A COMPARATIVE ANALYSIS OF CBERS-2 CCD AND LANDSAT-TM SATELLITE IMAGES IN VEGETATION MAPPING

Análise Comparativa do CBERS-2 e Imagens de Satélite Landsat-TM em Cartografia da Vegetação

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ABSTRACT

Moderate resolution sensors such as Landsat satellites are a vital component of earth observation and required in a wide variety of applications across many disciplines. Failure of Landsat 7 and the aging Landsat 5 could create a data gap for studies depending on medium resolution satellite data in the near future. The objective of this paper is to investigate the compatibility of CBERS-2 satellite data with the Landsat-TM satellite in land use and land cover change studies. We compared Landsat-TM and CBERS-2 Charge Coupled Device (CCD) images using four methods: intra bands similarities of reflectance values, land cover classification, vegetation indices (SR, NDVI, and TNDVI), and water index (NDWI), and found that CBERS-2 and Landsat-TM are very similar. Despite the differences in spatial resolution, coverage area and data availability between CBERS-2 and Landsat-TM, CBERS-2 was comparable to Landsat-TM and thus appears to be useful in the studies requiring vegetation mapping. To confirm the similarities of CBERS-2 and Landsat-TM data in vegetation mapping, more studies in different eco-regions are needed. Furthermore, inconsistencies in CBERS-2 data quality and availability are limitations of using CBERS-2 as an alternative source of medium resolution data in vegetation mapping.

Keywords: Landsat-TM, CBERS-2, NDVI, SR, TNDVI, NDWI

1. INTRODUCTION

The Landsat program has played an important role in providing earth observation data since 1972 (WILLIAMS et al., 2006). Unfortunately, the future of this vital data source is uncertain. Landsat-7 lost its Scan Line Corrector (SLC) in 2003 (MARKHAM et al., 2004), and there are problems with the solar array drive mechanism onboard Landsat-5 since 2005 (FREDERICK, 2005). Landsat-5, launched in 1984, is expected to run out of fuel soon (WULDER et al., 2008). Its original design life was 3 years (ENGEL, 1987); however, it still provides quality data. Landsat 7, despite the SLC failure, continues to provide degraded data set and is useful in certain earth observation studies (COHEN & GOWARD, 2004). The U.S. administration recognized possible gaps in Landsat data collections. As a result, the Landsat Data Continuity Mission (LDCM) has been commissioned to deal with the Landsat data concerns (WULDER et al., 2008). The LDCM is scheduled to be launched in December 2012. Even if the LDCM spacecraft is launched, there could be a gap between the data procured by the current working Landsat satellites and the new one. Uncertainties over secure funding and operational strategies, however, have caused scientific communities to think that there could be a crisis in Earth observation programs and to recognize the need for studies to identify the capabilities of Landsat like satellites with Landsat satellites in various applications (WULDER et al., 2008; MALAKOFF, 2000). Deteriorating quality of Landsat-7 and the uncertainty of Landsat-5 are the two major concerns that call for an investigation into the effectiveness of Landsat-like satellites in studies that use medium resolution satellite data.

The Landsat Data Gap Study Team (LDGST), formed in 2005, has examined several Landsat-like satellites to identify alternate data sources before the launch of the LDCM. Among various systems considered by the LDGST, IRS ResourceSat and CBERS sensors were relevant because of their comparable spectral, spatial, and temporal attributes, and the potential capability to acquire large-area coverage needed for land cover studies (CHANDER, 2007). Other similar and promising data sets are Satellite Pour l'Observation de la Terre (SPOT), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and the Advanced Land Imager (ALI) satellite.

Many environmental studies, vegetation studies, land-use change studies, landscape ecology, and urban planning studies within the last 30 years have extensively used Landsat satellite data. Therefore, any data gap in Landsat satellites will adversely affect these studies that have temporal components. This is an immediate problem and must be addressed. It is critical to find a fairly inexpensive and similar image quality/dependability alternative to Landsat. Therefore, this study examines the potential of using the Chinese-Brazilian earth resource satellite (CBERS-2) images as alternative data to Landsat images, especially in vegetation studies. In this study, we use Landsat-TM and CBERS-2 images to compare and contrast the two satellite data in vegetation mapping using vegetation indices and land use and land cover classifications. Section 2 discusses data and methods. The results are presented in section 3. Key ideas and findings are summarized in the conclusions section.

2. DATA AND METHODS

There are four satellite sensors (SPOT, IRS – ResourceSat and CBERS-2) that cover similar wavelengths as Landsat-TM. Table 1 shows the comparison of Landsat-TM and CBERS-2 sensors. CBERS-2 is similar to Landsat-TM in visible bands and infrared bands. Although IRS- ResourceSat and SPOT satellites also resemble Landsat-TM with respect to wavelength, only CBERS-2 is used in this study because of its close resemblance in the range of electro-magnetic spectrum to the Landsat-TM. CBERS-2 satellite images are selected also because they are relatively new and have not been used extensively in vegetation mapping unlike ResourceSat and SPOT images.

TABLE 1 – SENSOR COMPARISON BETWEEN LANDSAT-TM AND CBERS-2

LANDSAT-TM		**CBERS-2***	
Spectral Band (μm)	Resolution (m)	Spectral Band (μm)	Resolution (m)
0.45-0.52	30	0.45-0.52	20
0.52-0.60	30	0.52-0.59	20
0.63-0.69	30	0.63-0.69	20
0.76-0.90	30	0.77-0.89	20
1.55-1.75	30	1.55-1.75	80
10.4-12.4	120	10.4-12.5	160
2.08-2.35	30	2.08-2.35	80
0.52-090	15	0.50-1.10	80

* Note: CBERS-2 has two sensors: CCD for spectral bands 0.45-0.89 and IRMSS for spectral bands 1.55-2.34 and panchromatic band 0.50-1.10

2.1 CBERS Satellites

The China–Brazil Earth Resources Satellite (CBERS) program consists of two satellites. The CBERS-1 was launched in 1999, and the CBERS-2 was launched in 2003. CBERS-1 and 2 are identical in technical structure, space mission, and payload. Both satellites have sun-synchronous orbits at an altitude of 778 km (INPE, 2004). We selected CBERS-2 because the data was readily available. CBERS-2 carries three sensors including the following:

i) high-resolution (20 m) Charge Coupled Device sensor (113 km swath-width and 26 days revisit period),

ii) moderate-resolution (80/160 m) scanner - Infrared Multispectral Scanner (IRMSS) (120 km swath-width and 26 days revisit period), and

iii) coarse-resolution (260 m) Wide Field Imager (WFI) (885 km swath width and 3–5 day revisit period).

The CCD and IRMSS sensors in CBERS are similar to Landsat-TM sensors. The CCD has coverage in the visible and near infrared, whereas IRMSS has coverage in the shortwave and thermal infrared. The spatial resolution of the CCD is 20 meters in four spectral bands, which has great potential in applications within agriculture, environment, water, cartography, geology and soil (ZHAO et al. 2001, CHANDER 2007, WU et al. 2006).

2.2 Study Area

CBERS-2 and Landsat-TM images used in this study were acquired within a 5 day period (Table 2). The images covered the area close to Sao Paulo, Brazil (Fig 1). CBERS-2 CCD and Landsat-TM scenes were obtained for free from the National Institute for Space Research (INPE) for Latin America (http://www.cbers.inpe.br/en/index_en.htm).

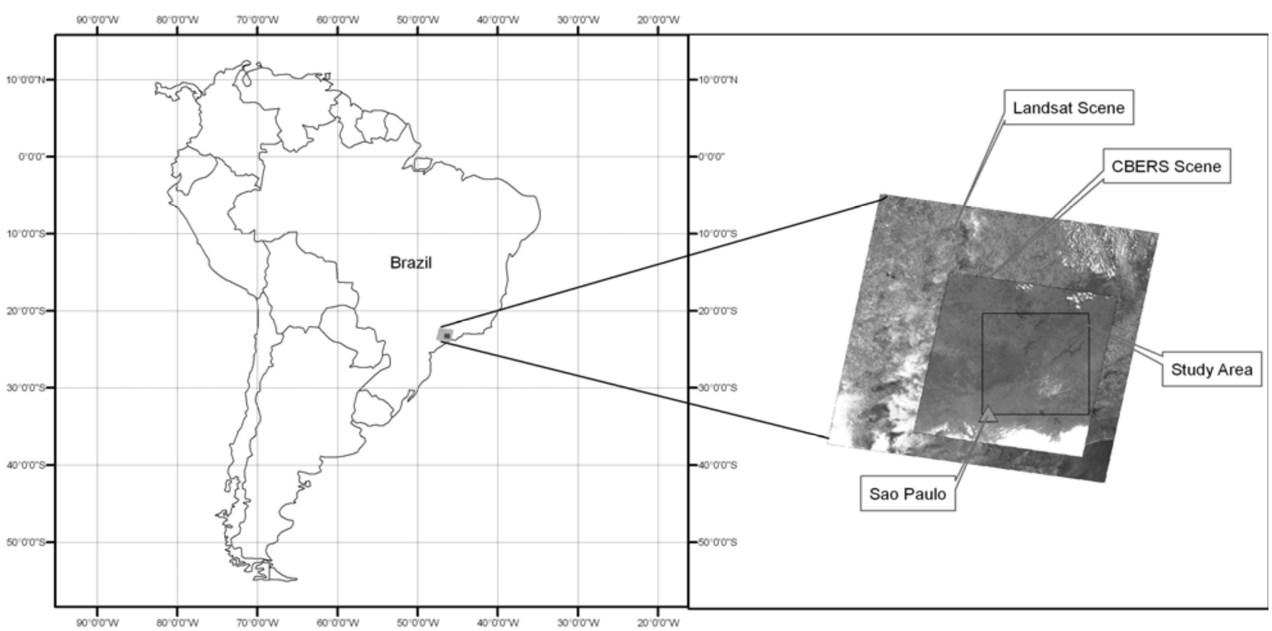

Fig. 1 Study area

The CBERS-2 image was first geo-referenced to Landsat-TM image to rectify the possible locational shift in the satellite images. Because of the lower spatial resolution of Landsat-TM compared to CBERS-2, the Landsat-TM scene had a higher area of coverage compared to the CBERS scene. The Landsat-TM image, therefore, was clipped to the size of CBERS-2 scene. Clouds in both images were masked out and excluded from the analysis.

TABLE 2 – ATTRIBUTES OF THE IMAGES USED IN THE STUDY

	CBERS-2	Landsat TM
Path	154	219
Row	126	076
Date	September 16, 2005	September 11, 2005

2.3 Comparison of Landsat-TM and CBERS-2

In this study, four types of comparisons of Landsat-TM and CBERS were used: intra band correlation, land cover classification, vegetation indices, and water index. For the comparison of images from two different sensors, at-satellite reflectance values of individual images were derived from DN values. Procedure to convert Landsat-TM DN values to radiance and then to reflectance is well documented in CHANDER et al. (2009). However, conversion of CBERS-2 DN values to reflectance values requires a different set of equations.

To convert DN to radiance following equation is used (INPE, 2004).

$$L_{apa\lambda} = \frac{DN_\lambda}{CC_\lambda} \qquad (1)$$

where $L_{apa\lambda}$ is the apparent at-sensor radiance given by W.m^{-2}.sr^{-1}.μm^{-1}.

CC$_\lambda$ is the calibration coefficient for CBERS-2 CCD spectral band λ (λ = 1, 2, 3, 4).

Calibration coefficients used are 1.009, 1.930, 1.154, and 2.127 for bands 1, 2, 3 and 4 respectively (PONZONI et al. 2008).

DN$_\lambda$ is the digital number from the CCD images in spectral band λ

The reflectance for CBERS-2 images can be derived from radiance as shown in equation 2.

$$\rho_{apa\lambda} = \frac{\pi \times L_{apa\lambda} \times D^2}{E_{sun\lambda} \times \cos(zen)} \qquad (2)$$

where, D = Earth-Sun distance in astronomic units, $Esun\lambda$ = Solar Exoatmospheric Irradiance in the top of the atmosphere in band λ. $Esun\lambda$ values used are 1934.03, 1787.10, 1548.97 and 1069.21 respectively for CBERS band 1, 2, 3 and 4 (INPE, 2004). cos(*zen*) = cosine of the solar zenith angle at the image acquisition time.

After calculating the reflectance values, 500 random sample points were generated in the study area. YAMANE (1967) provided a simplified formula (n = N/(1+NxE^2)) to calculate sample sizes. In this formula, n, N, and E represent the sample size, number of population, and sampling error, respectively. If the population is large enough, the minmum sample size goes to 400 with 5% sampling error (ISRAEL, 2009). Therfore, this study used 500 samples that is higher than 95% confidence level. The at-satellite reflectance values for each point from all four bands of both Landsat-TM and CBERS-2 were extracted. Correlation coefficients were calculated between similar bands of Landsat-TM and CBERS-2.

A combination of unsupervised and supervised classification methods was used to classify images (AMBINAKUDIGE 2006, ALVES & SKOLE, 1996). Both images were classified into 3 land cover classes: open field, urban, and vegetation. Then classified areas of each land cover class were compared.

In the next step, spectral vegetation indices (SVIs) of Landsat-TM and CBERS-2 were calculated and compared. SVIs reveal insight into the relative measurement performance through the inspection of multi-band combinations. There are multitudes of transformations available for visible-near infrared spectral measurements for monitoring vegetation. The purpose of these indices is to compensate for variable background (e.g. soil and litter) reflectance and atmospheric attenuation, while emphasizing vegetation spectral features (TRISHCHENKO et al., 2002). In this study, three SVIs generated from Landsat-TM and CBERS-2 images were used: simple ratio (SR), normalized difference vegetation index (NDVI), and transformed normalized difference vegetation index (TNDVI).

1. Simple ratio: This index is soil dependent and is sensitive to differences in sunlit and shaded soil components (HUETE, 1987; SELLERS, 1985).

$$\mathrm{SR} = \frac{\rho_{\mathrm{nir}}}{\rho_{vis}} \qquad (3)$$

where, ρ_{nir} = near infrared reflectance; ρ_{vis} = visible reflectance.

2. Normalized Difference Vegetation Index: It is a spectral transformation applied to red and near infrared bands to assess the health and vigor of vegetated surfaces.

$$NDVI = \frac{\rho_{\mathrm{nir}} - \rho_{vis}}{\rho_{nir} + \rho_{vis}} \qquad (4)$$

3. Transformed Normalized Difference Vegetation Index: This index has a more complex ratio for calculating the vegetation but only uses visible reflectance and infrared reflectance.

$$TNDVI = \sqrt{0.5 + \left(\frac{\rho_{\mathrm{nir}} - \rho_{vis}}{\rho_{nir} + \rho_{vis}}\right)} \qquad (5)$$

TNDVI values range from 0.0 and 1.0. The values approaching 1.0 are associated with vegetation cover and/or vigor, and the values approaching 0.0 are areas of low vigor or low vegetation cover (ROBERT AND DUNNO, 2001).

Finally, normalized difference water index (NDWI) values from CBERS-2 and Landsat-TM images were compared. The water content is useful to identify soil and plant moistures (JENSEN 2004). To assess water content in a normalized way, MCFEETERS (1996) introduced NDWI as:

$$NDWI = \frac{Green - NIR}{Green + NIR} \qquad (6)$$

where Green is a green band such as TM band 2, and NIR is a near infrared band such as TM band 4.

This index maximizes the reflectance of water by using green wavelengths and minimizes the low reflectance of NIR by water features. It takes advantage of high reflectance of NIR by vegetation and soil features. As a result, water features have positive values, while vegetation and soil usually have zero or negative values (MCFEETERS 1996).

3. RESULTS

3.1 Inter Band Comparison

The inter band comparison using correlation coefficients showed that the bands of Landsat-TM images are highly correlated to the corresponding bands in CBERS-2 (Fig. 2). Band 4 in CBERS and Landsat-TM had 91 percent correlation. Similarly, band 1 ($r = 0.73$), band 2 ($r = 0.84$) and band 3 ($r = 0.84$) also had very high correlations (all correlations are significant at the 0.01 level) indicating CBERS could give results very similar to the results of Landsat-TM based vegetation mapping.

TABLE 3 – LAND-COVER CLASSIFICATION (ha)

Land Cover	**Landsat-TM**	**CBERS-2**	**Difference**
Open field	987.30	912.84	74.46 (Landsat-TM 8% more)
Urban	3566.52	3595.24	-28.72 (CBERS has 0.8% more)
Vegetation	1231.20	1254.60	-23.4 (CBERS has 1.9% more)

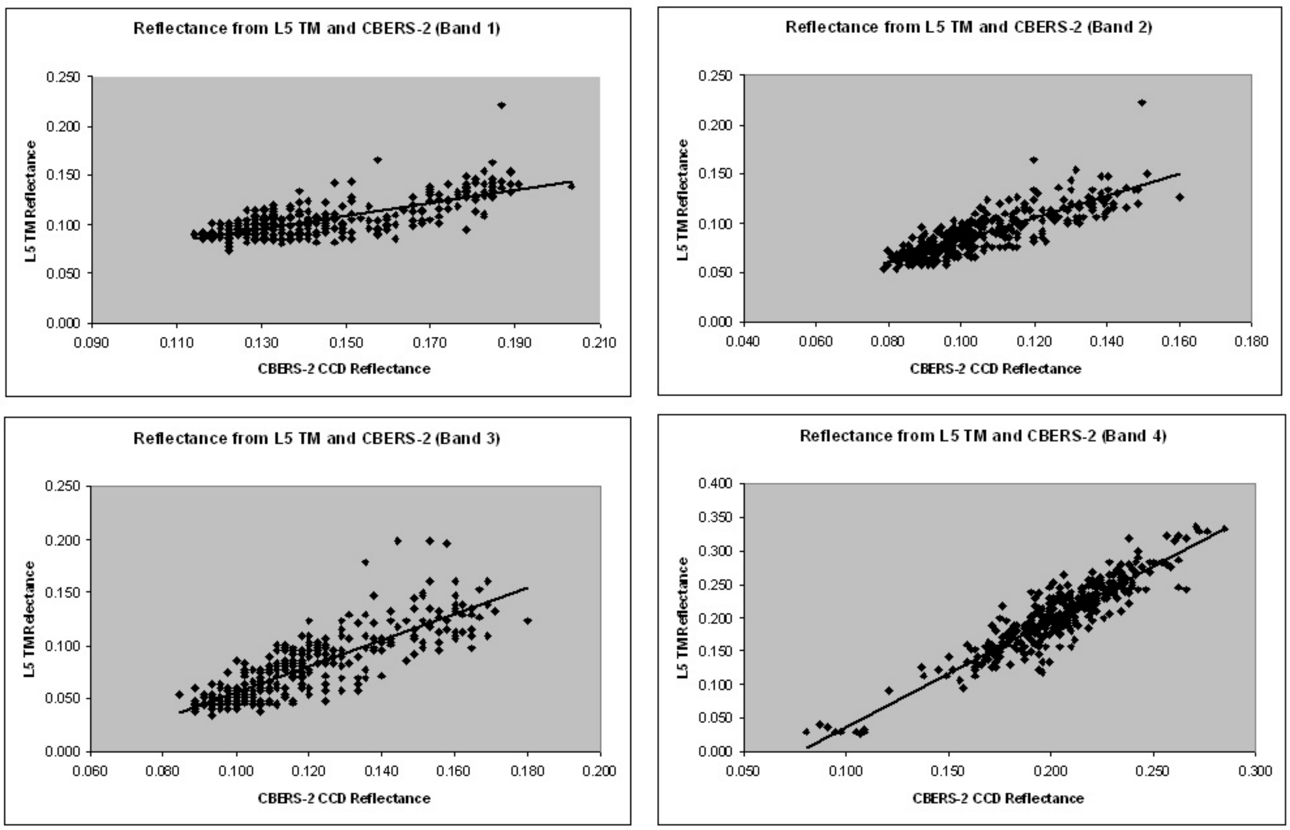

Fig 2. Correlations between CBERS-2 AND LANDSAT-TM bands

3.2 Comparison using Land Cover Classification

In the study area, three land cover classes were identified using a combination of unsupervised classification and supervised classification methods. Only a small area is selected for this analysis because of the lack of ground familiarity of the study area.

In this small area, we could visually identify the open field, urban, and vegetation land-cover classes.

It was found that CBERS-2 image classified more area as vegetation than the Landsat-TM image. The Landsat-TM image, on the other hand, had more urban area compared to that in CBERS-2 (Table 3). For 'Open field' category, the Landsat-TM image had about 8% larger area than that in CBERS-2 image. Both urban and vegetation areas classified in Landsat-TM image are 0.8 % and 1.9 % smaller than those in CBERS-2 image, respectively. Differences could be attributed to differences in spatial resolutions and difference in image acquisition dates. Overall accuracy of CBERS land cover classification was 80% and

Landsat-TM classification was 81%. High resolution images from Google Map were used in accuracy assessment.

3.3 Comparison using Vegetation Indices

In this section, results of three vegetation indices from the Landsat-TM and CBERS-2 images are discussed. The results of the experiments (Table 4) indicate that vegetation indices of Landsat-TM and CBERS-2 are correlated to each other. The mean NDVI values calculated from Landsat-TM (0.35) and CBERS-2 (0.37) are very close to each other. There is a high correlation between the values of NDVI derived from Landsat-TM and CBERS-2 ($r = 0.92$ and $p < 0.01$). Similarly, TNDVI ($r = 0.92$) and SR values ($r = 0.88$) are also significantly highly correlated at 0.01 level. This comparative analysis of vegetation indices also confirms that Landsat-TM and CBERS-2 images produce very similar outcomes when used for vegetation mapping.

To compare water areas in CBERS-2 and Landsat-TM images, we computed NDWI and compared their values with each other. We also found a high correlation ($r = 0.92$ & $p < 0.01$) in water areas between Landsat-TM and CBERS-2 data. Fig. 3 shows the scatter plots of NDVI, NDWI, SR and TNDVI indices derived from Landsat-TM and CBERS-2 images. This comparative analysis using spectral indices clearly indicates that land cover classes from Landsat-TM and CBERS-2 images are highly comparable to each other.

TABLE 4 – CORRELATION BETWEEN THE VEGETATION INDICES CALCULATED FROM LANDSAT-TM AND CBERS-2.

Vegetation Index	Landsat (Mean Value)	CBERS (Mean Value)	Correlation between Landsat-TM and CBERS-2
NDVI	0.35	0.37	0.923**
TNDVI	0.95	0.87	0.919**
SR	3.05	2.90	0.879**
NDWI	-0.37	-0.31	0.917**

** Correlation is significant at 0.01 level (2 tailed)

4. CONCLUSIONS

Uncertainties in Landsat program have created a potential for future data gap for the studies that depend on medium resolution satellite data. There is a need to explore the potential of using Landsat-like satellite data to bridge the data gap. In this study, we

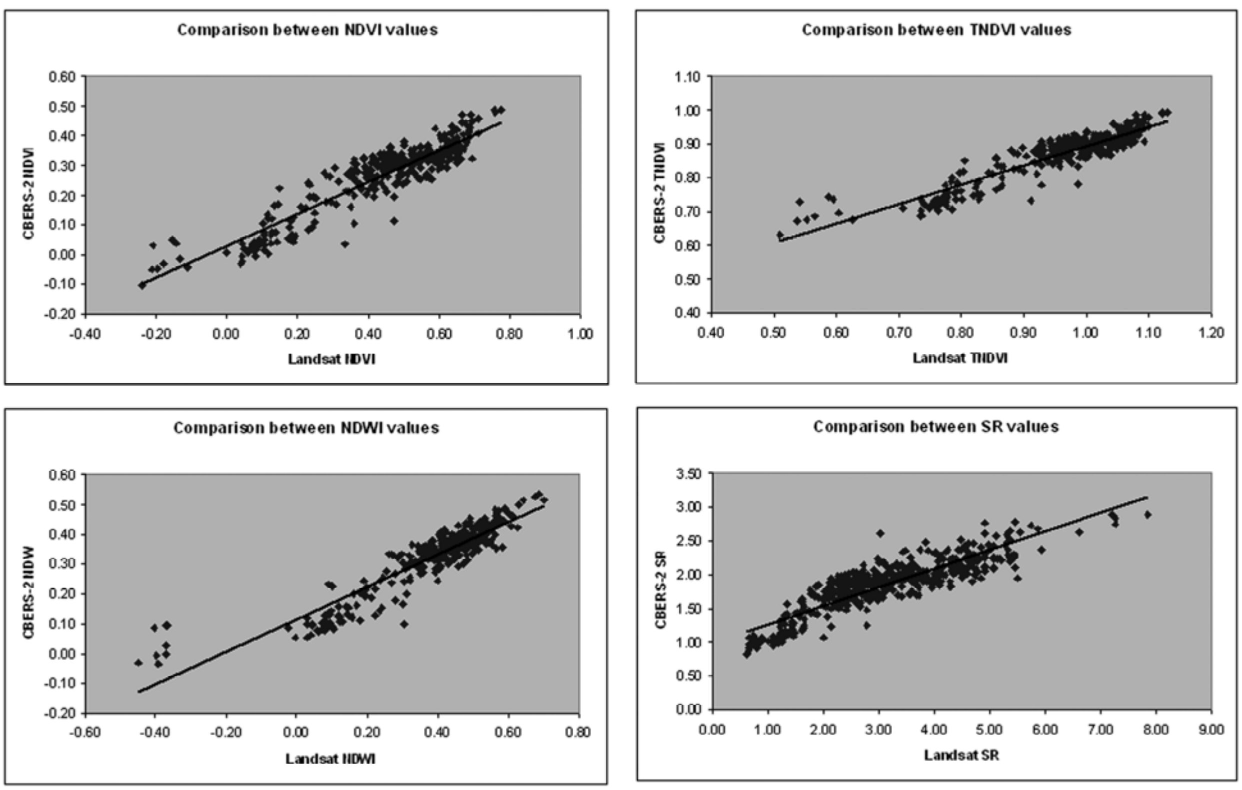

Fig 3. Comparison between cbers-2 and Landsat-TM in NDVI, TNDVI, NDWI and SR indices

examined the potential of using Chinese Brazilian Earth Resource Satellite (CBERS-2 CCD) images in absence of Landsat images. Despite some minor differences between Landsat-TM and CBERS-2 in spectral and spatial resolutions, CBERS-2 is very similar to Landsat-TM in various other aspects, especially in image quality and spectral bandwidth. This makes CBERS-2 a potential candidate for an alternative source in the case of data gap in Landsat program.

This study compared CBERS-2 with Landsat-TM through four methods: band-by-band at-satellite reflectance value, land cover classification, vegetation indices, and NDWI. Landsat-TM and CBERS-2 images had an average 89% correlation between the at-satellite reflectance values of similar bands. There was only about 3% difference in the areas of three Land-cover classes estimated by each satellite image. Mean values of NDVI, TNDVI, and SR of Landsat-TM and CBERS-2 images were very close to each other. There is about 87 % correlation between the indices estimated by TM and CBERS-2 images. NDWI indices are also highly correlated. The discrepancies, though very small could be attributed to the differences in spectral resolution, and five days gap between the acquisition dates of these two images.

This study showed that Landsat-TM and CBERS-2 satellite data are very similar, and they can be used interchangeably in studies that require vegetation mapping. To confirm the compatibility of CBERS-2 data with Landsat-TM data in vegetation mapping, more studies in various eco-regions are needed. Moreover, inconsistent data quality and availability of CBERS-2 satellite images reported recently is an issue that could affect the outcome of using it as an alternative data source for vegetation studies.

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