Journal of Scientific Research and Reports

Volume 29, Issue 9, Page 22-34, 2023; Article no.JSRR.104548
ISSN: 2320-0227

Qualitative Analysis of the Cooling Potential of the Streetside Vegetation of Kharagpur, West Bengal, India

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Authors' contributions

This work was carried out in collaboration between both authors. Author SPB designed the study, supervised through writing the protocol of the study and the analyses and checked the draft of the manuscript and suggested different ways to improve the same. Author AC managed the literature searches, wrote the protocol, collected the primary survey, performed the analyses and wrote the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2023/v29i91781

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/104548

Original Research Article

Received: 09/06/2023
Accepted: 13/08/2023
Published: 22/08/2023

ABSTRACT

The urban heat island (UHI) effect is a major challenge in contemporary urban planning. The large number of paved surfaces, anthropogenic activities and combustion of fossil fuels are the major contributors of this phenomenon. Urban green spaces are known to mitigate the UHI. Since streets constitute a major portion of the urban areas, greening the streets can help reduce heat stress significantly. To study the impact of orientation and density of the street side vegetation on their cooling potential in Kharagpur, West Bengal, India.
A suitable site, meeting the orientation and the density of vegetation criteria, was chosen for collecting the primary data through an instrument survey. Ambient temperature, surface temperature and solar radiation data was collected from the thirteen cross-sections marked across

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the site. As part of the preliminary data processing, relative variations of ambient temperature, surface temperature and the solar radiation attenuation was calculated. The values pertaining to these three secondary parameters were used to form matrices corresponding to each of the trees of each of the cross-sections. These matrices were then compared with their corresponding matrices to estimate which side exhibited a higher cooling potential. Besides, a colour-coded matrix was also generated from the calculated shade index to evaluate the amount of incident solar radiation blocked by each of these trees.

This study corroborates the previous findings that the shade providing trees can alter the microclimate of the area. Besides, it was also observed that the Northern pavements of the east-west oriented streets are cooler than the Southern pavement. Furthermore, it was also noticed that if the crown of the tree is present at a greater height from the ground, then lower solar angle results in less blockage of the incident solar radiation. Also, it was evident that a higher density of tall, shade providing trees, maximally block incident solar radiation on a street. This study can help in understanding the pattern of cooling potential of the street side vegetation in a warm and humid climatic zone like Kharagpur so that the plantation can be planned judiciously.

Keywords: Qualitative matrix analysis; shade index; urban heat island; colour-coded matrix; cooling potential.

1. INTRODUCTION

The urban heat island (UHI) effect refers to the phenomenon whereby urban air temperatures are greater than the surrounding rural areas. The difference in air temperatures between the urban and rural areas, referred to as the UHI intensity, has been constantly rising [1], and this has become a growing concern for climate scientists and urban planners. Hence an important goal in urban planning and climate science research is to devise methods to mitigate the UHI effect.

Previous research has suggested that microclimatic planning and design can ameliorate the negative effects of global climate change [2]. Scientists are also of the opinion that strategic planning of urban green infrastructure, such as planting street trees, creating parks, and using green roofs and facades, can help achieve temperature reductions in urban areas. Such strategic planning is also predicted to reduce pollution and enhance habitat biodiversity [3].

Many researchers have concurred that urban green spaces create a cooling effect [4,5,6] which lasts up to a certain distance [7,8]. Additionally, the urban green spaces also reduce the incident solar radiation [9].

However, Zhifeng Wu and Liding Chen claim that the amount of outdoor temperature reduced by the trees is determined by their spatial arrangement [10]. Furthermore, Arpit Shah, Amit Garg and Vimal Mishra have found out that an average urban green space reduces the temperature by about 2.23°C [11]. Whereas, Carlos Bartesaghi-Koc, Paul Osmond, and Alan Peters have come to the conclusion that trees in rows or small clusters with well-irrigated grasses provide the best thermal cooling both at day and night by about 8°C [12].

To sum it up, few researchers are of the opinion that optimum improvement of both indoor and outdoor environment can be influenced by three major physical factors, namely, larger tree quantity, higher canopy density and cool materials [13]. Moreover, some of them have also claimed that increasing the green cover by 20% could lead to a reduction in the surface temperature by 2°C [14]. They further state that this increase in green cover could also reduce a third to half of the expected rise in UHI effect by 2050 [14].

Streets comprise a large part of the outdoor space in an urban area. Hence if the microclimate in and around the streets is controlled, the UHI can be controlled to a great extent. One of the most effective ways to create a cooling effect in the streets is by planting trees along the sides, as claimed by many scientists across the globe.

However, two contradicting schools of thought exist here… One group of scientists claim that optimum improvement of outdoor environment can be influenced by larger tree quantity [13]. In contrast, others have mentioned in their studies that the heat flux in streets with tree crowns was similar to that without tree crowns, although there was a large difference in road surface temperature between them [15].

Similarly, some researchers are of the view that ambient temperature is independent of street greenery, though it results in a transient perception of enhanced thermal comfort [16]. This idea is also supported by the findings of the studies of some other researchers who mentioned that the differences in the surface temperatures of the tree shaded areas are more pronounced compared to the air temperatures [17]. However on the contrary, some authors claimed that the cooling effect mediated by shading from trees is more significant than that by evapotranspiration from lawns [18].

Additionally, some scientists have also mentioned in their studies that in the streets with a high percentage of canopy cover, air temperature, relative humidity, solar radiation and mean radiant temperature were significantly lower than in streets with low percentage canopy cover [19 20,21,22] as urban street geometry and ways of street greening affect the microclimate in street canyons [23]. These findings are corroborated by studies that have shown that the shade provided by trees reduce mean radiant temperature, and hence the daytime universal thermal climate index (UTCI). During the summer, the reduction in thermal stress was quantified as transitioning from very strong (UTCI > 38^{O}C), to strong (UTCI > 32 ^{O}C) [24].

Contextually, a major group of scientists are of the opinion that greenery has been proven to mitigate the urban heat island effect. Hence, vegetation along the streets ameliorates the thermal comfort of the canyon [7]. Moreover, the authors Limor Shashua-Bar and Milo E. Hoffman, in the year 2003, claimed that the cooling effect depended mainly on the amount and extent of the partial shaded area [25]. Again, in the year 2012, Mohd Fairuz Shahidan et al. stated that higher levels of tree canopy density (LAI 9.7), coupled with “cool” materials (albedo of 0.8), produced the largest urban air temperature reduction [13]. Additionally, Edward NG et al., in the same year, suggested that trees could be more effective than grass surfaces in cooling pedestrian areas [26]. The author further stated that about 33% of the urban area, if planted with trees, can lower the atmospheric temperature by 1ºC for the pedestrians.

Considering the cooling potential of the various kinds of trees, the deciduous species were found to be better than the evergreen variants [27,28,29]. Cynthia Skelhorn et al. (2014) further claims that increasing the mature deciduous trees by 5% can reduce the mean hourly surface temperatures by 1ºC during the summers in the suburban areas of temperate cities [28]. Additionally, Loyde Vieira De Abreu-Harbich et al. (2015) states that the species Caesalpinia Pluviosa is capable of reducing PET by 12 to 16ºC, when planted in a cluster [30].

A significant body of literature has demonstrated that increasing vegetation cover mitigates the UHI effect, and hence influences urban microclimate [31,32,17,33,12,8,6,34,35]. Mature trees are better at mediating this effect, and hence are preferred constituents of roadside vegetation [36].

This study aims to evaluate the impact of street side vegetation on climatic temperature, in a warm and humid climatic zone. An instrument survey was conducted to collect primary data, and the cooling potential of vegetation was evaluated. The geometric orientation of streets was systematically varied, and the cooling potential of different orientations were evaluated across seasons. Data analysis indicates that trees planted along northern pavements of east-west oriented streets mediate a greater cooling effect than trees planted along southern pavements. In addition, a shade index was generated to quantify the amount of incident solar radiation blocked by the trees at different times of the day.

2. METHODOLOGY

2.1 Site Location

The study was conducted in Kharagpur, a city in the Indian state of West Bengal. (22°19'59.88"N, 87°19'16.66"E), (22°19'54.84"N, 87°19'17.79"E), (22°19'48.73"N, 87°19'9.31"E) and (22°19'58.07"N, 87°19'7.19"E) are the precise coordinates of the site. It is located in a warm and humid climatic zone. This study aims to investigate the impact of orientation on the cooling potential of the street trees. Hence, another vital criterion that was kept in mind while selecting the site was that it should consist of four streets oriented along the four main directions in such a way that two of them should be oriented in the East-West direction, while the other two should be aligned in the North-South direction. Besides, this study also aims to study the impact of the density of the street side vegetation over their cooling potential. So, one of the streets from each of the orientations was required to have a higher vegetation of trees than the other. Fig. 1 shows the map of the site and its location.

These streets are hereafter referred to as East-West high density (EWHD) road, East-West low density (EWLD) road, North-South high density (NSHD) road and North-South low density (NSLD) road. All of these roads are shown in Fig. 1.

2.2 Data Collection

The data was collected through a primary survey with the help of instruments that are described in the following sections. For the ease of the survey, thirteen cross-sections were marked throughout these four streets so that the one round of survey could be completed within the scheduled time-interval i.e., two hours. The main consideration in selecting these cross-sections was the presence of trees on the sides. A subset contained trees on both sides, others had trees on one side, while a few had no trees at all.

For instance, the East-West high density (EWHD) road was marked with four cross-sections viz., CS-01, CS-02, CS-03 and CS-04. Out of these, the first two cross-sections have trees on both the sides, while the other two have trees only on one side. Cross-section CS-03 has a tree on the left side, which is also the Southern direction; whereas, the cross-section CS-04 has a tree on the right side, which is also the Northern direction.

Further, in the street North-South high density (NSHD), three cross-sections were singled out viz., CS-05, CS-06 and CS-07. The first two had trees on both sides, while CS-07 had trees only on the left side, corresponding to the western direction.

Next, three cross-sections were selected from each of the North-South low density (NSLD) and the East-West low density (EWLD) roads, namely, CS-08, CS-09 and CS-10 from the former and CS-11, CS-12 and CS-13 from the latter. Incidentally, one cross-section (CS-09 in the former and CS-12 in the latter) in each of these roads had no trees on either side; whereas, all the other cross-sections in both these roads had only one tree on the alternate sides. CS-08 had a tree on its right side, which also corresponds to the Eastern direction, whereas; CS-10 had a tree on the opposite side. Similarly, CS-11 had a tree on its right side which corresponds to the Southern direction while, the cross-section CS-13 had a tree on the opposite side.

Solar parameters were measured at these cross-sections. These parameters were the surface temperature, ambient temperature, and incident solar radiation. The measurements were taken with an infrared thermometer, a thermos-hygrometer, and a solar power meter, respectively. The readings were taken on either side of the cross-sections, and also at the middle of the road. In the instance where there was a tree present at the side of a cross-section, the readings were taken both, under as well as outside the shade.

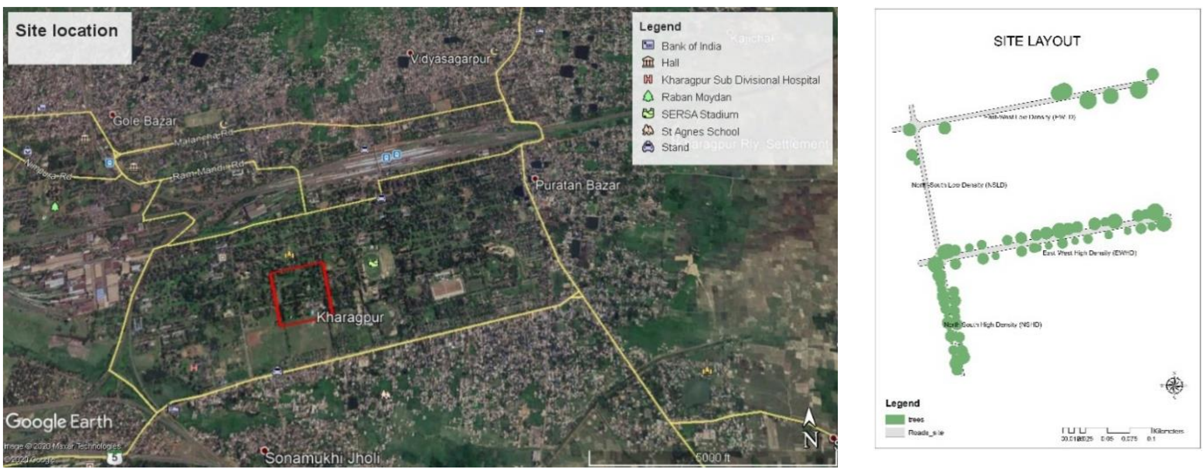

Fig. 1. Site location

3. RESULTS AND DISCUSSION

3.1 Primary Data Processing

3.1.1 Computation of relative variations

The relative variations in ambient temperature (RVAT), surface temperature (RVST), and the solar radiation attenuation (SRA), were calculated by the following formulae:

Relative Variation in Ambient Temperature (RVAT) = ((Ambient temperature under sun - Ambient temperature under shade))/Ambient temperature under sun x 100 (1)

Relative Variation in Surface Temperature (RVST) = ((Surface temperature under sun - Surface temperature under shade))/Surface temperature under sun x 100 % (2)

Solar Radiation Attenuation (SRA) = ((Solar Radiation under sun - Solar Radiation under shade))/Solar Radiation under sun x 100 % (3)

The SRA formula was introduced by Bueono-Bartholomei and Labaki [37], and we adopted a similar logic in computing the relative variations in temperature.

3.1.2 Qualitative matrix analysis

Temperature and radiation data were collected for each of the cross-sections, across five different time intervals, during April, May, June, November and December. The time intervals chosen were 8 am, 10 am, noon, 2 pm and 4 pm because the data needed to be captured during the peak solar hours with due time in between to complete the survey. Hence an interval of two hours was scheduled between the survey timings. The RVST, RVAT and SRA values were computed for each data point, and these values were represented as matrices. In the instances where the cross-sections had trees on both sides, the data was represented as two matrices, corresponding to each side.

The resulting matrices were converted into a binary format by comparing the terms with the corresponding matrix comprising of the data collected from the other side of the road. The value that was greater one was marked as “1”, while the lesser one was marked as “0”. So now each of the aforementioned matrices had a corresponding binary matrix. Subsequently, the binary matrices corresponding to the left and right side of each of these cross-sections were compared, and the side consisting of more number of “1’s” was marked as heavier. The matrix with the greater number of one’s thus indicated a greater cooling effect mediated by the trees on the corresponding side of the cross-section. For the cross-sections which consisted of only one tree, those were compared with another such cross-section corresponding to the same street, but with a tree on the opposite side. Accordingly, the qualitative matrix analysis was effectuated and is shown in the following tables.

From the qualitative matrix analysis, it was apparent that the right side of the EWHD Street, which corresponds to the Northern direction, is cooler as compared to the Southern side. Though in the EWLD street, the left side was cooler. However, in this street the left side itself corresponds to the Northern side. On the other hand, there was no such pattern observed for the North-South oriented streets.

3.1.3 Shade Index

The shade index [34] has been calculated by the following formula for each of the tree of each of the cross-section for each and every time the data was collected.

$$Shade\ Index\ (SI) = 1 - \frac{Solar\ Radiation\ inside\ shade}{Solar\ Radiation\ outside\ shade}$$

The resultant values were in the range of 0 to 1. These values were categorized in five different categories viz., “excellent”, “good”, “average”, “bad” and “poor”. The values which were greater than or equal to 0.9 were termed in the first category, followed by the ones between 0.8 to 0.9. The values ranging between 0.7 and 0.8 were termed as “average”, followed by the category “bad” which comprised of values between 0.6 and 0.7. Finally, the category “poor” comprised of all the values lesser than 0.6. These categories were then represented in the form of a colour-coded matrix which is given in the Fig. 2.

It was observed that in the month of April, the left side of CS-01 (which corresponds to the Southern direction) facing West, receives sunlight in the morning 8:00 a.m. and evening 4:00 p.m. As mentioned during the qualitative matrix analysis, this is due to the presence of a wide gap in the streetside plantation fabric because of a cross-road just ahead of this cross-section. In addition, the rays of the sun are at a low incident angle during this time of day, bypassing the high crown of the trees situated on this side.

Table 1. Qualitative matrix analysis for cross-section CS-01

Street-EWHD; Cross-section: CS-01												
Months	**Matrix (Left Side)**			**Binary of Matrix (Left Side)**			**Binary of Matrix (Right Side)**			**Matrix (Right Side)**		
April	13	0.2	28	0	0	0	1	1	1	24	0.9	89
	30	0.4	86	1	0	0	0	1	1	27	0.6	90
	28	0.1	82	0	1	0	1	0	1	38	0	86
	16	1	83	0	0	0	1	1	1	33	1.1	87
	2	0	29	0	0	0	1	0	1	16	0	79
May	17	0.8	75	1	0	0	0	1	1	11	1.6	87
	32	3	84	1	0	0	0	1	1	26	6.1	91
	38	2.2	88	1	1	0	0	0	1	35	2	89
	12	1.3	84	0	1	0	1	0	1	41	1	90
	15	2.3	78	0	1	1	1	0	0	24	1.4	72
June	27	3.6	80	1	0	1	0	0	0	16	3.2	78
	26	9.2	79	1	0	0	0	1	1	22	11	89
	41	6.1	85	1	1	0	0	0	1	38	5.1	93
	31	6.7	89	1	1	1	0	0	0	26	6.2	88
	33	7.2	74	1	1	0	0	0	1	32	5.6	84
Possible Explanation for the higher cooling potential on the concerned side												
This is the very first cross-section not just for the study but also in the concerned street. Ahead of this cross-section there's a wide cross-road creating a considerable length of gap in the green fabric of the street. Hence apart from the physical characteristics of the trees concerned, the position of the sun and other factors like the position from which the readings have been taken also plays a major role in the measured data. Incidentally, the tree on the right side of this cross-section has a greater foliage and crown-density as compared to that on the other side. Besides, during the times of the day when the solar angle is low, there's a considerable amount of sunlight even under the tree (on the right side) due to the gap created by the cross-road ahead.												

Table 2. Qualitative matrix analysis of cross-section CS-02

Street-EWHD; Cross-section: CS-02												
Months	**Matrix (Left Side)**			**Binary of Matrix (Left Side)**			**Binary of Matrix (Right Side)**			**Matrix (Right Side)**		
April	21	0.4	81	1	0	0	0	1	1	16	1.1	83
	31	0.1	87	1	0	0	0	0	0	28	0.1	87
	34	0.4	90	1	0	0	0	0	1	26	0.4	92
	36	0.9	62	1	1	0	0	0	1	30	0.5	80
	10	0	52	1	0	1	0	0	0	7	0	44
May	16	0.3	85	0	0	0	1	0	1	19	0.2	89
	24	7.3	86	0	1	1	1	0	0	34	0.9	86
	38	1.1	91	0	1	1	1	0	0	46	0.8	88
	25	11	83	0	1	0	1	0	1	35	0.9	90
	17	0.3	67	1	0	1	0	1	0	13	0.7	66
June	17	2	69	0	0	0	1	0	1	19	1.9	81
	28	9.8	92	0	1	1	1	0	0	33	8.2	91
	38	7.7	94	0	0	1	1	1	0	41	8.1	94
	25	7	93	0	1	0	1	0	1	31	5.9	93
	26	2.9	82	1	1	0	0	0	1	18	0.9	84
Possible Explanation for the higher cooling potential on the concerned side												
As evident, the right side is mostly showing a higher relative variation in the readings of the outside shade and inside the shaded regions as the tree on this side has a greater foliage.												

Table 3. Qualitative matrix analysis of cross-sections CS-03 and CS-04

Street-EWHD; Cross-section: CS-03 and CS-04												
Months	**Matrix: CS-04 (Left Side)**			**Binary of CS-04 (Left Side**			**Binary of CS-03 (Right Side)**			**Matrix: CS-03 (Right Side)**		
April	22	1	74	1	0	1	0	1	0	18	2.6	59
	27	0.4	86	1	0	0	0	1	1	20	2.5	88
	30	0.4	85	0	0	0	1	0	0	30	0.4	85
	35	1	89	1	1	1	0	0	0	21	0.4	80
	24	0.1	54	1	0	0	0	0	1	14	0.1	63
May	21	1.1	52	0	0	0	1	1	1	23	2	84
	30	4.3	87	0	1	0	1	0	1	36	2.2	89
	31	3.9	90	0	1	0	1	0	1	37	2.6	92
	26	3.5	84	0	1	0	1	0	1	31	1.5	89
	19	1.2	68	1	1	1	0	0	0	17	0.6	26
June	21	3.7	85	1	1	0	0	0	0	19	3.3	86
	27	6.9	91	1	0	1	0	1	0	24	7.1	89
	29	5.7	88	0	0	0	0	0	1	29	5.6	92
	29	4.6	86	0	0	0	1	1	1	31	7.3	31
	31	3.7	75	1	0	0	0	1	1	81	5.1	28
Possible Explanation for the higher cooling potential on the concerned side												
The tree in the cross-section CS-03 of the street EWHD has very large foliage as compared to the one in CS-04. Hence the matrices corresponding to the former is clearly heavier than that of the other cross-section. In other words, the tree in the cross-section CS-03 has a greater cooling potential as that compared to the one in the cross-section CS-04												

Table 4. Qualitative matrix analysis of cross-sections CS-11 and CS-13

Street-EWLD; Cross-section: CS-11 and CS-13												
Months	**Matrix: CS-13 (Left Side)**			**Binary of CS-13 (Left Side)**			**Binary of CS-11 (Right Side)**			**Matrix: CS-11 (Right Side)**		
April	23	2.4	86	0	1	1	1	0	0	30	0.7	81
	40	0.3	82	1	0	0	0	1	1	30	0.5	83
	29	0	84	1	0	1	0	1	0	24	0.2	62
	20	0.3	84	0	0	1	1	1	0	21	0.4	21
	10	0	45	0	0	1	1	0	0	16	0	41
May	27	2.3	76	1	1	0	0	0	1	22	0.3	78
	32	0.6	76	1	0	0	0	1	1	23	2.5	82
	31	1.3	82	0	1	1	1	0	0	34	1.0	56
	19	1.7	82	1	1	1	0	0	0	12	0.9	45
	14	0.4	73	0	0	1	1	1	0	25	0.7	53
June	19	3.5	70	1	0	1	0	1	0	17	3.7	68
	23	2.9	71	0	0	1	0	1	0	24	3.7	48
	35	9.4	88	1	0	1	0	1	0	27	9.6	73
	20	2.0	62	1	0	1	0	1	0	11	3.6	32
	12	1.5	71	0	1	1	0	0	0	12	1.2	41
Possible Explanation for the higher cooling potential on the concerned side												
The tree present in the cross-section CS-11 of the street EWLD is a deciduous tree and is placed at a greater distance from the road such that its shade hardly falls on the road during the summer season. Whereas, the one in the cross-section CS-13 has its shade falling on the road during the summer season. Hence the latter is exhibiting a greater cooling potential than the former.												

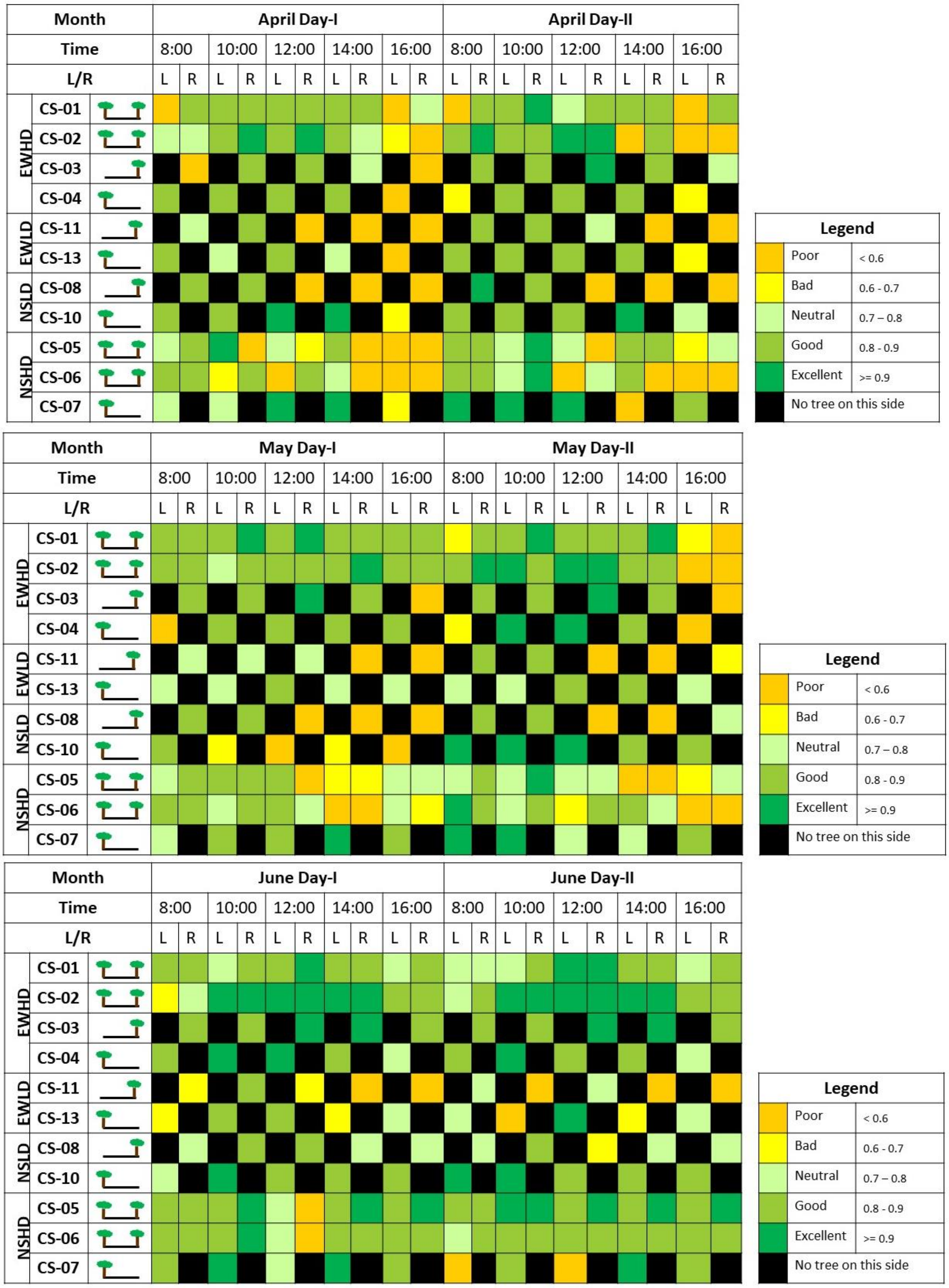

Fig. 2. Colour-coded matrix representing shade index

Table 5. Qualitative matrix analysis of cross-section CS-05

Street-NSHD; Cross-section: CS-05												
Months	**Matrix (Left Side)**			**Binary of Matrix (Left Side)**			**Binary of Matrix (Right Side)**			**Matrix (Right Side)**		
April	33	0.1	83	1	0	0	0	0	1	31	0	86
	23	1.1	81	0	0	1	1	0	0	27	0.9	71
	24	0.8	76	0	1	1	1	0	0	26	0.5	70
	18	0.4	56	1	1	0	0	0	1	14	0.1	70
	19	0.6	58	1	0	0	0	0	1	16	0.6	66
May	19	0.3	76	0	0	0	1	0	1	28	0.4	86
	30	4.1	80	1	1	0	0	0	1	28	3.6	90
	23	1.3	78	1	1	1	0	0	0	22	0.9	63
	16	1.3	41	1	0	1	0	0	0	10	1.3	41
	7	0.3	72	1	0	0	0	1	1	6.2	0.6	76
June	17	3.7	85	0	1	0	1	0	1	20	2.6	89
	29	4.7	91	0	1	0	1	0	1	31	2.2	94
	13	2	78	0	0	1	1	1	0	15	2.6	67
	5	5.9	87	0	1	0	1	0	1	20	4.5	94
	20	6.4	87	0	1	0	1	0	1	25	6.1	92
Possible Explanation for the higher cooling potential on the concerned side												
As evident, the right side is mostly showing a higher relative variation in the readings of the outside shade and inside the shaded regions as the tree on this side has a greater crown density												

Table 6. Qualitative matrix analysis of cross-sections CS-06

Street-NSHD; Cross-section: CS-06												
Months	**Matrix (Left Side)**			**Binary of Matrix (Left Side)**			**Binary of Matrix (Right Side)**			**Matrix (Right Side)**		
April	30	1.3	84	1	1	0	0	0	1	29	0.4	87
	29	0.4	70	0	0	0	1	0	1	30	0.3	90
	20	0	28	1	0	0	0	0	1	13	0	77
	12	0.3	78	1	1	1	0	0	0	4	0	25
	15	0.6	31	1	0	0	0	0	1	13	0.6	41
May	21	2.1	86	0	0	0	1	1	1	25	3.2	86
	22	4.3	75	0	1	0	1	0	1	37	2.9	84
	13	3.8	73	0	0	0	1	0	1	23	3.8	76
	13	2.4	68	1	0	1	0	0	0	11	2.5	54
	7	0.3	37	1	0	1	0	1	0	6.2	0.7	35
June	16	5.4	81	0	1	0	1	0	1	21	2.4	87
	26	4.1	87	0	1	0	1	0	1	29	2.6	90
	10	2.7	80	0	1	1	1	0	0	11	1.3	62
	12	2.5	86	0	0	0	1	1	1	16	5.4	88
	22	6.6	84	0	0	0	1	0	1	28	6.6	88
Possible Explanation for the higher cooling potential on the concerned side												
As evident, the right side is mostly showing a higher relative variation in the readings of the outside shade and inside the shaded regions as the tree on this side has a greater crown density												

Table 7. Qualitative Matrix Analysis of cross-sections CS-08 and CS-10

Street-NSLD; Cross-section: CS-08 and CS-10												
Months	**Matrix: CS-10 (Left Side)**			**Binary of CS-10 (Left Side)**			**Binary of CS-08 (Right Side)**			**Matrix: CS-08 (Right Side)**		
April	34	0.4	86	1	0	0	0	1	1	31	1.1	87
	37	0.1	86	1	0	1	0	1	0	34	0.5	85
	40	1.7	89	1	1	1	0	0	0	19	0.1	41
	31	0.2	93	1	0	1	0	0	0	16	0.1	35
	16	0	73	0	0	1	1	0	0	24	0	55
May	28	0.4	90	1	0	1	0	1	0	17	1.0	89
	30	1.1	78	1	1	0	0	0	1	22	0.5	83
	35	3.0	66	1	1	1	0	0	0	29	1.0	36
	31	1.0	75	1	1	1	0	0	0	30	0.1	46
	21	0.6	67	0	1	1	1	0	0	23	0.3	64
June	27	4.1	83	1	1	1	0	0	0	14	2.2	73
	46	7.4	95	1	1	1	0	0	0	31	3.6	84
	32	10	89	1	1	1	0	0	0	22	2.9	71
	37	2.3	84	1	0	1	0	0	0	13	2.2	73
	32	2.6	83	1	1	1	0	0	0	14	2.3	71
Possible Explanation for the higher cooling potential on the concerned side												
The tree in the cross-section CS-10 of the street NSLD has a large foliage and greater crown density as compared to the one in the cross-section CS-08 of the same street. Hence the former has a greater cooling potential than the latter												

However, it's interesting to note that in the streets with lower tree density, this pattern is rippled to around 2:00 p.m. in the EWLD street and to around 12:00 noon in the NSLD street. Nevertheless, this pattern was observed to gradually fade away as the summer season advances to the months of May and June.

The results of the qualitative matrix analysis were corroborated by the shade index, reinforcing the findings of previous researchers that a shade providing tree creates a cooling effect. In addition, a deciduous tree blocks certain amount of incident solar radiation. The amount blocked depends on the solar angle, as well as how closely the branches of the tree are placed.

4. CONCLUSION

The idea behind conducting this study was to evaluate the cooling potential of the street canopy based on its physical characteristics and orientation, scientifically. However, this study was based solely in a warm and humid climatic zone. In future this study could be extended to other climate zones as well. Besides, more species of trees used for roadside plantation could be considered for assessing their cooling potential. Additionally, more advanced instruments such as drones could be used for the survey. Furthermore, longwave and shortwave radiation fluxes could be measured for the calculation of the MRT, which in turn may add further insights to the study.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/104548