Research Article

Characterizing spatial structure of urban tree cover (UTC) and impervious surface cover (ISC) density using remotely sensed data in Osmaniye, Turkey

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Received: 29 October 2019 / Accepted: 1 February 2020 / Published online: 10 February 2020

Abstract

Urban trees provide a wide range of significant benefits, and their degradation can result in air pollution and floods, and can damage public health and decrease social welfare. The purpose of this research was to estimate the urban tree cover (UTC) and impervious surface cover (ISC) density and to evaluate how they influence forest gain and loss in Turkey. Accordingly, i-Tree Canopy random point sampling and remote sensing methods were applied using the most current Landsat 7 Enhanced Thematic Mapper Plus images of Osmaniye City. The results indicate that the majority ($n=217$) of random points were overlapped with buildings on aerial photograph with a percent cover estimate of 34.1 ± 1.88%. Also, the second highest number of the randomly selected points ($n=166$) overlapped with road cover at estimate of 26.1 ± 1.74%. Grass cover ($n=68$), ISC ($n=59$), and shrub cover ($n=52$) percentages were estimated as 10.7 ± 1.22%, 9.26 ± 1.15%, and 8.16 ± 1.08%, respectively. UTC ($n=41$) percentage was estimated as 6.44 ± 0.97% in the urban city center. The lowest percent cover of randomly selected points was parking lots ($n=34$) estimated as 5.34 ± 0.89%. Also, the forest loss intensity was unevenly distributed and reflected areas with high population density, and forest cover loss was estimated at the highest level on the east side of the city center. The findings of this research suggest that urbanization around the city center of Osmaniye has altered the local vegetative cover due to deforestation activities to create areas for building construction and new developments.

Keywords Green infrastructure · Impervious surface · Random sampling method · Remote sensing · Urban tree cover

1 Introduction

During the twentieth century, the population of the world increased from 220 million to 2.84 billion people and is expected to reach 5 billion by 2030 [1]. Also, urbanization has become one of the most important land-cover processes around the world, and today, more than half of the world's population resides in urban areas [2, 3]. Urban vegetation is a well-studied ecological component and has been recognized by urban dwellers as a fundamental feature for human well-being [4–6].

Urban trees provide a wide range of significant benefits such as reducing energy consumption and urban heat island effect, managing storm water, improving air quality, controlling soil erosion, and creating wildlife habitat and species dispersal routes [4, 7–9]. Urban trees also supply improvement in scenic beauty of a city neighborhood, privacy, reduction in stress of public, decrease in cognitive fatigue, enhancement in stronger social cohesion and community empowerment, and creation of attractive areas to consumers for retail purposes [10–12].

Urban tree canopy (UTC) is a beneficial metric which calculates the proportion of area occupied by tree and shrub

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canopies when viewed from vertical direction [13]. UTC is a rapid metric in terms of time of computation, and it does not include tree species, leaf volume, health, and spatial distribution of trees [1]. Non-field-based methods used to estimate UTC can be categorized as random point sampling and remote sensing methods. UTC also differs from other technologies such as LiDAR because it is a cheap and quick method, and estimates more accurate data of temporal depth than satellite-based metrics [14–16].

i-Tree Canopy is a software which estimates vegetation (tree, shrub, grass) and other cover classes (buildings, roads, other impervious surfaces) within a city boundary using a random sampling method. The software allows users to define points randomly onto Google Earth imagery which provides percentage estimates of cover classes and vegetation benefits (annual economic and air pollutant removal estimates) [17, 18]. The photo-interpreted tree canopy estimation has been discussed as an economically efficient and less time-consuming method in several studies [1, 16, 19, 20]. On the other hand, field measurements of tree canopy cover are usually considered as expensive methods and cannot provide a complete coverage of large-scale areas, but it is possible to determine individual trees and their canopy cover with field-based estimation techniques [21, 22].

There are several studies focusing on UTC monitoring [12, 14, 16], and their findings show that UTC calculation is a less complex method for accurately producing maps in contrast to satellite metrics. However, the existing monitoring system is limited for low-resolution aerial photographs in terms of random sampling method application using a rapid and satellite-based metrics. In this regard, there is a gap in the literature monitoring the UTC and impervious surface cover (ISC) and their relationship with forest cover and loss in the city of Osmaniye, Turkey. Also, this is the first prospective research that estimated the UTC, ISC, and vegetation benefits of the said city. Therefore, the purpose of this study is to estimate the relationship between UTC, ISC, and the forest cover change between 2000 and 2019 in Osmaniye, Turkey. This assessment was conducted to provide a better understanding of the most current urban tree canopy and impervious surface cover area along within the city boundaries of study area. It also aims to provide how urbanization has impacted the tree canopy distribution and impervious surface cover revealed by the growth of urban landscape over the mentioned time period.

2 Materials and methods

2.1 Study area

The city of Osmaniye is located on the eastern edge of the Çukurova plain. The coordinates from the northern hemisphere are 30°00″–37°08″ north latitude and 36°13″–36°20″ east longitude. The city is surrounded by Gaziantep to the east, Kahramanmaras to the north, Hatay to the south, and Adana to the west. The city is lowland and flat, and the mean altitude of the study area is 121 m. The city was established in 1996, and the city center has been characterized with increasing population in recent years from 146,788 people in 2000 to 534,415 people in 2018 due to migration from rural areas (Fig. 1) [3, 23, 24]. The major problems encountered in the city are unemployment, internal migration, deforestation, and urbanization.

2.2 Data acquisition and methodology

i-Tree Canopy random sampling method was created by the US Department of Agriculture (USDA) Forest Service and provides an accurate estimate of tree canopy and other cover classes such as grass, building, and impervious surface within the boundary of areas preferred [16, 17]. The tool allows users to select random points on aerial photographs, and the user classifies each point into a cover class (e.g., tree, building, grass) [18]. Estimated UTC and ISC can be also derived as percent or area, and also accuracy and precision of cover types can be calculated using i-Tree Canopy tool. The tool suggests 500–1000 random sample points to increase the accuracy of UTC estimation with a confidence level at 95% [16].

Estimation of UTC and ISC was carried out for 1000 randomly selected points in the study area. Due to cloudy aerial imagery, 637 of 1000 sample points were determined to be used for the i-Tree Canopy estimation tool (Fig. 2). The selected random points were classified into seven categories as tree, shrub, grass, building, road, parking lot, and impervious surface. The descriptions of defined cover types are provided in Table 1.

Percent tree cover, forest loss, and forest gain data are associated with the time series metrics using a decision tree which are hierarchical classifiers that determine land-use class membership [19]. In this study, the oldest cloud-free aerial image of study area (2000) and the most recent available year for Landsat imagery (2019) were chosen. To calculate the forest cover change estimate for the years 2000 and 2019, two images (for the years 2000 and 2019) of the most recent available the US Geological Survey (USGS) Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

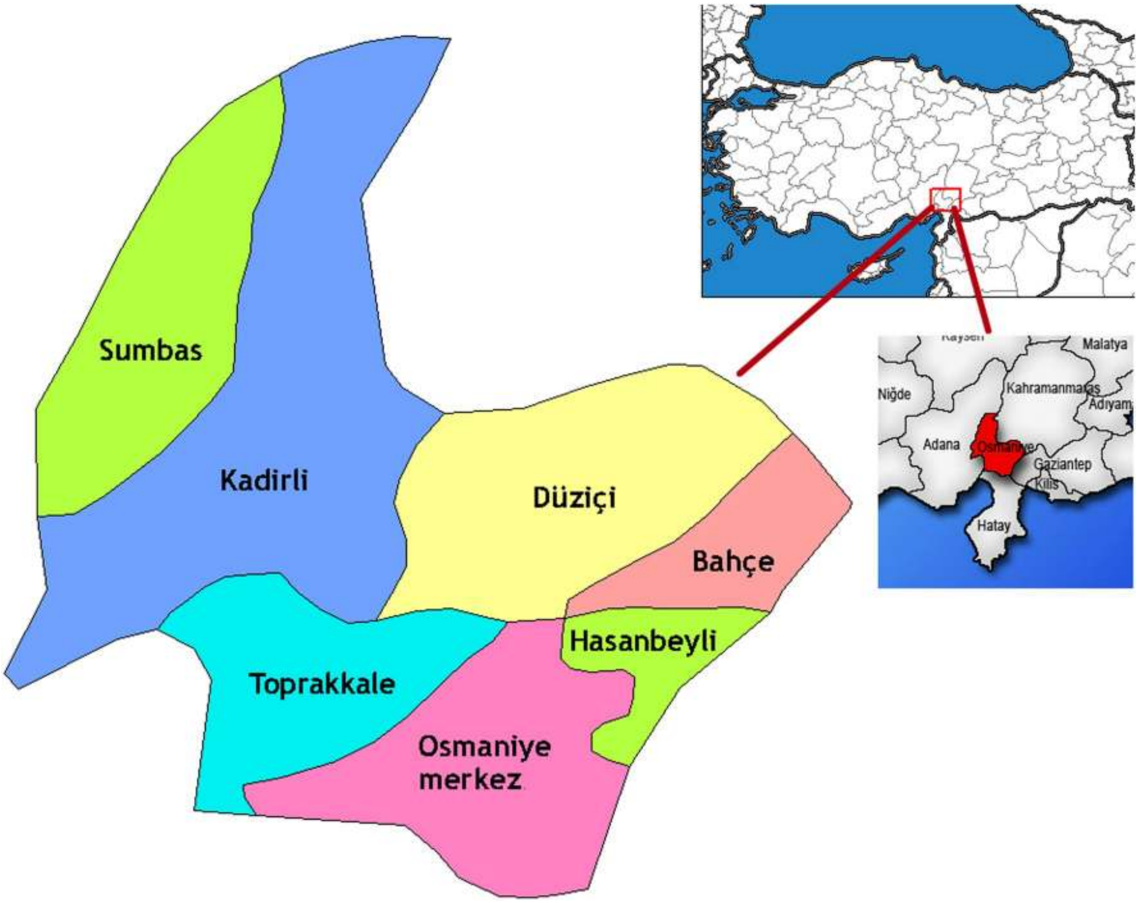

Fig. 1 Location of the city of Osmaniye and its towns

of the study area obtained on May 1, 2019, were used. The Landsat 7 ETM + images projected with World Geodetic System (WGS) 1984 coordinate system were projected with the Universal Transverse Mercator (UTM) projection at 30 m resolution using ArcGIS 10.3 software. The forest cover change, forest loss, and forest gain data of the study area were derived from Global Forest Watch database with the data accuracy at 99.6% [25].

The method classifies plants taller than 5 meters high as trees. Forests were determined as 30% or greater canopy cover for trees in the study area. To verify the dataset and improve interpretation, QuickBird images derived from Google Earth™ were applied as reference materials [26]. To estimate the tree cover change, decision tree method derived from [19] was used. The method applies ordinary least squares (OLS) of the regression, where y = annual loss and x = year in Eq. 1:

$$y_i = \beta_0 + \beta_1 x_i + u_i \quad (1)$$

where all β's were estimated by OLS. β_0 is a constant term, and β_1 is the slope of the equation. y_i is dependent variable, x_i is independent variable, and u is a white noise error term in the equation.

3 Results and discussions

The results of i-Tree Canopy estimation tool analysis showed that the majority ($n = 217$) of random points were overlapped with buildings on aerial photographs with a percent cover estimate of 34.1 ± 1.88%. Also, 166 of the randomly selected points ($n = 166$) overlapped with road cover for an estimate of 26.1 ± 1.74%. Grass cover ($n = 68$), impervious surface cover ($n = 59$), and shrub cover ($n = 52$) percentages were estimated as 10.7 ± 1.22, 9.26 ± 1.15%, and 8.16 ± 1.08, respectively. Tree cover ($n = 41$) percentage was estimated as 6.44 ± 0.97% in the urban city center.

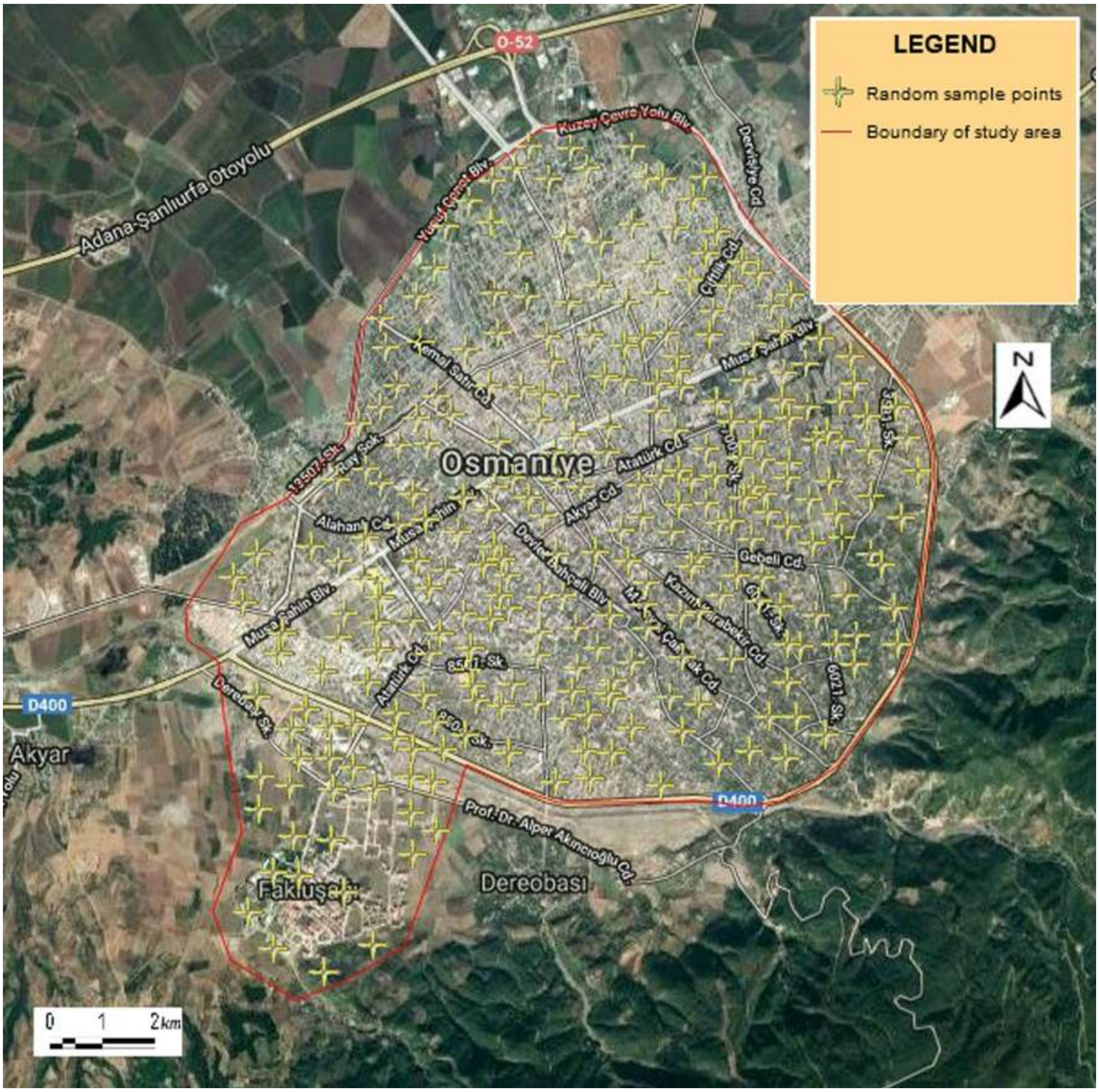

Fig. 2 Distribution of random sample points ($n=637$) on aerial imagery to estimate UTC and ISC of study area [18]

Table 1 Results of UTC and ISC estimation using random sampling method ($n=637$) with the i-Tree Canopy estimation tool

Cover class	Description	Points defined on map	% Cover estimate (± SE)
Tree	Trees located in the urban city center	41	6.44 ± 0.97
Shrub	Shrubs with smaller canopy cover	52	8.16 ± 1.08
Grass	Open space with grass cover	68	10.7 ± 1.22
Building	Buildings located in the urban city center	217	34.1 ± 1.88
Road	Primary and secondary roads	166	26.1 ± 1.74
Parking lot	Parking lots adjacent to buildings and roadsides	34	5.34 ± 0.89
Impervious surface	Surfaces other than roads and parking lots	59	9.26 ± 1.15

The lowest percent cover of randomly selected points was parking lots ($n=34$) estimated as 5.34 ± 0.89% (Table 1).

The geospatial analysis results are presented in Fig. 3 which designates the percentage of tree cover and forest

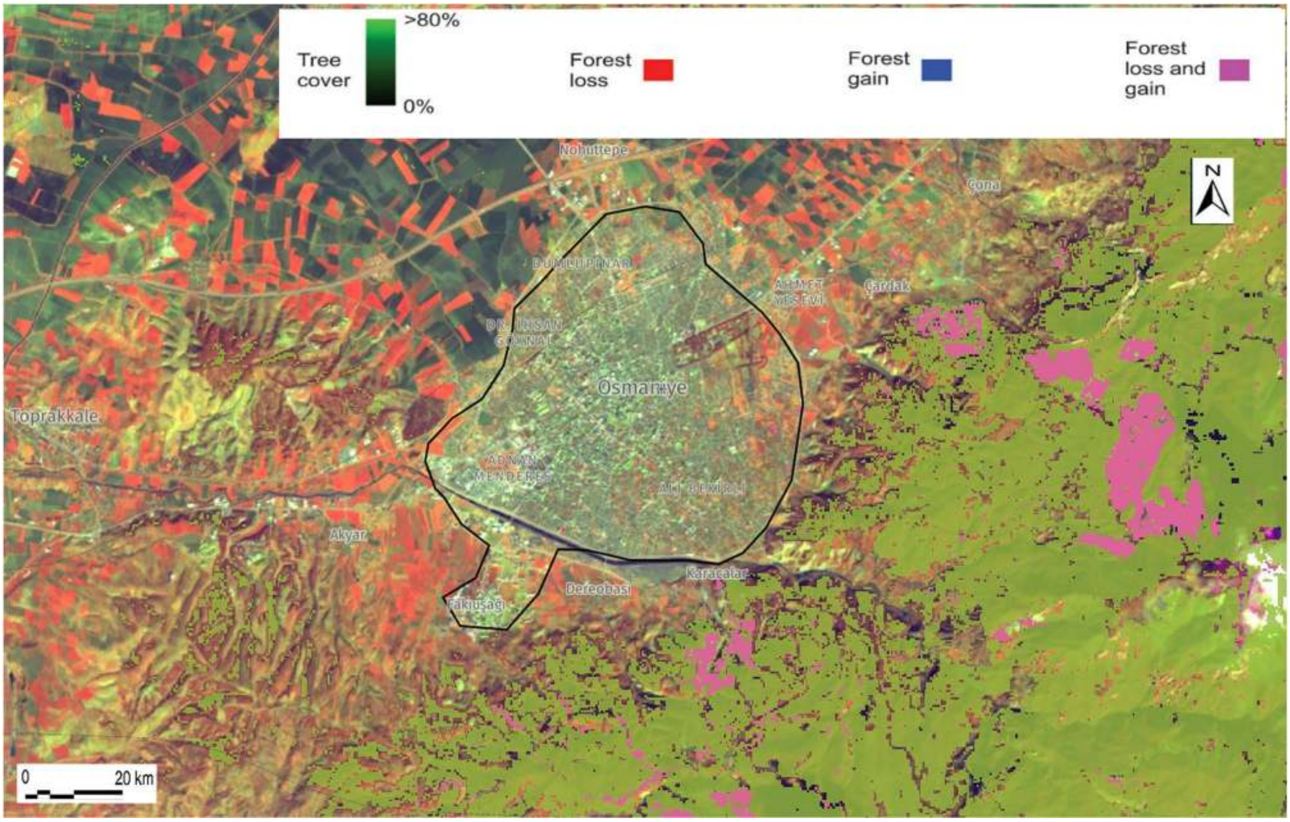

Fig. 3 Map of estimated the most current UTC with forest loss, forest gain, and forest loss and gain between 2000 and 2019 for the study area

gain and loss distribution throughout the study area. The results showed that the forest loss intensity was unevenly distributed and overlaid the areas with high population rates in the study area. UTC was estimated approximately 25% in the urban city core, and forest cover loss was higher on the east side of the delineated city center boundary on the map. As radiating out from the city center boundary, the forest cover loss increased with distance from the city center, yet tree cover was highest 80% on the southeast side of the study area for the years 2000 and 2019 (Fig. 3).

In many cases, non-field-based methods used to estimate UTC such as random point sampling and remote sensing methods can be more beneficial and effective for small-scale landscapes than field-based methods [16]. More importantly, National Land Cover Database (NLCD)-derived tree canopy estimates can be lower than cover estimates derived from higher imagery resolution due to fine-scale variations in UTC and ISC which were not considered by the NLCD technique [27]. Thus, in this study, both random sampling method and geospatial analysis were used to increase the estimation accuracy of UTC and ISC, thereafter to evaluate how forest cover loss and gain distributed for the years 2000 and 2019 in the study area.

The random sampling method analysis results showed that the majority of the sample points ($n = 217$) at 34.1% were overlapped with buildings located in the urban city center. On the contrary, the tree cover ($n = 41$) was 6.44% as the second lowest percent cover of selected random points in the study area. In addition, geospatial analysis results showed that forest loss intensity was unevenly distributed and observed on remarkably populated landscapes. UTC was estimated at approximately 40% in the urban city core, and forest cover loss was higher on the east side of the city center. Since Osmaniye City has been negatively influenced by urbanization and land-use change over the last two decades [3, 24], the results of this research may suggest that UTC has been altered by ISC increase due to development factors such as clearing trees to create space for impervious surfaces.

Based on the geospatial analysis (Fig. 3) of current UTC with forest loss, forest gain, and forest loss and gain results, forest loss has significantly increased along an urban–rural gradient of the study area. However, the forest cover of southeast neighborhood of the urban city center was highest (80%) which is the mountainous landscape and rural area. These results can help explain that except for the southeast side rural area, forest cover loss has been negatively impacted by urban development, whereas forest cover gain had the lowest distribution in the urban city core of study area. Some researchers [28–30] have derived tree cover and "greenness" distribution relying on high-resolution land-cover data to provide high diversity and variation of land-cover change in urbanized areas. However, in this study, due to insufficient data and lower aerial imagery resolution of the study area, individual tree canopy cover estimates could not be calculated.

Several previous studies [5, 6, 31] discussed the public health benefits and social life quality of public driven by the increase in urban tree cover density. For example, Ulmer et al. [30] examined the health benefits of tree cover density in urban areas and they concluded that the increase in urban tree cover density was related to lower obesity rates and better social cohesion. In another study, Troy et al. [32] evaluated impacts of vegetative cover on private lands and residents in Baltimore, Maryland, and found that income and level of education were positively correlated with urban vegetation and tree cover. As a result, for the present study, the increase in UTC density by afforestation activities and forest management practices in urban neighborhood and roadsides could help promote public health benefits in city of Osmaniye.

4 Conclusions

This study highlights estimation of the UTC, ISC density and their relationship with forest cover change for the years 2000 and 2019 in city of Osmaniye, Turkey. The integrated i-Tree Canopy estimation tool made it possible to test the effects of urbanization by combining geospatial analysis of forest gain and loss of the study area. The results of this research suggest that urban tree cover density was negatively influenced by urban expansion in city center due to the fact that buildings were the most dominant cover type in the study area. One major leading factor of the decrease in UTC and the increase in ISC could be that urbanization around the city center of Osmaniye has altered the local vegetative cover due to deforestation activities to create areas for building construction and new developments. Insufficient maintenance of current open green spaces could also be one of the most important risks concluding with major forest loss and increase in ISC in the study area.

Another possible consequence of the decrease in vegetative cover can be public health issues and the increase in surface runoff in the urban city center, but further data and analyses are required to determine driving factors of urbanization in the study area. The i-Tree Canopy tool supports the inclusion of individual pixels of aerial imagery which plays a vital role in regional planning, decision making, and planning of green infrastructure in contrast to gray infrastructure. By implementing urban green space improvement studies using urban design and development alongside open-source software estimation tools such as the i-Tree Canopy, developing small-scale landscapes can further benefit from scenarios that aim to understand negative impacts of urbanization in the future.

Acknowledgements The author would like to thank anonymous reviewers for their constructive comments.

Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

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