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Original Article

A novel method for Sentinel-2 satellite images radiometric calibration

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ABSTRACT

Background and objective: To use the data from any remote sensing satellite, accurate radiometric calibration is needed, so various algorithms and methods have been developed. Absolute and Relative Models of Radiometric Corrections Due to the relative information provided from different parts of the globe, there are always errors when correcting images, which has led many researchers to develop local models or design tools to obtain information about the situation of Atmospheric of the area under study when the satellite passes. The present study aims to present a new method for radiometric correction of satellite images.
Material and methods: To apply the proposed method for correcting the calibration of satellite images, a sun-photometer was first designed and developed that can obtain atmospheric data and attenuate sunlight in the range of 400 to 950 nm in a hyperspectral mode. Sentinel-2 satellite images related to the city of Tehran were selected as a sample and in 2 days with clean and high pollution, data were obtained and the coefficients obtained were applied through a sun-photometer.
Results and conclusions: Based on made assessments, the importance of radiometric corrections based on local information for satellite images become more apparent. Evaluation of the research results shows the high capability of the designed sun-photometer in accurately assessing the attenuation of sunlight in different spectral. The amount of sunlight attenuation in the green band is more than the blue and red bands, which indicates the type of urban pollution in the region, which had the greatest impact on the green band and the least impact on the red band.

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1. Introduction

Satellite images provide information about phenomena of the Earth and atmosphere based on radiation reflected from those objects (Read & Torrado 2009; Dehestani Ardakani 2021; Ghane Ezabadi et al., 2021). Ensuring the quality and accuracy of the earth-orbiting satellite sensor's image data throughout its operating lifetime requires regular monitoring of its radiometric and geometric performance (Farhad et al., 2020). To use the data from any remote sensing satellite, accurate radiometric calibration is needed (Kabir et al., 2020), so various algorithms and methods have been developed (Liu et al., 2020). Gaofen-6 (Yang et al., 2020), Landsat-8 (Xu et al., 2020 & Helder et al., 2018), Landsat-7 (Obata et al., 2018), MODIS (Angal et al., 2014), examples of research that has been done to radiometric correction of satellite images. Sentinel-2 was launched in 2015, by the European Space Agency (ESA) as part of the Copernicus program (Isbaex & Margarida 2021). Sentinel-2 satellite collects imagery by two satellites with a revisit cycle of 5 days (Szantoi & Strobl 2019, & Ariza et al., 2018). Radiometric correction of Sentinel-2 images has been done using various tools and methods as one of the satellites that provide images free for users (Goryl et al., 2017). One of the most important components of radiometric correction used for this satellite imagery is radiometric calibration sites (Gao et al., 2020). Various tools are used for radiometric correction of satellite images, one of which is the sun-photometer (Huseynova 2015 & Chen et al., 2016). Using a sun-photometer, the amount of attenuation of sunlight is measured based on atmospheric components and at different wavelengths and is applied to it to correct the images as coefficients (Li et al., 2016). In one of the researches done for radiometric correction, Rapid Eye satellites have been used. They dedicated calibration concepts to optimize the spectral and spatial homogeneity across all the imagers over the foreseen mission. This will be achieved by a temporal calibration for the radiometric corrections using both camera alignment and scale calibration and camera focal plane calibration (Read et al., 2020). Calibration and verification of remote sensing instruments are one of the most important steps in preparing satellite data. Many satellite sensors (especially in the visible spectra) are not adjusted by on-board calibration. Hence, post-launch satellite radiometric calibration is quite a challenging process, but is necessary for physically defined retrieval of essential variables. Providing methods to overcome the problems of satellite data calibration has been always a major challenge that has been investigated in numerous studies and provided solutions to them (Muller 2014).

The present study aims to present a new method for radiometric correction of visible and NIR images of the Sentinel-2 satellite. For this purpose, a sun-photometer capable of obtaining data at visible and NIR wavelengths was designed and built to use to obtain the atmospheric conditions of the region during the passage of the satellite. Then, using a special software environment, the coefficients obtained by a sun-photometer were applied to Sentinel-2 images. In this study, for the first time in Iran, satellite images are corrected using local atmospheric data derived from sun-photometer information. One of the innovations of this research is the development of a single-channel sun-photometer to hyperspectral, which makes it possible to cover a wide range of remote sensing satellites. Based on the capabilities of the designed system, it is assumed that the use of local information has better results than radiometric corrections with software models. Based on the information provided, it is expected that the designed system will meet the needs of Iranian researchers about radiometric corrections of satellites and be a step towards self-sufficiency in this industry.

2. Material and methods

The following figure provides an overview of the flowchart of this research. (Figure. 1).

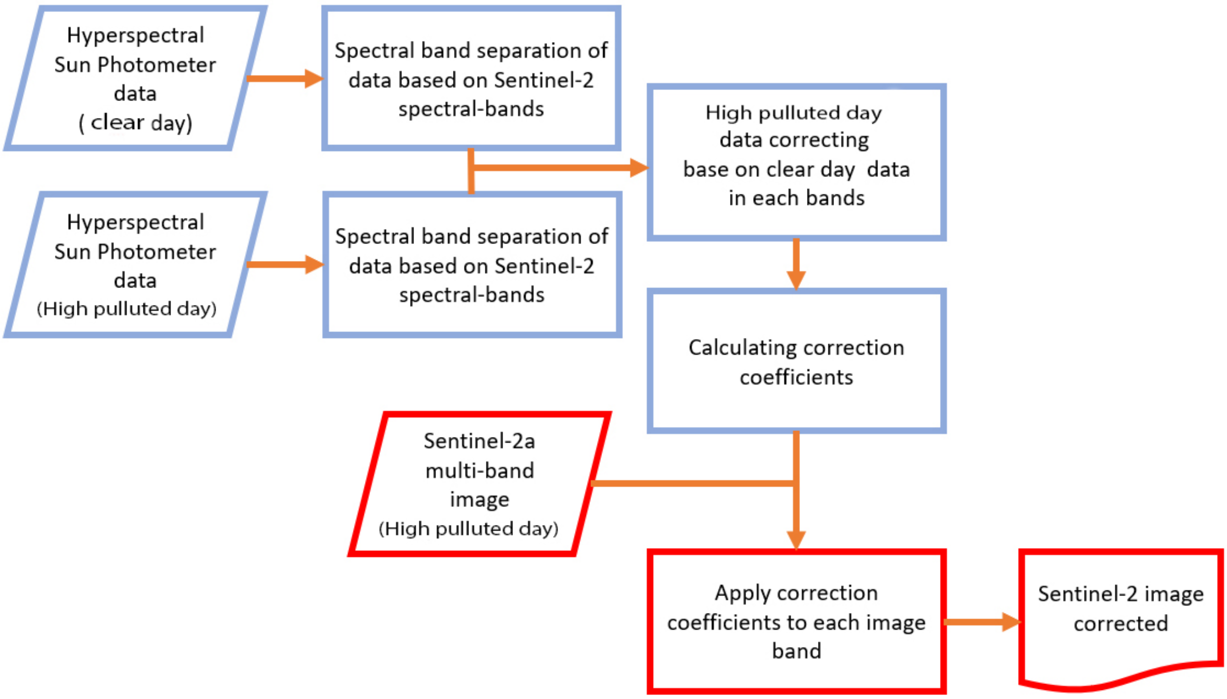

Fig 1. Research flowchart

2.1. Study area

Tehran province is one of the 32 provinces of Iran, with a total area of 12981 km². It is located to the north of the central plateau of Iran, spanning over 34º to 36º5´N and 50º to 53ºE. (Figure. 2).

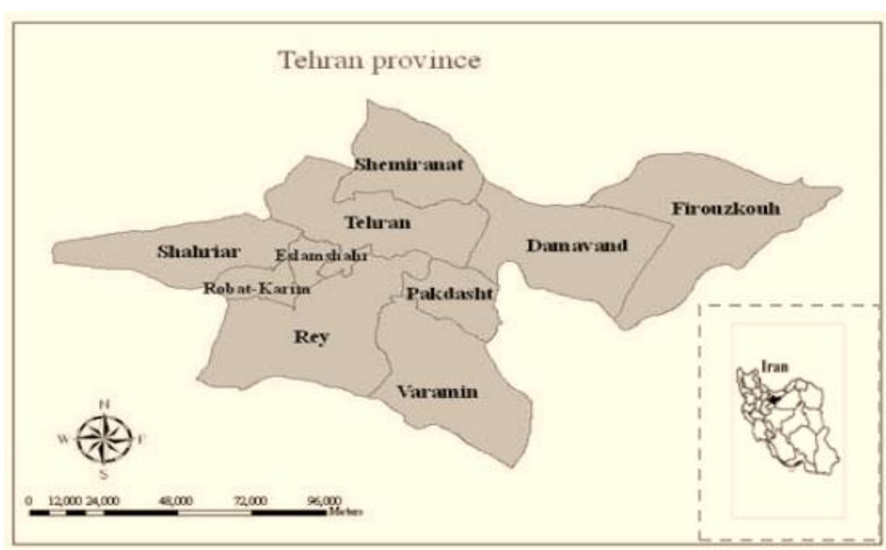

Fig 2. Geographic location of study area (Soltani et al., 2011)

2.2. Data used

Sentinel-2 remote sensing satellites have multispectral imaging systems and acquire optical images in VIS, NIR, and SWIR (Nedkov. 2018). Sentinel-2 operated by ESA, and the satellites were manufactured by a consortium led by Airbus Defense and Space (Karim & Van Zyl). The mission supports several services and applications such as land monitoring, cities management and land cover/use classification (Huryna et al., 2019). More information about the Sentinel 2 satellite is provided below (Table.1).

Table 1. Sentinel-2 satellites properties (Phiri et al., 2020)

		Sentinel-2A		**Sentinel-2B**	
Spatial Resolution(m)	Bands	Central wavelength(nm)	Bandwidth(nm)	Central wavelength(nm)	Bandwidth(nm)
10	Band2- Blue	492.4	66	492.1	66
	Band3- Green	559.8	36	559	36
	Band4- Red	664.6	31	664.9	31
	Band8- NIR	832.8	106	832.9	106
20	Band6- Red edge	740.5	15	739.1	15
	Band7- Red edge	782.8	20	779.7	20
	Band8A- Narrow NIR	864.7	21	864	22
	Band11- SWIR	1613.7	91	1610.4	94
	Band12- SWIR	2202.4	175	2185.7	185
60	Band1- Coastal aerosol	442.7	21	442.2	21
	Band9- Water vapor	945.1	20	943.2	21
	Band10- SWIR cirrus	1373.5	31	1376.9	30

Sentinel-2 data is in different forms. This is because Sentinel-2 MSI satellites images face in different stages of processing to reach a best level that can be accessed by the whole of users. The main processing formats include Level-0, Level-1A, Level-1B, Level-1C and Level 2A. Level-0 and Level- 1A are not accessible by the users. Level-1B product is made with 25 by 23. Level 1B images provide radiometrically corrected imagery with Top-Of-Atmosphere (TOA) radiance values. Level-1C is made in an orthorectified format. Using DEM data, Level-1C is produced in cartographic. Level 2A images can also be processed from level 1C images by using the Sentinel-2 Toolbox and SNAP software. From all these data products, Level-1C (Top-of- Atmospheric reflectance) and Level-2A (Bottom-of-Atmospheric reflectance) are the most commonly used products in many field of land, air and resource management (Phiri et al., 2020). The data used in this research are presented in the table below.

Table 2. Sentinel-2 satellites images used

Satellite	acquisition date	Image mode	Properties
Sentinel-2	12 January 2021	TOA	High pollution day
Sentinel-2	12 January 2021	BOA	
Sentinel-2	23 January 2021	TOA	Clear day
Sentinel-2	23 January 2021	BOA	

2.3. Sun-photometer

A sun-photometer is a type of photometer imaged in such a way that it points at the sun. Recent sun-photometers are automated instruments incorporating a sun-tracking unit, an appropriate optical system, a spectrally filtering device, a photo detector, and a data acquisition system. The measured quantity is called direct-sun radiance. To track the sun's momentum to measure direct light and the scattered light of particles in the Earth's atmosphere, the camera must track the sun in both Azimuth and Elevation directions with high accuracy. For this reason, two DC motors equipped with an encoder were used to track the moment of the sun in two directions, Azimuth and Elevation. Also, due to the need for high torque or power, a 12-volt DC motor was used. To direct sunlight and eliminate stray lights, a collimator and a pin-hole were used. To scatter the incoming light towards a linear sensor is used as a detector component, it is necessary to place a diffraction grating in the light path. The light reflected from the diffraction grating is sent by the linear sensor to the driver and the spectrum of the sun is displayed in the sensor software.

Fig 3. View of the designed sun-photometer

3. Results and discussion

Radiometric correction of satellite images is one of the most important preprocessing operations to optimize data to extract more accurate information from images. To radiometrically correction the Sentinel-2 images, the information obtained from the sun-photometer was used in this study. In the first step, a suitable place was selected for the installation and operation of the sun-photometer to perform the data collection operation. Based on the nature of the research and to evaluate the efficiency of the system and the proposed method, which was radiometric correction based on local information, signaling was performed in 2 days with clean and high pollution. The designed sun-photometer is capable of measuring the attenuation of sunlight from a wavelength of 400 to 950 nm. In this study, we used the range of 400 to 700 nm and bands 2, 3, and 4 of the Sentinel-2 satellite. Based on the selected spectral range and bands of the images used, the signals obtained from the sun-photometer were segmented and the signals related to the desired spectral ranges were separated. In the next step, a special software package was designed and developed to fit clean day and polluted day signals to determine the degree of signal attenuation in each spectral band and present it as coefficients applicable to the images. Below is a view of the software designed for radiometric calibration of Sentinel-2 images. (Figure. 4).

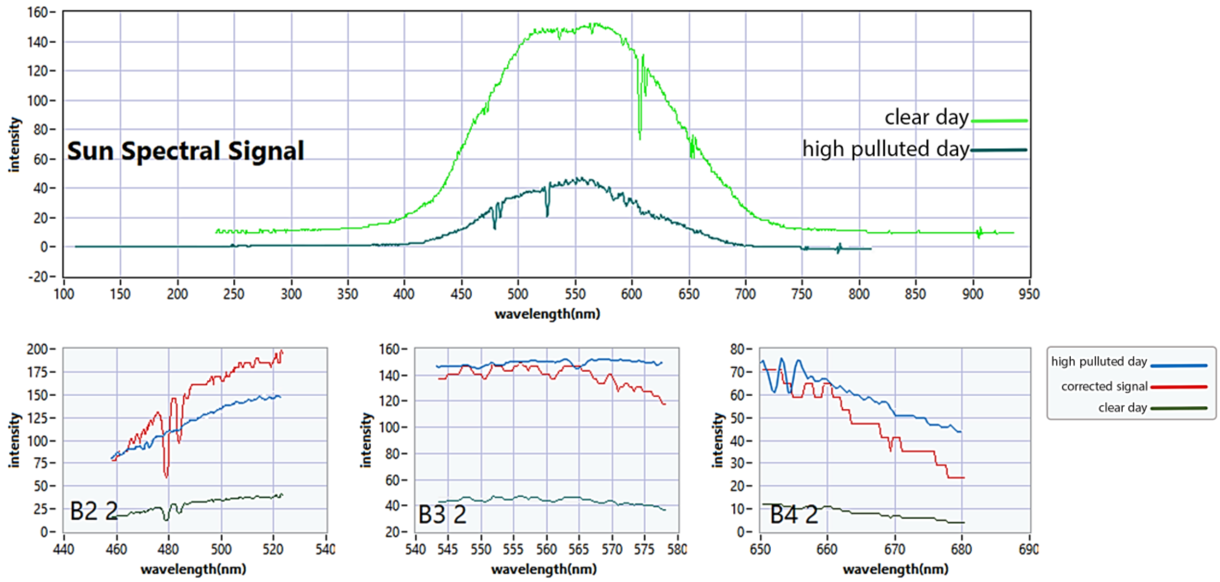

Fig 5. Designed software

Based on the information obtained from the software, gain and offset values were calculated for each of the bands, which are shown below. (Table. 3).

Table 2. Gain and offset value for visible bands of Sentinel-2 based on sun-photometer data

	Blue	Green	Red
Gain	4.85291	3.18544	5.92622
Offset	0.256259	0.0885208	-0.239741

In the next step, we applied the obtained gain and offset on the visible single bands of the Sentinel-2 sensor. The results of this correction are shown in the following figures. In these images, the raw data of the high pollution day of the study area and the corrected data of each band are shown.

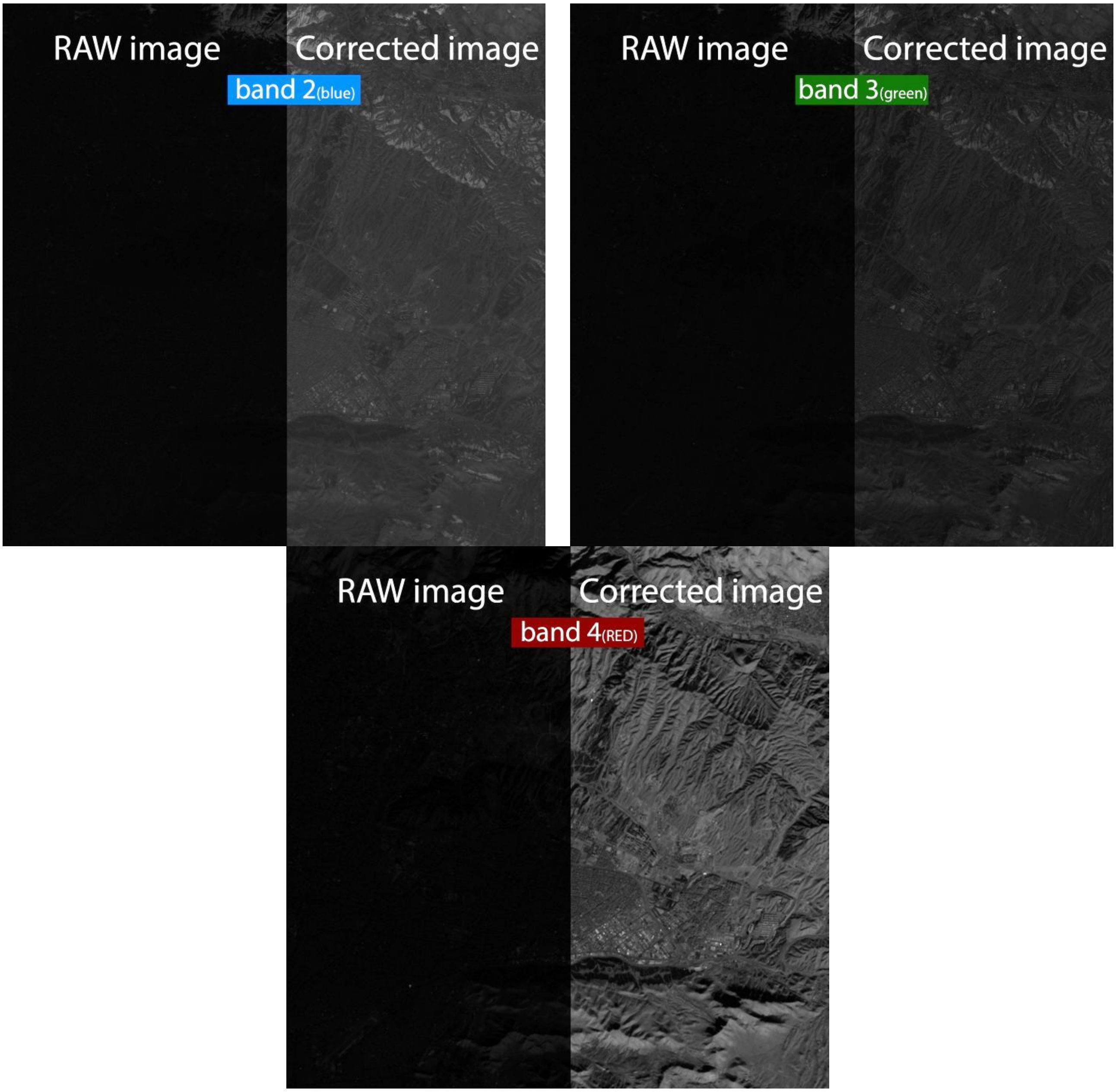

Fig 5. Raw and corrected images of sentinel-2 visible bands

Based on the information presented in the images above, the importance of radiometric corrections based on local information for satellite images becomes more apparent. Evaluation of the research results shows the high capability of the designed sun-photometer in accurately assessing the attenuation of sunlight in different spectral. The amount of sunlight attenuation in the green band is more than the blue and red bands, which indicates the type of urban pollution in the region, which had the greatest impact on the green band and the least impact on the red band. To better compare and validate the sun-photometer data and the proposed method, the raw image of the clean satellite day was also obtained and a comparison was made with the calibrated data of the contaminated day, which is shown below.

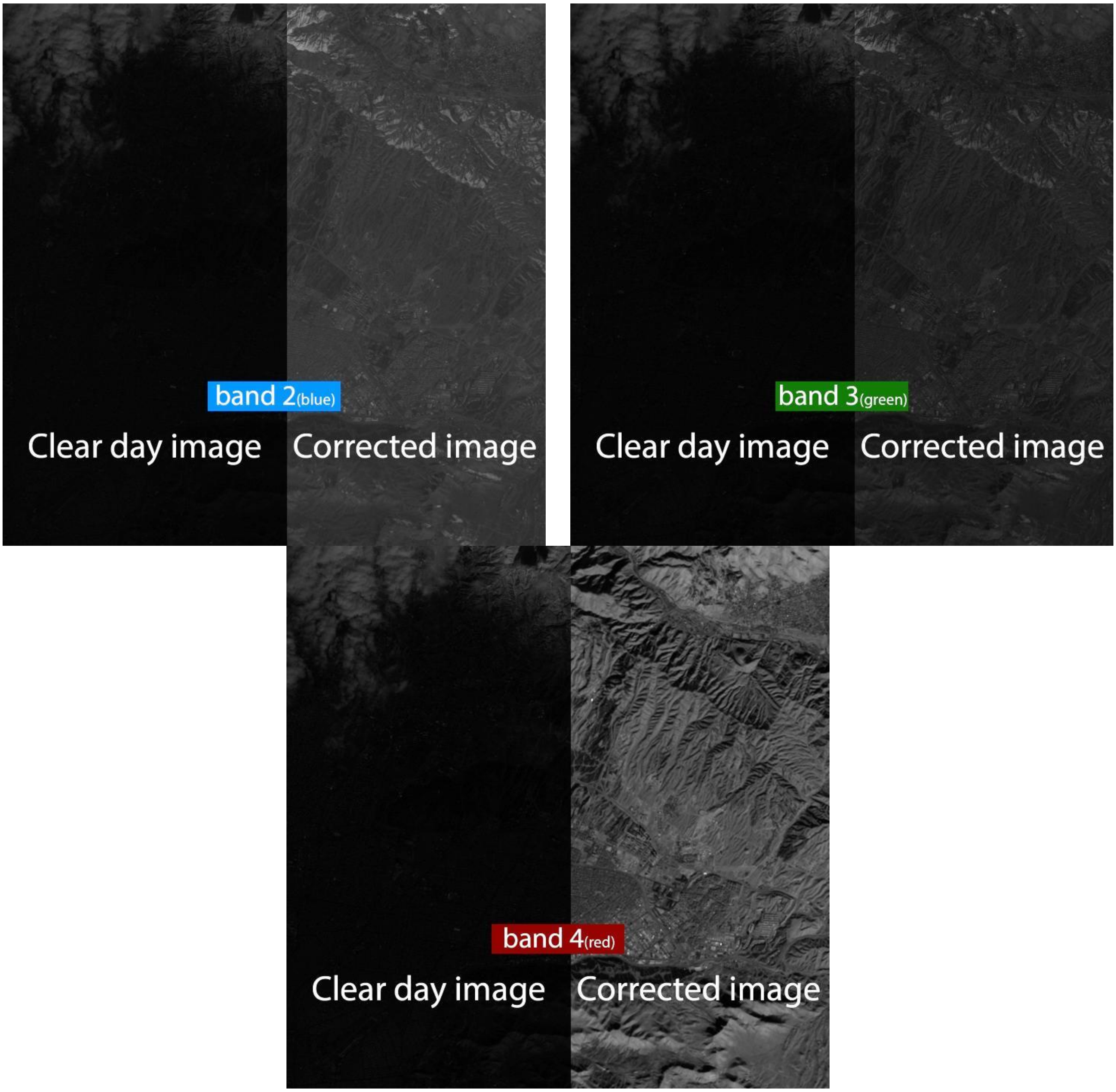

Fig 6. Raw clear day images and calibrated images

Compared with (Angal et al., 2014), in this research, field data has been used. Also, in the mentioned research, MODIS data has been used for calibration, which in a way has errors in the data and needs corrections based on local information. Also compared to (Chen et al., 2016), they have used the Dunhuang site, which is a reference site and has been used extensively to obtain the required information. The present study was conducted for the first time in the geographical area of Iran and for the first time, such information has been used in the field of remote sensing in Iran to calibrate satellite images.

4. Conclusions

Radiometric correction of satellite images is one of the most important preprocessing required for all remote sensing images to obtain high-precision ground-based data. Various methods and algorithms have been developed to do this, generally based on predefined models or generalized to local models on images. But the point is that sometimes different areas are much different in terms of the presence of aerosols and contaminants than predicted in ready-made models. When faced with such errors during radiometric correction of images, it is necessary to use local atmospheric information to correct the errors, which in turn requires accurate tools to be able to provide accurate and comprehensive information about atmospheric conditions at the moment of satellite passage. In this research, to radiometric correct the images of the Sentinel-2 satellite, a sun-photometer is designed and developed that is capable of obtaining atmospheric information in various ranges of the electromagnetic spectrum. The results of this study show the great importance of using local information when using satellite images, which necessitates the development of tools to obtain local information about the atmosphere and the state of the sun. Because in this research, raw satellite data was used, so the data was not entered in software environments that manipulate images for visualization, and all stages of the research were performed based on software developed. One of the most important challenges of this research was the lack of similar domestic research and the lack of similar foreign projects. According to the evaluations, similar sun-photometers manufactured in different countries of the world can only be operated in a few spectrums, while by overcoming obstacles and localizing the knowledge of these devices, in this research it developed as hyperspectral mode, and a big step in the development of science Remote sensing and satellite images calibrating technology has been taken. Based on the results obtained in this study, the hypothesis of improving the image calibration process using local information by a sun-photometer is confirmed.

Declarations

Funding Information (private funding by authors, or funding’s ID)
Conflict of Interest /Competing interests (None)
Availability of Data and Material (Data are available when requested)
Code availability (available when requested)

REFERENCES

Angal, A., Mishra, N., Xiong, X., & Helder, D. (2014). Cross-calibration of Landsat 5 TM and Landsat 8 OLI with Aqua MODIS using PICS. Earth Observing Systems XIX.https://doi.org/10.1117/12.2062165

Ariza, A. , Irizar, M.R. , & Bayer, S. (2018). Empirical line model for the atmospheric correction of sentinel-2A MSI images in the Caribbean Islands. European Journal of Remote Sensing , 51(1), 765–776. https://doi.org/10.1080/22797254.2018.1482732

Chen, L., Jing, Y., Zhang, P., & Hu, X. (2016). Analysis of aerosol properties derived from sun photometer and lidar over Dunhuang radiometric calibration site. Remote Sensing of the Atmosphere, Clouds, and Precipitation VI. https://doi.org/10.1117/12.2228016

Dehestani Ardakani, M. R. (2021). Dust time series analysis using long-term monthly images of MERRA2 satellites and Sentinel5 images in Google Earth Engine. *Journal of Nature and Spatial Sciences (JONASS)*, *1*(2), 16-26.

Farhad, M. M., Kaewmanee, M., Leigh, L., & Helder, D. (2020). Radiometric Cross Calibration and Validation Using 4 Angle BRDF Model between Landsat 8 and Sentinel 2A. Remote Sensing, 12(5), 806. https://doi.org/10.3390/rs12050806

Gao, C., Liu, Y., Liu, J., Ma, L., Wu, Z., Qiu, S., … Wang, N. (2020). Determination of the Key Comparison Reference Value from Multiple Field Calibration of Sentinel-2B/MSI over the Baotou Site. Remote Sensing, 12(15), 2404. https://doi.org/10.3390/rs12152404

Ghane Ezabadi, N., Azhdar, S., & Jamali, A. A. (2021). Analysis of dust changes using satellite images in Giovanni NASA and Sentinel in Google Earth Engine in western Iran. *Journal of Nature and Spatial Sciences (JONASS)*, *1*(1), 17-26.

Goryl, P., Nieke, J., Dransfeld, S., Mecklenburg, S., Berruti, B., Donlon, C., … Hoersch, B. (2017). Status of copernicus Sentinel-2A and Sentinel-3A optical calibration and validation activities. 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). https://doi.org/10.1109/igarss.2017.8126957

Helder, D., Markham, B., Morfitt, R., Storey, J., Barsi, J., Gascon, F., … Pahlevan, N. (2018). Observations and Recommendations for the Calibration of Landsat 8 OLI and Sentinel 2 MSI for Improved Data Interoperability. Remote Sensing, 10(9), 1340. https://doi.org/10.3390/rs10091340

Huryna, H., Cohen, Y., Karnieli, A., Panov, N., Kustas, W. P., & Agam, N. (2019). Evaluation of TsHARP Utility for Thermal Sharpening of Sentinel-3 Satellite Images Using Sentinel-2 Visual Imagery. Remote Sensing, 11(19), 2304. https://doi.org/10.3390/rs11192304

Huseynova, R. O. (2015). Two-Wavelength Method for Calibration of High-Precision Sun Photometer. Izvestiâ Vysših Učebnyh Zavedenij. Priborostroenie, 393–396. https://doi.org/10.17586/0021-3454-2015-58-5-393-396

Isbaex, C., & Margarida Coelho, A. (2021). The Potential of Sentinel-2 Satellite Images for Land-Cover/Land-Use and Forest Biomass Estimation: A Review. Forest Biomass - From Trees to Energy. https://doi.org/10.5772/intechopen.93363

Kabir, S., Leigh, L., & Helder, D. (2020). Vicarious Methodologies to Assess and Improve the Quality of the Optical Remote Sensing Images: A Critical Review. Remote Sensing, 12(24), 4029. https://doi.org/10.3390/rs12244029

Karim, Z., & van Zyl, T. (2020). Deep Learning and Transfer Learning applied to Sentinel-1 DInSAR and Sentinel-2 optical satellite imagery for change detection. 2020 International SAUPEC/RobMech/PRASA Conference. https://doi.org/10.1109/saupec/robmech/prasa48453.2020.9041139

Li, Z., Li, K., Li, D., Yang, J., Xu, H., Goloub, P., & Victori, S. (2016). Simple transfer calibration method for a Cimel Sun–Moon photometer: calculating lunar calibration coefficients from Sun calibration constants. Applied Optics, 55(27), 7624. https://doi.org/10.1364/ao.55.007624

Liu, Y.-K., Ma, L.-L., Wang, N., Qian, Y.-G., Zhao, Y.-G., Qiu, S., … Li, C.-R. (2020). On-orbit radiometric calibration of the optical sensors on-board SuperView-1 satellite using three independent methods. Optics Express, 28(8), 11085. https://doi.org/10.1364/oe.388387

Müller, R. (2014). Calibration and Verification of Remote Sensing Instruments and Observations. Remote Sensing, 6(6), 5692–5695. https://doi.org/10.3390/rs6065692

Nedkov, R. (2018). Quantitative Assessment of Forest Degradation after Fire Using Ortogonalized Satellite Images from Sentinel-2. https://doi.org/10.7546/grabs2018.1.11

Obata, K., Tsuchida, S., & Yoshioka, H. (2018). Evaluating radiometric calibration of ASTER VNIR band with Terra MODIS, Landsat 7 ETM+, and Landsat 8 OLI. Earth Observing Missions and Sensors: Development, Implementation, and Characterization V.https://doi.org/10.1117/12.2324419

Phiri, D., Simwanda, M., Salekin, S., Nyirenda, V., Murayama, Y., & Ranagalage, M. (2020). Sentinel-2 Data for Land Cover/Use Mapping: A Review. Remote Sensing, 12(14), 2291. https://doi.org/10.3390/rs12142291

Read, J. M., & Torrado, M. (2009). Remote Sensing. International Encyclopedia of Human Geography, 335–346. https://doi.org/10.1016/b978-008044910-4.00508-3

Read, J. M., Chambers, C., & Torrado, M. (2020). Remote Sensing. International Encyclopedia of Human Geography, 411–422. https://doi.org/10.1016/b978-0-08-102295-5.10589-x

Soltani, S. R., Monavari, S. M., & Mahiny, A. S. (2011). Urban land use management, based on GIS and multicriteria assessment (Case study: Tehran Province, Iran). 2011 International Conference on Multimedia Technology. https://doi.org/10.1109/icmt.2011.6001730

Szantoi, Z., & Strobl, P. (2019). Copernicus Sentinel-2 Calibration and Validation. European Journal of Remote Sensing, 52(1), 253–255.https://doi.org/10.1080/22797254.2019.1582840

Xu, Y., Feng, L., Zhao, D., & Lu, J. (2020). Assessment of Landsat atmospheric correction methods for water color applications using global AERONET-OC data. International Journal of Applied Earth Observation and Geoinformation, 93, 102192. https://doi.org/10.1016/j.jag.2020.102192

Yang, A., Zhong, B., Hu, L., Wu, S., Xu, Z., Wu, H., … Liu, Q. (2020). Radiometric Cross-Calibration of the Wide Field View Camera Onboard GaoFen-6 in Multispectral Bands. Remote Sensing, 12(6), 1037. https://doi.org/10.3390/rs12061037