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Case Study

# Day Length Estimation over India: A Case Study

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**_Abstract_**

*The day length $S_o$ is the essential parameter for calculating the solar radiation data. In order to determine the day length, two correlations have been developed by Cooper and Hay, and both correlations have been frequently used by different researchers. The main objective of this study is to test the applicability of these two correlations available for computing the day length value on horizontal surface in India. For this purpose, the developed correlations are employed to estimate the day length values on horizontal surface for nine locations with latitude between $8.5^0$ N to $28.63^0$ N. The performances of these correlations have been checked by it with the measured value. From this study, a close agreement has been observed between the Cooper correlations and the measured data on the duration between sunrise and sunset. Furthermore, in order to evaluate the accuracy of Cooper's method reported in this paper for computing the day length $S_0$ for India, the developed correlations were then compared on the basis of statistical error indices such as root mean square error (RMSE), mean bias error (MBE), relative percentage error, and t-statistics test. According to the results the Cooper method showed the best estimation of day length values for nine Indian stations.*

***Keywords**: Cooper, Hay, Day length*

## 1. Introduction

The day length $S_o$, refers to the time each day from the moment the upper limb of the sun's disk appears above the horizon during sunrise to the moment when the upper limb disappears below the horizon during sunset..Solar energy engineers, architects, agriculturists, hydrologists etc. often require a reasonably accurate knowledge of the availability of the solar radiations for their relevant applications at their local. Knowledge of solar radiation is essential for the proper design of buildings, solar energy systems and a good evaluation of thermal environment within buildings (Lu Z*et al*, 1998, Machler MA *et al*, 1985, Trujillo JHS, 1998, ASHRAE handbook1999, Li DHW *et al*, 2000). It is measured in terms of sunshine duration or in terms of direct, diffuse and global radiation. In response to the crucial needs of solar radiation data, some empirical correlations have been developed by different researchers for estimating direct, diffuse and global solar radiation. The determination of solar energy capacity effectively through the empirical models plays a key role in developing solar energy technologies and sustainability of natural resources (Karakoti *et al*, 2012).These empirical can be mainly classified into four following categories based on employed meteorological parameters (Besharat F *et al*, 2013)

1. Sunshine based models
2. Cloud based models
3. Temperature based models
4. Other meteorological parameters.

Among all such meteorological parameters, bright sunshine hours are the most widely and commonly used to predict global solar radiation. Most of the models for estimating solar radiation that appear in the literature only use sunshine ratio ($S/S_o$) for prediction of monthly average daily global radiation, given as-Angstrom-Prescott model- (Angstrom A, 1924, Prescott JA,1940), Glower and McCulloch model (Glower J *et al*,1958), Page model (Page JK, 1961), Rietveld model (Rietveld M, 1978), Dogniaux and Lemoine model (Dogniaux R *et al*, 1983), Kilic and Ozturk model (Kilic A *et al*, 1983), Benson et al. model (Benson RB *et al* ,1984), Ogelman model (Ogelman H *et al*, 1984), Bahel et al. model (Bahel V *et al*, 1986), Zabara model (Zabara K, 1986), Bahel model (Bahel V *et al*, 1987), Gopinathan model (Gopinathan KK, 1988), Newland model (Newland FJ, 1988), Monthly specific Rietveld model (Soler A, 1990), Luhanga and Andringa model (Luhanga PVC *et al*, 1990), Louche et al. model (Louche A *et al*, 1991), Samuel model (Samuel TDMA, 1991), Gopinathan and Soler model (Gopinathan KK *et al*, 1992 ), Raja model (Raja IA, 1994), Coppolino

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model (Coppolino S, 1994), Tiris et al. model (Tiris M *et al*,1996), Ampratwum and Dorvlomodel (Ampratwum D B *et al*, 1999), Klabzuba et al. model (Klabzuba J *et al*, 1999), Togrul et al (Togrul IT *et al*, 2000), Elagib and Mansell model (Elagib N *et al*, 2000) Monthly specific Elagib and Mansellmodel (Elagib N *et al*, 2000), Togrul et al. (Togrul IT *et al*, 2000) Almorox and Hontoria model (Almorox J *et al*, 2004), Jin et al. model (Jin Z *et al*, 2005), El-Metwally model (El-Metwally M, 2005), Almorox model (Almorox J *et al*, 2005), Rensheng model (Rensheng C *et al*, 2006), Sen model (Sen Z, 2007), Bakirci model (Bakirci K, 2008), Bakirci model (Bakirci K, 2009) and Katiyar .model (Katiyar VK *et al*, 2009). Further diffuse solar radiation is the prime parameter which directs the quality of global solar radiation and also of direct normal irradiance which is input parameter for concentrating solar power projects. Estimation of diffuse solar radiation is essential for evaluation of thermal performance of buildings and other thermal technologies. The measured value of diffuse solar radiation is available at only few locations of India. Hence, a number of Empirical models have been developed to calculate diffuse solar radiation using various parameters, such as global solar radiation (Liu BYH *et al*, 1960, Al-Mohamad A, 2004, Diez-Mediavilla M *et al*, 2005, Tarhan S *et al*, 2005, A ras H *et al*, 2006, Noorian AM *et al*, 2008, El-sebali AA *et al*, 2010, Bolanda J *et al*, 2008, Jiang Y, 2009) and sunshine duration (Tiris M *et al*, 1996, Barbaro S *et al*, 1981, Jain PC, 1990, Haydar A *et al*, 2006, Pandey CK *et al*, 2009).

That is for the estimation of either global or diffuse solar radiation, a crucial need of day length value. Cooper (Cooper PI, 1969) proposed a method for calculating $S_o$ and that has been extensively used by different researchers (Karakoti I *et al*, 2012, Besharat F *et al*, 2013, Zabara K, 1986, Gopinathan KK, 1988, Gopinathan KK *et al*, 1992, Ampratwum DB *et al*, 1999, Togrul IT *et al*, 2000, Elagib N *et al*, 2000, Almorox J *et al*, 2004, Jin Z *et al*, 2005, Almorox J *et al*, 2005, Katiyar VK *et al*, 2009, Jiang Y, 2009, Pandey CK *et al*, 2009, Khorasanizadeh H *et al*, 2013) across the globe. Hay (Hay JE, 1979) modified Cooper's formula and found that data shows less scattering with this modification for nine Canadian cities. This is also frequently being used by different researchers (Noorian AM *et al*, 2008, Wenxian L, 1988, Wenxian L *et al*, 1996, Sambo AS, 1986, Feuillard T *et al*, 1989,Ma CCY *et al*, 1984, Bashahu M, 2003).

The objective of the work reported in this paper is the comparison of Cooper's and Hay methods with the measured data for estimating the day length value and then to find out the most suitable correlation for computing the day length $S_o$ for locations under consideration in India.

## 2. Background and selected correlations

### *2.1. Cooper's formula*

The day length $S_o$, is defined as the time from sunrise to sunset, can be calculated as follows (Cooper PI, 1969)

$$S_o = 2/15\ \text{Cos}^{-1}(-\tan\delta\tan\phi) \quad (1)$$

where $\delta$ is the solar declination in degrees and $\phi$ is the latitude of the location in degrees. A convenient approximate relation for solar declination of the day of the year, $D_n$, is given by Cooper (Cooper PI, 1969) as:

$$\delta = 23.45\ \text{Sin}\,[360/365(284+D_n)] \quad (2)$$

Cooper's formula computes the day length based on a solar elevation angle of $0^o$ i.e. for zenith angle of $90^o$, when $S_o$ calculated from Cooper's formula and used in traditional Angstrom-Prescott equation there is substantial temporal and spatial scatter in the values of the regression coefficients $a_1$ and $b_1$.

### *2.2. Hay's Formula*

Hay (Hay JE, 1979) has suggested that the scatter in the values of the regression coefficient is due to two effects. The first, and the most significant, is the apparent increase in the measured global irradiation due to the solar radiation transmitted by the atmosphere being augmented by multiple reflections between the earth's surface and atmosphere. The second but less significant, is related both to performance characteristics of the Campbell-Stokes sunshine recorder, which fails to burn the trace on the card when sun elevation is less than $5^o$. Hay observed for nine Canadian stations that incorporation of these effects into traditional Angstrom-Prescott equation decreases the temporal scatter for each station and the spatial scatter.
Modification of Hay over Cooper's formula as:

$$S_O = 2/15\ \cos^{-1}(\cos 85^0/\cos\delta\cos\phi - \tan\delta\tan\phi) \quad (3)$$

Hay, to bright sunshine until the sun is $5^o$ above the horizon. Thus the modified form is used for solar zenith angle of less than or equal to $85^0$. Based on the definition of each formula, one should expect some difference between the values obtained by either one, with day lengths by Hay's formula to be shorter than those by Cooper formula.

## 3. Data and Comparison methods

### *3.1. Measured data*

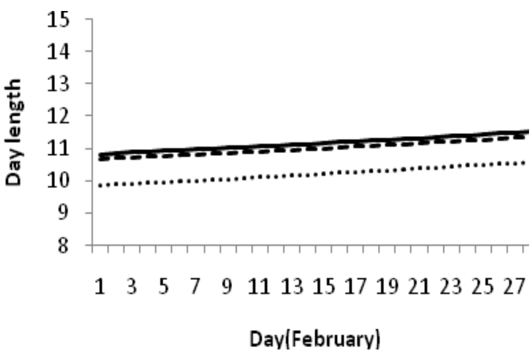
In this study, measured data of sunshine duration of nine Indian locations for the year 2010 are used. These locations are shown in Fig. 1. The latitude and altitude used for each analyzed location are reported in Table 1. In order to calculate the maximum possible sunshine duration $S_0$ from Cooper's and Hay's formula, firstly calculations were carried out for solar declination $\delta$ using equation (2), for each day of year. At calculated values of solar declination ($\delta$) and given values of latitude (Table 1) calculations were made for maximum possible sunshine duration $S_O$ from both Hay and Cooper formula using equations (1) and (3). These results are being compared with the measured data of day length for nine stations (viz.

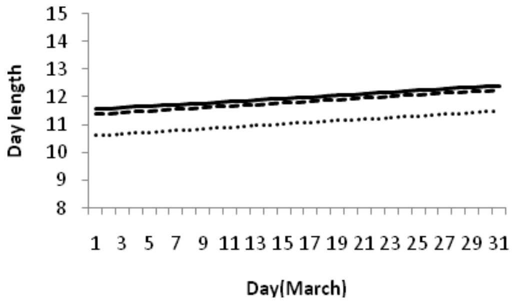
New Delhi, Agra, Kanpur, Patna, Kolkata, Surat, Mumbai, Chennai and Thiruavananthapuram). Trend analysis of day length versus day for selected locations is given in Figs. 2-10.

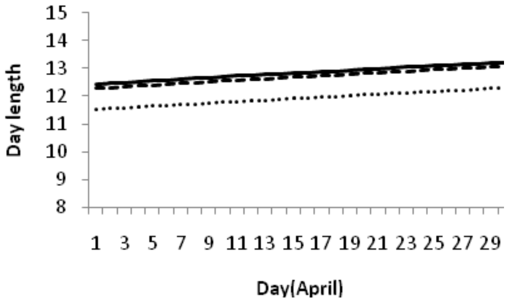

**Fig.1**Indian locations analyzed in the present study

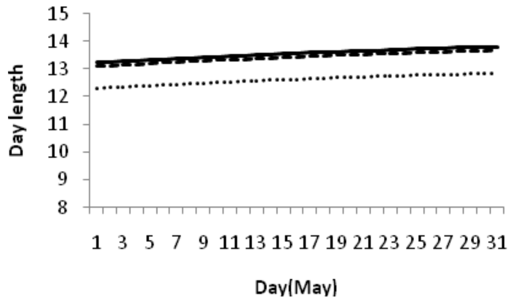
**Table 1** Summary of testing cities

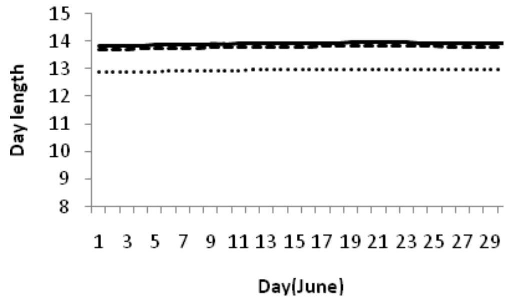
| Sr. No. | Stations | Latitude (Degree) | Longitude(Degrees) |
|---|---|---|---|
| 1 | New Delhi | 28.63 | 77.20 |
| 2 | Agra | 27.16 | 78.01 |
| 3 | Kanpur | 26.45 | 80.31 |
| 4 | Patna | 25.61 | 85.13 |
| 5 | Kolkata | 22.56 | 88.36 |
| 6 | Surat | 21.17 | 72.83 |
| 7 | Mumbai | 18.91 | 72.82 |
| 8 | Chennai | 13.08 | 80.27 |
| 9 | Thiruavanthapuram | 8.50 | 76.90 |

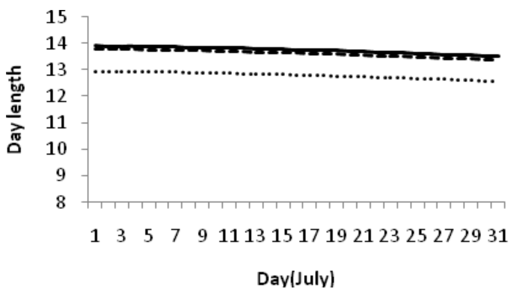


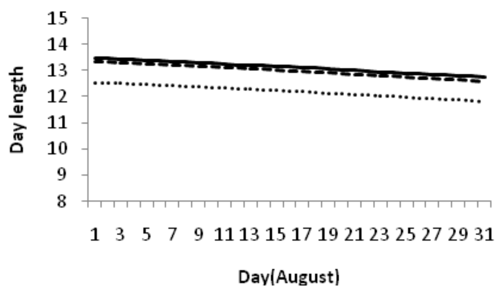



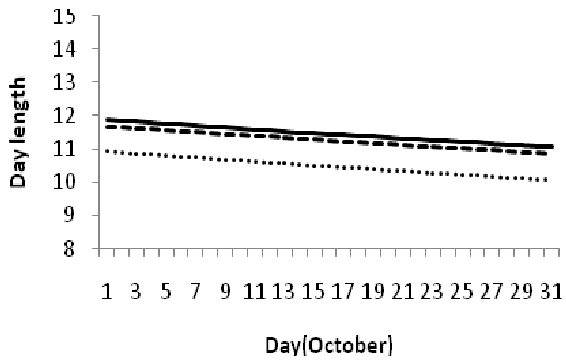



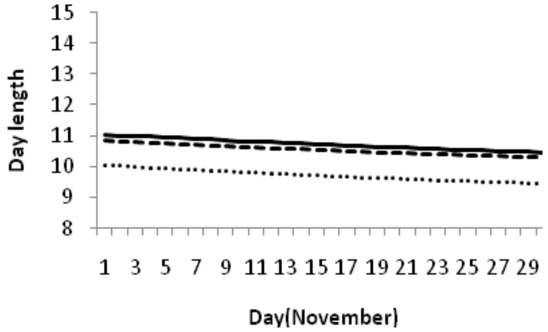



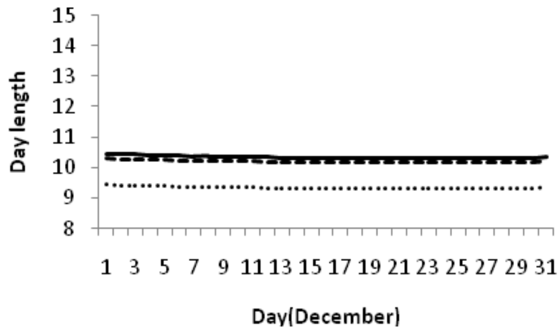



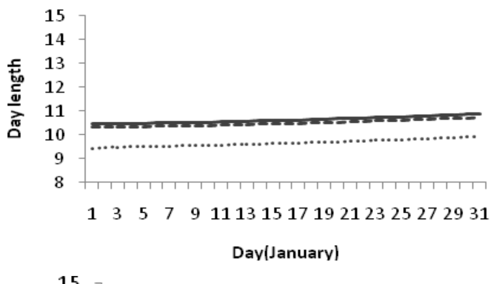


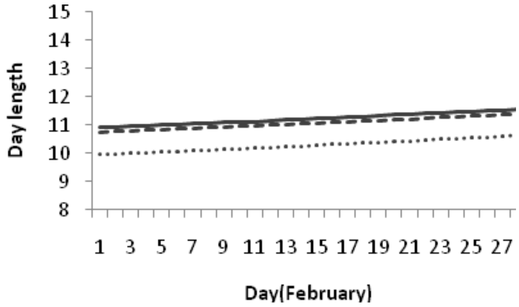



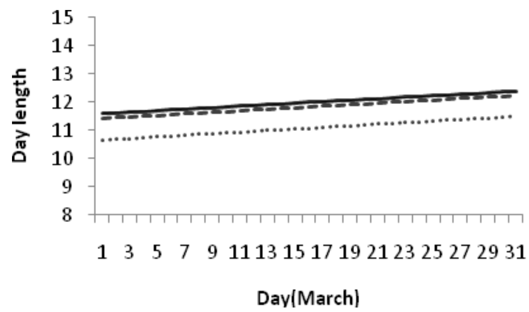



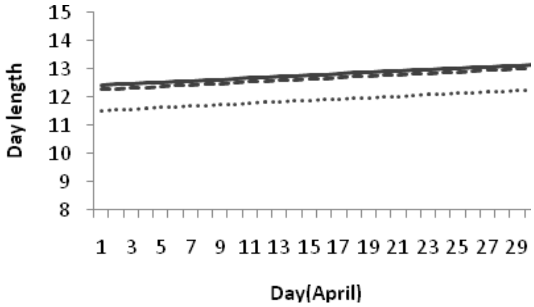

Measured values of day length in New Delhi for the year 2010 are represented by (—),calculated values from Hay and Cooper formulae are represented by (·····) and (----) respectively

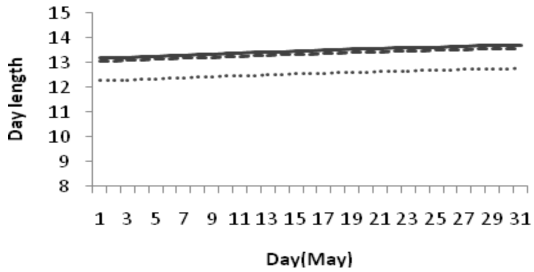
**Fig 2**: Daily variation in Day length values at New Delhi

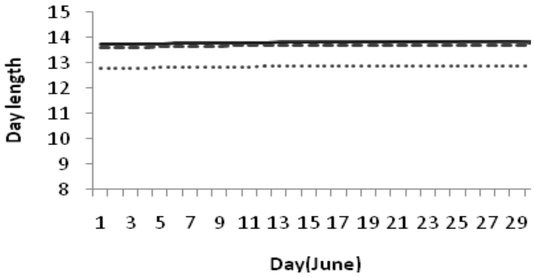


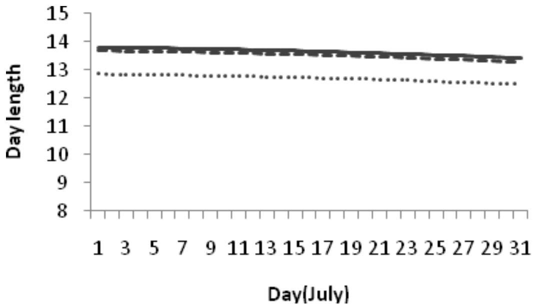



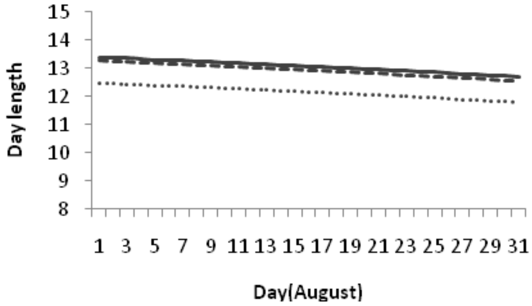



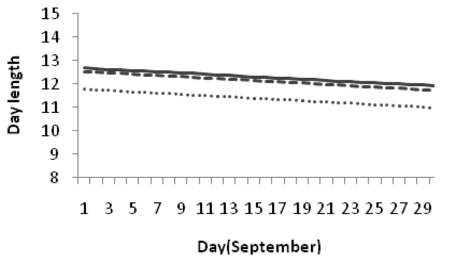



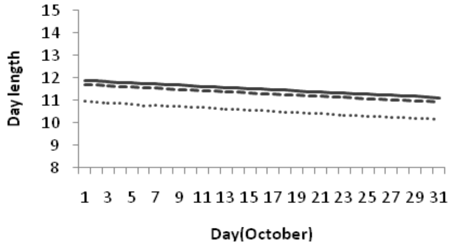



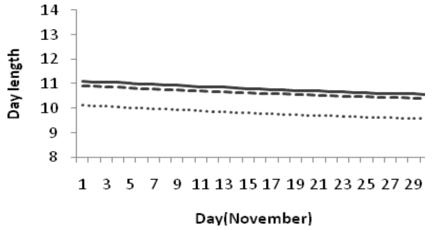



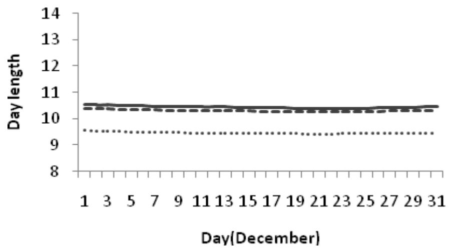





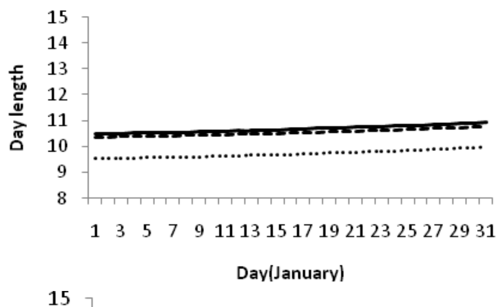



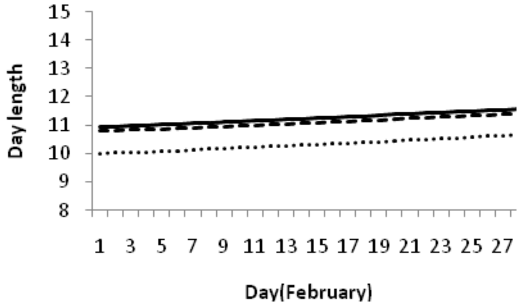



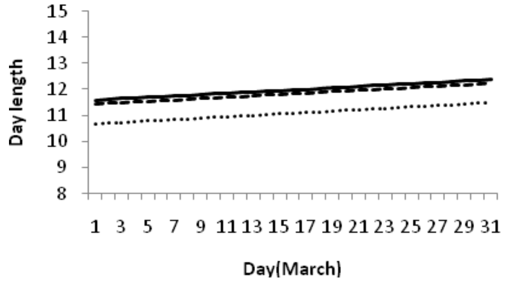



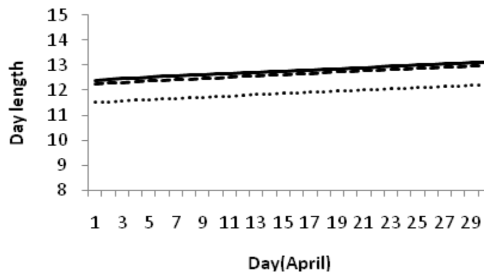

Measured values of day length in Agra for the year 2010 are represented by (—),calculated values from Hay and Cooper formulae are represented by (·····) and (----) respectively.

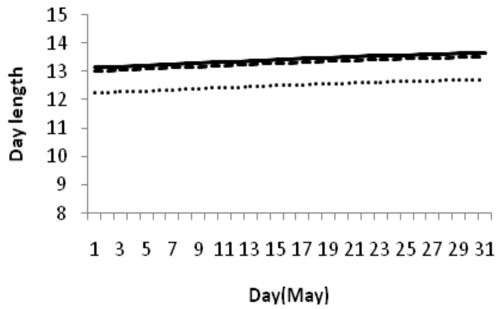
**Fig 3:** Daily variation in Day length values at Agra

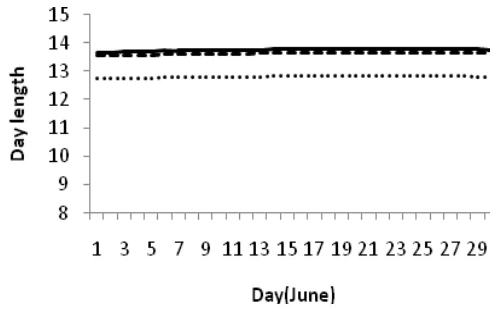


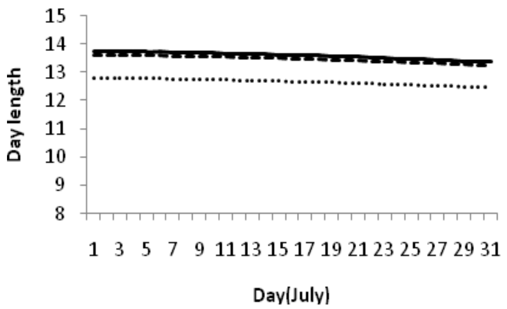



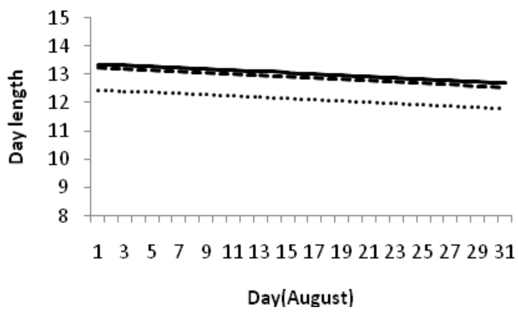



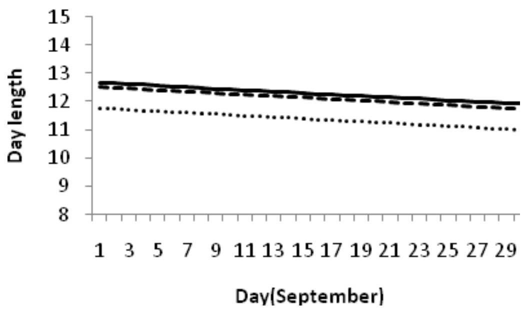



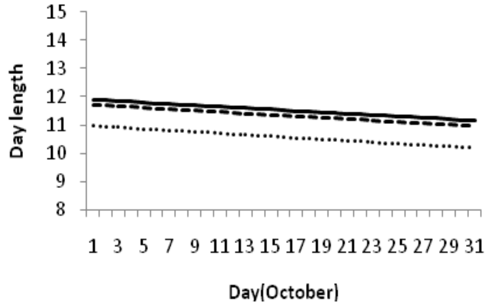



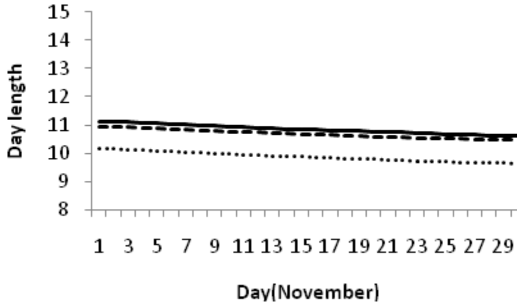



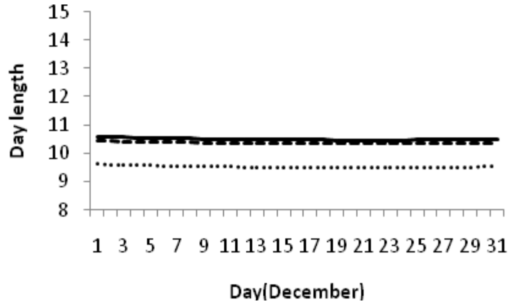





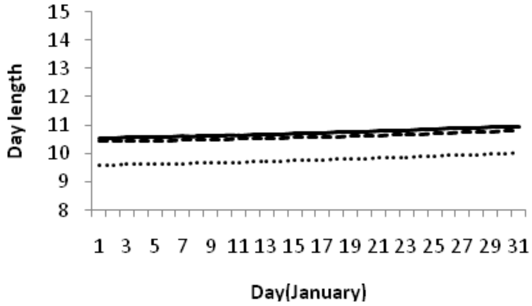



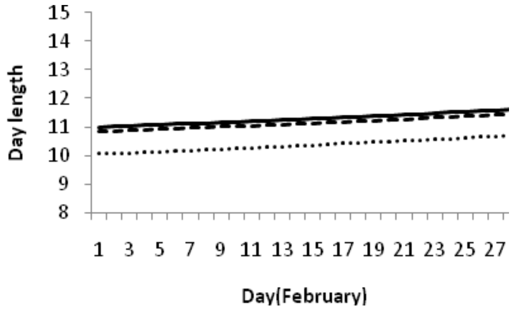



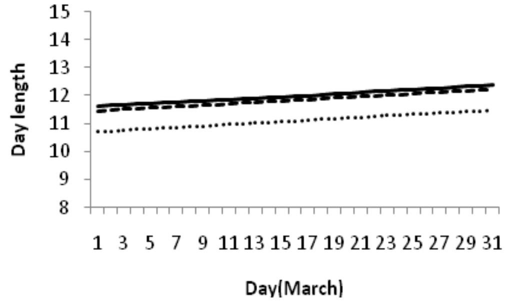



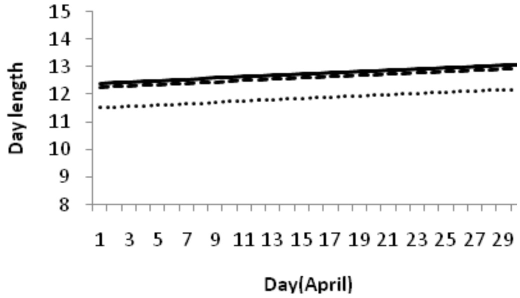

Measured values of day length in Kanpur for the year 2010 are represented by (—), calculated values from Hay and Cooper formulae are represented by ( ·····) and (----) respectively

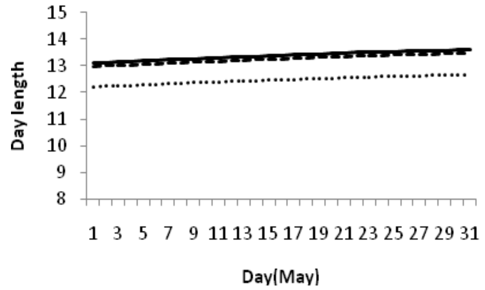
**Fig 4**: Daily variation in Day length values at Kanpur

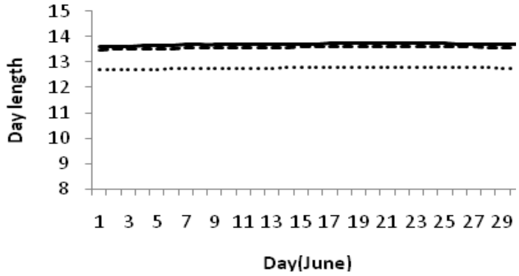


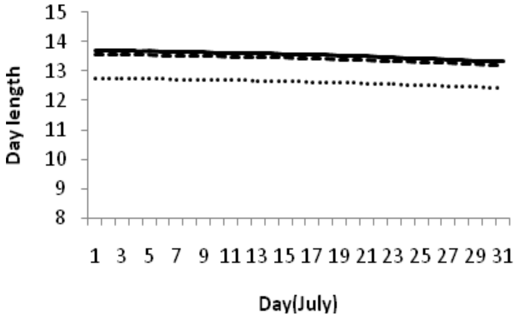



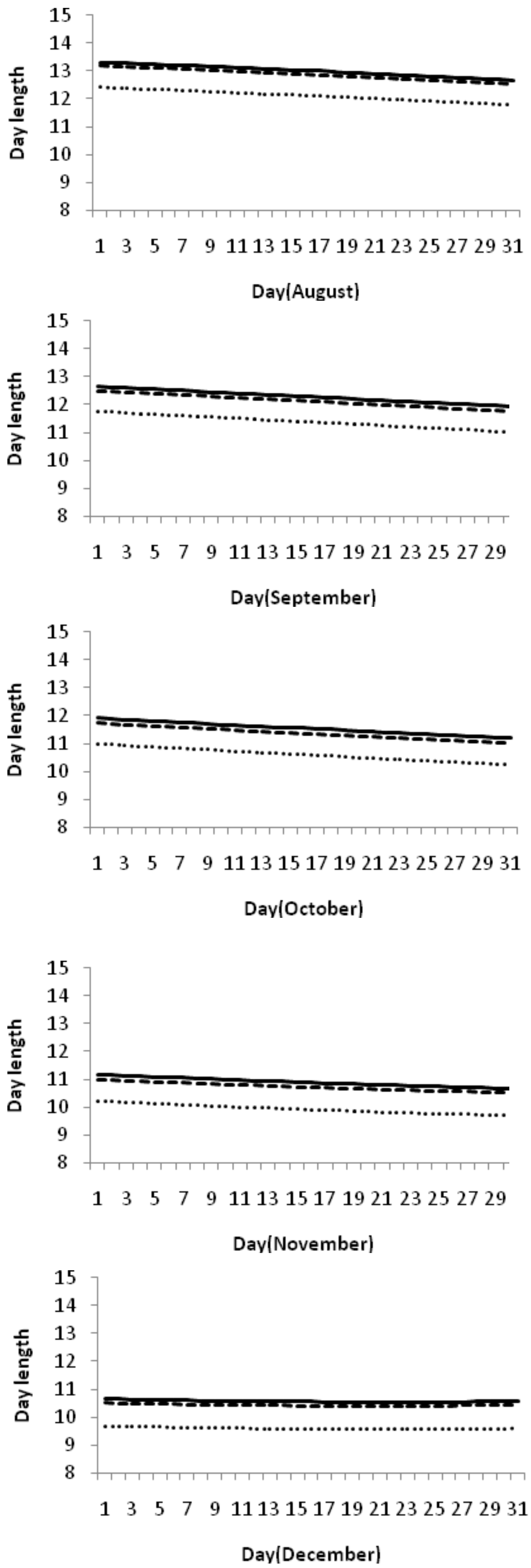



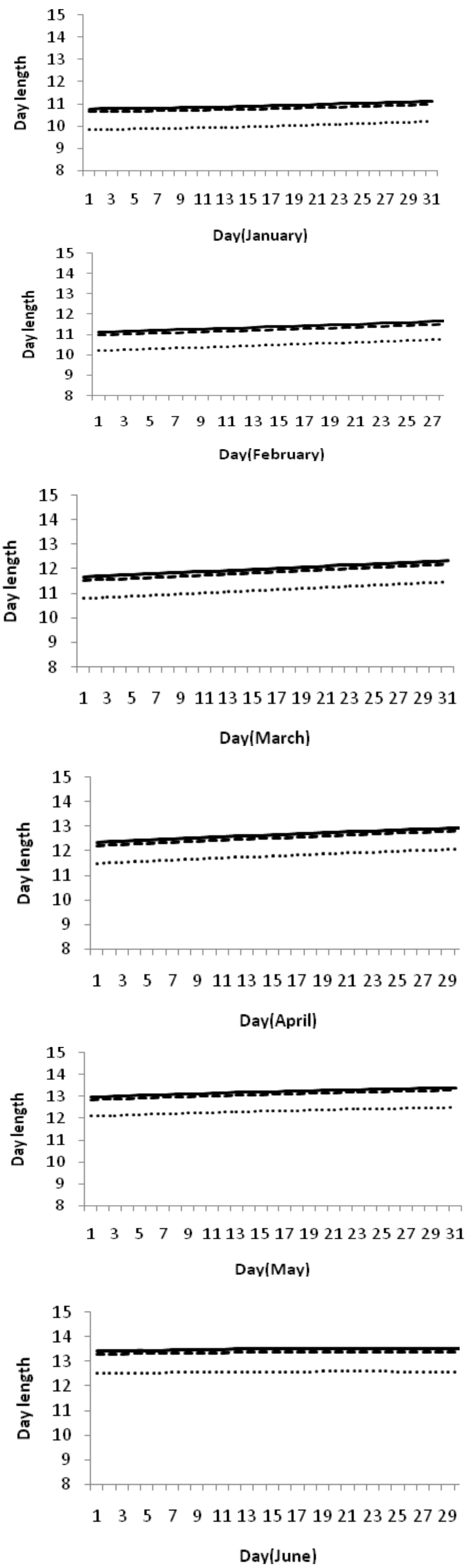



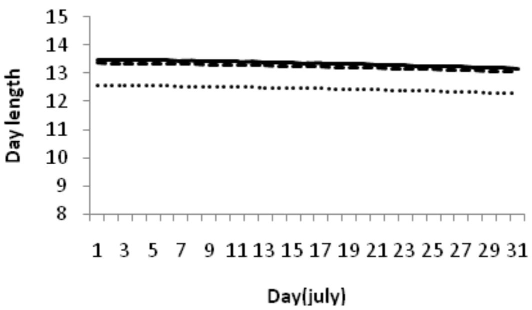



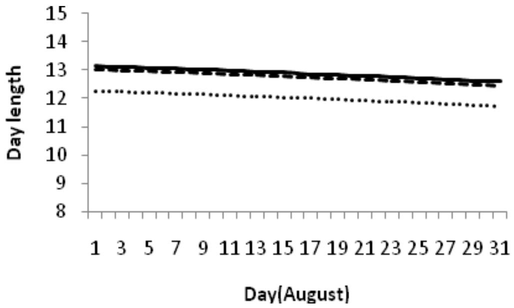


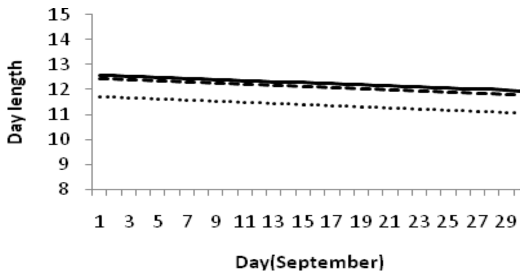



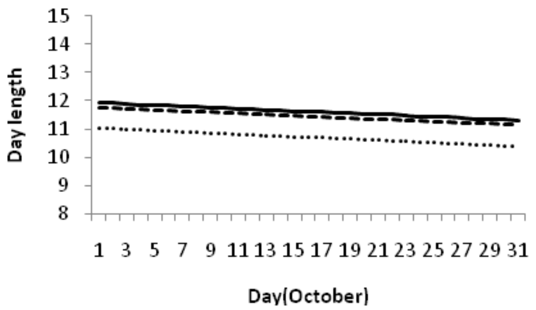

Measured values of day length in Patna for the year 2010 are represented by (—), calculated values from Hay and Cooper formulae are represented by (·····) and (----) respectively

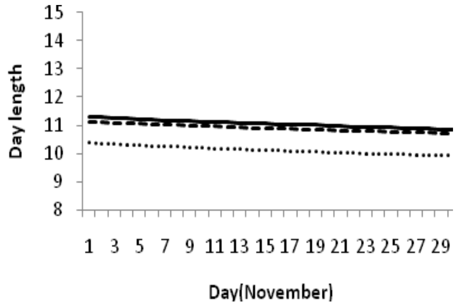
**Fig 5**: Daily variation in Day length values at Patna

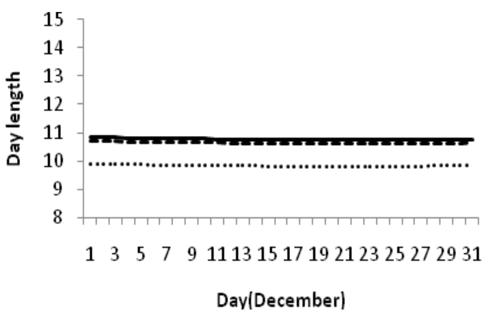


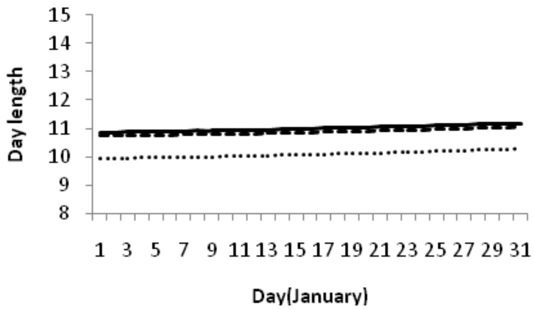



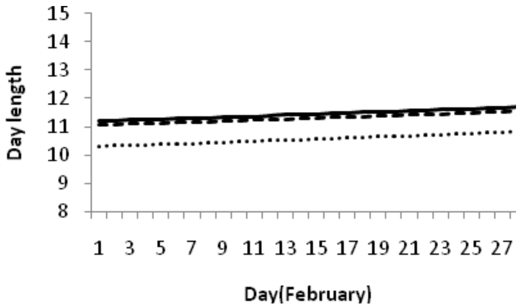



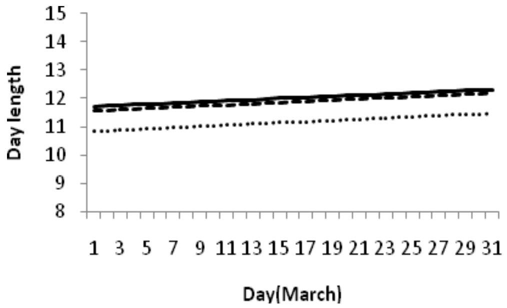



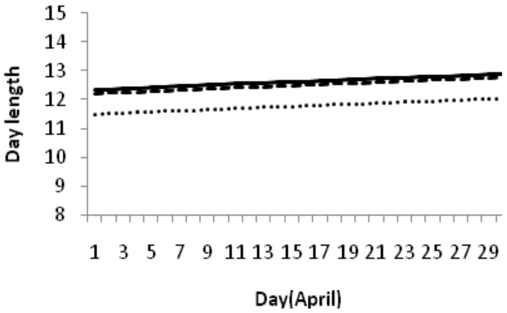

Measured values of day length in Kolkata for the year 2010 are represented by (—), calculated values from Hay and Cooper formulae are represented by (·····) and (----) respectively

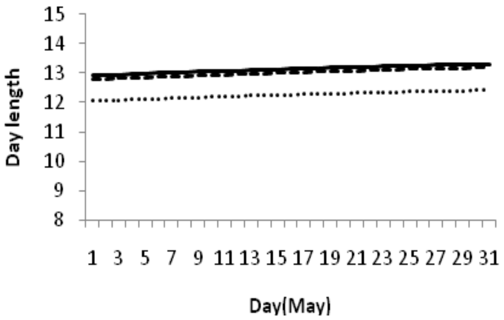
**Fig 6**: Daily variation in Day length values at Kolkata

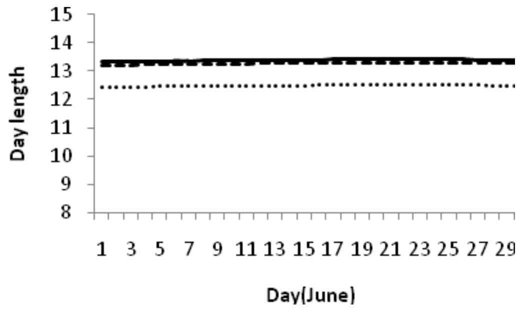


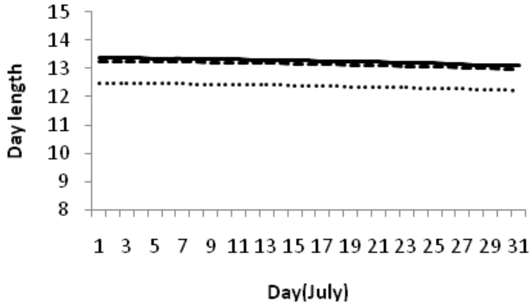



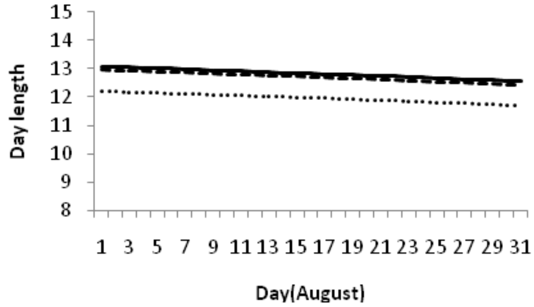



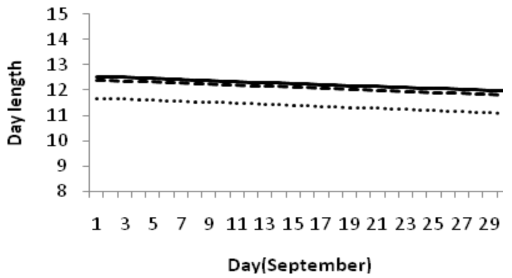



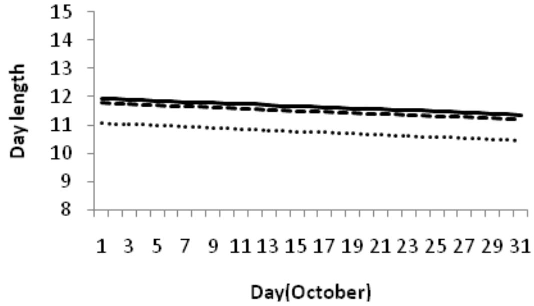



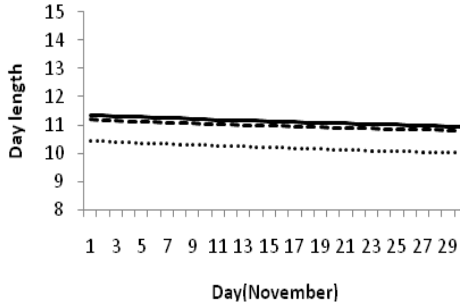


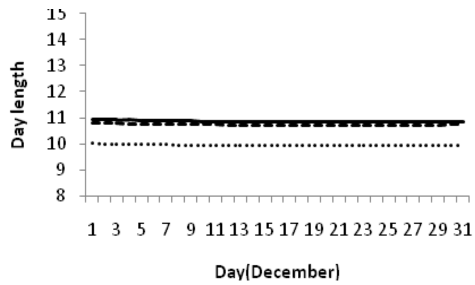



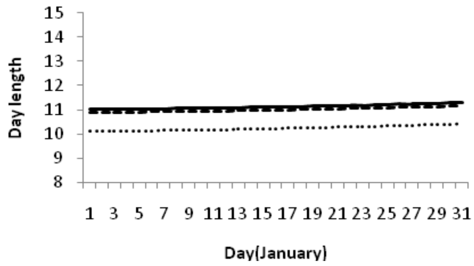



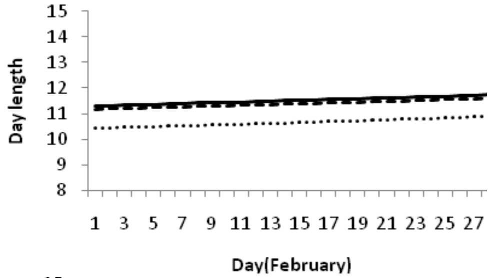



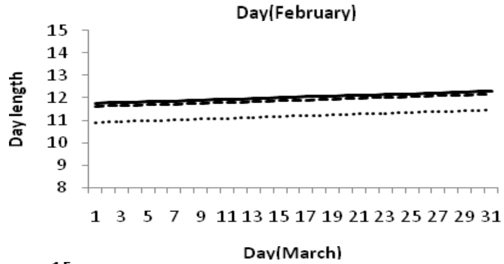



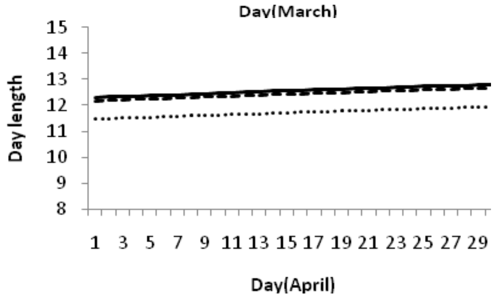

Measured values of day length in Surat for the year 2010 are represented by (—), calculated values from Hay and Cooper formulae are represented by (·····) and (----) respectively

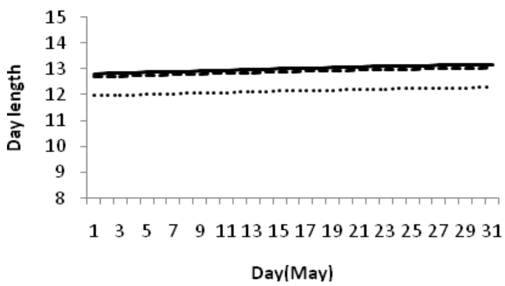
**Fig 7**: Daily variation in Day length values at Surat

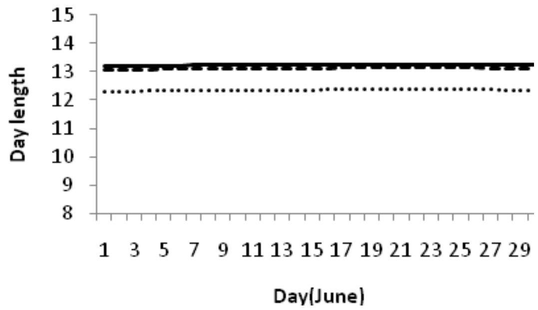


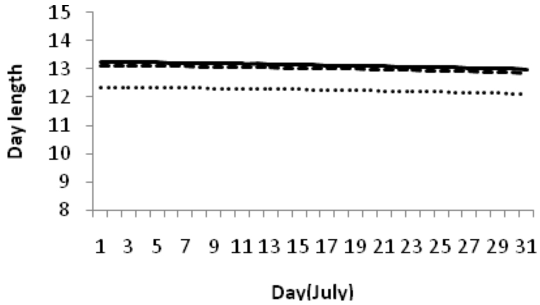



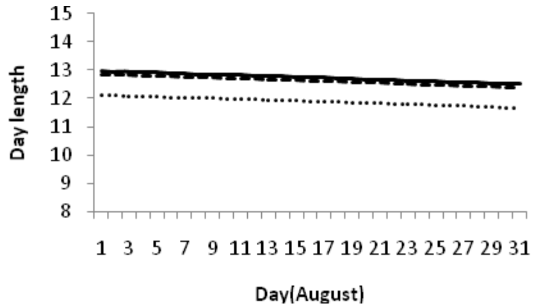



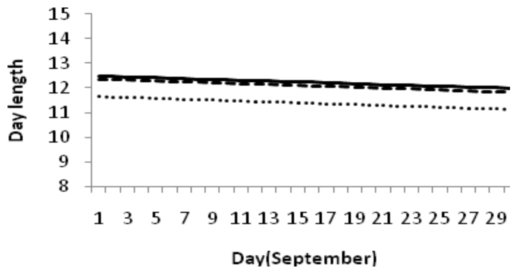



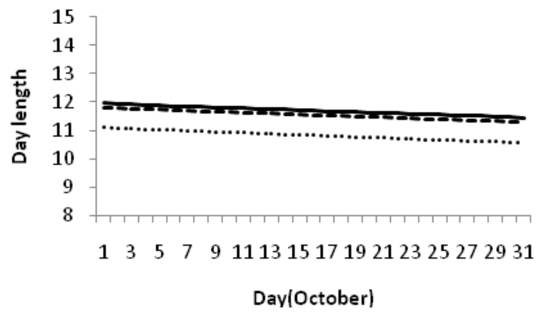



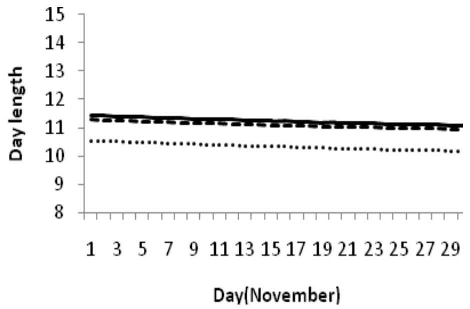


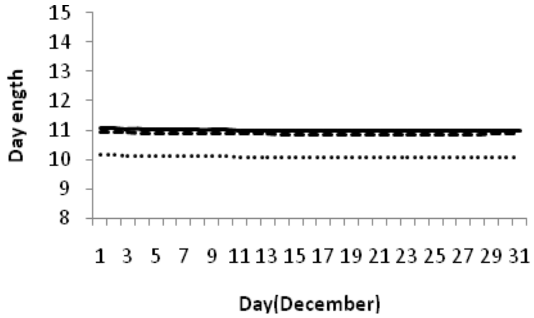



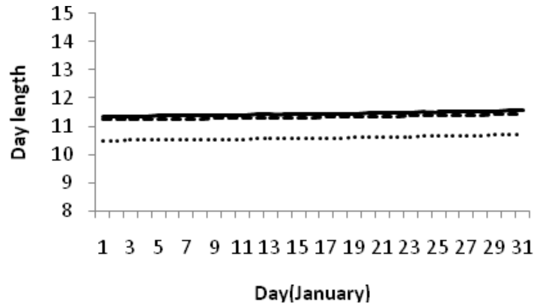



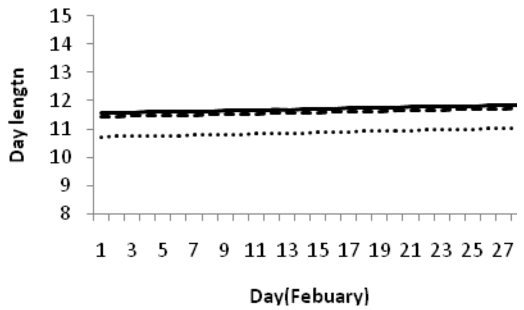



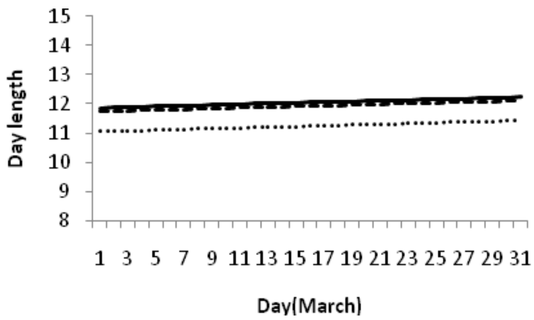



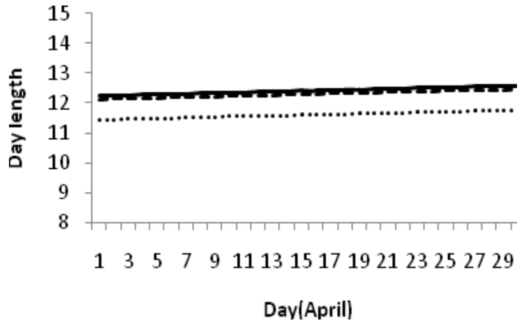

Measured values of day length in Mumbai for the year 2010 are represented by (—), calculated values from Hay and Cooper formulae are represented by (·····) and (----) respectively

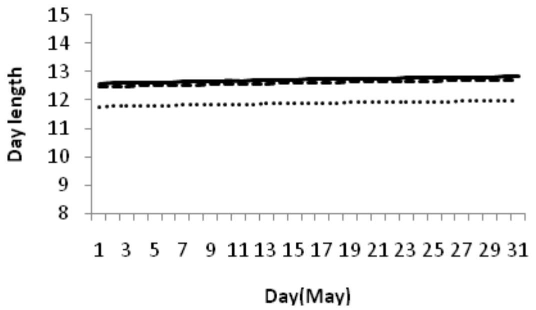
**Fig8**: Daily variation in Day length values at Mumbai

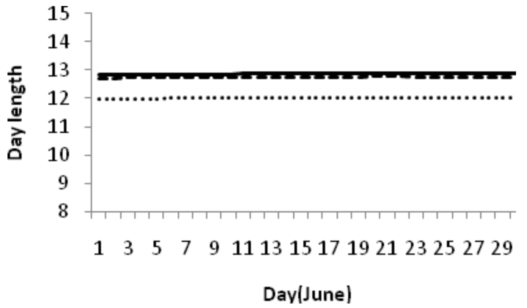


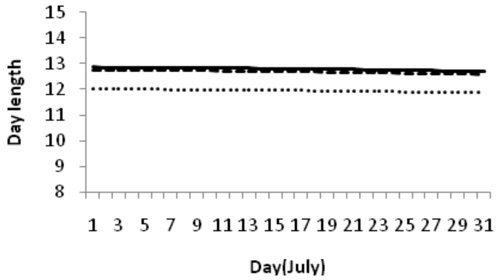



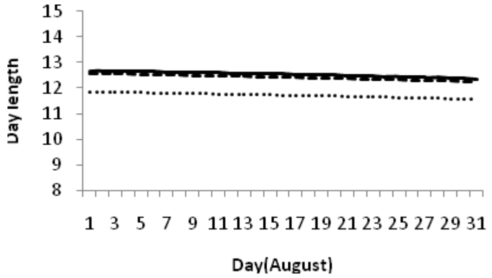



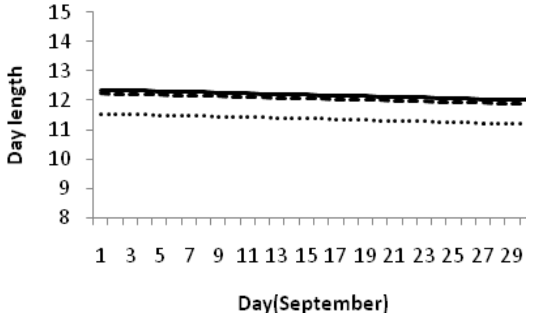



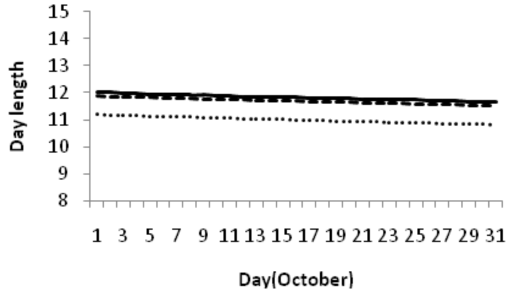


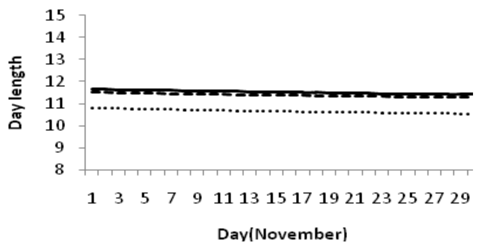



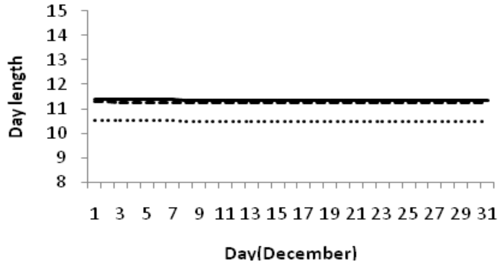



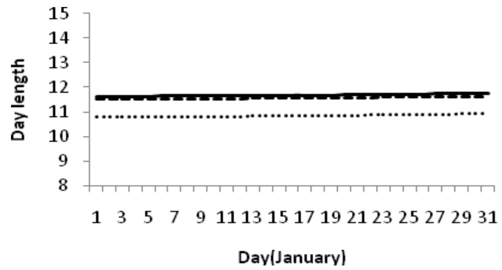



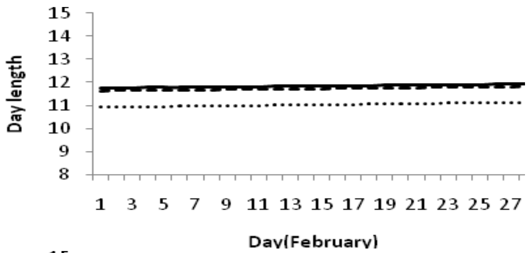



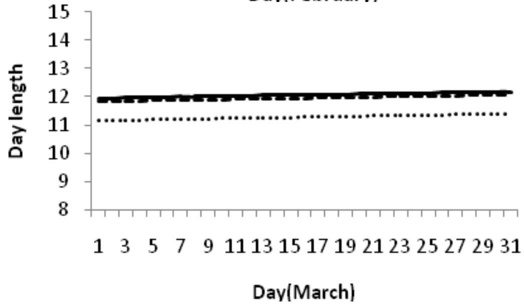



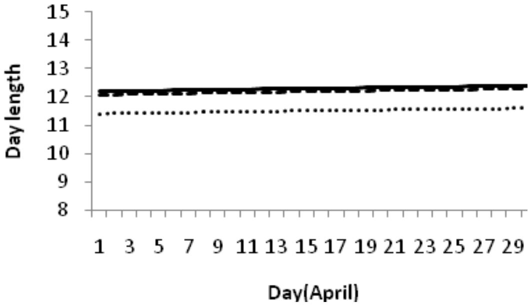

Measured values of day length in Chennai for the year 2010 are represented by (—), calculated values from Hay and Cooper formulae are represented by (·····) and (----) respectively

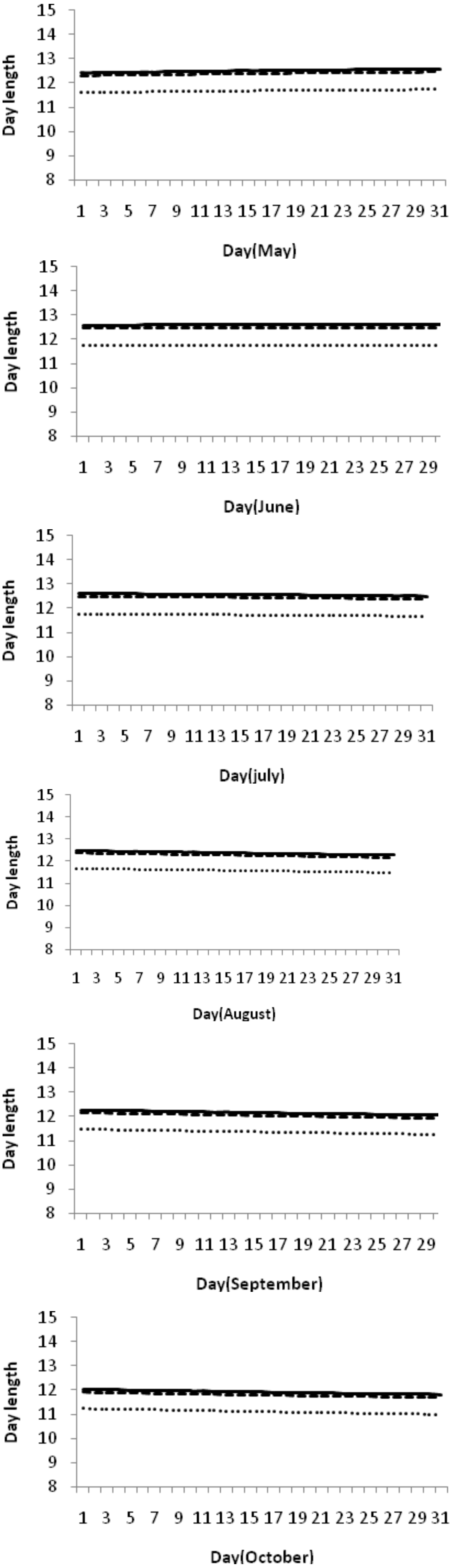
**Fig 9**: Daily variation in Day length values at Chennai

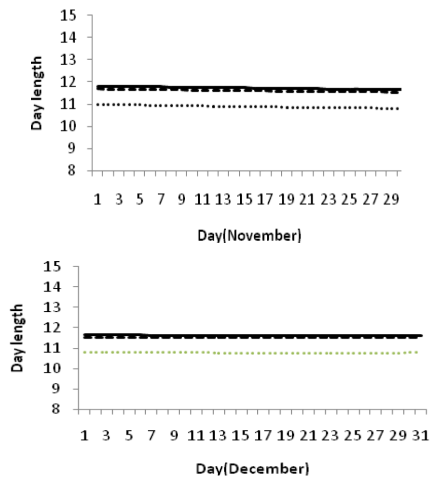





Measured values of day length in Thiruavanthapuram for the year 2010 are represented by (—), calculated values from Hay and Cooper formulae are represented by (·····) and (----) respectively.

**Fig 10**: Daily variation in Day length values at Thiruavanthapuram.

### *3.2. Statistical evaluation*

The accuracy and performance of the derived correlations in predicting of day length was evaluated on the basis of the following statistical error tests which are coefficient of determination root mean square error (RMSE), mean bias error (MBE), relative percentage error (RPE) and t-test statistic. These error indices are defined as:

*3.2.1 Root mean square error*

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(c_i - m_i)^2}$$

where n is the number of data pairs and $c_i$ is the $i^{th}$ calculated and $m_i$ is the $i^{th}$ measured value. The value of RMSE is always positive, representing zero in ideal case.

*3.2.2 Mean bias error*

$$MBE=\frac{1}{n}\sum_{i=1}^{n}(c_i - m_i)$$

low value is desired. The ideal value of MBE is zero.

*3.2.3 Relative percentage error*

$$RPE=\left(\frac{c_i - m_i}{m_i}\right) 100$$

the RPE provides the percentage deviation between the calculated and measured data. The ideal value is zero.

*3.2.4 t-statistic method*

$$t=\sqrt{\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}}$$

the smaller the t-value indicates the better the model performance.

**Table: 2** Statistical results for the validation of selected correlations of this work

| City | Month | Cooper | | | | Hay | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MBE | RMSE | RPE | t-static | MBE | RMSE | RPE | t-static |
| Agra | January | 0.1400 | 0.7807 | -1.3184 | 0.9983 | 0.9690 | 5.4000 | - 9.1186 | 0.9991 |
| | February | 0.1588 | 0.8402 | -1.4145 | 1.0001 | 0.9410 | 4.9796 | -8.3834 | 0.9999 |
| | March | 0.1560 | 0.8687 | -1.3012 | 0.9998 | 0.9100 | 5.0641 | -7.5851 | 1.0005 |
| | April | 0.1349 | 0.7386 | -1.0542 | 1.0004 | 0.8960 | 4.9072 | -7.0033 | 1.0001 |
| | May | 0.1282 | 0.7137 | -0.9516 | 1.0001 | 0.9260 | 5.1557 | -6.8737 | 1.0000 |
| | June | 0.1295 | 0.7091 | -0.9373 | 1.0003 | 0.9549 | 5.2302 | -6.9132 | 1.0000 |
| | July | 0.1272 | 0.7083 | -0.9320 | 0.9999 | 0.9388 | 5.2270 | -6.8774 | 1.0000 |
| | August | 0.1377 | 0.7669 | -1.0540 | 0.9997 | 0.9105 | 5.0691 | -6.9667 | 1.0001 |
| | September | 0.1675 | 0.9174 | -1.3613 | 1.0000 | 0.9186 | 5.0311 | -7.4656 | 1.0001 |
| | October | 0.1897 | 1.0564 | -1.6491 | 0.9998 | 0.9603 | 5.3466 | -8.3464 | 1.0000 |
| | November | 0.1741 | 0.9535 | -1.6104 | 1.0001 | 0.9888 | 5.4160 | -9.1465 | 1.0000 |
| | December | 0.1372 | 0.7640 | -1.3130 | 0.9999 | 0.9831 | 5.4734 | -9.4059 | 1.0001 |
| | | | | | | | | | |
| Chennai | January | 0.1180 | 0.6572 | -1.0318 | 0.9997 | 0.8571 | 4.7720 | -7.4916 | 1.0000 |
| | February | 0.1237 | 0.6547 | -1.0574 | 0.9998 | 0.8310 | 4.3972 | -7.1012 | 1.0000 |
| | March | 0.1195 | 0.6654 | -0.9922 | 0.9999 | 0.8063 | 4.4894 | -6.6942 | 1.0000 |
| | April | 0.1135 | 0.6216 | -0.9145 | 1.0001 | 0.8080 | 4.4254 | -6.5100 | 1.0000 |
| | May | 0.1124 | 0.6257 | -0.8836 | 1.0002 | 0.8358 | 4.6532 | -6.5712 | 1.0001 |
| | June | 0.1128 | 0.6178 | -0.8765 | 1.0001 | 0.8571 | 4.6944 | -6.6594 | 1.0000 |
| | July | 0.1110 | 0.6216 | -0.8724 | 0.9941 | 0.8450 | 4.7080 | -6.6072 | 0.9993 |
| | August | 0.1143 | 0.6364 | -0.9119 | 1.0000 | 0.8180 | 4.5540 | -6.5260 | 1.0001 |
| | September | 0.1250 | 0.6845 | -1.0256 | 1.0001 | 0.8110 | 4.4418 | -6.6544 | 1.0001 |
| | October | 0.1360 | 0.7574 | -1.1502 | 0.9997 | 0.8339 | 4.6429 | -7.0510 | 1.0000 |
| | November | 0.1328 | 0.7271 | -1.1525 | 1.0004 | 0.8628 | 4.7255 | -7.4903 | 1.0001 |
| | December | 0.1195 | 0.6652 | -1.0517 | 1.0002 | 0.8712 | 4.8506 | -7.6681 | 1.0000 |
| | | | | | | | | | |
| Kanpur | January | 0.1395 | 0.7765 | -1.3057 | 1.0003 | 0.9606 | 5.3483 | -8.9927 | 1.0000 |
| | February | 0.1557 | 0.8237 | -1.3836 | 1.0002 | 0.9326 | 4.9346 | -8.2886 | 1.0001 |
| | March | 0.1525 | 0.849 | -1.2715 | 1.0001 | 0.9008 | 5.0152 | -7.5105 | 1.0000 |
| | April | 0.1348 | 0.7384 | -1.0554 | 0.9999 | 0.8911 | 4.8806 | -6.9761 | 1.0000 |
| | May | 0.1270 | 0.7066 | -0.9451 | 1.0007 | 0.9193 | 5.1183 | -6.8452 | 1.0000 |
| | June | 0.1279 | 0.7005 | -0.9295 | 1.0001 | 0.9471 | 5.1876 | -6.8834 | 1.0000 |
| | July | 0.1242 | 0.6913 | -0.9129 | 1.0003 | 0.9301 | 5.1783 | -6.8381 | 1.0001 |
| | August | 0.1370 | 0.7625 | -1.0503 | 1.0004 | 0.9046 | 5.0366 | -6.9371 | 1.0000 |
| | September | 0.1645 | 0.9009 | -1.3376 | 1.0001 | 0.9110 | 4.9896 | -7.4079 | 1.0000 |
| | October | 0.1853 | 1.0318 | -1.6084 | 0.9999 | 0.9492 | 5.2851 | -8.2383 | 1.0000 |
| | November | 0.1720 | 0.9418 | -1.5848 | 1.0003 | 0.9804 | 5.3699 | -9.0353 | 1.0000 |
| | December | 0.1352 | 0.7526 | -1.2872 | 1.0002 | 0.9742 | 5.4240 | -9.2763 | 1.0000 |
| | | | | | | | | | |
| Kolkata | January | 0.1287 | 0.7166 | -1.1793 | 1.0000 | 0.9185 | 5.1140 | -8.4160 | 1.0000 |
| | February | 0.1437 | 0.7605 | -1.2620 | 0.9998 | 0.8942 | 4.7319 | -7.8519 | 0.9999 |
| | March | 0.1410 | 0.7853 | -1.1746 | 0.9997 | 0.8661 | 4.8223 | -7.2128 | 1.0000 |
| | April | 0.1280 | 0.7013 | -1.0113 | 0.9997 | 0.8609 | 4.7152 | -6.7995 | 1.0000 |
| | May | 0.1235 | 0.6874 | -0.9347 | 1.0003 | 0.8894 | 4.9521 | -6.7332 | 1.0000 |
| | June | 0.1259 | 0.6894 | -0.9334 | 1.0003 | 0.9162 | 5.0184 | -6.7944 | 1.0000 |
| | July | 0.1221 | 0.6799 | -0.9145 | 0.9999 | 0.9004 | 5.0132 | -6.7429 | 1.0000 |
| | August | 0.1284 | 0.7151 | -0.9971 | 0.9997 | 0.8718 | 4.8539 | -6.7676 | 1.0000 |
| | September | 0.1521 | 0.8330 | -1.2402 | 1.0001 | 0.8757 | 4.7965 | -7.1412 | 1.0000 |
| | October | 0.1690 | 0.9404 | -1.4542 | 1.0006 | 0.9080 | 5.0547 | -7.8160 | 1.0002 |
| | November | 0.1564 | 0.8563 | -1.4143 | 1.0004 | 0.9050 | 5.1208 | -8.4572 | 0.9669 |
| | December | 0.1307 | 0.7276 | -1.2134 | 1.0002 | 0.9363 | 5.2128 | -8.6932 | 1.0001 |
| | | | | | | | | | |
| Mumbai | January | 0.1239 | 0.6899 | -1.1140 | 0.9999 | 0.8903 | 4.9570 | -8.0039 | 1.0000 |
| | February | 0.1324 | 0.7005 | -1.1502 | 1.0001 | 0.8630 | 4.5667 | -7.4980 | 1.0000 |
| | March | 0.1338 | 0.7451 | -1.1131 | 0.9998 | 0.8413 | 4.6844 | -6.9971 | 0.9999 |
| | April | 0.1240 | 0.6792 | -0.9871 | 1.0000 | 0.8392 | 4.5963 | -6.6796 | 1.0000 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | May | 0.1192 | 0.6636 | -0.9159 | 1.0001 | 0.8654 | 4.8184 | -6.6500 | 1.0000 |
| | June | 0.1219 | 0.6676 | -0.9206 | 1.0001 | 0.8908 | 4.8792 | -6.7278 | 1.0000 |
| | July | 0.1195 | 0.6653 | -0.9099 | 1.0001 | 0.8772 | 4.8840 | -6.6792 | 1.0000 |
| | August | 0.1203 | 0.6700 | -0.9445 | 0.9997 | 0.8454 | 4.7069 | -6.6351 | 1.0000 |
| | September | 0.1402 | 0.7680 | -1.1464 | 0.9999 | 0.8466 | 4.6367 | -6.9210 | 1.0001 |
| | October | 0.1546 | 0.8606 | -1.3213 | 1.0002 | 0.8747 | 4.8699 | -7.4768 | 1.0000 |
| | November | 0.1451 | 0.7948 | -1.2913 | 0.9999 | 0.9013 | 4.9368 | -8.0205 | 1.0000 |
| | December | 0.1227 | 0.6830 | -1.1150 | 1.0002 | 0.9034 | 5.0298 | -8.2107 | 1.0000 |
| | | | | | | | | | |
| New Delhi | January | 0.1440 | 0.8017 | -1.3658 | 1.0001 | 0.9860 | 5.4900 | -9.3530 | 1.0000 |
| | February | 0.1642 | 0.8689 | -1.4701 | 1.0000 | 0.9586 | 5.0721 | -8.5807 | 1.0001 |
| | March | 0.1590 | 0.8851 | -1.3266 | 1.0002 | 0.9225 | 5.1362 | -7.6976 | 1.0000 |
| | April | 0.1401 | 0.7675 | -1.0913 | 0.9998 | 0.9118 | 4.9943 | -7.1010 | 1.0000 |
| | May | 0.1283 | 0.7140 | -0.9466 | 1.0005 | 0.9383 | 5.2239 | -6.9196 | 1.0001 |
| | June | 0.1306 | 0.7154 | -0.9381 | 0.9999 | 0.9691 | 5.3082 | -6.9603 | 1.0000 |
| | July | 0.1296 | 0.7215 | -0.9424 | 1.0001 | 0.9539 | 5.3111 | -6.9362 | 1.0000 |
| | August | 0.1405 | 0.7821 | -1.0697 | 1.0002 | 0.9242 | 5.1456 | -7.0377 | 1.0000 |
| | September | 0.1722 | 0.9432 | -1.3981 | 1.0000 | 0.9337 | 5.1142 | -7.5802 | 1.0000 |
| | October | 0.1956 | 1.0889 | -1.7055 | 1.0001 | 0.9760 | 5.4338 | -8.5104 | 1.0001 |
| | November | 0.1820 | 0.9970 | -1.6964 | 0.9998 | 1.0104 | 5.5342 | -9.4157 | 1.0000 |
| | December | 0.1418 | 0.7894 | -1.3703 | 1.0001 | 1.0032 | 5.5857 | -9.6960 | 1.0000 |
| | | | | | | | | | |
| Patna | January | 0.1379 | 0.7677 | -1.2847 | 1.0001 | 0.9516 | 5.2984 | -8.8655 | 1.0000 |
| | February | 0.1536 | 0.8125 | -1.3611 | 1.0004 | 0.9243 | 4.8907 | -8.1922 | 1.0001 |
| | March | 0.1502 | 0.8364 | -1.2522 | 0.9998 | 0.8931 | 4.9723 | -7.4442 | 1.0001 |
| | April | 0.1349 | 0.7386 | -1.0577 | 1.0004 | 0.8856 | 4.8507 | -6.9461 | 1.0000 |
| | May | 0.1265 | 0.7045 | -0.9457 | 0.9997 | 0.9127 | 5.0816 | -6.8207 | 1.0000 |
| | June | 0.1267 | 0.6937 | -0.9247 | 1.0004 | 0.9391 | 5.1435 | -6.8557 | 1.0000 |
| | July | 0.1252 | 0.6970 | -0.9241 | 1.0001 | 0.9246 | 5.1478 | -6.8246 | 1.0000 |
| | August | 0.1356 | 0.7548 | -1.0424 | 1.0003 | 0.8975 | 4.9971 | -6.9010 | 1.0000 |
| | September | 0.1627 | 0.8910 | -1.3236 | 1.0002 | 0.9038 | 4.9503 | -7.3537 | 1.0000 |
| | October | 0.1820 | 1.0134 | -1.5768 | 0.9999 | 0.9401 | 5.2341 | -8.1439 | 1.0000 |
| | November | 0.1699 | 0.9307 | -1.5594 | 0.9999 | 0.9714 | 5.3203 | -8.9135 | 1.0001 |
| | December | 0.1347 | 0.7499 | -1.2753 | 1.0001 | 0.9658 | 5.3773 | -9.1442 | 1.0000 |
| | | | | | | | | | |
| Surat | January | 0.1305 | 0.7249 | -1.1839 | 1.0024 | 0.9105 | 5.0692 | -8.2782 | 1.0001 |
| | February | 0.1413 | 0.7477 | -1.2354 | 1.0000 | 0.8837 | 4.6763 | -7.7265 | 1.0000 |
| | March | 0.1394 | 0.7763 | -1.1605 | 0.9998 | 0.8574 | 4.7736 | -7.1356 | 1.0000 |
| | April | 0.1263 | 0.6915 | -1.0002 | 1.0004 | 0.8519 | 4.6660 | -6.7488 | 1.0000 |
| | May | 0.1202 | 0.669 | -0.9150 | 1.0004 | 0.8781 | 4.8889 | -6.6864 | 1.0000 |
| | June | 0.1219 | 0.6678 | -0.9107 | 0.9998 | 0.9035 | 4.9489 | -6.7487 | 1.0000 |
| | July | 0.1201 | 0.6688 | -0.9055 | 0.9998 | 0.8900 | 4.9553 | -6.7084 | 1.0000 |
| | August | 0.1239 | 0.6898 | -0.9660 | 1.0001 | 0.8598 | 4.7871 | -6.7035 | 1.0000 |
| | September | 0.1459 | 0.7993 | -1.1915 | 0.9998 | 0.8626 | 4.7243 | -7.0416 | 1.0001 |
| | October | 0.1636 | 0.9106 | -1.4043 | 1.0003 | 0.8948 | 4.9823 | -7.6826 | 0.9999 |
| | November | 0.1535 | 0.8408 | -1.3797 | 0.9999 | 0.9230 | 5.0554 | -8.2949 | 1.0000 |
| | December | 0.1288 | 0.7172 | -1.1861 | 0.9999 | 0.9242 | 5.1460 | -8.5096 | 0.9999 |
| | | | | | | | | | |
| Triavananthapuram | January | 0.1144 | 0.6370 | -0.9797 | 0.9999 | 0.8394 | 4.6735 | -7.1871 | 1.0000 |
| | February | 0.1157 | 0.6124 | -0.9772 | 0.9997 | 0.8110 | 4.2911 | -6.8466 | 1.0001 |
| | March | 0.1110 | 0.6182 | -0.9206 | 0.9997 | 0.7873 | 4.3833 | -6.5263 | 1.0000 |
| | April | 0.1078 | 0.5903 | -0.8764 | 1.0003 | 0.7918 | 4.3370 | -6.4381 | 1.0000 |
| | May | 0.1082 | 0.6023 | -0.8656 | 1.0002 | 0.8202 | 4.5668 | -6.5630 | 1.0000 |
| | June | 0.1139 | 0.6236 | -0.9036 | 1.0004 | 0.8460 | 4.6339 | -6.7142 | 1.0000 |
| | July | 0.1108 | 0.6166 | -0.8824 | 1.0005 | 0.8330 | 4.6379 | -6.6364 | 1.0000 |
| | August | 0.1084 | 0.6036 | -0.8758 | 0.9999 | 0.8015 | 4.4624 | -6.4745 | 1.0000 |
| | September | 0.1148 | 0.6286 | -0.9443 | 1.0003 | 0.7904 | 4.3291 | -6.5028 | 1.0000 |
| | October | 0.1218 | 0.6781 | -1.0215 | 1.0001 | 0.8082 | 4.5000 | -6.7788 | 1.0000 |
| | November | 0.1220 | 0.6680 | -1.0400 | 1.0003 | 0.8385 | 4.5925 | -7.1500 | 1.0000 |
| | December | 0.1143 | 0.6365 | -0.9833 | 0.9998 | 0.8511 | 4.7389 | -7.3202 | 1.0000 |

## Results and Discussion

A comparative analysis presents for daily day-length for the twelve months, computed for the nine stations under consideration by both formulae, Cooper's and Hay's, respectively. The figures show variation of difference of Cooper over Hay formula for different months of the year for different locations under consideration. Calculated data of bright sunshine hours from both formulae have been plotted for nine Indian cities along with the measured data of entire year. The months of January to December, the measured values are closer to Cooper than Hay. A slight variation occurred for the months of September, October and November which are reflected through Figs 2-10. The deviation in Cooper formula than Hay is comparatively less and could be used for the calculation of maximum possible sunshine hours. If Hay formula is used the value of $S_O$ will be much smaller than the measured values. So on the basis of this calculation which has performed for nine Indian locations, we give merit to Cooper formula over Hay. Table 2 summarizes the results of the RMSE, MBE, RPE and t value as computed for both correlations. According to the results, Hay formula is not extremely recommended for using to estimate $S_0$ at stations of India.

## Conclusion

The formulae developed by Hay and Cooper for calculating day length give considerable different values, when it is compared with the measured bright sunshine hours. Cooper values close to the measured value even for clear sky. And on the basis of all statistical tests : RMSE, MBE, RPE and t test, the Cooper method showed the best estimation of day length values for nine Indian stations. Therefore, Cooper formula extremely recommended for predicting day length at any location in India.

## References


Lu Z,PledrahitaRH,Neto CDS.(1998),Generation of daily and hourly solar radiation values for modeling water quality in agriculture ponds, *Transactions of the ASAE* 41(6):1853-9.

Machler MA, Iqbal M. (1985), A modification of the ASHRAE clear sky irradiation model, *ASARE Transactions* 9(1a):106-15.

Trujillo JHS. (1998), Solar performance and shadow behavior in building-case study with computer modeling of a building in Loranca, Spain, *Building and Environment* 33(2-3):117-30.

ASHRAE handbook.(1999), HVAC applications. Atlanta (GA): AHRAE.

Li DHW, Lam JC. (2000), Solar heat gain factors and the implications for building design in subtropical regions, *Energy and buildings* 32(1):47-55.

Karakoti I, Das PK and Singh SK. (2012), Predicting monthly mean daily diffuse radiation for India, *Applied Energy* 91:412-425.

Besharat F, Dehghan Ali A, Faghih Ahmad A.(2013),Empirical models for estimating global solar radiation: A review and case study, *Renewable and Sustainable Energy Reviews* 21:798-821.

Angstrom A. (1924), Solar and terrestrial radiation, *Quarterly Journal of Royal Meteorological society* 50:121-5.

Prescott JA.(1940), Evaporation from water surface in relation to solar radiation, *Transactions of the Royal Society of Australia* 46:114-8.

Glower J, McGulloch JSG. (1958), The empirical relation between solar radiation and hours of sunshine, *Quarterly Journal of Royal Meteorological society* 84:172.

Page JK. (1961), The estimation of monthly mean values of daily total short wave radiation on vertical and inclined surfaces from sunshine records for latitudes $40^oN$-$40^oS$,*In: Proceedings of UN conference on new source of energy* 378-90.

Rietveld M. (1978), A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine, *Agricultural Meteorology* 19:243-52.

Dogniaux R, Lemoine M. (1983), Classification of radiation sites in terms of different indices of atmospheric transparency, Solar radiation data, Solar energy research and development in the European community series F, 2:94-107.

Kilic A, Oztruck A. (1983), Solar energy, Kipas Distribution, Istanbul, Turkey.

Benson RB, Paris MV, Sherry JE, Justus CG. (1984), Estimation of daily and monthly direct diffuse and global solar radiation from sunshine duration measurements, *Solar Energy* 32(4):523-35.

Ogelman H, Ecevit A, Tasdemiroglu E. (1984), A new method for estimating solar radiation from bright sunshine data, *Solar Energy* 33:619-25.

Bahel V, Srinivasan R, Bakhsh H. (1986), Solar radiation for Dhahran, Saudi Arabia, *Energy* 11:985-9.

Zabara K. (1986), Estimation of the global solar radiation in Greece, *Solar and wind technology* 3(4):267-72.

Bahel V, Srinivasan R, Bakhsh H. (1987), A correlation for estimation of global solar radiation, *Energy* 12:131-5.

Gopinathan KK. (1988), A simple method for predicting global solar radiation on a horizontal surface, *Solar and Wind Technology* 5:581–3.

Newland FJ. (1988), A study of solar radiation models for the coastal region of South China, *Solar Energy* 31:227–35.

Soler A. (1990), Monthly specific Rietveld's correlations, *Solar and Wind Technology* 7:305–8.

Luhanga PVC, Andringa J. (1990), Characteristic of solar radiation at Sebele, Gaborone, Botswana, *Solar Energy* 44:71–81.

Louche A, Notton G, Poggi P, Simonnot G. (1991), Correlations for direct normal and global horizontal irradiation on a French Mediterranean site, *Solar Energy* 46:261–6.

Samuel TDMA. (1991), Estimation of global radiation for Sri Lanka, *Solar Energy* 47:333–7.

Gopinathan KK, Soler A. (1992), A sunshine dependent global insolation model for latitudes between $60^oN$ and $70^oN$, *RenewableEnergy* 2(4/5):401–4.

Raja IA. (1994), Insolation sunshine relation with site elevation and latitude, *Solar Energy* 53:53–6.

Coppolino S. (1994), A new correlation between clearness index and relative sunshine, *Renewable Energy* 4(4):417–23.

Tiris M, Tiris C, Ture IE. (1996), Correlations of monthly-average daily global diffuse and beam radiations with hours of bright sunshine in Gebze, Turkey, *Energy Conversion and Management* 37:1417–21.

Ampratwum DB, Dorvlo ASS. (1999), Estimation of solar radiation from the number of sunshine hours, *Applied Energy* 63:161–7.

Klabzuba J, Bures R, Koznarova V. (1999), Model calculation of daily sums of global radiation used in growth models, *In: Proceedings of the bioclimatology labour hours, Zvolen*, p. 121–2.

Togrul IT, Togrul H, Evin D. (2000), Estimation of monthly global solar radiation from sunshine duration measurements in Elazig, *Renewable Energy* 19:587–95.

Elagib N, Mansell MG. (2000), New approaches for estimating global solar radiation across Sudan, *Energy Conversion and Management* 41:419–34.

Togrul IT, Togrul H, Evin D. (2000), Estimation of global solar radiation under clear sky radiation in Turkey, *Renewable Energy* 21:271–87.

Almorox J, Hontoria C. (2004), Global solar radiation estimation using sunshine duration in Spain, *Energy Conversion and Management* 45:1529–35.

Jin Z, Yezheng W, Gang Y. (2005), General Formula for estimation of monthly average daily global solar radiation in China, *Energy Conversion and Management* 46:257–68.

El-Metwally M. (2005), Sunshine and global solar radiation estimation at different sites in Egypt, *Journal of Atmospheric and Solar-Terrestrial Physics* 67:1331–42.

Almorox J, BenitoM, Hontoria C. (2005), Estimation of monthly Angstrom–Prescott equation coefficients from measured daily data in Toledo, Spain, *Renewable Energy* 30:931–6.

Rensheng C, Shihua L, Ersi K, Jianping Y, Xibin J. (2006), Estimating daily global radiation using two types of revised models in China, *Energy Conversion and Management* 47:865–78.

Sen Z. (2007), Simple nonlinear solar irradiation estimation model, *Renewable Energy* 32:342–50.

Bakirci K. (2008), Correlations for estimation of solar radiation on horizontal surface, *Journal of Energy Engineering* 134(4):130–4.

Bakirci K. (2009), Correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey, *Energy* 34:485–501.

Katiyar VK, Katiyar AK, Srivastava SK. (2009), Empirical relationship of sixth order to estimate global solar radiation from hours of sunshine, *Journal of Agrometeorology* 11(2):97-101.

Liu BYH, Jordan RC. (1960), The relationship and characteristics distribution of direct diffuse and total radiation, *Solar Energy* 4(3):1-19.

Al-Mohamad A. (2004), Global, direct and diffuse solar radiation in Syria, *Applied Energy* 79(2):191-200.

Diez-Mediavilla M, Miguel AD, Bilbao J. (2005), Measurement and comparison of diffuse solar irradiance models on inclined surfaces in Valladolid (Spain), *Energy conversion and management* 46(13-14):2075-92.

Tarhan S, Sari A. (2005), Model selection for global and diffuse over the central Black Sea (CBS) region of Turkey, *Energy conversion and management* 46(4): 605-13.

Aras H, Balli O, Hepbasli A. (2006), Estimating the Horizontal diffuse solar radiation over the central Anatollio region of Turkey, *Energy conversion and management* 47(15-16): 2240-9.

Noorian AM, Moradi I, Kamali GA. (2008), Evaluation of 12 models to estimate hourly diffuse radiation on inclined surfaces, *Renewable Energy* 33(6): 1406-12.

El-sebali AA, Al-Hazmi FS, Al-Ghamdi, Yaghmour SJ. (2010), Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia, *Applied Energy* 87: 568-76.

Bolanda J, Ridleya B, Brownb B. (2008), Models of diffuse solar radiation, *Renewable Energy* 33: 575-584.

Jiang Y. (2009), Estimation of monthly mean daily diffuse radiation in China, *Applied Energy* 86: 1458-1464.

TirisM,Tiris C, Ture IE. (1996), Correlations of monthly average daily global diffuse and beam radiations with hours of bright sunshine in Gebze, Turkey, *Energy conversion and management* 37(9): 1417-21.

Barbaro S, Cannato G, Coppolina S, Leone C, Sinagra E. (1981), Diffuse solar radiation statistics for Italy, *Solar Energy* 26: 429-35.

Jain PC. (1990), A model for diffuse and global irradiation on horizontal surfaces, *Solar Energy* 45:301-8.

Haydar A, BalliO,Hepbasli A. (2006), Estimating the horizontal diffuse solar radiation over the central Anatolia region of Turkey, *Energy conversion and management* 47: 2240-9.\

Pandey CK, Katiyar AK. (2009), A comparative study to estimate daily diffuse solar radiation over India, *Energy* 34: 1792–1796

Cooper PI. (1969), *Solar Energy* 12: 333-346.

Hay JE. (1979), *Solar Energy* 23(4): 301-307.

Khorasanizadeh H, Mohammadi K. (2013), Introducing the best model for predicting the monthly mean global solar radiation over six major cities of Iran, *Energy* 51:257-266

Wenxian L. (1988), A general correlation for estimating the monthly average daily direct radiation incident on a horizontal surface in Yannan Province, China, *Solar Energy* 41(1):1-3.

Wenxian L, Enrong L, Wenfeng G, Shaoxuan P and Tao L. (1996), Distribution patterns of diffuse solar radiation in Yannan Province, China, *Energy Conversion and Management*37(5):553-560.

Sambo AS. (1986), Empirical models for the correlation of global solar radiation with meteorological data for northern Nigeria, *Solar &Wind Technology*3(2): 89-93.

Feuillard T, Abillon JM and Bonhomme R. (1989), Relationship between global solar irradiation and sunshine duration in Guadeloupe, *Solar Energy*43(6): 359-361.

Ma CCY, Iqbal M. (1984), Statistical comparison of solar radiation correlations: monthly average global and diffuse radiation on horizontal surfaces, *Solar Energy* 33(2): 143-148.

Bashahu M. (2003), Statistical comparison of models for estimating the monthly average daily diffuse radiation at a subtropical African site, *Solar Energy* 75: 43-51.