Appendix A

Categories of GSR models

1. Group 1: sunshine-duration-based models

The most commonly used parameter for calculating GSR is sunshine duration, widely available at weather stations (Almorox et al., 2005; Bakirci, 2009; Besharat et al., 2013; Al-Mostafa et al., 2014). In this section, models that use only the relative sunshine duration as the critical input parameter are presented and classified according to the year they were developed. Researchers employed measured data form different stations across China to obtain the regressions of these models using linear and nonlinear regression methods; these regressions are summarized in **Table A1**.

S1: A-P model

Angstrom (1924) applied the first sunshine-based model to estimate the monthly average daily GSR on a horizontal surface, which is a linear relationship between the ratio of the average mesured daily GSR to the corresponding value on a clear day and the reltive sunshine duration:

$$\frac{R_g}{R_c} = a_1 + a_2\left(\frac{n}{n_o}\right) \tag{A1}$$

To overcome the difficulty in determining the radiation on a clear day (R_c), Prescott Prescott (1940) modified the method to use the extraterrestrial radiation on a horizontal surface rather than the radiation on a completely clear day:

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) \tag{A2}$$

where R_{ex} can be calculated as (Duffie and Beckman, 2013):

$$R_{ex} = \frac{24}{\pi} R_o \left[1 + 0.033 \cos\left(\frac{2\pi N}{365}\right)\right] \times \left(\frac{\pi \omega_s}{180} \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_s\right) \quad \text{(A3)}$$

δ and ω_s can be calculated by Eqs. (4) and (5), respectively (Duffie and Beckman, 2013):

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + N)\right] \quad \text{(A4)}$$

$$\omega_s = \cos^{-1}(-\tan\varphi \tan\delta) \quad \text{(A5)}$$

For a given month, the maximum possible sunshine duration (n_o) can be calculated (Duffie and Beckman, 2013):

$$n_o = (2/15)\omega_s \quad \text{(A6)}$$

Although the A-P equation can be improved to produce more accurate results, it is used as such for many applications. Liu et al. (2017) tested A-P model using measured data obtained from 98 stations across China.

S2: Rietveld model

Rietveld (1978) proposed a combined correlation to compute GSR by using data from 42 stations worldwide, and making the model applicable anywhere in the world:

$$\frac{R_g}{R_{ex}} = 0.18 + 0.62\left(\frac{n}{n_o}\right) \quad \text{(A7a)}$$

In addition, he examined several published values of the a_1 and a_2 coefficients of the A-P model and noted that a_1 and a_2 are linearly related to the appropriate mean value of the ratio of sunshine duration as follows:

$$a_1 = 0.10 + 0.24\left(\frac{n}{n_o}\right) \quad \text{(A7b)}$$

$$a_2 = 0.38 + 0.08\left(\frac{n}{n_o}\right) \tag{A7c}$$

Liu et al. (2012) used data obtained from 80 sites across China to test the Rietveld model.

S3: Ögelman model

Ögelman et al. (1984) correlated the ratio of global radiation to extraterrestrial radiation in the form of a second-order polynomial function of the relative sunshine duration:

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3\left(\frac{n}{n_o}\right)^2 \tag{A8}$$

Liu et al. (2017) tested Ögelman model using measured data obtained from 98 stations across China.

S4: Newland model

Newland (1989) suggested the following equation, which includes a logarithmic term for the coastal region of south China:

$$\frac{R_g}{R_{ex}} = 0.34 + 0.45\left(\frac{n}{n_o}\right) + \log\left(\frac{n}{n_o}\right) \tag{A9}$$

S5: Bahel model

Bahel et al. (1987) developed a relationship between R_g/R_{ex} and relative sunshine duration in a polynomial form to estimate the monthly-average daily GSR at 48 stations around the world:

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3\left(\frac{n}{n_o}\right)^2 + a_4\left(\frac{n}{n_o}\right)^3 \tag{A10}$$

Liu et al. (2017) tested Bahel model using measured data obtained from 98 stations across China.

S6: Samuel model

Samuel (1991) correlated R_g/R_{ex} with n/n_o in the form of a third-order polynomial equation, similar to Eq. (A10). Many researchers have applied this model and determined the regression coefficients for many locations in China.

S7: Elagib and Mansell model

Elagib and Mansell (2000) developed new techniques for predicting solar radiation based on the sunshine duration and geographical parameters:

$$\frac{R_g}{R_{ex}} = a_1 \, exp\left[a_2\left(\frac{n}{n_o}\right)\right] \quad \text{(A11a)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2 \times (\pi/180)\varphi + a_3 Z + a_4\left(\frac{n}{n_o}\right) \quad \text{(A11b)}$$

Liu et al. (2017) tested Eq. (A11a) using measured data obtained from 98 meteorological stations across China.

S8: Gopinathan model

Gopinathan (1988b) suggested that the a_1 and a_2 coefficients of the A-P model are a function of the relative sunshine duration and altitude of the location for the Southern African region, as given in the following equations:

$$a_1 = 0.265 + 0.07Z - 0.135\left(\frac{n}{n_o}\right) \quad \text{(A12a)}$$

$$a_2 = 0.401 - 0.108Z + 0.325\left(\frac{n}{n_o}\right) \quad \text{(A12b)}$$

Additionally, he suggested the following equation in terms of the altitude and latitude of the location (Gopinathan, 1988a):

$$\frac{R_g}{R_{ex}} = \left(-0.309 + 0.539\cos\varphi + 0.0693Z + 0.290\left(\frac{n}{n_o}\right)\right) + \left(1.527 - 1.027\cos\varphi + 0.0926Z - 0.3590\left(\frac{n}{n_o}\right)\right)\left(\frac{n}{n_o}\right) \quad \text{(A13)}$$

Liu et al. (2012) used data from 80 sites across China to test and calibrate these two models.

S9: Liu model

Liu et al. (2009) employed data from 33 sites in the Yellow River Basin in China to propose a new model based on the A-P model. They used a two-step procedure, i.e., predicting a_1 (or a_2) and ($a_1 + a_2$) first and then a_2 (or a_1) in the second step by subtracting a_1 (or a_2) from the sum ($a_1 + a_2$).

$$a_1 = 0.1705 + 0.0157Z \quad \text{(A14a)}$$

$$(a_1 + a_2) = 0.7121 + 0.358Z \quad \text{(A14b)}$$

Liu et al. (2012) calibrated this model using data from 80 sites in China.

S10: Jin model

Jin et al. (2005) proposed the following models by using solar radiation data from 69 meteorological stations in China and geographical parameters such as latitude and altitude:

$$\frac{R_g}{R_{ex}} = a_1 + a_2\cos\varphi + a_3Z + a_4\left(\frac{n}{n_o}\right) \quad \text{(A15a)}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\varphi + a_3Z) + (a_4 + a_5\varphi + a_6Z)\left(\frac{n}{n_o}\right) \quad \text{(A15b)}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\cos\varphi + a_3Z) + (a_4 + a_5\cos\varphi + a_6Z)\left(\frac{n}{n_o}\right) \quad \text{(A15c)}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\varphi + a_3Z) + (a_4 + a_5\varphi + a_6Z)\left(\frac{n}{n_o}\right) + (a_7 + a_8\varphi + a_9Z)\left(\frac{n}{n_o}\right)^2 \quad \text{(A15d)}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2 \cos\varphi + a_3 Z) + (a_4 + a_5 \cos\varphi + a_6 Z)\left(\frac{n}{n_o}\right) + (a_7 + a_8 \cos\varphi + a_9 Z)\left(\frac{n}{n_o}\right)^2 \tag{A15e}$$

Liu et al. (2012) used data from 80 sites across China to evaluate Eq. (A15c).

S11: Rensheng model

Rensheng et al. (2006) proposed new models based on the A-P model to estimate GSR using data from 86 stations taken between 1994 and 1998. These models are as follows:

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\varphi + a_3 Z) + a_4\left(\frac{n}{n_o}\right) + a_5\left(\frac{n}{n_o}\right)^2 + a_6\left(\frac{n}{n_o}\right)^3 \tag{A16a}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2 \cos\varphi + a_3 Z) + a_4\left(\frac{n}{n_o}\right) + a_5\left(\frac{n}{n_o}\right)^2 + a_6\left(\frac{n}{n_o}\right)^3 \tag{A16b}$$

$$\frac{H_g}{H_{ex}} = (a_1 + a_2 \cos\varphi + a_3 Z) + (a_4 + a_5 \cos\varphi + a_6 Z)\left(\frac{n}{n_o}\right) + (a_7 + a_8 \cos\varphi + a_9 Z)\left(\frac{n}{n_o}\right)^2 + (a_{10} + a_{11} \cos\varphi + a_{12} Z)\left(\frac{n}{n_o}\right)^3 \tag{A16c}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\varphi + a_3 Z + a_4\lambda) + a_5\left(\frac{n}{n_o}\right) \tag{A16d}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2 \cos\varphi + a_3 Z + a_4\lambda) + a_5\left(\frac{n}{n_o}\right) \tag{A16e}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\varphi + a_3 Z + a_4\lambda) + (a_5 + a_6\varphi + a_7 Z + a_8\lambda)\left(\frac{n}{n_o}\right) \tag{A16f}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2 \cos\varphi + a_3 Z + a_4\lambda) + (a_5 + a_6 \cos\varphi + a_7 Z + a_8\lambda)\left(\frac{n}{n_o}\right) \tag{A16g}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\varphi + a_3 Z + a_4\lambda + a_5\lambda^2) + a_6\left(\frac{n}{n_o}\right) + a_7\left(\frac{n}{n_o}\right)^2 + a_8\left(\frac{n}{n_o}\right)^3 \tag{A16h}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2 \cos\varphi + a_3 Z + a_4\lambda + a_5\lambda^2) + a_6\left(\frac{n}{n_o}\right) + a_7\left(\frac{n}{n_o}\right)^2 + a_8\left(\frac{n}{n_o}\right)^3 \tag{A16i}$$

$$\frac{R_g}{R_{ex}} = (a_1 + a_2 \cos\varphi + a_3 Z + a_4 \lambda + a_5 \lambda^2) + (a_{66} + a_7 \cos\varphi + a_8 Z + a_9 \lambda + a_{10} \lambda^2)\left(\frac{n}{n_o}\right) + (a_{11} + a_{12} \cos\varphi + a_{13} Z + a_{14} \lambda + a_{15} \lambda^2)\left(\frac{n}{n_o}\right)^2 + (a_{16} + a_{17} \cos\varphi + a_{18} Z + a_{19} \lambda + a_{20} \lambda^2)\left(\frac{n}{n_o}\right)^3 \quad \text{(A16j)}$$

Liu et al. (2017) tested Rensheng model (Eq. A16e) using measured data obtained from 98 meteorological stations all over China.

S12: Li model

Li et al. (2013) presented sunshine-based model to calculate daily GSR at different solar radiation zones using data from 83 stations in China:

$$R_g = a_1\, n + a_2\, R_{ex} + a_3 \quad \text{(A17)}$$

S13: Yao model

Yao et al. (2014) employed 42 years of measured monthly-average daily GSR data in Shanghai from 1961 to 2002 to fit sunshine duration-based models:

$$\frac{R_g}{R_{ex}} = a_1 + a_2 \ln\left(\frac{n}{n_o}\right) \quad \text{(A18a)}$$

$$\frac{R_g}{R_{ex}} = a_1 \left(\frac{n}{n_o}\right)^{a_2} \quad \text{(A18b)}$$

$$\frac{R_g}{R_{ex}} = a_1 e^{a_2\left(\frac{S}{S_o}\right)} \quad \text{(A18c)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3\left(\frac{n}{n_o}\right)^2 + a_4\left(\frac{n}{n_o}\right)^3 + a_5\left(\frac{n}{n_o}\right)^4 \quad \text{(A18d)}$$

Table A1. Relationships of group-1 models used in China.

Model	Equation	Station number
A-P (Angstrom, 1924)	$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right)$	
Chen (Chen et al., 2004)	$\frac{R_g}{R_{ex}} = 0.19 + 0.53\left(\frac{n}{n_o}\right)$	48
Jin (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = 0.1332 + 0.6471\left(\frac{n}{n_o}\right)$	69
Rensheng (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = 0.176 + 0.563\left(\frac{n}{n_o}\right)$	86
Wu (Wu et al., 2007)	$\frac{R_g}{R_{ex}} = 0.143 + 0.567\left(\frac{n}{n_o}\right)$	1
Li (Li et al., 2011)	$\frac{R_g}{R_{ex}} = 0.2223 + 0.6529\left(\frac{n}{n_o}\right)$	4
Yao (Yao et al., 2014)	$\frac{R_g}{R_{ex}} = 0.2715 + 0.3837\left(\frac{n}{n_o}\right)$	1
Hamouda (Hamouda et al., 2016)	$\frac{R_g}{R_{ex}} = 0.134 + 0.547\left(\frac{n}{n_o}\right)$	1
Gouda (Gouda et al., 2018)	$\frac{R_g}{R_{ex}} = 0.009 + 0.0540\left(\frac{n}{n_o}\right)$	1
Ögelman (Ögelman et al., 1984)	$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3\left(\frac{n}{n_o}\right)^2$	
Jin (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = 0.1404 + 0.6126\left(\frac{n}{n_o}\right) + 0.0351\left(\frac{n}{n_o}\right)^2$	69
Hamouda (Hamouda et al., 2016)	$\frac{R_g}{R_{ex}} = 0.120 + 0.786\left(\frac{n}{n_o}\right) - 0.292\left(\frac{n}{n_o}\right)^2$	1
Bahel (Bahel et al., 1987)	$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3\left(\frac{n}{n_o}\right)^2 + a_4\left(\frac{n}{n_o}\right)^3$	
Chen (Chen et al., 2004)	$\frac{R_g}{R_{ex}} = 0.17a + 0.93\left(\frac{n}{n_o}\right) - 1.08\left(\frac{n}{n_o}\right)^2 + 0.73\left(\frac{n}{n_o}\right)^3$	48

Wu (Wu et al., 2007)	$\frac{R_g}{R_{ex}} = 0.116 + 1.318\left(\frac{n}{n_o}\right) - 1.835\left(\frac{n}{n_o}\right)^2 + 1.136\left(\frac{n}{n_o}\right)^3$	1
Jin (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = 0.1275 + 0.7251\left(\frac{n}{n_o}\right) - 0.2299\left(\frac{n}{n_o}\right)^2 + 0.1837\left(\frac{n}{n_o}\right)^3$	69
Rensheng (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = 0.150 + 1.145\left(\frac{n}{n_o}\right) - 1.474\left(\frac{n}{n_o}\right)^2 + 0.963\left(\frac{n}{n_o}\right)^3$	86
Hamouda (Hamouda et al., 2016)	$\frac{R_g}{R_{ex}} = 0.112 + 1.240\left(\frac{n}{n_o}\right) - 1.741\left(\frac{n}{n_o}\right)^2 + 1.161\left(\frac{n}{n_o}\right)^3$	1
Liu (Liu et al., 2012)	$\frac{R_g}{R_{ex}} = -0.27 + 3.07\left(\frac{n}{n_o}\right) - 4.27\left(\frac{n}{n_o}\right)^2 + 2.3\left(\frac{n}{n_o}\right)^3$	80
Gouda (Gouda et al., 2018)	$\frac{R_g}{R_{ex}} = 0.0112 + 0.0146\left(\frac{n}{n_o}\right) + 0.1521\left(\frac{n}{n_o}\right)^2 - 0.1522\left(\frac{n}{n_o}\right)^3$	1
Elagib and Mansell (Elagib and Mansell, 2000)	$\frac{R_g}{R_{ex}} = a_1 + a_2 \times (\pi/180)\varphi + a_3 Z + a_4\left(\frac{n}{n_o}\right)$	
Jin (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = 0.0855 + 0.0020\varphi + 0.030Z + 0.5654\left(\frac{n}{n_o}\right)$	69
Rensheng (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = 0.1220 + 0.060\varphi + 0.0227Z + 0.543\left(\frac{n}{n_o}\right)$	86
Jiang (Jiang, 2009)	$\frac{R_g}{R_{ex}} = 0.102 - 0.002\varphi + 0.0387Z + 0.5\left(\frac{n}{n_o}\right)$	8
Jin (a) (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = a_1 + a_2\cos\varphi + a_3 Z + a_4\left(\frac{n}{n_o}\right)$	
Jin (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = 2.1186 + 2.0014\cos\varphi + 0.0304Z + 0.5622\left(\frac{n}{n_o}\right)$	69
Rensheng (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = 0.280 - 0.141\cos\varphi + 0.026Z + 0.542\left(\frac{n}{n_o}\right)$	86
Jiang (Jiang, 2009)	$\frac{R_g}{R_{ex}} = 0.350 - 0.219\cos\varphi + 0.0394Z + 0.498\left(\frac{n}{n_o}\right)$	8
Jin (b) (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = (a_1 + a_2\varphi + a_3 Z) + (a_4 + a_5\varphi + a_6 Z)\left(\frac{n}{n_o}\right)$	

Jin (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = (0.1094 + 0.0014\varphi + 0.0212Z) + (0.5176 + 0.0012\varphi + 0.0150Z)\left(\frac{n}{n_o}\right)$	69
Jiang (Jiang, 2009)	$\frac{R_g}{R_{ex}} = (0.088 + 0.003\varphi + 0.179Z) + (0.514 - 0.002\varphi + 0.0351Z)\left(\frac{n}{n_o}\right)$	8
Jin (c) (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = (a_1 + a_2\cos\varphi + a_3Z) + (a_4 + a_5\cos\varphi + a_6Z)\left(\frac{n}{n_o}\right)$	
Jin (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = (1.8790 + 1.7516\cos\varphi + 0.0205Z) + (1.0819 - 0.5409\cos\varphi + 0.0169Z)\left(\frac{n}{n_o}\right)$	69
Rensheng (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = (0.329 - 0.196\cos\varphi + 0.0220Z) + (0.457 + 0.097\cos\varphi + 0.00672Z)\left(\frac{n}{n_o}\right)$	86
Jiang (Jiang, 2009)	$\frac{R_g}{R_{ex}} = (0.471 - 0.338\cos\varphi + 0.0179Z) + (0.3 + 0.189\cos\varphi + 0.0363Z)\left(\frac{n}{n_o}\right)$	8
Jin (d) (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = (a_1 + a_2\varphi + a_3Z) + (a_4 + a_5\varphi + a_6Z)\left(\frac{n}{n_o}\right) + (a_7 + a_8\varphi + a_9Z)\left(\frac{n}{n_o}\right)^2$	
Jin (Jin et al., 2005)	$\frac{R_g}{R_{ex}} = (0.0218 + 0.0033\varphi + 0.0443Z) + (0.9979 - 0.0092\varphi - 0.0852Z)\left(\frac{n}{n_o}\right) + (-0.5579 + 0.0120\varphi + 0.1005Z)\left(\frac{n}{n_o}\right)^2$	69
Jiang (Jiang, 2009)	$\frac{R_g}{R_{ex}} = (0.041 + 0.004\varphi + 0.0486Z) + (0.752 - 0.007\varphi - 0.083Z)\left(\frac{n}{n_o}\right) + (-0.261 + 0.006\varphi)\left(\frac{n}{n_o}\right)^2$	8

Jin (e) (Jin et al., 2005)	$$\frac{R_g}{R_{ex}} = (a_1 + a_2\cos\varphi + a_3 Z) + (a_4 + a_5\cos\varphi + a_6 Z)\left(\frac{n}{n_o}\right) + (a_7 + a_8\cos\varphi + a_9 Z)\left(\frac{n}{n_o}\right)^2$$	
Jin (Jin et al., 2005)	$$\frac{R_g}{R_{ex}} = (4.2510 - 4.1878\cos\varphi + 0.0437Z) + (-10.5774 + 11.4512\cos\varphi - 0.0832Z)\left(\frac{n}{n_o}\right) + (12.7247 - 13.0994\cos\varphi + 0.1000Z)\left(\frac{n}{n_o}\right)^2$$	69
Jiang (Jiang, 2009)	$$\frac{R_g}{R_{ex}} = (0.41 + \cos\varphi + 0.0437Z) + (-10.5774 + 11.4512\cos\varphi - 0.0832Z)\left(\frac{n}{n_o}\right) + (12.7247 - 13.0994\cos\varphi + 0.1000Z)\left(\frac{n}{n_o}\right)^2$$	8
Rensheng (a) (Rensheng et al., 2006)	$$\frac{R_g}{R_{ex}} = (0.109 + 0.001\varphi + 0.0241Z) + 1.029\left(\frac{n}{n_o}\right) - 1.216\left(\frac{n}{n_o}\right)^2 + 0.787\left(\frac{n}{n_o}\right)^3$$	86
Rensheng (b) (Rensheng et al., 2006)	$$\frac{R_g}{R_{ex}} = (0.234 - 0.112\cos\varphi + 0.0243Z) + 1.026\left(\frac{n}{n_o}\right) - 1.209\left(\frac{n}{n_o}\right)^2 + 0.782\left(\frac{n}{n_o}\right)^3$$	86
Rensheng (c) (Rensheng et al., 2006)	$$\frac{R_g}{R_{ex}} = (a_1 + a_2\cos\varphi + a_3 Z) + (a_4 + a_5\cos\varphi + a_6 Z)\left(\frac{n}{n_o}\right) + (a_7 + a_8\cos\varphi + a_9 Z)\left(\frac{n}{n_o}\right)^2 + (a_{10} + a_{11}\cos\varphi + a_{12} Z)\left(\frac{n}{n_o}\right)^3$$	
Rensheng (Rensheng et al., 2006)	$$\frac{R_g}{R_{ex}} = (0.336 - 0.112\cos\varphi + 0.0264Z) + (-0.670 + 2.140\cos\varphi - 0.1Z)\left(\frac{n}{n_o}\right) + (2.744 - 5\cos\varphi + 0.3Z)\left(\frac{n}{n_o}\right)^2 + (-1.638 + 3.042\cos\varphi - 0.2Z)\left(\frac{n}{n_o}\right)^3$$	86

Liu (Zone I) (Liu et al., 2017; Gouda and Yuan, 2018a; Gouda and Yuan, 2018b; Gouda and Yuan, 2018c; Liu et al., 2018)	$$\frac{R_g}{R_{ex}} = (0.27 - 1.09\cos\varphi + 4.07\times10^{-3}Z) + (-1.68 - 0.087\cos\varphi + 2.12\times10^{-3}Z)\left(\frac{n}{n_o}\right) + (-5.30 + 2.37\cos\varphi + 5.41\times10^{-9}\,Z)\left(\frac{n}{n_o}\right)^2 + (-5.42\times10^{-6} + 1.92\times10^{-5}\cos\varphi - 1.91\times10^{-8}Z)\left(\frac{n}{n_o}\right)^3$$	17
Liu (Zone II) (Liu et al., 2017; Gouda and Yuan, 2018a; Gouda and Yuan, 2018b; Gouda and Yuan, 2018c; Liu et al., 2018)	$$\frac{R_g}{R_{ex}} = (0.19 - 0.78\cos\varphi + 4.95\times10^{-3}Z) + (-3.67 - 0.089\cos\varphi + 1.82\times10^{-3}Z)\left(\frac{n}{n_o}\right) + (-7.25 + 5.47\cos\varphi - 3.31\times10^{-8}\,Z)\left(\frac{n}{n_o}\right)^2 + (1.73\times10^{-5} + 2.04\times10^{-5}\cos\varphi - 2.02\times10^{-8}Z)\left(\frac{n}{n_o}\right)^3$$	24
Liu (Zone III) (Liu et al., 2017; Gouda and Yuan, 2018a; Gouda and Yuan, 2018b; Gouda and Yuan, 2018c; Liu et al., 2018)	$$\frac{R_g}{R_{ex}} = (0.42 - 0.35\cos\varphi + 3.05\times10^{-3}Z) + (-2.41 - 0.31\cos\varphi + 1.5\times10^{-3}Z)\left(\frac{n}{n_o}\right) + (-4.99 + 3.83\cos\varphi + 9.73\times10^{-9}\,Z)\left(\frac{n}{n_o}\right)^2 + (2.46\times10^{-5} + 3.17\times10^{-5}\cos\varphi - 1.10\times10^{-8}Z)\left(\frac{n}{n_o}\right)^3$$	26

Liu (Zone IV) (Liu et al., 2017; Gouda and Yuan, 2018a; Gouda and Yuan, 2018b; Gouda and Yuan, 2018c; Liu et al., 2018)	$\frac{R_g}{R_{ex}} = (0.12 + 1.32\cos\varphi - 2.41\times10^{-3}Z) + (1.69 + 0.026\cos\varphi - 0.30\times10^{-3}Z)\left(\frac{n}{n_o}\right) + (1.22 - 0.94\cos\varphi + 8.64\times10^{-8}Z)\left(\frac{n}{n_o}\right)^2 + (5.29\times10^{-4} + 3.63\times10^{-4}\cos\varphi - 1.32\times10^{-7}Z)\left(\frac{n}{n_o}\right)^3$	20
Liu (Zone V) (Liu et al., 2017; Gouda and Yuan, 2018a; Gouda and Yuan, 2018b; Gouda and Yuan, 2018c; Liu et al., 2018)	$\frac{R_g}{R_{ex}} = (0.45 + 0.47\cos\varphi - 2.29\times10^{-3}Z) + (2.83 - 0.35\cos\varphi + 0.86\times10^{-3}Z)\left(\frac{n}{n_o}\right) + (0.69 - 2.03\cos\varphi + 2.10\times10^{-8}Z)\left(\frac{n}{n_o}\right)^2 + (-9.78\times10^{-5} + 5.64\times10^{-5}\cos\varphi - 8.84\times10^{-8}Z)\left(\frac{n}{n_o}\right)^3$	11
Rensheng (d) (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = (0.117 - 0.001\varphi + 0.0259Z + 4.11\times10^{-5}\lambda) + 0.543\left(\frac{n}{n_o}\right)$	86
Rensheng (e) (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = (0.275 - 0141\cos\varphi + 0.0267Z + 4.27\times10^{-5}\lambda) + 0.542\left(\frac{n}{n_o}\right)$	86
Rensheng (f) (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = (0.094 + 0.002\varphi + 0.0227Z + 0.0001\lambda) + (0.586 - 0.0008\varphi + 5.36\times10^{-3}Z - 0.0002\lambda)\left(\frac{n}{n_o}\right)$	86
Rensheng (g) (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = (0.313 - 0.195\cos\varphi + 0.0282Z + 0.0001\lambda) + (0.476 + 0.097\cos\varphi + 5.69\times10^{-3}Z - 0.0002\lambda)\left(\frac{n}{n_o}\right)$	86

Rensheng (h) (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = (0.370 + 0.0007\varphi + 0.0244Z - 0.005\lambda + 2.24 \times 10^{-5}\lambda^2) + 1.026\left(\frac{n}{n_o}\right) - 1.208\left(\frac{n}{n_o}\right)^2 + 0.783\left(\frac{n}{n_o}\right)^3$	86
Rensheng (i) (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = (0.426 - 0.87\cos\varphi + 0.0244Z - 0.004\lambda + 1.86 \times 10^{-5}\lambda^2) + 1.024\left(\frac{S}{S_o}\right) - 1.204\left(\frac{n}{n_o}\right)^2 + 0.779\left(\frac{n}{n_o}\right)^3$	86
Rensheng (j) (Rensheng et al., 2006)	$\frac{R_g}{R_{ex}} = (1.012 - 0.141\cos\varphi + 0.0284Z - 0.014\lambda + 6.7 \times 10^{-5}\lambda^2) + (-4.061 + 1.740\cos\varphi - 0.1Z + 0.069\lambda - 0.003\lambda^2)\left(\frac{n}{n_o}\right) + (12.402 - 3.867\cos\varphi + 0.3Z - 0.199\lambda + 0.0009\lambda^2)\left(\frac{n}{n_o}\right)^2 + (-9.442 + 2.115\cos\varphi - 0.2Z + 0.164\lambda - 0.0008\lambda^2)\left(\frac{n}{n_o}\right)^3$	86
Yao (Yao et al., 2014)	$\frac{R_g}{R_{ex}} = 0.6050 + 0.1917\ln\left(\frac{n}{n_o}\right)$	42
Yao (Yao et al., 2014)	$\frac{R_g}{R_{ex}} = 0.6673\left(\frac{n}{n_o}\right)^{0.5343}$	42
Yao (Yao et al., 2014)	$\frac{R_g}{R_{ex}} = 0.2674e^{1.0391\left(\frac{S}{S_o}\right)}$	42
Yao (Yao et al., 2014)	$\frac{R_g}{R_{ex}} = 0.1094 - 0.0098\left(\frac{n}{n_o}\right) + 5.3302\left(\frac{n}{n_o}\right)^2 - 10.3730\left(\frac{n}{n_o}\right)^3 + 5.6243\left(\frac{n}{n_o}\right)^4$	42

2. Group 2: air temperature-based models

The daily maximum and minimum air temperatures are easily and available in most of locations, hence, many researchers employed these data to develop several empirical models for estimating GSR, especially when the daily air temperature is the sole available parameters in the site of interest. For temperature-based models, the difference between the maximum and minimum temperatures is directly related to the extraterrestrial radiation's fraction on a horizontal surface. However, many factors rather than solar radiation can influence temperature, such as cloudiness, humidity, latitude, elevation, topography, or proximity to a water's large body (Allen, 1997). In this section, solar radiation models based on the maximum/minimum and mean air temperatures that have been applied in China are presented and classified according to the year they were developed. Researchers employed observed data form different stations across China to obtain the regressions of temperature-based models using linear and nonlinear regression methods; these regressions are summarized in **Table A2**.

T1: Hargreaves model

Hargreaves and Samani (1982) estimated the GSR based on the maximum and minimum air temperatures:

$$\frac{R_g}{R_{ex}} = a_1(T_{max} - T_{min})^{0.5} \quad \text{(A19)}$$

T2: Bristow and Campbell model

Bristow and Campbell (1984) suggested a relationship between daily GSR and air temperature:

$$\frac{R_g}{R_{ex}} = a_1\left(1 - exp\left(-a_2(T_{max} - T_{min})\right)^{a_3}\right) \quad \text{(A20)}$$

T3: Samani model

Samani (2000) proposed a relationship between the ratio of the GSR to the extraterrestrial solar radiation and the temperature difference between the maximum and minimum daily air temperatures. Li et al. (2010a); Li et al. (2014) tested this model at 65 meteorological stations:

$$\frac{R_g}{R_{ex}} = (a_1 + a_2(T_{max} - T_{min}) + a_3(T_{max} - T_{min})^2)(T_{max} - T_{min})^{0.5} \quad (A21)$$

T4: Chen model

Chen et al. (2004) suggested two relationships between the ratio of the daily GSR and the daily extraterrestrial solar radiation and the temperature difference using monthly average daily data obtained between 1994 and 1998 from 48 stations across China:

$$\frac{R_g}{R_{ex}} = a_1 + a_2 \ln(T_{max} - T_{min}) \quad (A22a)$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min})^{0.5} \quad (A22b)$$

Li et al. (2014) tested Eq. (A22b) at 65 meteorological stations.

T5: Li H model

Li et al. (2010b) developed new models to estimate the daily GSR in Chongqing using data of daily maximum and minimum temperatures, daily mean dew-point temperature, fog and rainfall from 1986 to 2000:

$$\frac{R_g}{R_{ex}} = a_1 + a_2 T_{max} + a_3 T_{min} \quad (A23)$$

They employed their model to determine the coefficients as follows:

$$\frac{R_g}{R_{ex}} = -0.072 + 0.043 T_{max} - 0.040 T_{min} \quad (A24)$$

T6: Chen and Li model

Chen and Li (2013) estimated the monthly-average daily GSR in Yangtze River Basin in China using new developed models based on the maximum and minimum air temperatures:

$$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min}) \quad \text{(A25a)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2T_{max} + a_3T_{min} + a_4T_{max} \times T_{min} \quad \text{(A25b)}$$

T7: Li model

Li et al. (2014) suggested a new model to estimate GSR as a function of average, maximum and minimum air temperatures using measured data from 65 meteorological stations:

$$\frac{R_g}{R_{ex}} = \left(a_1 + a_2T_{avg}\right)(T_{max} - T_{min})^{0.5} + a_3 \quad \text{(A26a)}$$

$$T_{avg} = \left[\frac{T_{max}+T_{min}}{2}\right] \quad \text{(A26b)}$$

Table A2. Relationships of group-2 models used in China.

Model	Equation	Station number
Hargreaves (Hargreaves and Samani, 1982)	$\frac{R_g}{R_{ex}} = a_1(T_{max} - T_{min})^{0.5}$	
Chen (Chen et al., 2004)	$\frac{R_g}{R_{ex}} = 0.39(T_{max} - T_{min})^{0.5}$	48
Wu (Wu et al., 2007)	$\frac{R_g}{R_{ex}} = 0.153(T_{max} - T_{min})^{0.5}$	1
Bristow and Campbell (Bristow and Campbell, 1984)	$\frac{R_g}{R_{ex}} = a_1\left(1 - exp\left(-a_2(T_{max} - T_{min})\right)^{a_3}\right)$	
Chen (Chen et al., 2004)	$\frac{R_g}{R_{ex}} = 0.64\left(1 - exp\left(-0.045(T_{max} - T_{min})\right)^{1.7}\right)$	48
Wu (Wu et al., 2007)	$\frac{R_g}{R_{ex}} = 0.601\left(1 - exp\left(-0.029(T_{max} - T_{min})\right)^{1.862}\right)$	1
Chen (a) (Chen et al., 2004)	$\frac{R_g}{R_{ex}} = a_1 + a_2 \ln(T_{max} - T_{min})$	
Chen (Chen et al., 2004)	$\frac{R_g}{R_{ex}} = -0.15 + 0.28 \ln(T_{max} - T_{min})$	48
Wu (Wu et al., 2007)	$\frac{R_g}{R_{ex}} = -0.236 + 0.333 \ln(T_{max} - T_{min})$	1
Chen (b) (Chen et al., 2004)	$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min})^{0.5}$	
Chen (Chen et al., 2004)	$\frac{R_g}{R_{ex}} = 0.19 - 0.13(T_{max} - T_{min})^{0.5}$	48
Wu (Wu et al., 2007)	$\frac{R_g}{R_{ex}} = -0.366 + 0.288(T_{max} - T_{min})^{0.5}$	1
Li (Li et al., 2010b)	$\frac{R_g}{R_{ex}} = -0.282 + 0.221(T_{max} - T_{min})^{0.5}$	1

3. Group 3: precipitation-based models

Researchers have used precipitation-based models to estimate GSR owing to the availability of precipitation data when sunshine duration and temperature data are not available.

P1: Li model

Li et al. (2010b) developed a new model to estimate the daily solar radiation from measured meteorological data of precipitation in Chongqing:

$$\frac{R_g}{R_{ex}} = a_1 + a_2 P_{re} \quad \text{(A27)}$$

Li et al. (2010b) employed their model to correlate the daily solar radiation using data obtained in Chongqing between 1986 and 2000:

$$\frac{R_g}{R_{ex}} = 0.319 - 0.153 P_{re} \quad \text{(A28)}$$

4. Group 4: dew-point temperature-based models

This category of models depends only on the dew-point temperature as the key input for estimating monthly average daily GSR in the absence of sunshine, temperature, and precipitation data.

DP1: Li model

Li et al. (2010b) suggested a new model to calculate the daily solar radiation using the monthly-average daily dew-point temperature from 1986 to 2000 in Chongqing:

$$\frac{R_g}{R_{ex}} = a_1 + a_2 DP \quad \text{(A29)}$$

They used their model to correlate the daily solar radiation in Chongqing:

$$\frac{R_g}{R_{ex}} = 0.112 + 0.01 DP \quad \text{(A30)}$$

5. Group 5: fog-based models

This section illustrates the estimation of GSR based only on fog as the key model input.

F1: Li model

Li et al. (2010b) suggested a new regression between GSR and the quantity of fog to estimate GSR in Chongqing:

$$\frac{R_g}{R_{ex}} = a_1 + a_2 Fog \qquad \text{(A31)}$$

They employed their equation to correlate GSR using measured data obtained between 1986 and 2000 in Chongqing:

$$\frac{R_g}{R_{ex}} = 0.246 + 0.05Fog \qquad \text{(A32)}$$

6. Group 6: cloud cover-based models

Cloud cover is an important atmospheric phenomenon which effect on the incident solar radiation on horizontal surface. Few studies have been found that uses the cloud cover as a sole key input parameter to estimate the GSR on a horizontal surface especially, for China. The models used in China can be presented as follows:

CL1: Badescu model

Badescu (1999) used the fractional total cloud amount to develop linear, quadratic and cubic relationships for estimating monthly-average-daily GSR. In China, only cubic equation was used.

$$\frac{R_g}{R_{ex}} = a_1 + a_2 C + a_3 C^2 + a_4 C^3 \qquad \text{(A33)}$$

Gouda et al. (2018) employed a long-term measured data from 2006 to 2011 in Wuhan, China to correlate Badescu model:

$$\frac{R_g}{R_{ex}} = 1.030 - 4.1018C + 5.5511C^2 - 2.4725C^3 \quad \text{(A34)}$$

7. Group 7: models based on the day of the year

Several solar energy researchers have attempted to determine the relationship between GSR and the day of the year without using any other parameters. These works are presented and discussed in the following subsections.

D1: Al-Salaymeh model I

Al-Salaymeh (2006) proposed 4 different correlations to estimate the daily GSR in Amman, Jordan. The first model is sine wave form:

$$R_g = a_1 + a_2 \sin\left(\frac{2\pi N}{a_3} + a_4\right) \quad \text{(A35)}$$

Li et al. (2010a) compared this model with three other models against data obtained from 79 stations across China. Gouda et al. (2019) calibrated this model among nine-day of the year-based models to estimate the daily GSR on a horizontal at 84 stations all over China and developed general model for five solar climatic zones in China. Zang et al. (2019) tested and compared this model with another 6 day of the year based models using daily GSR data from 35 meteorological stations across six climate zones in China.

D2: Al-Salaymeh model II

The second model is Lorentzin correlation (Al-Salaymeh, 2006):

$$R_g = \frac{a_1}{1 + \left(\frac{N - a_2}{a_3}\right)^2} \quad \text{(A36)}$$

Gouda et al. (2019) calibrated this model among nine-day of the year-based models to estimate the daily GSR on a horizontal at 84 stations all over China and developed general models for five solar climatic zones in China.

D3: Al-Salaymeh model III

Gaussian form is the third model (Al-Salaymeh, 2006):

$$R_g = a_1 \exp\left[-0.5 \times \left(\frac{N - a_2}{a_3}\right)^2\right] \quad \text{(A37)}$$

Gouda et al. (2019) calibrated this model among nine-day of the year-based models to estimate the daily GSR on a horizontal at 84 stations all over China. They found that Eq. (A37) is the best model for zone III and, therefore, it can be a general model:

$$R_g = 20.538 \exp\left[-0.5 \times \left(\frac{N - 168.631}{109.313}\right)^2\right] \quad \text{(A38)}$$

Zang et al. (2019) tested and compared this model with another 6 day of the year based models using daily GSR data from 35 meteorological stations across six climate zones in China.

D4: Al-Salaymeh model IV

A 4th order polynomial degree model is the forth proposed form (Al-Salaymeh, 2006):

$$R_g = a_1 + a_2 N + a_3 N^2 + a_4 N^3 + a_5 N^4 \quad \text{(A39)}$$

Gouda et al. (2019) evaluated this model among nine-day of the year-based models to estimate the daily GSR on a horizontal at 84 stations all over China and found that Eq. (A39) is the best accurate model for zone V and therefore, it can be a general model for this zone:

$$R_g = 6.791 - 0.065N + 1.999\times10^{-3}N^2 - 9.850\times10^{-6}N^3 + 1.330\times10^{-8}N^4 \quad \text{(A40)}$$

Zang et al. (2019) tested and compared this model with another 6 day of the year based models using daily GSR data from 35 meteorological stations across six climate zones in China.

D5: Bulut and Büyükalaca model

Bulut and Büyükalaca (2007) presented a simple model depending only on the day of the year to predict GSR using a sine wave form. The model was tested and applied by Zang et al. (2012) to predict daily GSR using data from 35 different weather stations in China, furthermore, it was evaluated by Gouda et al. (2019) using a long-term data of 84 stations all over China.

$$R_g = a_1 + a_2 \left|\sin\left(\frac{\pi(N+5)}{365}\right)\right|^{1.5} \quad \text{(A41)}$$

Li et al. (2010a) also compared this model and three other models using data from 79 stations. Zang et al. (2019) tested and compared this model with another 6 day of the year based models using daily GSR data from 35 meteorological stations across six climate zones in China.

D6: Kaplanis and Kaplani model

Kaplanis and Kaplani (2007) suggested the following cosine wave relationship to calculate GSR based on the day of the year:

$$R_g = a_1 + a_2 \, cos\left(\frac{2\pi N}{365} + a_3\right) \quad \text{(A42)}$$

Then, Zang et al. (2012) employed the model, compared the predicted values with those obtained at 35 different solar radiation stations and found the accuracy of the model to be in close agreement with the measured data. In addition, Li et al. (2010a) studied the model and compared the results with three other existing models using measured data from 79 different stations across China.

Recently, Gouda et al. (2019) evaluated this model to develop a general model for 5 solar climatic zones in China using a data of 84 station across China. Zang et al. (2019) tested and compared this model with another 6 day of the year based models using daily GSR data from 35 meteorological stations across six climate zones in China.

D7: Li model

Li et al. (2010a) proposed a trigonometric model in conjunction with sine- and cosine-waves to estimate the daily GSR by using daily-measured GSR data from 79 meteorological stations covering all China:

$$R_g = a_1 + a_2 \sin\left(\frac{2\pi N}{365} a_3 + a_4\right) + a_5 \cos\left(\frac{2\pi N}{365} a_6 + a_7\right) \tag{A43}$$

Gouda et al. (2019) employed a data from 84 stations all over China to calibrate and compare this model with other day of the year-based models and reached to this model is the best to be a general model for zone I:

$$R_g = 17.743 + 4.551 \sin\left(-0.976 \frac{2\pi N}{365} - 14.597\right) - 0.982 \cos\left(1.952 \frac{2\pi N}{365} - 0.170\right) \tag{A44}$$

Zang et al. (2019) tested and compared this model with another 6 day of the year based models using daily GSR data from 35 meteorological stations across six climate zones in China.

D8: Zang model I

Zang et al. (2012) developed a novel GSR model in conjunction with sine and cosine-wave correlations to simulate the long-term measured data over at least 10 years from 35 stations:

$$R_g = a_1 + a_2 \sin\left(\frac{2\pi N}{365} a_3\right) + a_4 \cos\left(\frac{2\pi N}{365} a_5\right) \tag{A45}$$

Gouda et al. (2019) calibrated this model using data of 84 stations from 5 solar zones across China and concluded that Eq. (A45) is the best general model to estimate the daily GSR in zones II and IV:

For zone II:

$$R_g = 16.841 - 49.939 \sin\left(0.004 \frac{2\pi N}{365}\right) - 8.271 \cos\left(1.0332 \frac{2\pi N}{365}\right) \quad \text{(A46)}$$

For zone II:

$$R_g = 13.009 - 0.523 \sin\left(1.269 \frac{2\pi N}{365}\right) - 4.779 \cos\left(0.977 \frac{2\pi N}{365}\right) \quad \text{(A47)}$$

D9: Quej model

Quej et al. (2017) presented a sum of two Gaussian correlation form to estimate the daily GSR in Yucatan Peninsula, Mexico:

$$R_g = a_1 + a_2 \exp\left[-0.5 \times \left(\frac{N - a_3}{a_4}\right)^2\right] + a_5 \exp\left[-0.5 \times \left(\frac{N - a_6}{a_7}\right)^2\right] \quad \text{(A48)}$$

Gouda et al. (2019) calibrated this model among nine-day of the year-based models to estimate the daily GSR at 84 stations all over China and developed general model for five solar climatic zones in China.

D10: Zang model II

(Zang et al., 2019) developed a new hybrid 3rd order polynomial and sine wave form to estimate the daily GSR across China using a daily GSR data obtained from 35 stations allover China:

$$R_g = a_1 + (a_2 + a_3 N + a_4 N^2 + a_5 N^3) \sin\left(\frac{2\pi N}{365} a_6 + a_7\right) \quad \text{(A49)}$$

8. Group 8: models based on different parameters (complex models)

Many researchers have tried to develop and improve sunshine- and temperature-based models, which require long-term average meteorological data, to acquire accurate predictions of the actual solar radiation for a given location. Thus, they attempted to use different available meteorological variables, e.g., precipitation, relative humidity, dew-point temperature, air temperature, evaporation, and pressure, along with other widely used parameters, such as sunshine and air temperature, to predict GSR. One such model is the meteorological radiation model (MRM), which uses air temperature, relative humidity, atmospheric pressure and sunshine duration (or alternatively cloud optical depth) for the estimation of solar radiation on horizontal surface at any location on Earth (Kambezidis et al., 2016; Kambezidis et al., 2017). In this section, the models used or developed in China are reported and classified according to the year they were developed. Researchers employed measured data form different stations across China to obtain the regressions of complex models using linear and nonlinear regression methods; these regressions are listed in **Table A3**.

C1: Wenxian model

Wenxian (1988) developed two models for the Yunnan Province:

For dry seasons:

$$\frac{R_g}{R_{ex}} = (-0.17 + 0.03AHd) + \left(3.22 - \frac{56.51}{\varphi} - 3.57/AHd\right)\left(\frac{n}{n_o}\right) \quad \text{(A50a)}$$

For wet seasons:

$$\frac{R_g}{R_{ex}} = \left(0.37 + \frac{17.06\times10^3}{Z} - 0.01AHw\right) + \left(0.34 - \frac{52.24\times10^3}{Z} + 0.01AHw\right)\left(\frac{n}{n_o}\right) \quad \text{(A50b)}$$

C2: Ododo model

Ododo et al. (1995) tested some existing and developed new one based on relative sunshine, air temperature and relative humidity to estimate the monthly-average daily GSR at 9 stations in different zones in Nigeria:

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 T_{\max} + a_4 RH + a_5 T_{\max}\left(\frac{n}{n_o}\right) \quad \text{(A51)}$$

C3: Chen model

Chen et al. (2004) developed a logarithmic relationship between the ratio of GSR to the extraterrestrial solar radiation and the difference between maximum and minimum air temperatures using data between 1994 and 1998 obtained from 48 stations in China:

$$\frac{R_g}{R_{ex}} = a_1 \ln(T_{max} - T_{min}) + a_2\left(\frac{n}{n_o}\right)^{a_3} + a_4 \quad \text{(A52)}$$

The researchers found the following equation, by using data from 48 stations in China:

$$\frac{R_g}{R_{ex}} = 0.04\, ln(T_{max} - T_{min}) + 0.48\left(\frac{n}{n_o}\right)^{0.83} + 0.11 \quad \text{(A53)}$$

C4: Wu model

Wu et al. (2007) developed models to predict the daily GSR from the maximum, minimum and average air temperature; total precipitation, and mean dew-point temperature:

$$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min})^{0.5} + a_3 T_{avg} + a_4 PT \quad \text{(A54a)}$$

where PT is the transformed rainfall data, which were calculated using $PT = 1$ when $P > 0$ and $PT = 1$ when $P = 0$, where P is the measured daily total precipitation (mm).

$$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min})^{0.5} + a_3 T_{avg} + a_4 PT + a_5 DP \quad \text{(A54b)}$$

The researchers employed their models to obtain the following expressions using data from the Nanchang station between 1994 and 2005:

$$\frac{R_g}{R_{ex}} = -0.158 + 0.193(T_{max} - T_{min})^{0.5} + 0.005T_{avg} - 0.155PT \quad \text{(A55a)}$$

$$\frac{R_g}{R_{ex}} = -0.185 + 0.164(T_{max} - T_{min})^{0.5} + 0.023T_{avg} - 0.119PT - 0.017DP \quad \text{(A55b)}$$

C5: Liu model

Liu et al. (2009) employed data from 33 sites in the Yellow River basin to calculate coefficients of the A-P model and proposed a new model. They used a two-step procedure, i.e., predicting a (or b) and a + b first and then b (or a) in the second step by subtracting a (or b) from the sum a + b:

$$a_2 = 0.6289 + 0.0126T_{avg} + 4.33 \times 10^{-4}(T_{avg})^2 \quad \text{(A56a)}$$

$$(a_1 + a_2) = 0.8424 - 0.00966T_{avg} \quad \text{(A56b)}$$

Liu et al. (2012) employed data from 80 sites across China to test this model.

C6: Zhao model

Zhao et al. (2013) developed several models based on linear, exponential and logarithmic functions by adjusting the coefficients of the A-P model using solar radiation, sunshine hour and air-pollution index (API) data obtained from nine meteorological stations in China between 2001 and 2011:

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3(API/100) + a_4\left(\frac{n}{n_o}\right)(API/100) \quad \text{(A57a)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 exp(API/100) + a_4\left(\frac{n}{n_o}\right) exp(API/100) \quad \text{(A57b)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 log(API/100) + a_4\left(\frac{n}{n_o}\right)\log(API/100) \quad \text{(A57c)}$$

They also developed a general equation based on sunshine duration data, API, and geographical information. This equation was validated using data sets from two other locations:

$$\frac{R_g}{R_{ex}} = [-0.043 - 0.191\cos\varphi + 0.155\lambda + 0.073Z + 0.169\log(API/100)] + [0.641 + 0.171\cos\varphi + 0.144\lambda + 0.056Z + 0.292\log(API/100)]\left(\frac{n}{n_o}\right) \quad \text{(A57d)}$$

C7: Li model I

Li et al. (2010b) developed new models to estimate GSR from observed meteorological data such as the maximum and minimum temperatures, mean dew-point temperature, fog and precipitation in Chongqing from 1986 to 2000:

$$\frac{R_g}{R_{ex}} = a_1 + a_2 T_{max} + a_3 T_{min} + a_4 P_{re} \quad \text{(A58a)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2 T_{max} + a_3 T_{min} + a_4 DP \quad \text{(A58b)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2 T_{max} + a_3 T_{min} + a_4 Fog \quad \text{(A58c)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2 T_{max} + a_3 T_{min} + a_4 P_{re} + a_5 DP \quad \text{(A58d)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2 T_{max} + a_3 T_{min} + a_4 P_{re} + a_5 Fog \quad \text{(A58e)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2 T_{max} + a_3 T_{min} + a_4 DP + a_5 Fog \quad \text{(A58f)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2 T_{max} + a_3 T_{min} + a_4 P_{re} + a_5 DP + a_6 Fog \quad \text{(A58g)}$$

C8: Chen and Li model

Chen and Li (2013) developed new models based on different meteorological variables such as relative sunshine duration, maximum and minimum ambient temperatures, atmospheric water vapor pressure, relative humidity and precipitation to estimate the monthly-average daily GSR at 13 stations in the Yangtze River Basin in China:

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3(T_{max} - T_{min})^{0.5} \quad \text{(A59a)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 AP \quad \text{(A59b)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 RH \quad \text{(A59c)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 P_{re} \quad \text{(A59d)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 T_{max} + a_4 T_{min} \quad \text{(A59e)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 T_{max} + a_4 T_{min} + a_5 AP \quad \text{(A59f)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 T_{max} + a_4 T_{min} + a_5 RH \quad \text{(A59g)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 T_{max} + a_4 T_{min} + a_5 P_{re} \quad \text{(A59h)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min})^{0.5} + a_3 AP \quad \text{(A59i)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min})^{0.5} + a_3 RH \quad \text{(A59j)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min})^{0.5} + a_3 P_{re} \quad \text{(A59k)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2(T_{max} - T_{min})^{0.5} + a_3AP + a_4RH \quad \text{(A59l)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2T_{max} + a_3T_{min} + a_4T_{max} \times T_{min} + a_5AP + a_6RH \quad \text{(A59m)}$$

C9: Li model II

Li et al. (2013) proposed empirical models based on the minimum and maximum air temperatures and relative humidity to estimate GSR in different solar radiation zones at 83 stations in mainland China:

$$R_g = a_1 + R_{ex} \times (a_2 + a_3T_{max} + a_4T_{min} + a_5RH) \quad \text{(A60a)}$$

$$R_g = a_1 + a_2RH + R_{ex} \times (a_3 + a_4T_{max} + a_5T_{min}) \quad \text{(A60b)}$$

$$R_g = a_1 + R_{ex} \times \left(a_2\sqrt{T_{max} - T_{min}} + a_3RH\right) \quad \text{(A60c)}$$

$$R_g = a_1 + a_2RH + a_3R_{ex} \times \sqrt{T_{max} - T_{min}} \quad \text{(A60d)}$$

C10: Meza and Yebra model

Meza and Yebra (2015) improved the Bristow and Cambell model (Bristow and Campbell, 1984) by incorporating relative humidity, precipitation and minimum/maximum air temperature:

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\,sin(2\pi N/365) + a_3\,cos(2\pi N/365) + a_4RH + a_5P_{re}) \times [1 - exp(-a_6(T_{max} - T_{min})^{a_7})] \quad \text{(A61)}$$

Wang et al. (2016) employed this model at 12 different stations in different climatic zones of China between 1961 and 2014. Additionally, Zou et al. (2017) employed the model at 3 stations (Changsha, Jishou, and Changning).

C11: Zou model

Zou et al. (2016) improved the A-P model by adding nonlinear analysis and considering other meteorological variables, such as the temperature difference, relative humidity and precipitation:

$$\frac{R_g}{R_{ex}} = a_1\left(\frac{n}{n_o}\right) + a_2\left(\frac{n}{n_o}\right)^2 + a_3\left(\frac{n}{n_o}\right)^3 + a_4(T_{max} - T_{min}) + a_5RH + a_6P_{re} + a_7 \quad \text{(A62a)}$$

They also expanded the Bristow and Cambell model (Bristow and Campbell, 1984) by adding sunshine duration, precipitation, and relative humidity to account for the effects of cloud transmittance.

$$\frac{R_g}{R_{ex}} = (a_1 + a_2\, sin(2\pi N/365) + a_3\, cos(2\pi N/365) + a_4RH + a_5P_{re} + a_6n) \times [1 - \exp(-a_7(T_{max} - T_{min})^{a_8})\ ] \quad \text{(A62b)}$$

The researcher employed their models to obtain the following model coefficients using data from 86 stations in China between 1994 and 1998.

$$\frac{R_g}{R_{ex}} = 0.37\left(\frac{n}{n_o}\right) + 0.34\left(\frac{n}{n_o}\right)^2 - 0.1\left(\frac{n}{n_o}\right)^3 + 0.001(T_{max} - T_{min}) - 0.001RH - 0.001P_{re} + 0.25 \quad \text{(A63a)}$$

$$\frac{R_g}{R_{ex}} = (0.55 + 0.02\sin(2\pi N/365) - 0.52\cos(2\pi N/365) + 0.004RH - 0.001Pre + 0.07S) \times [1 - \exp(-0.07(T_{max} - T_{min})^{0.94})] \quad \text{(A63b)}$$

The researchers also used the model given by Eq. (A63b) at three stations (Changsha, Jishou, and Changning) and compared the results with those obtained from adaptive Neuro-Fuzzy Inference Systems (Zou et al., 2017).

C12: Gouda model

Gouda et al. (2018) developed four new models using relative sunshine, relative humidity, dew point temperature and air temperature to estimate the monthly-average daily GSR in Wuhan, China:

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 DP \quad \text{(A64a)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 RH \quad \text{(A64b)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 DP + a_4 RH \quad \text{(A64c)}$$

$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3 DP + a_4 RH + a_5 T_{avg} \quad \text{(A64d)}$$

Table A3. Relationships of group-7 models used in China.

Model	Equation	Station number
Ododo (Ododo et al., 1995)	$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3T_{\max} + a_4RH + a_5T_{\max}\left(\frac{n}{n_o}\right)$	
Gouda (Gouda et al., 2018)	$\frac{R_g}{R_{ex}} = 0.0333 + 0.0417\left(\frac{n}{n_o}\right) - 0.0001T_{\max} - 0.0266RH + 0.0003T_{\max}\left(\frac{n}{n_o}\right)$	1
Li model I (a) (Li et al., 2010b)	$\frac{R_g}{R_{ex}} = -0.032 + 0.040T_{max} - 0.036T_{min} - 0.0064P_{re}$	1
Li model I (b) (Li et al., 2010b)	$\frac{R_g}{R_{ex}} = a_1 + a_2T_{max} + a_3T_{min} + a_4DP$	
Li model I (Li et al., 2010b)	$\frac{R_g}{R_{ex}} = -0.076 + 0.044T_{max} - 0.021T_{min} - 0.021DP$	1
Gouda (Gouda et al., 2018)	$\frac{R_g}{R_{ex}} = 0.0092 + 0.0015T_{max} + 0.0003T_{min} - 0.0012DP$	1
Li model I (c) (Li et al., 2010b)	$\frac{R_g}{R_{ex}} = -0.072 + 0.044T_{max} - 0.04T_{min} - 0.002Fog$	1
Li model I (d) (Li et al., 2010b)	$\frac{R_g}{R_{ex}} = -0.047 + 0.041T_{max} - 0.022T_{min} - 0.045P_{re} - 0.017DP$	1

Li model I (e) (Li et al., 2010b)	$$\frac{R_g}{R_{ex}} = -0.030 + 0.040T_{max} - 0.036T_{min} - 0.064P_{re} - 0.011Fog$$	1
Li model I (f) (Li et al., 2010b)	$$\frac{R_g}{R_{ex}} = -0.082 + 0.043T_{max} - 0.018T_{min} - 0.023DP + 0.036Fog$$	1
Li model I (g) (Li et al., 2010b)	$$\frac{R_g}{R_{ex}} = -0.053 + 0.041T_{max} - 0.020T_{min} - 0.042P_{re} - 0.018DP - 0.022Fog$$	1
Chen and Li (e) (Chen and Li, 2013)	$$\frac{R_g}{R_{ex}} = a_1 + a_2\left(\frac{n}{n_o}\right) + a_3T_{max} + a_4T_{min}$$	
Gouda (Gouda et al., 2018)	$$\frac{R_g}{R_{ex}} = 0.0082 + 0.0507\left(\frac{n}{n_o}\right) + 0.0003T_{max} - 0.0003T_{min}$$	1
Gouda (a) (Gouda et al., 2018)	$$\frac{R_g}{R_{ex}} = 0.0098 + 0.0531\left(\frac{n}{n_o}\right) + 3.3\times10^{-5}DP$$	1
Gouda (b) (Gouda et al., 2018)	$$\frac{R_g}{R_{ex}} = 0.0332 + 0.0469\left(\frac{n}{n_o}\right) - 0.0283RH$$	1
Gouda (c) (Gouda et al., 2018)	$$\frac{R_g}{R_{ex}} = 0.0333 + 0.0470\left(\frac{n}{n_o}\right) - 4.66\times10^{-6}DP - 0.0284RH$$	1

Gouda (d) (Gouda et al., 2018)	$\frac{R_g}{R_{ex}} = 0.0345 + 0.0469\left(\frac{n}{n_o}\right) + 4.77\times10^{-5}DP - 0.0296RH - 5.20\times10^{-5}T_{avg}$	1

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