Comparison of Lambertian and non-Lambertian topographic normalization algorithms: A case study in Gelibolu, Turkey

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ABSTRACT: Aim of this study is to compare the Lambertian and non Lambertian approaches and produce more accurate maps of land use and change in the region, which could be vital for land use decision makers of the region. In this study, both approaches were applied to TM images of Gelibolu located in the Western Turkey to reduce topographic effects of the rugged area extensively covered with forest. A digital elevation model (DEM) was compiled with a resolution of 30 meters in order to study the relationship between the reflectance and the local sun-surface-sensor geometry. The positive effect of topographic normalization methods performed in this study is tested through comparison of classification results carried out for uncorrected and corrected images. The results show that more robust approach, non-Lambertian, performs significantly better than the Lambertian model in terms of the classification accuracies estimated, and it is observed that topographically corrected satellite data provides more accurate assessment of species type than the uncorrected data.

1 INTRODUCTION

The operational use of remote sensing techniques is often obstructed by problems originating from topographic effects on the sensor response (Ekstrand, 1996). The images acquired by high resolution sensors, such as Landsat Thematic Mapper (TM) and the SPOT HRV sensors for mountainous areas are subject to topographic effects that involve different illumination of surfaces due to slope angle and aspect variations. This may have significant influence on any classification performed in such regions. In mountainous regions illumination effects depending on elevation and slopes lead to irradiance up to 600 Wm⁻². Therefore also the reflectance shows important terrain induced differences for pixels with the same landuse. These differences can cause incorrect classified pixels or a result with a few classes only (Parlow, 1996).

The correction of atmospheric and topographic effects is an important processing step to enhance the data quality, help the interpreter, and improve the subsequent processing, e.g., classification algorithms (Richter, 2001). Many studies have shown that topographic effect complicates greatly the correlation of stand characteristics with reflectance characteristics so they propose removal or reduction of this unwanted effect before further data processing and especially before classification (Walsh 1987, Justice et al. 1981, Woodcock et al. 1980).

By analyzing the data carefully, researchers can classify a particular location according to its dominant vegetation or land use type. Classification depends upon the spectral signature that is detected by the imaging satellite. There are two dominant factors influencing reflectance signatures of the land surface: the makeup of the surface and the topography. Classification errors arise when irregular topography alters the reflected radiance from that location. Changes in topography may be misinterpreted as changes in surface type, and an incorrect classification may result (Reeder, 1999).

In this study, Lambertian and non-Lambertian approaches were applied to TM images of Gelibolu located in the Western Turkey to reduce topographic effects of the rugged area with extensive forest cover and classification results were compared.

2 STUDY AREA

Forest covers around 20.6 million hectares of land in Turkey, constituting 26 % of the land surface of the country. Forest of Turkey has a rich mixture in terms of tree types. Most of the forest in Turkey is a penin-
sula among the Black Sea, the Marmara Sea and the Aegean Sea.

Gelibolu area which shown in figure 1 with rugged topography, climate of Marmara Region, which has crossroads climatic, features between the Mediterranean and The Black Sea climates. As general characteristics, springs and autumns are rainy, winters are cold and summers are hot. The Forest of these areas consist of mainly Norway spruce, and other leafed types, predominantly *Coccifera*, as well as brushwood groups.

3 METHOD

3.1 Data Used

The Landsat-5 Thematic Mapper (TM) data used in this study was acquired in July 1998 (figure 2). The image is the cloudless, and the sun elevation is 29.1° with an azimuth of 121°.

In order to analyze the topography of the area and to form Digital Elevation model, 11 topographic maps at 1/25 000 scale were used. Gelibolu forest maps had been used to check the classification results.

3.2 Rectification

Rectification was made to the satellite images by using 1/25000 and 1/5000 scale maps of the study area. The images were transformed into the UTM co-ordinate system by using 1st degree Affin transformation and 0.5 pixels RMS.

3.3 Digital Elevation Model (DEM)

In general sense, digital elevation model is the digital and three-dimensional expression of the surface of the land. As the digital elevation models bear elevation information, they are used in obtaining resolutions which can not be obtained by two-dimensional analysis. By means of the interpolation methods applied to the elevation values which have been digitized from topographic maps, ground measurements, photogrammetry or remote sensing data and them transferred to computer media; brightness values at raster data at the desired pixel size and radiometric resolution can be obtained from the elevation values. The selection of the data sources, frequency of the points selected on the land and the mathematical method used in conversion are important for the quality and accuracy of the digital elevation model. Therefore, a method has to be established according to the purpose of the study and the desired accuracy before the digital elevation model is formed (Musaoğlu, 1999, Kaya et al. 2001).

Slope-aspect topographic correction methods commonly require a digital elevation model of study area. In this study, topographic contours have been digitised at every 20 m from the map of 1/25000 scale. Because the pixel size of the Landsat TM images is 30 m, the DEM was interpolated to 30 m spatial resolution. Then digital elevation model was obtained from these data and converted into raster data form (figure 3). In the study area, highest point is the Karaburun Peak and elevation of this point is 400 m. The vegetation coverage is considerate high.
3.4 Lambertian and Non-Lambertian Models

A Lambertian surface is presumed to be a perfectly diffuse reflector, appearing equally bright from all viewing directions (Ekstrand, 1996). Therefore a Lambertian surface is presumed to be a perfectly diffuse reflector, appearing equally bright from all viewing directions (Ekstrand, 1996). Therefore, a Lambertian correction function attempts to correct only for differences in illumination caused by the orientation of the surface (Jones et al., 1988). The incidence angle \( i \) is the angle between the surface normal and the solar beam, and may be calculated at equation 1 (Smith et al., 1980). When the sun is not zenith, correction of the radiance of a projected horizontal surface would be achieved by the equation 2 (Teillet et al., 1982). The most common way to account for the non Lambertian behavior of vegetation has been to employ the Minnaert constant. The Belgian astrophysicist G.J. Minnaert modified the common cosine correction by adding a constant \( k \) (Ekstrand, 1996, Colby, 1991, Smith et al., 1980). The parameter \( k \) is considered to be a measure of the extent to which a surface is Lambertian (in which case \( k = 1 \) ) (equation 3). The values of \( k \) varies between 0 and 1.

\[
\cos i = \cos e \cdot \cos z + \sin e \cdot \sin z \cdot \cos (\phi - \phi_i) \\
\text{Lambertian model:}
\]

\[
\ln(\lambda) = L(\lambda) \cdot \cos z / \cos i
\]

\[
\ln(\lambda) = L(\lambda) \cdot (\cos e / (\cos k\lambda_1 \cdot \cos k\lambda e))
\]

\[
e = \text{surface normal zenith angle or terrain slope},
\]

\[
z = \text{zonal zenith angle},
\]

\[
\phi = \text{zonal azimuth angle},
\]

\[
\phi_n = \text{surface aspect of the slope angle}
\]

\[
\ln = \text{normalized radiance}
\]

\[
L = \text{observed radiance}
\]

\[
k = \text{minnaert coefficient}
\]

In this study, an artificial illumination of the DEM was generated by calculating the \( \cos i \) (figure 4). For that purpose the sun position can in either been extracted from the image file header of the delivered TM scene or may easily be calculated for the known acquisition date through an astronomy program. The sun azimuth for the used image is 121°, the sun elevation is 29.1° causing deep shadows on slopes of north western exposition steeper than 29.1°. Figure 4 shows a detail of the \( \cos i \)-“illuminated” DEM. The black coded patches are areas with sun incidence angles greater than equal or 90°(Jansa,1998).

3.5 Classification

Different feature types in digital images constitute combinations, which contain different digital values depending on the natural spectral reflection and emission features. The aim of the classification is to group the objects carrying same spectral features. In classification stage, Maximum Likelihood supervised classification algorithm was performed on this data sets. Before the classification, preliminary information was required of the region in order to determine statistical limits. Various maps (orthophoto maps and land use maps) and photographs were used to select classes and ground truth studies have been done.

4 RESULTS

Topography does not only affect the geometric properties of an image but will as well has an impact on the illumination and the reflection of the scanned area. This effect is caused by the local variations of view and illumination angles due to mountainous terrain.

The topographic correction methods that we tested include the Lambertian correction and the Minnaert correction. Study results show that the Lambertian correction is not satisfactory because natural surfaces have more complex bidirectional reflectance distribution functions (BRDF). They are not Lambertian, and simple cosine corrections are grossly inadequate but the other method has the desired results of variation in brightness values between slopes and improving the likelihood of a correct classification for the regions that might be confused due to varied illumination.

Topographic effects are easily observed in the satellite image shown in figure 2. This image was taken about 10 a.m. with the sun at an elevation of 29.1 degrees above the horizon. Ridgelines oriented NE-SW are characterized by bright pixels on their SE-
facing slopes, and darker pixels on their NW-facing slopes. Although there may be some important vegetation differences between these slopes, it is more likely that the same type of trees grow on each side. When sun elevation is low and northern slopes are in shadow no radiance would occur according to the Lambertian assumption (equation 2). According to Deering et al. (1994) sky irradiance may contribute to up to 15 percent of the total near infrared irradiance, and in the visible bands to as much as 25 percent.

In terms of supervised classification problems, in seasons of low sun angles for example, pixels from northerly facing forested slopes exhibit reflectance lower than the overall true reflectance for this cover type and are often misclassified (Figure 5). Also, pixels from southerly facing deciduous forested slope exhibit reflectances higher than the mean reflectance for the class and are often falsely assigned to a non-forest category, such as fallow pastures or bare ground (Civco, 1989).

The result of Lambertian correction is shown in figure 6. The Lambertian correction was found to be unsatisfactory. The cosine correction usually underestimates reflectance on sun-facing slopes and overestimate reflectance on slopes facing away from the sun. Except for situations with high sun elevations, the cosine correction has proved to be inadequate for forest vegetation (Teillet et al., 1982). The Minnaert correction (Equation 3) is a variation of the cosine correction and is based on the Minnaert law (Minnaert, 1941). A constant $k$, which is no real constant since it is wavelength and surface dependent, is introduced to simulate the non-Lambertian behaviour of the earth surface. The Minnaert constant is a measure of how close a surface is to the ideal reflector, for $k=1$ (Smith et al., 1980). When the classification results are examined, the Minnaert correction produced more accurate results than the cosine correction (figure 7).

Preliminary results indicate that topographically corrected satellite data used for more accurate assessments of species type and damage than uncorrected data. The Lambertian correction was found to be unsatisfactory, as it overcorrected the darker northern slopes, and undercorrected the brighter southern slopes. The "backwards Minnaert correction" allows the surface to favor certain directions of scattering over others, unlike the perfectly diffuse reflector assumed by the Lambertian correction. This correction appears to be an improvement over the Lambertian correction, as similar surfaces on opposite sides of the ridges appear to have similar brightness values.

Initial examination of classification results before and after topographic normalization indicated that a ‘better’ spectral classification has resulted.

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