CAN DEM LEVE-1 ADEQUATLY REPLACE LEVEL-2 FOR RADIOMETRIC CORRCETION OF SATELLITE IMAGERY FOR LANDCOVER MAPPING OF SAUDI ARABIA

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ABSTRACT: The Kingdom of Saudi Arabia has not yet had a full (national) land cover mapping survey. The very limited areas in Saudi Arabia covered by the 30m resolution DEM level-2 that is compatible with the fine and medium resolution (SPOT and TM) imagery makes it unreliable as a topographic source. The validity of the lower spatial resolution (100m) DEM level-1 of full coverage of the Kingdom as a substitute is tested for that purpose. Radiometric (atmospheric and topographic) correction of satellite imagery for the desert bare soil study area is achieved by using Radiance and two Reflectance (Chavez (1996) COST and Radiative Ttransfer Code in ATCOR-3) based techniques, implementing four Lambertian and non-Lambertian topographic correction models. The results show that the adequacy of DEM level-1 decreases with increase of terrain slope and DEM level-1 can be an adequate alternative to DEM level-2 for areas of flat to gently sloping (0º to 5º). Moreover, for better performance of topographic correction using DEM level-1 for high sun angle images in flat to moderate terrain (0º to 25º), C-correction should be used as the optimum model, followed by Minnaert and last by Cosine. But for rugged terrain (steeper than 25º), the Cosine should be used, followed by C-correction and last by Minnaert. Using low sun angle imagery in flat to gentle terrain (0º to 5º), C-correction is the optimum, Minnaert comes as second and Cosine is the last. For moderate to rugged terrain (steeper than 5º), C-correction should be used, followed by Cosine and last by Minnaert. Results also demonstrates that for better DEM level-1 topographic correction, fine resolution and high sun angle imagery should be used. Finally, the worth of using the Radiative Transfer Code-RTC (ATCOR-3) accurate atmospheric correction compared with simplified ones for operational use is found questionable.

1. INTRODUCTION

The Kingdom of Saudi Arabia (about two million square kilometers area) has not yet had a full (national) land cover mapping survey. To perform accurate land cover classification, satellite imagery must be radiometrically corrected for atmospheric and topographic effects. Correction for those effects requires an accurate DEM that is compatible with the satellite image resolution, such that derived slope and aspect will match image pixel in size and location. The very limited areas in Saudi Arabia covered by the 30m resolution DEM level-2 that is compatible with the fine and medium resolution (SPOT and TM) imagery received by King Abdulaziz City for Science and Technology (KACST) in Riyadh makes it unreliable as a topographic source. DEM level-1 of full coverage of the Kingdom as a substitute makes testing its validity for that purpose essential. If DEM level-1 is substitutable then land cover mapping for the Kingdom using DEM level-1 instead of level-2 for radiometric correction can be carried out on an immediate operational basis. To reach this goal, two questions are to be answered. The first is to what extent in terms of terrain slope and orientation is DEM level-1 an adequate alternative to DEM level-2 in radiometric correction and consequently in land cover mapping? The second is what is the optimum combination of temporal (sun angle) selections, sensor images and radiometric correction techniques that leads to the best performance of DEM level-1? Thus, performance of DEM level-1 against level-2 is tested under the effect of the variable image sun angles and resolutions: SPOT-XI (representing finer resolutions and higher sun elevation angles), TM8-5 (representing coarser resolution and higher sun angle) and TM16-1 (representing coarser resolution and lower sun angle) acquired on 14-5-2001, 8-5-2001 and 16-1-2001, respectively, at sun zenith angles at the image acquisition times of 17.4º, 26º and 54º, respectively; and at sun azimuth angles of 118.7º, 102º, and 145º, respectively. For same purpose, finding the optimum techniques for radiometric correction of atmospheric and topographic effects is investigated by comparing three different atmospheric correction based techniques: Radiance, Chavez (1996) COST simplified reflectance and ATCOR-3 accurate reflectance compiled using Radiative Transfer Code (RTC), and four different simplified topographic and anisotropic correction methods: Lambert (Cosine) and non-Lambert Minnaert, C-correction and Cicone and Malila's (1972) Modified Lambert.

2. RADIOMETRIC CORRECTION TECHNIQUES USED IN THIS STUDY

Before radiometric (atmospheric and topographic) corrections, all satellite images involved in this study were ortho-rectified. Slope and aspect values used for topographic correction were derived from DEM level-1 and level-2 using Erdas Imagine© software. Programs were written by the authors to perform all the radiometric corrections of image data, except for ATCOR3 Lambert correction. Minnaert and C topographic correction of the satellite images were performed using single (global) *K* and *C* coefficients.

2.1 Radiance-based Radiometric Correction

The atmospheric effect was corrected by removing path radiance from apparent (i.e., at satellite) radiance using the Chavez (1988) improved Dark Object Subtraction (DOS) method. The main disadvantages of the improved DOS method are its low accuracy and its correction only for additive scattering effects (due to path radiance) and the assumption of full upward and downward transmission.

The Lambertian (Cosine) topographic correction model has the following formula:

$$L_n = \frac{L_T}{cos(i)} \quad (1)$$

where $cos(i)$ is the cosine of the incidence angle between the sun and the normal vector to the surface; L_n is the normalised radiance (i.e., corrected for topographic effect) that would be measured when $i = e$ (exitance angle) = 0; and L_T is the radiance at tilted surface (i.e., uncorrected).

Developed by Smith et al. (1980), the Backward Radiance Correction Transformation (BRCT) employing the Minnaert law (Minnaert, 1941) can be described as:

$$L_n = \frac{L_T}{cos^k(i) * cos^{k-1}(e)} \quad (2)$$

where k is Minnaert coefficient; and e is terrain slope angle.

The C-correction formula is:

$$L_n = L_T\left(\frac{cos\ (\theta_s) + C}{cos\ (i) + C}\right) \tag{3}$$

where θ_s is sun zenith angle.

The Modified Lambertian model (Cicone and Malila, 1977) can be described as:

$$L_n = \frac{L_T}{F_{RI}} \tag{4}$$

where

$$F_{RI} = tan\ (\theta_s)\ sin\ (e)\ cos\ (\phi) + cos\ (e)$$

where ϕ is phase angle (difference between sun azimuth and terrain aspect).

2.2 Simplified Reflectance-based Radiometric Correction

This technique, which is supposedly corrects for atmospheric effects more accurately than the previously discussed radiance based technique, is implemented using the Chavez (1996) COST model, in which atmospheric downward transmittance is approximated by the cosine of the sun zenith angle, and upward transmittance is assumed 1.0 (full transmittance).

The Lambertian topographically corrected surface reflectance based on Chavez (1996) technique is expressed as:

$$\rho_{Lamb} = \frac{\pi d^2 (L_s - L_p)}{Eo * cos(i) * cos(\theta_s)} \tag{5}$$

where:
ρ_{lamb} : target surface reflectance under the assumption of surface Lambertian behavior;
L_p : path radiance for TM and SPOT images computed with an assignment of one-percent (0.01) reflectance to the dark features (Song et al., 2001);
E_0 : sun exo-atmospheric irradiance.
d: relative earth-sun distance to the mean distance in astronomical units at the image acquisition day;
$cos(\theta_s)$: cosine of sun zenith angle representing downward transmittance.

In similar manner, the Minnaert correction model integrated into the Chavez (1996) COST reflectance model is:

$$\rho_{Minneart} = \frac{\pi d^2 (L_{sat} - L_{path}) cos(e)}{E_0 cos(\theta_s)[cos(i) * cos(e)]^k} \tag{6}$$

The C-correction reflectance formula is expressed as:

$$\rho_C = \frac{\pi d^2 (L_{sat} - L_{path})[cos(\theta_s) + C]}{E_0 * cos(\theta_s)[cos(i) + C]} \quad (7)$$

The reflectance formula of the Modified Lambertian model will be similar to the Lambertian formula, except that the incidence angle is replaced by the relative insolation factor (F_{RI}):

$$\rho_{mod} = \frac{\pi d^2 (L_{sat} - L_{path})}{E_0 F_{RI} cos(\theta_s)} \quad (8)$$

2.3 Accurate Reflectance-based Radiometric Correction

The third technique to radiometric correction used in this study is assumed to be the most accurate technique in atmospheric correction, for that it uses Radiative Transfer Code (RTC). This technique is implemented using the ATCOR-3 program for atmospheric (compiled using the MODTRAN-4) and topographic correction of rugged terrain, developed by the DLR-German Aerospace Centre and integrated in Erdas Imagine© by Geosystems© Gmbh.

ATCOR-3 was used to estimate visibility, adjusted sensor calibration coefficients and aerosol type and standard atmosphere and to perform the atmospheric and topographic correction for the three satellite images used in this study.

The three images were corrected for topographic effects under the Lambertian assumption using ATCOR-3 and with Minnaert model implemented for ATCOR-3 by the present authors using the formula:

$$\rho_{Minnaert} = \frac{\rho_{Lamb}}{Cos^{k-1} i * Cos^{k-1} e} \quad (9)$$

where ρ_{Lamb} is the output Lambertian reflectance from ATCOR-3.

3. STUDY AREA

Figure 1. The study area. (a) A picture of the desert bare soil covering the study area. (b) A picture of one side of one of the waterways (Wadis) tearing the study area plateau(same small Jeep in the waterway bed is illustrated for scale purpose.

The study area is 10 km by 10 km, located in the central part of Saudi Arabia in an area between two small towns: Malham and Huraimla, 65 km to the Northwest of Riyadh, the capital city. It is composed of desert bare soil of gentle slope on top of plateau ruptured by areas of rock protrusions in steep to semi-orthogonal rock outcrops, and torn by wide waterways and small gullies (figure 1).This study area was chosen to represent the overwhelming majority of the Kingdom areas covered by same desert bare soil.

4. RESULTS AND ANALYSIS

Number of studies (e.g. Cicone and Malila, 1977; Justice et al., 1981; Thomson and Jones, 1990; Chen et al., 2001; Falkenstrum and Ekstrand, 2002) have demonstrated the effect of terrain slope on satellite image data, and consequently on topographic and anisotropic correction (using cosine, Minnaert, C-Correction, etc. techniques).

Most earth surfaces reflects unequally in all directions (anisotropy or non-Lambertian). Surface anisotropy (BRDF effects), generally speaking, is strongly manifested in backward and forward scattering, with the maximum in backward scattering. Considering desert areas, however, some studies (e.g. Holben and Justice, 1980; Takemata et al., 2000) have suggested Lambertian behaviour whereas others (e.g. Shoshany, 1993; Karnieli and Cierniewski, 2001) have suggested anisotropic (BRDF) effects. Thus, correcting for topography and BRDF effects in this study has involved Lambertian and simple empirical BRDF (non-Lambertian) models, such as Minnaert and the semi-empirical C-correction.

Owing to the major effects of terrain slope on satellite image data and topographic correction discussed earlier, performance of DEM level-1 against level-2 in topographic correction has been investigated thoroughly in this study as described below. This investigation includes the effect of terrain slope in determining terrain slope limitation, optimum topographic correction models, optimum sun elevation angles and resolution, and optimum radiometric (atmospheric) correction techniques for optimum performance of DEM level-1 compared to level-2.

4.1 Effect of *Terrain Slope* on correlation between the two DEMs radiometrically corrected data

Performance of DEM level-1 against level-2 for radiometric correction is measured here by the degree of correlation between DEM level-1 and level-2 corrected radiance images. Higher correlation indicates a greater likelihood of DEM level-1 to replace level-2. Hence, only the high correlation values ($r>0.5$) were considered. For that purpose, four monochromic (0-255; representing correlation value range of 0-1.0) images of correlation between DEM level-1 and level-2 corrected (using Minnaert, C, Modified Lambertian and Cosine models) TM8-5 NIR were produced using MIPS software (Mather, 1999). To investigate the effect of terrain slope on performance of DEM level-1 against level-2, the study area slopes were separated into four classes: 0º-5º (flat to gentle terrain), 6º-15º (moderate terrain), 16º-25º (steep terrain) and 25º+ (very steep terrain). DEM level-2 slope image was used as a source for its higher accuracy compared with that of level-1. For that purpose, Spatial Analyst Model Builder of ArcView3.3 was used to perform the slope and correlation images classifications and the arithmetic overlay analysis.

Figure 2 illustrates the results. Performance of DEM level-1 against level-2 is expressed by what we called " Relative Area Covered Percentage-RACP", which is the number of pixels of high correlation (i.e., $r>0.5$ or grey values of 127 to 255) divided by the total number of pixels in that slope class. This is to provide unbiased results to slope classes occupying larger area. Higher RACP indicates higher performance of DEM level-1 against level-2. Sharp decrease in RACP starts after the first terrain slope class 0º-5º (a drop of about 40%), then decreases asymptotically with increase of slope. This indicates that adequacy of DEM level-1 decreases with increase in terrain slope and DEM level-1 can not be an adequate alternative to DEM level-2 for topographic correction of areas with terrain slope higher than 5º. Figure 2 also shows that the differences between the four topographic correction models are unsubstantial, except possibly for the Modified Lambertian model for slopes higher than 5º, which may confirms the same coming (in the classification test) found lower sensitivity of this model to topographic effect.

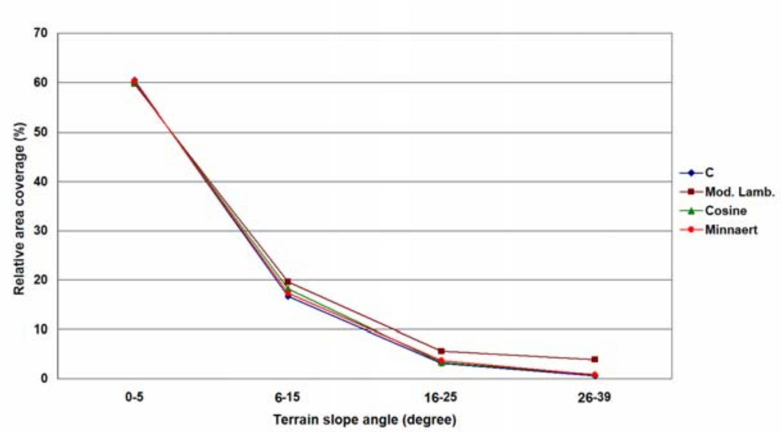

Figure 2. effect of terrain slope on the high correlation (r>0.5) between DEM level-1 and level-2 corrected radiance of NIR of TM8-5 for the four topographic correction models. Performance of DEM level-1 against level-2 represented by Relative Area Covered Percentage-RACP of high correlation values in the four slope classes.

4.1 Effect of *Terrain Slope* on Classification Accuracy Using the two DEMs radiometrically corrected data

The effectiveness of radiometric (atmospheric and topographic) correction in improving classification accuracy is still arguable in literature. Some researchers (e.g. Itten and Meyer 1993; Gitas and Devereux, 2006) have reported noticeable success in improving classification by radiometric correction, others (e.g. Teillet et. al., 1982; Song et al., 2001), however, have reported otherwise.

The DEM level-1 and level-2 radiometrically corrected images were unsupervised classified (using Erdas© ISODATA) into six spectral classes. This number of classes was chosen arbitrarily, owing to the limited number of desert bare soil types of study area and to that no limitation for the number of spectral classes that can be derived spectrally using unsupervised classification.

The effect of terrain slope on performance of using DEM level-1 instead of level-2 in classification is investigated for low and high sun elevation angles (TM8-5 and TM16-1, respectively), for the three level of atmospheric correction accuracies (Radiance, Chavez (1996) and ATCOR-3 radiometric correction techniques) and for the four topographic correction models. Each of DEM level-1 and level-2 classified images was separated into four images based on the four slope classes (0º-5º, 6º-15º, 16º-25º and >25º) using programs written by the authors. Other programs were also developed to calculate the Khat (estimate of Kappa) values (classification accuracy) of the error matrices, produced from comparing DEM level-1 classified images with those of level-2, as a reference, for the four slope classes. Classified DEM level-2 radiometrically corrected images were used in the error matrices as reference for the DEM level-1 corrected images due to the absence of ground truth (i.e., reference data) and to the fact that the assessment of DEM level-1 performance is relative to that of level-2. Khat is adopted against Overall Accuracy due to the fact that it is more informative, as it incorporates omission and commission errors (Congalton and Green, 1999).

Performance of DEM level-1 against level-2 is evaluated through the relationship between classification accuracy (Khat value) of DEM level-1 images (compared with those of level-2) and terrain slope. Figures 3(a), (b) and (c) illustrate the relationship of Khat values for the four topographic correction models with terrain slope for Radiance, Chavez (1996) and ATCOR-3, respectively. A similar general trend to that found in the previously discussed correlation test is also found here. The rate of decrease in Khat values for the high sun angle images TM 8-5 and SPOT-XI is rapid from about 80% for slope class 0º-5º to about 20% for slope class >25º. However, the rapid decrease slows by the slope class 6º-15º for the low sun angle image (TM16-1), then decreases moderately until slope class >25º. The continuous sharp drop of Khat values (classification accuracy) after slope class 0º-5º in the high sun angle images and the low Khat values in the low sun angle image beyond slopes 0º-5º indicates limitation of DEM level-1 adequacy to replace DEM level-2 to flat to gentle terrain (0º-5º) only.

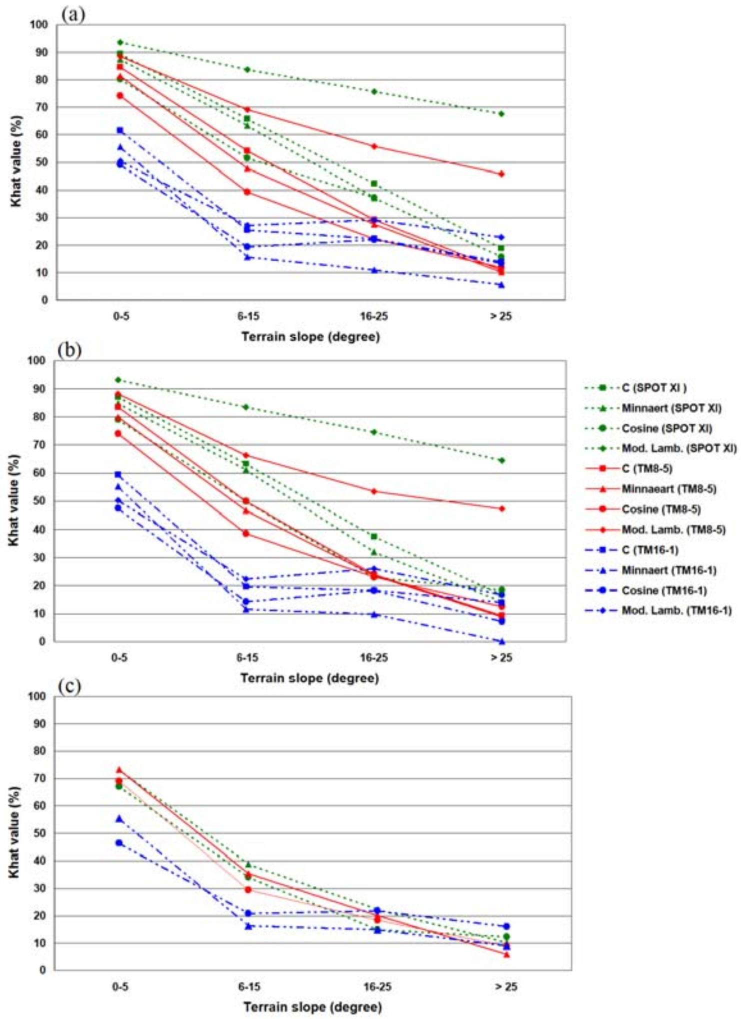

Figure 3. Effect of terrain slope on classification accuracy of DEM level-1 classified radiometrically corrected high (TM8-5 and SPOT XI) and low (TM16-1) sun elevation angle images (with reference to their corresponding DEM level-2 classified images) with the four topographic correction models using the three radiometric correction techniques. (a) Radiance results. (b) Chavez (1996) results. (c) ATCOR-3 results.

In figure 3 and based on the high sun angle SPOT-XI image using the Radiance technique, with the exception of Modified Lambertian model, C is the optimum model at all slope classes, followed by Minnaert and last by Cosine. Similar results apply for the other high sun angle TM8-5 image, but Cosine replaces C as optimum at the slope class (>25º). The higher performance of the Modified Lambertian model compared with other models in high sun angle images and its comparable performance with other models in low sun angle image TM16-1 indicates to its sensitivity to sun angle rather than to topographic effect (slope and aspect), which lowers its reliability. The Chavez (1996) technique shows similar results for SPOT-XI, except Cosine replacing C as optimum at the slope class (>25º). TM 8-5 is similar to SPOT-XI, except that C is the optimum only up to 15º, whereas Cosine is the optimum above 15º. For ATCOR-3 where only Minnaert and Cosine models are used, model ranking is similar to that of Chavez (1996), such that Minnaert is the optimum up to 25º and Cosine is the optimum above. For the low sun angle image (TM16-1), and based on Radiance and Chavez (1996) results, C is the optimum model, followed by Minnaert and least by Cosine in the flat to gentle terrain (0º to 5º). In moderate to rugged terrain (i.e., slopes higher than 5º), C is optimum, followed by Cosine and last by Minnaert. Using ATCOR-3, model ranking is similar to those for Radiance and Chavez (1996), such that Minnaert is the optimum below 5^0 and Cosine above 5º. To summarise, for optimum performance of DEM level-1, with few exceptions, if high sun angle images are used in flat to moderate terrain (slopes of 0º to 25º) using any radiometric (atmospheric) correction technique, one should use C as the optimum model, followed by Minnaert and last by Cosine. However, if the terrain is rugged (slopes higher than 25º), one should use Cosine, followed by C and last by Minnaert. For using low sun angle imagery in flat to gentle terrain (slope of 0º to 5º), C is the optimum, Minnaert comes as second and Cosine is the last. For moderate to rugged terrain (slopes higher than 5º), one should use C, followed by Cosine and last by Minnaert whose performance with DEM level-1 deteriorates with the increase of terrain slope.

For optimum sun angle, figure 3 shows that the performance of DEM level-1 against level-2 in TM8-5 is better (higher Khat values) than in TM16-1 for flat to moderate slopes (i.e., 0º-15º), then the differences decrease with increase of slope until for slopes higher than 25º where performance in TM16-1 is better than that for TM8-5 using C and Cosine models in Radiance technique (figure 3a) and C in Chavez (1996) technique (figure 3b). The better performance of DEM level-1 for TM16-1 in this slope class using Minnaert and Cosine in ATCOR-3 confirms this (figure 3c). Thus, for better performance of DEM level-1 with any topographic correction model using any radiometric (atmospheric) correction technique, high sun angle images should be used instead of low sun angle images. However and oddly, low sun angle images are better used in areas with terrain slopes higher than 25º. The reason is not clear to the authors and worthy future investigation.

For optimum image resolution, figure 3 shows that the performance of DEM level-1 in association with the fine resolution SPOT-XI image is better than that with coarser resolution TM8-5 image, except when using the Cosine model for slopes between 16º and 25º for Chavez (1996) and ATCOR-3 techniques. This exception can be ignored owing to the insignificant difference between the two images (Khat = 23.0% compared with 23.1% for Chavez (1996)) and to the many findings of weakness of the Cosine with DEM level-1. Hence, it can be said that for better performance of DEM level-1, one should use finer resolution instead of coarser resolution images for all terrain types. Differences in DEM level-1 performance (i.e., Khat values) between the two images get smaller with the increase of terrain slope.

For optimum radiometric correction technique, figure 3 illustrates that the differences in DEM level-1 performance between the three radiometric correction techniques for the high sun angle image TM8-5 decrease with increase of slope until slopes higher than 25º, after which the performances are almost identical. For the low sun angle image TM16-1, the differences increase continuously with the increase of slope for the favor of ATCOR-3. The reason for this for the hazy (visibility of 12km) TM8-5 may be the increase of dominance of atmospheric effect compared to topographic effect with the decrease of slope in flatter slopes, which lead to higher differences in atmospheric correction between the three techniques for the favor of Radiance and Chavez (1996) compared with ATCOR-3. The dominance of topographic effect in steeper slopes makes the differences smaller due to the use of marginally similar topographic correction methods by the three radiometric correction techniques. For the clearer sky (visibility of 25km) TM16-1, the explanation may be the accurate estimation of terrain contribution in radiation by ATCOR-3 (e.g. adjacency effect and terrain radiation) in the absence of or very slight atmospheric effect in a clear sky compared with other two techniques that do not consider them. From the above, it can be stated that more accurate atmospheric correction using Radiative Transfer Code-RTC (ATCOR-3) will not add substantial improvement in performance of DEM level-1 for rugged terrain (slopes higher than 25º) for high sun angle high atmospheric effect images (like TM8-5). Despite that, the accurate atmospheric correction technique ATCOR-3, which demonstrates the true but the weaker performance of DEM level-1, are preferred to be used, owing to that the apparent better DEM level-1 performances in the Radiance and Chavez (1996) are due to their poorer atmospheric effect removal and lower topographic effect influence. The performance of DEM lvel-1 compared with level-2 for all three techniques for the clear sky low sun elevation angle TM16-1 image is almost identical for flat to gentle terrain (slopes of 0º to 5º), and as slope increases, its performance using ATCOR-3 improves compared with the other two techniques. Moreover and for same image, performance of DEM level-1 using Radiance and ATCOR-3 techniques is considerably better than that for Chavez (1996).

Despite its higher accuracy and fidelity, using RTC based (ATCOR-3) atmospheric correction technique for operational use for the anticipated national land cover mapping of the Kingdom is questionable, considering the uncertainties involved in estimation of the atmospheric parameters (especially for aerosols), the cost and practicality of collecting required information about atmospheric condition for uninhabited areas

3. CONCLUSIONS

The validity of using the 100m resolution DEM level-1 of full coverage as an a adequate alternative to the 30m resolution DEM level-2 of very limited coverage for radiometric correction of satellite imagery and consequently in land cover mapping of the Kingdom of Saudi Arabia has been investigated in this study. Results have shown that the adequacy of DEM level-1 as an alternative to DEM level-2 for radiometric correction decreases with the increase of terrain slope for both high and low sun elevation angle imagery. The results have also shown that DEM level-1 can be an adequate alternative to level-2 for areas of flat to gently sloping (slopes of 0º to 5º). Although the correlation analysis have revealed insignificant differences in DEM level-1 performance between the four topographic correction models, results based on the classification analysis have clarified (emphasised) theses small differences and shown that if high sun elevation angle images are used in flat to moderate terrain (slopes of 0º to 25º) using any atmospheric correction technique (Radiance, Chavez (1996) COST simplified reflectance and ATCOR-3 accurate reflectance compiled using Radiative Transfer Code-RTC), one should use C as the optimum model, followed by Minnaert and last by Cosine. But for rugged terrain (slopes higher than 25º), one should use Cosine, followed by C and last by Minnaert. Using low sun elevation angle imagery in flat to gentle terrain (slopes of 0º to 5º), C is the optimum, Minnaert comes as second and Cosine is the last. For moderate to rugged terrain (slopes higher than 5º), one should use C, followed by Cosine and last by Minnaert whose performance with DEM level-1has been found to deteriorates with the increase of terrain steepness. The Modified Lambertian model has been found more sensitive to sun elevation angle rather than to topography (i.e., DEM information), which lowers its reliability. Results have also demonstrated the low efficiency in topographic correction of low sun elevation angle imagery, and high sun elevation angle imagery should be used for better DEM level-1 topographic correction. Oddly, performance of DEM level-1 with low sun elevation angle imagery for terrain slopes higher than 25^0 has been found better than that with high sun elevation angle imagery. The reason is not known to the authors and worthy future investigation. In addition, for better DEM level-1 topographic correction, finer resolution imagery (e.g. SPOT-XI) should be used instead of coarser resolution (e.g. TM). Use of accurate atmospheric correction implementing the Radiative Ttransfer Code in ATCOR-3 is recommended compared with the simplified models employed in the Radiance and Chavez (1996) COST reflectance techniques, for its greater fidelity in revealing the actual but weaker performance of DEM level-1 compared with DEM level-2. However, for operational use for the anticipated national land cover mapping of the Kingdom, the worth of using accurate atmospheric correction is questionable, considering the uncertainties involved in estimation of the atmospheric parameters (especially for aerosols), the cost and practicality of collecting required information about atmospheric condition for uninhabited areas. In case the use of the accurate atmospheric correction technique in ATCOR-3 is not feasible, Radiance technique has more potentiality compared with Chavez (1996) COST reflectance for better performance of DEM level-1 radiometric correction.

The authors here see the importance of performing these types of investigations on the new generation of high resolution satellite imagery, such as SPOT-5, IKONOS, etc., and see if this study derived conclusions can still be generalised and adopted.

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