Identifying the Best Global Solar Radiation Model for Hutat Suder, Saudi Arabia

H. Al-Sholigom, Z. Al-Mostafa

***Abstract*—**Many associations and experimental models have been developed to estimate solar radiation around the world. The duration of sunshine is the most commonly used parameter for estimating global solar radiation because it can be easily and reliably measured. To estimate the global monthly solar average on horizontal surfaces, we used 52 models with widely available data in Hutat Suder, Saudi Arabia. After testing the models, some were not suitable for use in this area, while others differed in performance. The best models have been identified.

***Keywords*—**Earth, Global solar radiation, Hutat Suder, Saudi Arabia, sunshine, measured data.

I. Introduction

KNOWLEDGE of solar radiation data is essential for many solar energy applications, including the design and analysis of energy conversion devices. Unfortunately, due to the high cost of monitoring equipment and the need for calibration and maintenance, solar radiation data are not readily available for many developing countries. The objective of the present study is to test the performance of several sunshine based models against global radiation measured in Hutat Suder and to determine the most suitable model for predicting the measured data. The city of Hutat Suder is located 170 km north of Riyadh, and is located specifically halfway between the cities of Riyadh and Qassim, and the astronomical position of the city of Hutat Suder shows that it is located between 25 degrees latitude and 40 degrees longitude. The Majmaah University Astronomical Observatory is located in Hutat Suder and is specialized in preparing reports on the crescent moon observing conditions for each month, and following the movement of celestial bodies and star constellations. This was helped by the city's location on rocky, mountainous terrain that is rarely disturbed by the wind, its altitude ranging from 780 to 930 meters above sea level, and its distance from areas of industrial and environmental pollution. The climate of this region is characterized by extremely high temperatures in summer and fluctuations in winter.

The Public Investment Fund announced the Suder Solar Energy Project in Suder Industrial City on April 8, 2021, and the first operational phases of the project began in the second half of 2022 [1], [2]. The production capacity of the project reaches 1,500 megawatts, making it one of the largest solar stations. In the world [3] Global Solar Radiation (GSR) is the most commonly used measure of global solar radiation. The duration of sunshine can be measured easily and reliably, and data can be widely used [1]-[4]. The monthly average of daily radiation with clear-day radiation is related to the original Angstrom regression equation at the place in question and to the average fraction of possible sunshine hours [1]:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_o}\right) \quad (1)$$

The monthly average daily global radiation is denoted by H, the monthly average daily extra-terrestrial radiation is denoted by H_o, the monthly average daily hours of bright sunshine is denoted by S, the maximum possible duration of sunlight is denoted by the symbol S_o, and the empirical coefficients are a and b and can be determined either experimentally or empirically using some well-known models There are several types of regression models that have been proposed in the literature for estimating GSR based solely on the S/ S_o[8].

Fig. 1 Huhah Suder's location

II. Models

Models used to calculate the daily monthly average GSR on a horizontal surface have different forms of dependence on the S/S_o ratio. According to Al-Mostafa et al. [9], these models are classified as following. The data are shown in Table I.

The relative percentage error of each model was calculated for each month during the year in Hutat Suder.

I. Group 1 (Linear models): It has a shape similar to the Angstrom type regression equation; but the experimental coefficients A and B vary, depending on the results

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obtained for first-order regression analysis.

II. Group 2 (second order models): Some researchers have used a quadratic polynomial equation for the S/So ratio to calculate the daily monthly mean GSR on a horizontal surface [8].

III. Group 3 (third order models): The monthly average daily GSR is parameterised as a function of the S/S_0 ratio's third order dependence.

IV. Group 4 (Logarithmic models).

V. Groups 5 and 6 (Exponential models): These groups include simple power equations and exponential power equations.

VI. Group 7 (Angular models).

The following models were used in the study:

Model 1: [6]

$$\frac{H}{H_o} = 0.6307 - 0.7251\left(\frac{S}{S_o}\right) + 1.2089\left(\frac{S}{S_o}\right)^2 - 0.4633\left(\frac{S}{S_o}\right)^3 \quad (2)$$

Model 2: [7]

$$\frac{H}{H_o} = 0.1520 - 1.1334\left(\frac{S}{S_o}\right) - 1.1126\left(\frac{S}{S_o}\right)^2 + 0.4516\left(\frac{S}{S_o}\right)^3 \quad (3)$$

Model 3: [7]

$$\frac{H}{H_o} = 0.1874 + 0.8591\left(\frac{S}{S_o}\right) - 0.4764\left(\frac{S}{S_o}\right)^2 \quad (4)$$

Model 4: [8]

$$\frac{H}{H_o} = 0.3078 + 0.4166\left(\frac{S}{S_o}\right) \quad (5)$$

Model 5: [8]

$$\frac{H}{H_o} = 0.3398 + 0.2868\left(\frac{S}{S_o}\right) + 0.1187\left(\frac{S}{S_o}\right)^2 \quad (6)$$

Model 6: [8]

$$\frac{H}{H_o} = 0.4832 - 0.6161\left(\frac{S}{S_o}\right) + 1.8932\left(\frac{S}{S_o}\right)^2 - 1.0975\left(\frac{S}{S_o}\right)^3 \quad (7)$$

Model 7: [9]

$$\frac{H}{H_o} = 0.324 + 0.405\left(\frac{S}{S_o}\right) \quad (8)$$

Model 8: [9]

$$\frac{H}{H_o} = 0.348 + 0.320\left(\frac{S}{S_o}\right) + 0.070\left(\frac{S}{S_o}\right)^2 \quad (9)$$

Model 9: [10]

$$\frac{H}{H_o} = -0.0271 + 0.3096\exp\left(\frac{S}{S_o}\right) \quad (10)$$

Model 10: [11]

$$\frac{H}{H_o} = 0.2854 + 0.2591\left(\frac{S}{S_o}\right) + 0.6171\left(\frac{S}{S_o}\right)^2 - 0.4834\left(\frac{S}{S_o}\right)^3 \quad (11)$$

Model 11: [11]

$$\frac{H}{H_o} = 0.2671 + 0.4754\left(\frac{S}{S_o}\right) \quad (12)$$

Model 12: [12]

$$\frac{H}{H_o} = 0.23 + 0.38\left(\frac{S}{S_o}\right) \quad (13)$$

Model 13: [13]

$$\frac{H}{H_o} = 0.318 + 0.449\left(\frac{S}{S_o}\right) \quad (14)$$

Model 14: [13]

$$\frac{H}{H_o} = 0.698 + 0.2022\ln\left(\frac{S}{S_o}\right) \quad (15)$$

Model 15: [13]

$$\frac{H}{H_o} = 0.1541 + 1.1714\left(\frac{S}{S_o}\right) - 0.705\left(\frac{S}{S_o}\right)^2 \quad (16)$$

Model 16: [13]

$$\frac{H}{H_o} = 0.1796 + 0.9813\left(\frac{S}{S_o}\right) - 0.2958\left(\frac{S}{S_o}\right)^2 - 0.2657\left(\frac{S}{S_o}\right)^3 \quad (17)$$

Model 17: [13]

$$\frac{H}{H_o} = 0.3396e^{0.8985\left(\frac{S}{S_o}\right)} \quad (18)$$

Model 18: [20]

$$\frac{H}{H_o} = 0.7316\left(\frac{S}{S_0}\right)^{0.4146} \quad (19)$$

Model 19: [14]

$$\frac{H}{H_o} = 0.3092\cos(\emptyset) + 0.4931\left(\frac{S}{S_o}\right) \quad (20)$$

where $\emptyset$ is the latitude of the site in degrees.

Model 20: [14]

$$\frac{H}{H_o} = 0.2408 + 0.3625\left(\frac{S}{S_o}\right) + 0.4597\left(\frac{S}{S_o}\right)^2 - 0.3708\left(\frac{S}{S_o}\right)^3 \quad (21)$$

Model 21: [14]

$$\frac{H}{H_o} = 0.309 + 0.368\left(\frac{S}{S_o}\right) \quad (22)$$

Model 22: [15]

$$\frac{H}{H_o} = 0.367 + 0.367\left(\frac{S}{S_o}\right) \quad (23)$$

Model 23: [15]

$$\frac{H}{H_o} = 0.233 + 0.591\left(\frac{S}{S_o}\right) \quad (24)$$

Model 24: [16]

$$\frac{H}{H_o} = -2.4275 + 11.946\left(\frac{S}{S_o}\right) - 16.745\left(\frac{S}{S_o}\right)^2 - 7.9575\left(\frac{S}{S_o}\right)^3 \quad (25)$$

Model 25: [17]

$$\frac{H}{H_o} = 0.2424 + 0.5014\left(\frac{S}{S_o}\right) \quad (26)$$

Model 26: [17]

$$\frac{H}{H_o} = 0.0959 + 0.9958\left(\frac{S}{S_o}\right) - 0.3922\left(\frac{S}{S_o}\right)^2 \quad (27)$$

Model 27: [18]

$$\frac{H}{H_o} = 0.215 + 0.527\left(\frac{S}{S_o}\right) \quad (28)$$

Model 28: [18]

$$\frac{H}{H_o} = 0.1 + 0.874\left(\frac{S}{S_o}\right) - 0.255\left(\frac{S}{S_o}\right)^2 \quad (29)$$

Model 29: [19]

$$\frac{H}{H_o} = 0.148 + 0.668\left(\frac{S}{S_o}\right) - 0.079\left(\frac{S}{S_o}\right)^2 \quad (30)$$

Model 30: [20]

$$\frac{H}{H_o} = 0.2262 + 0.418\left(\frac{S}{S_o}\right) \quad (31)$$

Model 31: [21]

$$\frac{H}{H_o} = 0.34 + 0.32\left(\frac{S}{S_o}\right) \quad (32)$$

Model 32: [21]

$$\frac{H}{H_o} = 0.27 + 0.65\left(\frac{S}{S_o}\right) \quad (33)$$

Model 33: [22]

$$\frac{H}{H_o} = 0.1538 + 0.7874\left(\frac{S}{S_o}\right) \quad (34)$$

Model 34: [22]

$$\frac{H}{H_o} = 0.1961 + 0.7212\left(\frac{S}{S_o}\right) \quad (35)$$

Model 35: [23]

$$\frac{H}{H_o} = 0.41 + 0.57\left(\frac{S}{S_o}\right) \quad (36)$$

Model 36: [23]

$$\frac{H}{H_o} = 0.81 - 3.34\left(\frac{S}{S_o}\right) + 7.38\left(\frac{S}{S_o}\right)^2 - 4.51\left(\frac{S}{S_o}\right)^3 \quad (37)$$

Model 37: [24]

$$\frac{H}{H_o} = 0.225 + 0.014\left(\frac{S}{S_o}\right) + 0.001\left(\frac{S}{S_o}\right)^2 \quad (38)$$

Model 38: [25]

$$\frac{H}{H_o} = -0.14 + 2.52\left(\frac{S}{S_o}\right) - 3.71\left(\frac{S}{S_o}\right)^2 + 2.24\left(\frac{S}{S_o}\right)^3 \quad (39)$$

Model 39: [26]

$$\frac{H}{H_o} = 0.313 + 0.474\left(\frac{S}{S_o}\right) \quad (40)$$

Model 40: [26]

$$\frac{H}{H_o} = 0.307 + 0.488\left(\frac{S}{S_0}\right) \quad (41)$$

Model 41: [26]

$$\frac{H}{H_o} = 0.309 + 0.599\left(\frac{S}{S_o}\right) \quad (42)$$

Model 42: [27]

$$\frac{H}{H_o} = 0.335 + 0.367\left(\frac{S}{S_o}\right) \quad (43)$$

Model 43: [28]

$$\frac{H}{H_o} = 0.388\cos(\emptyset) + 0.367\left(\frac{S}{S_o}\right) \quad (44)$$

Model 44: [29]

$$\frac{H}{H_o} = 0.241 + 0.488\left(\frac{S}{S_o}\right) \quad (45)$$

Model 45: [30]

$$\frac{H}{H_o} = 0.240 + 0.513\left(\frac{S}{S_0}\right) \quad (46)$$

Model 46: [3]

$$\frac{H}{H_o} = -0.309 + 0.539\cos(\emptyset) - 0.0693Z + 0.290\left(\frac{S}{S_o}\right) + \left(1.527 - 1.027\cos(\emptyset) + 0.0926Z - 0.359\left(\frac{S}{S_o}\right)\right) \quad (47)$$

Model 47: [31]

TABLE I
RELATIVE PERCENTAGE ERROR %

Model	Name group	Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	BAKIRCI 3	3	-18.65	-15.58	-14.95	-10.68	-12.93	-9.87	-12.18	-8.35	-7.28	-5.82	-6.87	-8.86
2	TAHRAN&SARI2	2	-18.59	-16.27	-14.73	-10.38	-12.87	-12.51	-15.78	-12.48	-10.70	-8.94	-8.66	-8.91
3	TAHRAN&SARI3	3	-18.76	-16.06	-15.00	-10.73	-13.04	-11.28	-13.99	-10.39	-9.04	-7.45	-7.90	-9.03
4	ARAS etal1	1	-12.72	-8.63	-9.15	-5.05	-6.59	-1.58	-3.82	0.46	1.45	2.94	1.35	-2.03
5	ARAS etal2	2	-12.93	-8.55	-9.45	-5.45	-6.81	-0.95	-2.93	1.49	2.29	3.70	1.74	-2.20
6	ARAS etal3	3	-12.21	-8.11	-8.68	-4.68	-6.04	-1.47	-4.57	-0.56	0.90	2.59	1.62	-1.43
7	AHMAD&ULFAT1	1	-11.50	-7.47	-7.82	-3.60	-5.28	-0.52	-2.85	1.45	2.50	4.03	2.52	-0.68
8	AHMAD&ULFAT2	2	-11.71	-7.58	-8.07	-3.88	-5.50	-0.39	-2.61	1.75	2.71	4.20	2.53	-0.90
9	ALMOROX&HONTORIA exp	5	-13.77	-8.11	-10.48	-7.42	-7.71	1.62	0.49	5.40	5.58	6.71	3.44	-2.87
10	ULGEN&HEPBASLI1	1	-12.83	-8.29	-9.44	-5.56	-6.70	-0.61	-2.63	1.79	2.63	4.05	2.09	-2.05
11	ULGEN&HEPBASLI3	3	-12.16	-8.11	-8.60	-4.58	-5.98	-1.73	-4.47	-0.42	0.96	2.63	1.59	-1.38
12	AKPABIO&ETUK1	1	-27.89	-24.23	-25.04	-21.78	-22.82	-18.02	-19.74	-16.12	-15.39	-14.20	-15.74	-18.99
13	TOGRUL&TOGRUL1	1	-7.97	-3.57	-4.22	0.06	-1.50	3.97	1.64	6.18	7.20	8.76	7.02	3.33
14	TOGRUL&TOGRUL1LN	4	-8.45	-5.27	-4.28	0.46	-2.02	0.23	-2.83	1.23	2.77	4.56	4.02	2.53
15	TOGRUL&TOGRUL2	2	-7.77	-5.40	-3.32	1.66	-1.28	-1.74	-5.72	-2.15	0.08	2.17	2.88	3.15
16	TOGRUL&TOGRUL3	3	-7.49	-5.19	-3.03	1.96	-0.98	-1.85	-6.06	-2.60	-0.19	1.98	2.95	3.46
17	TOGRUL&TOGRULexp	5	-7.63	-2.29	-4.20	-0.24	-1.13	6.98	5.35	10.33	10.84	12.18	9.37	3.90
18	TOGRUL&TOGRUL ^	6	-7.94	-4.12	-3.99	0.50	-1.47	2.39	-0.34	3.95	5.27	6.96	5.85	3.24
19	ULGEN&HEPBASIL1	1	-8.39	-3.67	-4.81	-0.70	-1.95	4.33	2.18	6.81	7.71	9.21	7.19	2.93
20	ULGEN&HEPBASIL3	3	-13.88	-9.49	-10.65	-6.79	-7.82	-2.49	-4.89	-0.74	0.41	1.94	0.48	-3.23
21	CHEGAAR&CHIBANI11	1	-17.43	-13.74	-13.96	-9.99	-11.62	-7.36	-9.58	-5.59	-4.59	-3.15	-4.49	-7.35
22	CHEGAAR&CHIBANI12	1	-8.96	-5.19	-5.02	-0.51	-2.56	1.42	-1.17	3.14	4.35	5.98	4.74	2.08
23	CHEGAAR&CHIBANI13	1	-6.26	-0.78	-2.86	1.04	0.33	8.36	6.47	11.41	12.11	13.55	10.94	5.47
24	ERTEKIN&YALDIZ3	3	-32.82	-30.52	-29.77	-26.41	-28.10	-25.27	-26.12	-22.36	-22.45	-21.62	-23.30	-24.77
25	ULGEN&OZBALTA1	1	-13.87	-9.15	-10.62	-6.89	-7.81	-1.20	-3.09	1.35	2.10	3.47	1.33	-3.16
26	ULGEN&OZBALTA2	2	-12.64	-8.34	-9.22	-5.36	-6.49	-1.51	-4.02	0.14	1.35	2.93	1.60	-1.86
27	SAID1	1	-15.34	-10.45	-12.26	-8.71	-9.39	-2.27	-3.99	0.45	1.10	2.41	0.09	-4.77
28	SAID2	2	-14.89	-10.09	-11.80	-8.27	-8.91	-2.36	-4.38	-0.07	0.80	2.21	0.26	-4.27
29	AKSOY2	2	-16.47	-11.37	-13.56	-10.22	-10.60	-3.00	-4.64	-0.20	0.40	1.67	-0.76	-5.97
30	TIRIS etal1	1	-24.63	-20.66	-21.72	-18.39	-19.33	-13.93	-15.66	-11.82	-11.12	-9.89	-11.63	-15.30
31	VEERAN&KUMAR11	1	-17.67	-14.35	-14.07	-9.95	-11.88	-8.50	-10.88	-7.01	-5.89	-4.40	-5.45	-7.70
32	VEERAN&KUMAR12	1	5.13	11.17	8.98	13.39	12.52	21.28	19.12	24.63	25.45	27.08	24.23	18.26
33	GOPINATHAN&SOLER11	1	1.77	8.80	5.00	8.72	8.92	20.32	18.81	24.52	24.90	26.29	22.56	14.73
34	GOPINATHAN&SOLER12	1	1.37	7.90	4.78	8.71	8.49	18.68	16.94	22.48	23.02	24.49	21.16	14.18
35	LEWIS 1	1	-22.10	-16.96	-19.52	-16.56	-16.62	-8.50	-9.78	-5.49	-5.11	-4.00	-6.66	-12.23
36	LEWIS 3	3	-21.27	-17.85	-18.35	-15.21	-15.73	-15.24	-20.08	-17.73	-14.57	-12.28	-10.54	-11.54
37	TASDEMIROGLU&SEVER2	2	-65.30	-64.80	-63.41	-61.26	-62.87	-63.64	-65.08	-63.73	-62.95	-62.19	-61.89	-61.30
38	SAMUEL3	3	24.39	30.50	29.57	35.61	33.13	42.54	40.77	47.65	47.92	49.57	45.66	39.62
39	JAIN11	1	-13.69	-9.97	-10.01	-5.80	-7.62	-3.49	-5.88	-1.75	-0.65	0.87	-0.42	-3.19
40	JAIN12	1	-5.67	-0.96	-1.93	2.37	0.96	7.07	4.78	9.50	10.47	12.04	10.09	5.95
41	JAIN13	1	5.77	11.44	9.81	14.45	13.20	21.01	18.63	24.05	25.01	26.71	24.19	18.88
42	RAJA&TWIDELL1	1	-13.69	-9.97	-10.01	-5.80	-5.05	-3.49	-5.88	-1.75	-0.65	0.87	-0.42	-3.19
43	RAJA&TWIDELLcos1	7	-11.46	-7.71	-7.65	-3.30	-5.23	-1.17	-3.65	0.56	1.71	3.29	2.02	-0.70
44	LUHANGA&ANDRINGA1	1	-15.42	-10.82	-12.21	-8.54	-9.47	-3.07	-4.93	-0.58	0.16	1.51	-0.56	-4.92
45	JAIN&JAIN1	1	-13.06	-8.24	-9.80	-6.06	-6.94	-0.15	-2.02	2.48	3.21	4.58	2.39	-2.24
46	GOPINATHAN cos2	7	-9.56	-5.20	-5.97	-1.91	-3.20	1.79	-0.81	3.49	4.73	6.37	5.02	1.57
47	OGELMAN2	2	-13.03	-8.49	-9.69	-5.87	-6.92	-0.99	-3.13	1.21	2.14	3.61	1.79	-2.26
48	BENSONetal11	1	-13.18	-7.72	-10.20	-6.77	-7.08	1.33	0.23	4.47	4.98	6.25	3.51	-2.24
49	BENSONetal12	1	-11.35	-6.39	-8.05	-4.26	-5.12	1.94	0.05	4.66	5.39	6.78	4.50	-0.31
50	KHOLAGIetal11	1	-14.47	-9.24	-11.47	-8.02	-8.46	-0.55	-2.15	2.43	2.99	4.26	1.69	-3.72
51	KHOLAGIetal12	1	-12.77	-8.56	-9.25	-5.20	-6.64	-1.35	-3.53	0.79	1.74	3.21	1.52	-2.06
52	KHOLAGIetal13	1	-15.73	-11.39	-12.44	-8.66	-9.81	-4.02	-5.99	-1.73	-0.91	0.47	-1.39	-5.32

$$\frac{H}{H_o} = 0.195 + 0.676\left(\frac{S}{S_o}\right) - 0.142\left(\frac{S}{S_o}\right)^2 \quad (48)$$

Model 48: [32]

$$\frac{H}{H_o} = 0.18 + 0.60\left(\frac{S}{S_o}\right) \quad (49)$$

Model 49: [32]

$$\frac{H}{H_0} = 0.24 + 0.53\left(\frac{S}{S_o}\right) \tag{50}$$

Model 50: [26]

$$\frac{H}{H_o} = 0.191 + 0.571\left(\frac{S}{S_o}\right) \tag{51}$$

Model 51: [33]

$$\frac{H}{H_o} = 0.297 + 0.432\left(\frac{S}{S_o}\right) \tag{52}$$

Model 52: [33]

$$\frac{H}{H_o} = 0.262 + 0.454\left(\frac{S}{S_o}\right) \tag{53}$$

III. Data and Validation Methods

The monthly average of global solar radiation on a horizontal surface (H) for the Hutat Suder city was obtained from the Saudi National Center for Science and Technology (now known as King Abdulaziz City for Science and Technology) [34]. The atlas is based on data collected by the Ministry of Agriculture and Water in Saudi Arabia over 9 years (1971-1980). This dataset contains information about sunshine duration, daylight hours, and global solar radiation on horizontal surfaces.

The performance of each model ensemble was evaluated, and the calculated values of global solar radiation were evaluated using four equations, mean percentage error (MPE) (54), mean bias error (MBE) (55), root mean square error (RMSE) (56), and the MAE score is measured as the average of the absolute error values. The absolute value is a mathematical function that makes a number positive (57) [38] as follows:

$$MPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{H_{imeas}-H_{ical}}{H_{imeas}} \times 100\right) \tag{54}$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(H_{imeas} - H_{ical}) \tag{55}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{N}}(H_{imeaas} - H_{ical})^2} \tag{56}$$

$$\mathrm{MAE} = \frac{\sum_{i=1}^{N}\left|H_{imeas}-H_{ical}\right|}{N} \tag{57}$$

where H_{imeas} is the experimentally measured value, H_{ical} is the value calculated mathematically, and N is the total number of observations. To calculate the percentage of relative error for each person The month is defined as:

$$e = \frac{H_{imeas}-H_{ical}}{H_{imeas}} \times 100 \tag{58}$$

From published studies, Stone [36] demonstrated that MBE and RMSE can lead to incorrect selection of the best model from the set of candidate models because they alone do not reliably represent model performance Therefore, the t-value was calculated for estimates equation to be significant using (58). This is because you can have a low RMSE while having a high MBE, or vice versa. Sometimes models face the challenge of producing contradictory results in terms of model performance [37].

We used the t-statistical method, following the lead of Ulgen and Hepbasli [35], to determine whether the equation estimates differed significantly from the measured data at a given confidence level. Stone [36] suggested calculating t as follows:

$$Tstat = \left[\frac{(n-1)MBE^2}{RMSE^2-MBE^2}\right]^{1/2} \tag{59}$$

The statistical indicator allows for comparisons between models while also indicating that the lower the value, the better the model performs.

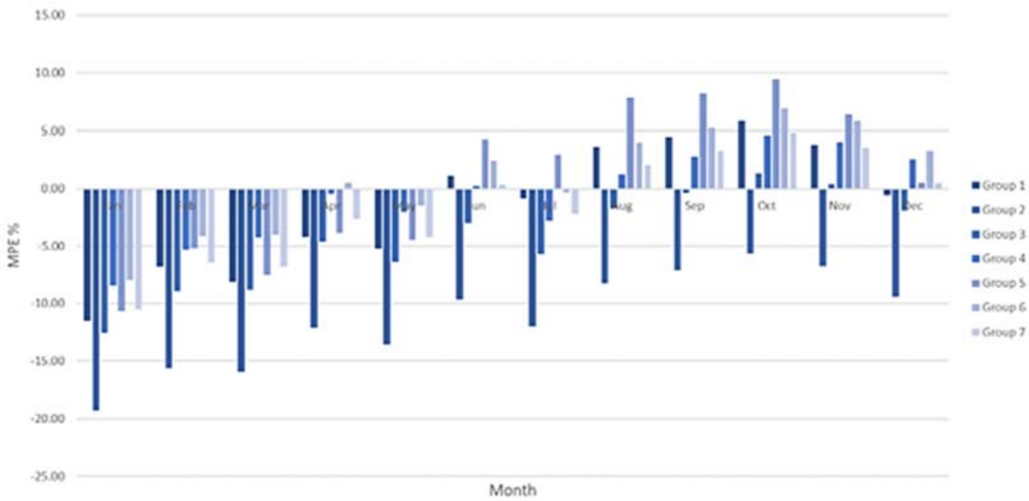
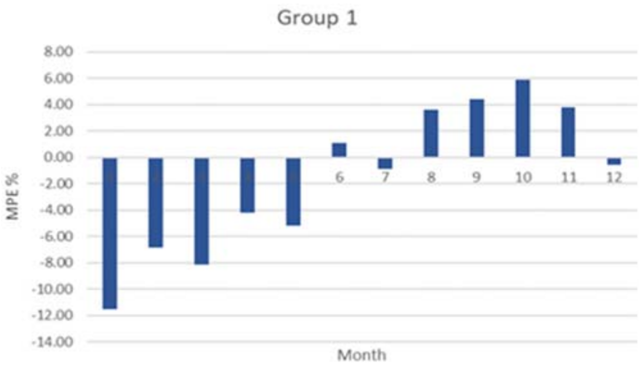
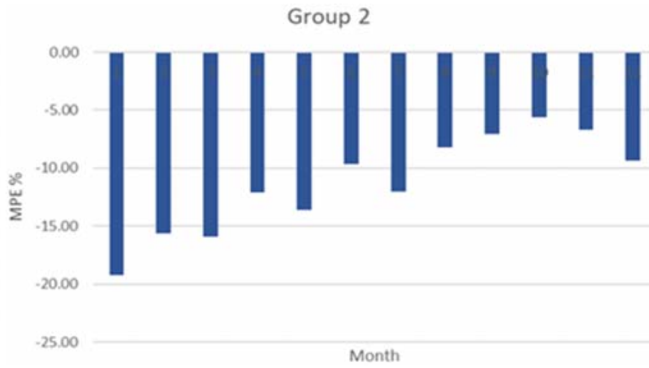


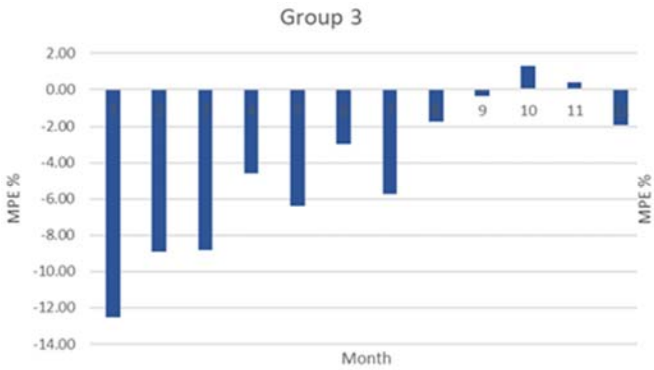
Fig. 2 Relative percentage error for each group's performance



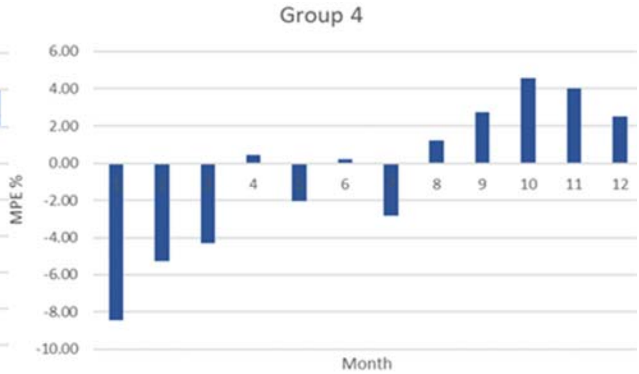
(a)



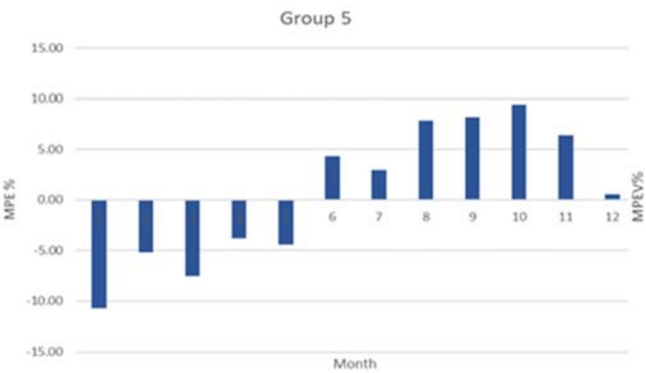
(b)



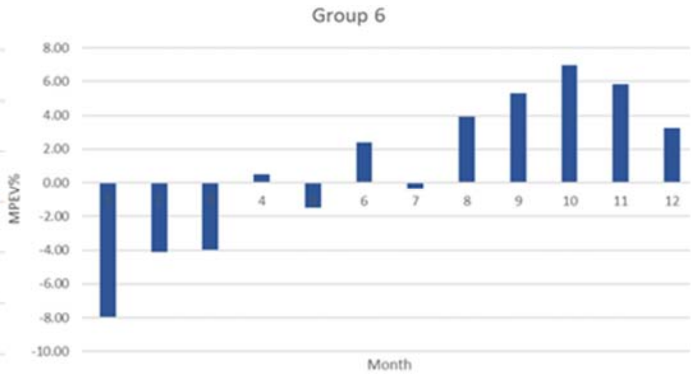
(c)



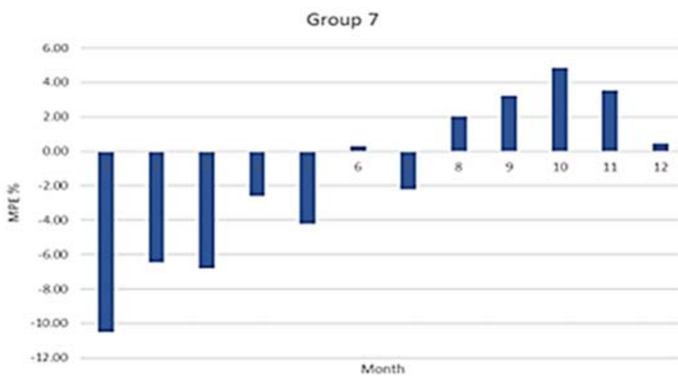
(d)



(e)



(f)



(g)

Fig. 3 Models with best and poorest performance for mean percentage error from (a) group 1, (b) group 2, (c) group 3, (d) group 4, (e) group 5, (f) group 6, (g) group 7

IV. Results and Discussion

A. Monthly Variations

The performance of each model differs from month to month, Table I lists the relative percentage error for each model. Some models performed well in some months and had higher e values in other months.

I. There are 32 models with errors between-15 and 15% as follows: in group 1, Models 4, 7, 10, 13, 19, 22, 23, 25, 39, 40, 42, 45, 48, 49, 50 and 51; in group 2, models 5, 8, 15, 26, 28 and 47; in group 3, Models 6, 11, 16 and 20; in group 4, Model 14; in group 5, Models 9 and 17; in group 6, Model 18; in group 7, Models 43 and 46.
II. There are 9 models with errors ranging from -20 to -15 and from 15 to 20 as follows: in group 1, Models 21, 27, 31, 44 and 52; in group 2, Models 2 and 29; in group 2, Models 1 and 3.
III. There are 8 models with errors ranging from -30 to -20 and from 20 to 30 as follows: in group 1, Models 12, 30, 32, 33, 34, 35 and 41; in group 3, Models 36.
IV. There are 2 models with errors ranging from -40 to -30 and from 30 to 40 as follows: in group 3, Models 24, 38.

We excluded Model 37 because of the high percentage of errors shown in all months.

TABLE II
The Overall Performance (Average Values) of the Models from Each Group

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Mean	5.80	5.22	5.62	5.84	5.93	5.93	5.79
MBE	-0.08	-0.66	0.26	-0.04	0.17	0.05	-0.09
MAE	0.42	0.66	0.77	0.04	0.05	0.05	0.09
RMSE	0.40	1.77	1.18	0.04	0.17	0.06	0.07
RMSEsq	0.55	0.78	0.85	0.20	0.41	0.24	0.27
MPE	-1.55	-11.28	-4.36	-0.59	0.67	0.86	-1.54
MABE	0.48	0.71	0.79	0.17	0.35	0.21	0.23
t	4.23	4.90	7.43	0.63	1.54	0.73	1.26
a	-0.20	-0.06	-0.01	0.06	-0.35	-0.40	-0.08
b	1.02	0.90	0.96	0.98	1.07	1.02	1.00
r	0.94	0.96	0.96	0.97	0.92	0.97	0.96

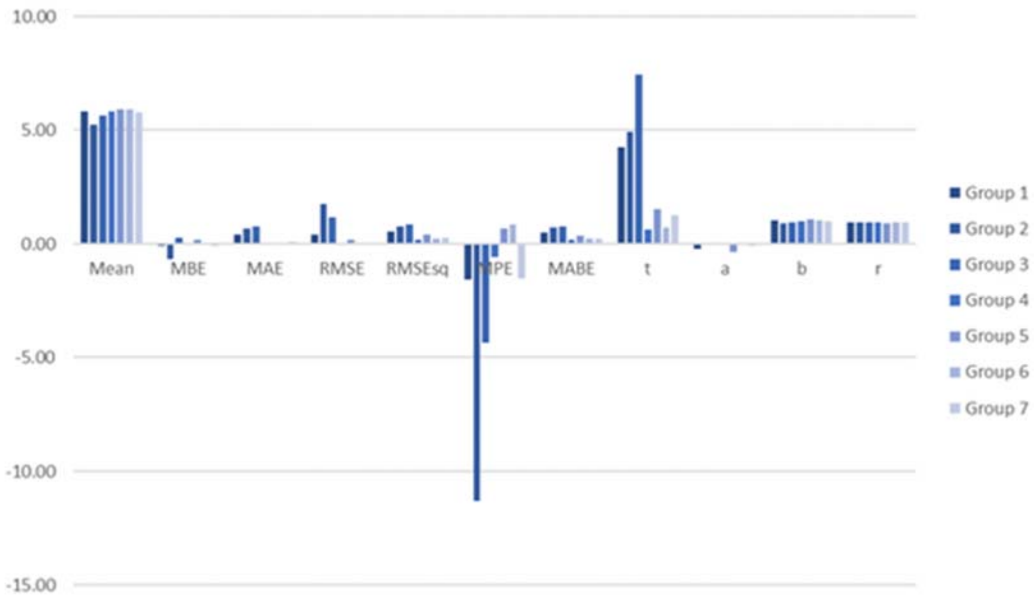


Fig. 4 Performance of each group in terms of Mean, MPE, RMSEsq, MBE, RMSE, MABE, Tstat, R, MAE, slope and intercept for regression line

Group 3 models showed the best performance, while group 2 models had the highest e values. It is worth noting that the performance of a group is affected by that of models within the group. For example, model 37 showed the poorest performance in group 2, which impacted on the performance of the entire group in Fig. 5.

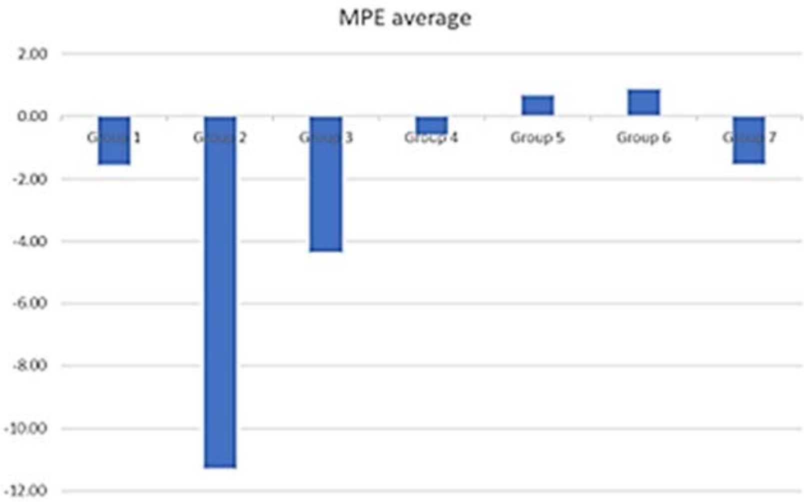
B. Annual Performance

Table II shows the overall statistics for all the models. The models can be categorized according to MPE values: 38 models had MPE of 0 to -20 %, 10 models had MPE of 0.1 to 20%, 2 models had MPE of < -20% and model 38 had MPE values of 38.91% respectively shown in Table III.

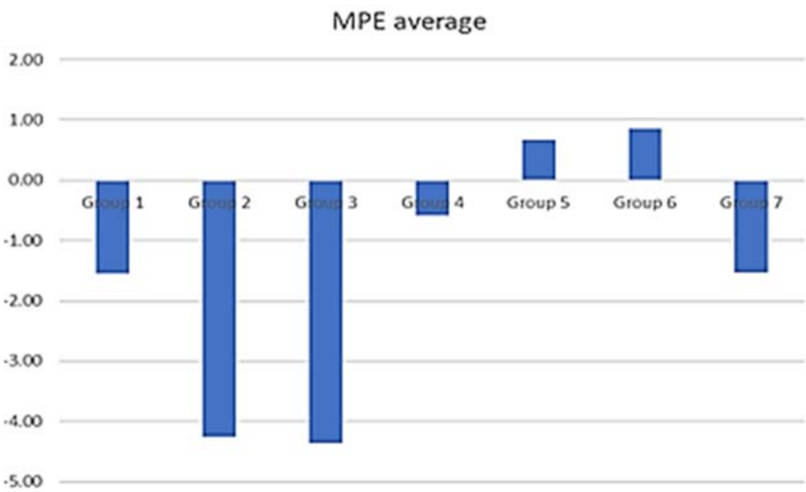
Based on the above results, models 22 and 46 yielded the best estimates of GSR measured in Hutat Suder during most of the year shown in Fig. 6, which influenced the overall performance. We consider that both models are suitable to predict the global radiation on horizontal surface in Hutat Suder with high accuracy.

V. Conclusions

The performance of 52 sun-based models of different functional forms was tested for the determination of monthly GSR on horizontal surfaces in Hutat Suder, Saudi Arabia. It was found that model 37 is totally unsuitable for use in this region owing to their poor performance for both annual and monthly data. The other models showed reasonable performance and good statistical parameters in some months but poorer predictions and some non-significant statistical parameters for the other months. Among the models considered, the model that was best suited for estimating the GSR for Hutat Suder was model 22 [22] and model 46 [10].

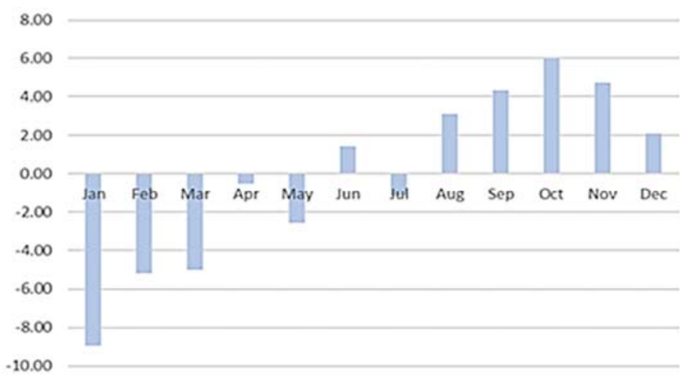


(a)

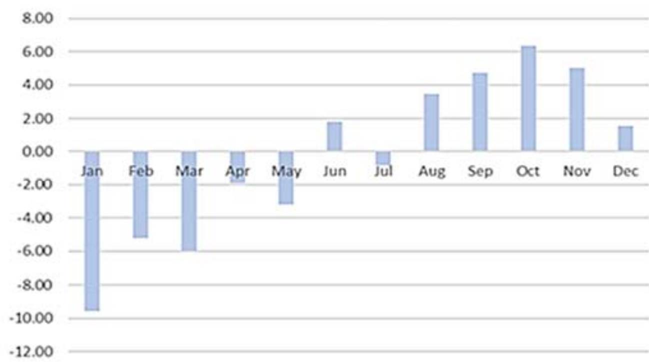


(b)

Fig. 5 Mean percentage error a with model 37 b without model 37



(a)



(b)

Fig. 6 The best estimates of GSR a model 22 and b model 46

TABLE III
TYPICAL REGRESSION RESULTS FOR MEASURED AND CALCULATED DATA

Model	Model name	Group	Mean	MBE	MAE	RMSE	RMSEsq	MPE%	MABE	Tstat	a	b	R
1	BAKIRCI 3	3	5.23	-0.65	0.65	0.47	0.69	-11.00	0.65	9.20	-0.03	0.90	0.97
2	TAHRAN&SARI2	2	5.13	-0.75	0.75	0.62	0.78	-12.57	0.75	10.24	0.17	0.84	0.98
3	TAHRAN&SARI3	3	5.18	-0.70	0.70	0.55	0.74	-11.89	0.70	10.09	0.06	0.87	0.97
4	ARAS etal1	1	5.67	-0.21	0.21	0.11	0.33	-3.61	0.26	2.74	-0.12	0.99	0.96
5	ARAS etal2	2	5.69	-0.19	0.19	0.11	0.33	-3.34	0.28	2.29	-0.18	1.00	0.95
6	ARAS etal3	3	5.67	-0.21	0.21	0.10	0.31	-3.58	0.25	2.97	-0.04	0.97	0.96
7	AHMAD&ULFAT1	1	5.74	-0.14	0.14	0.08	0.28	-2.43	0.24	1.87	-0.11	0.99	0.96
8	AHMAD&ULFAT2	2	5.74	-0.14	0.14	0.09	0.29	-2.45	0.24	1.81	-0.13	1.00	0.96
9	ALMOROX&HONTORIA exp	5	5.76	-0.12	0.12	0.16	0.40	-2.29	0.35	1.03	-0.40	1.05	0.92
10	ULGEN&HEPBASLI1	1	5.70	-0.18	0.18	0.11	0.33	-3.13	0.28	2.09	-0.19	1.00	0.95
11	ULGEN&HEPBASLI3	3	5.67	-0.21	0.21	0.10	0.31	-5.32	0.25	2.93	-0.04	0.97	0.96
12	AKPABIO&ETUK1	1	4.71	-1.17	1.17	1.47	1.21	-20.00	1.17	12.62	-0.14	0.82	0.95
13	TOGRUL&TOGRUL1	1	5.99	0.11	0.11	0.09	0.30	1.74	0.26	1.29	-0.14	1.04	0.95
14	TOGRUL&TOGRUL1LN	4	5.84	-0.04	0.04	0.04	0.20	-0.59	0.17	0.63	0.06	0.98	0.97
15	TOGRUL&TOGRUL2	2	5.78	-0.10	0.10	0.04	0.21	-1.45	0.18	1.72	0.25	0.94	0.98
16	TOGRUL&TOGRUL3	3	5.78	-0.10	0.10	0.05	0.21	-1.42	0.18	1.68	0.29	0.93	0.98
17	TOGRUL&TOGRULexp	5	6.10	0.22	0.22	0.18	0.43	3.62	0.36	2.05	-0.31	1.09	0.93
18	TOGRUL&TOGRUL ^	6	5.93	0.05	0.05	0.06	0.24	0.86	0.21	0.73	-0.04	1.02	0.97
19	ULGEN&HEPBASIL1	1	5.99	0.11	0.11	0.10	0.32	1.74	0.28	1.21	-0.19	1.05	0.95
20	ULGEN&HEPBASIL3	3	5.60	-0.28	0.28	0.14	0.38	-4.75	0.30	3.53	-0.12	0.97	0.95
21	CHEGAAR&CHIBANI11	1	5.35	-0.53	0.53	0.34	0.58	-9.07	0.53	7.24	-0.09	0.92	0.96
22	CHEGAAR&CHIBANI12	1	5.87	-0.01	0.01	0.05	0.23	-0.14	0.21	0.10	-0.06	1.01	0.96
23	CHEGAAR&CHIBANI13	1	6.18	0.30	0.30	0.23	0.47	4.98	0.39	2.76	-0.28	1.10	0.94
24	ERTEKIN&YALDIZ3	3	4.35	-1.53	1.53	2.46	1.57	-26.13	1.53	15.05	-0.13	0.76	0.96
25	ULGEN&OZBALTA1	1	5.65	-0.22	0.22	0.14	0.37	-3.96	0.30	2.53	-0.22	1.00	0.94
26	ULGEN&OZBALTA2	2	5.67	-0.21	0.21	0.11	0.33	-3.62	0.26	2.78	-0.09	0.98	0.96
27	SAID1	1	5.58	-0.30	0.30	0.18	0.43	-5.26	0.34	3.23	-0.25	0.99	0.94
28	SAID2	2	5.58	-0.30	0.30	0.17	0.42	-5.15	0.32	3.36	-0.20	0.98	0.94
29	AKSOY2	2	5.52	-0.36	0.36	0.23	0.48	-6.23	0.37	3.67	-0.27	0.99	0.93
30	TIRIS etal1	1	4.93	-0.94	0.94	0.98	0.99	-16.17	0.94	10.70	-0.17	0.87	0.95
31	VEERAN&KUMAR11	1	5.30	-0.58	0.58	0.39	0.62	-9.81	0.58	8.24	-0.04	0.91	0.97
32	VEERAN&KUMAR12	1	6.93	1.05	1.05	1.31	1.15	17.60	1.05	7.41	-0.30	1.23	0.94
33	GOPINATHAN&SOLER11	1	6.81	0.93	0.93	1.15	1.07	15.44	0.93	5.71	-0.46	1.24	0.91
34	GOPINATHAN&SOLER12	1	6.74	0.86	0.86	0.98	0.99	14.35	0.86	5.81	-0.39	1.21	0.92
35	LEWIS 1	1	5.19	-0.69	0.69	0.59	0.77	-11.96	0.69	6.74	-0.32	0.94	0.92
36	LEWIS 3	3	4.93	-0.95	0.95	0.99	0.99	-15.87	0.95	10.50	0.33	0.78	0.97
37	TASDEMIROGLU&SEVER2	2	2.16	-3.72	3.72	14.45	3.80	-63.20	3.72	15.83	0.11	0.35	0.97
38	SAMUEL3	3	8.18	2.30	2.30	5.79	2.41	38.91	2.30	10.96	-0.40	1.46	0.94
39	JAIN11	1	5.58	-0.30	0.30	0.14	0.38	-5.13	0.31	4.27	-0.07	0.96	0.96
40	JAIN12	1	6.15	0.27	0.27	0.17	0.41	4.56	0.34	2.98	-0.17	1.08	0.95
41	JAIN13	1	6.93	1.05	1.05	1.30	1.14	17.76	1.05	7.93	-0.25	1.22	0.94
42	RAJA&TWIDELL1	1	5.58	-0.30	0.30	0.14	0.38	-5.13	0.31	4.27	-0.07	0.96	0.96
43	RAJA&TWIDELLcos1	7	5.72	-0.16	0.16	0.08	0.28	-2.78	0.23	2.32	-0.07	0.98	0.96
44	LUHANGA&ANDRINGA1	1	5.55	-0.33	0.33	0.19	0.44	-5.74	0.34	3.79	-0.21	0.98	0.94
45	JAIN&JAIN1	1	5.71	-0.17	0.17	0.12	0.34	-2.99	0.29	1.84	-0.32	1.01	0.94
46	GOPINATHAN cos2	7	5.86	-0.02	0.02	0.07	0.26	-0.31	0.23	0.20	-0.09	1.01	0.96
47	OGELMAN2	2	5.68	-0.20	0.20	0.12	0.34	-3.47	0.28	2.38	-0.17	0.99	0.95
48	BENSONetal11	1	5.76	-0.12	0.12	0.14	0.37	-2.24	0.32	1.13	-0.32	1.03	0.93
49	BENSONetal12	1	5.83	-0.05	0.05	0.10	0.32	-1.01	0.28	0.54	-0.24	1.03	0.94
50	KHOLAGIetal11	1	5.66	-0.22	0.22	0.16	0.40	-3.89	0.33	2.17	-0.29	1.01	0.93
51	KHOLAGIetal12	1	5.68	-0.20	0.20	0.11	0.33	-3.51	0.27	2.57	-0.14	0.99	0.95
52	KHOLAGIetal13	1	5.51	-0.37	0.37	0.21	0.46	-6.41	0.37	4.52	-0.17	0.97	0.95

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