-Kramer test ($p < 0.05$) there are significant differences in both iTVDI and NDVI values among land cover types.

The NDVI has a positive relationship with fraction of

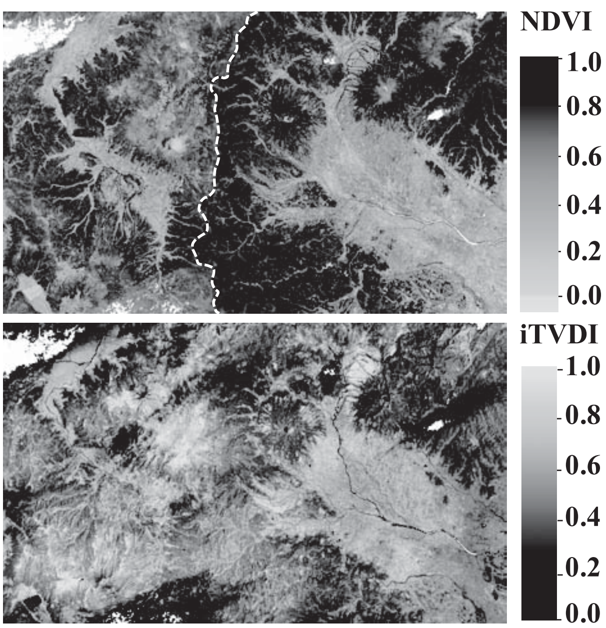

Fig. 4. The spatial variation of NDVI and iTVDI. The dot line on the NDVI map shows a division of western and eastern parts of the mountainous area. The white-colored areas are the masked part due to the cloud.

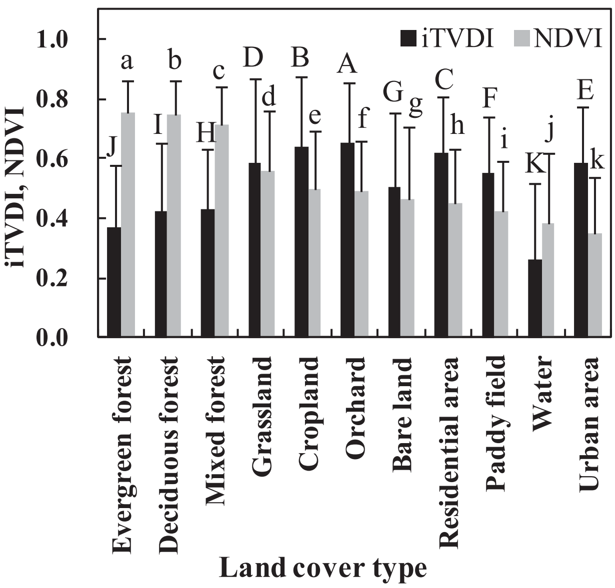

Fig. 5. The mean values of NDVI and iTVDI of respective land cover type. The bar represents the standard deviation. The letters written in uppercase and lowercase represent statistical differences of iTVDI and NDVI according to the Tukey-Kramer test.

vegetation cover and LAI, and high LAI could increase the maximum transpiration rate of canopy (Mauser and Schädlich, 1998; Jones and Vaughan, 2010). Consequently, the forest regions which have high LAI, had higher NDVI values and lower iTVDI values in comparison to the other types except for water, and this is in accordance with the results of Naito et al. (2012). And under the influences of different dominant species and the season used in the analysis, the NDVI values of each type of the forests and grassland were quite lower and iTVDI were higher than the results of Naito et al. (2012).

On the other hand, the iTVDI of the paddy field, grassland, cropland and the orchard were higher while their NDVI were not very low. Therefore, in order to identify the reason, the paddy field was classified into water-covered and not water-covered based on the reflectance value of the Landsat image, and it was resulted in that the water-covered pixels just account for 15.5% of the whole paddy field. This can interpret why the iTVDI value of paddy field was higher than expectation. The mean values of NDVI and iTVDI of the two classes are shown in Fig. 6. The mean value of iTVDI of water-covered class reduced while that of not water-covered class increase and the mean values of NDVI for both classes decreased little. In the same way, the grassland, cropland and the orchard were also classified into two classes (full-covered and partial-covered), respectively. The results are shown in Fig. 6. In the case of the full-covered pixels of these three types, the mean values of the iTVDI reduced in comparison to before classification while the NDVI increased. On the contrary, in the case of the partial-vegetated pixels of them, the mean values of iTVDI increased while the NDVI decreased in comparison to the values before classification.

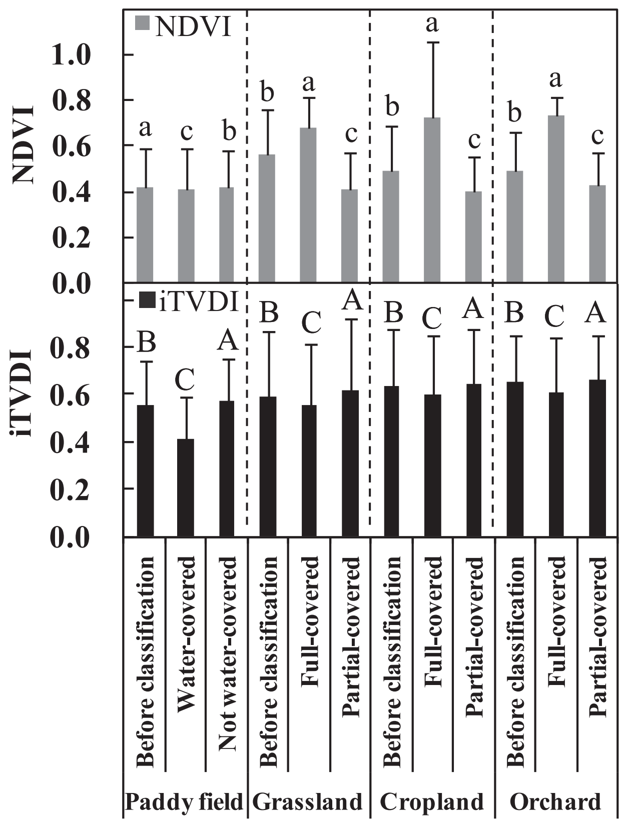

Fig. 6. The mean values of NDVI and iTVDI of the paddy field, orchard, grassland and cropland before and after further classification. The bar represents the standard deviation. The letters written in uppercase and lowercase represent statistical differences of iTVDI and NDVI according to the Tukey-Kramer test for each of the land cover types.

These results suggest that the different land cover types could cause the differences in iTVDI and NDVI values, moreover, the regions with high LAI always result in low iTVDI values and the regions with low LAI always result in high iTVDI values except for water. It means that the different land cover types even the different plant communities of a land cover type have different transpiration rate which, to an extent, can reflect the vegetation condition. According to Sagar and William (1988), air pollutant would injures the leaves by entering the stomata and changing the integrity of cells. Thereby it may influence the transpiration rate. Therefore, the iTVDI may have potential to be used in detecting the vegetation damage caused by air pollutant.

References

Huete, A. R., 1988 : A soil-Adjusted Vegetation Index (SAVI). *Remote. Sens. Environ.*, **25**, 295-309.

Ishimura, A., Shimizu, Y., Rahimzadeh-Bajgiran, P. and Omasa, K., 2011 : Remote sensing of Japanese beech forest decline using an improved Temperature Vegetation Dryness Index (iTVDI). *iForest*, **4**, 195-199.

Jones, H. G. and Vaughan, R. A., 2010 : *Remote Sensing of Vegetation.* Oxford University Press, New York, 353 pp.

Kogan, F. N., 1995 : Application of vegetation index and brightness temperature for drought detection. *Adv. Sp. Res.*, **15**, 91-100.

Mauser, W. and Schädlich, S., 1998 : Modeling the spatial distribution of evapotranspiration on different scales using remote sensing data. *J. Hydrol.*, **212-213**, 250-267.

Motohka, T., Nasahara, K. N., Hiroyuki, O. and Tsuchida, S., 2010 : Applicability of green-red vegetation index for remote sensing of vegetation phenology. *Remote. Sens.*, **2**, 2369-2387.

Naito, H., Rahimzadeh-Bajgiran, P., Shimizu, Y., Hosoi, F. and Omasa, K., 2012 : Summer-season differences in NDVI and iTVDI among vegetation cover types in lake Mashu, Hokkaido, Japan using landsat TM data. *Environ. Control Biol.*, **50 (2)**, 163-171.

Omasa, K., Saji, H., Youssefian S. and Kondo, N., 2002 : *Air Pollution and Plant Biotechnology.* Springer, Tokyo, 455 pp.

Omasa, K., Nouchi, I. and De Kok, L. J., 2005 : *Plant response to Air Pollution and Global Change.* Springer, Tokyo, 300 pp.

Rahimzadeh-Bajgiran, P., Darvishsefat, A. A., Khalili, A. and Makhdoum, M. F., 2008 : Using AVHRR-based vegetation indices for drought monitoring in the Northwest of Iran. *Arid Environ.*, **72**, 1086-1096.

Rahimzadeh-Bajgiran, P., Shimizu, Y., Hosoi, F. and Omasa, K., 2009 : MODIS vegetation and water indices for drought assessment in semi-arid ecosystems of Iran. *J. Agric. Metorol.*, **65**, 349-355.

Rahimzadeh-Bajgiran, P., Omasa, K. and Shimizu, Y., 2012 : Comparative evaluation of the Vegetation Dryness Index (VDI), the Temperature Vegetation Dryness Index (TVDI) and the improved TVDI (iTVDI) for water stress detection in semi-arid regions of Iran. *Photogramm. Remote. Sens.*, **68**, 1-12.

Rouse, J. W., Haas, R. H., Schell, J. A. and Deering, D. W., 1973 : Monitoring vegetation systems in the Great Plains with ERTS. *Third ERTS Symp.*, NASA SP-351 I, 309-317.

Rundquist, B. C. and Harrington J. J., 2000 : The effects of climatic factors on vegetation dynamics of tallgrass and shortgrass cover. *Geocarto Int.*, **15 (3)**, 33-38.

Sagar, V. K. and William, J. M., 1988 : Atmospheric ozone : Formation and effects on vegetation. *Environ. Pollut.*, **50**, 101-137.

Sandholt, I., Rasmussen, K. and Andersen, J., 2002 : A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status. *Remote Sens. Environ.*, **79**, 212-224.

Tucker, C. J., 1979 : Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sens. Environ.*, **8**, 127-150.

Wan, W., Manning W. J., Wang., X., Zhang H. and Sun, X., 2014 : Ozone and Ozone injury on plants in and around Beijing, China. *Environ. Pollut.*, **191**, 215-222.

Wang, J., Price, K. P. and Rich, P. M., 2001: Spatial patterns of NDVI in response to precipitation and temperature in the central Great Plains. *Int. J. Remote Sens.*, **22**, 3827-3844.

Yoshino, M., 1986: *Microclimate.* Chijin shokan. Tokyo, 298 pp.