



TREND AND VARIABILITY OF SUNSHINE DURATION OVER SAUDI ARABIA USING THE EUMETSAT SATELLITE APPLICATION

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ABSTRACT

Information on sunshine duration variations and the availability of solar energy is vital for atmospheric and climate change analysis. Based on the analysis of data from 1983 to 2022 the monthly mean sunshine duration in Saudi Arabia was 283 ± 18 hours. Generally, the COV test showed that sunshine duration varies by about two percent annually in Saudi Arabia, but about three percent in the Al Bahah region. According to the MK/MMK test results, there has been an increase in the availability of SDU in Saudi Arabia between 1983 and 2022. Some regions, such as Riyadh and the southwest part, do not show statistically significant increases. According to Sen's slope test, the southwest and northern parts of the country experienced an increase of 0.7-0.8 and 0.5-0.6 hours per year (h/yr) in sunshine duration during the spring. In the summer season, there was a downward trend of SDU in most parts of the country, with a range of -0.49-0.0 h/yr. A statistically significant trend is observed in 34 out of 65 case scenarios according to the MK/MMK trend test. In contrast, statistically significant trends were found in about 97 percent (63 out of 65) of cases from the ITA method.

Keywords: Sunshine Duration, Coefficient of Variation, Modified Mann-Kendall test, Mann-Kendall test, Sen's Slope, Innovative Trend Analysis, Solar energy

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1. INTRODUCTION

On a global scale, almost 90% of the world's energy consumption is provided by fossil fuels like oil, coal, natural gas etc. [1]. The rising threat of global warming and depleting fossil fuel resources have encouraged the global scientific community to find an alternative energy source to stabilize climate change. There are some alternative energy resources such as wind, thermal, biomass and solar energy which are pure and renewable [2]. Sun is the main viable energy source which has the capacity to maintain all the physical, chemical and biological activities and processes that control the earth's climate system and life [2]. Approximately 17.300 GW can be generated by 0.1% of solar energy reaching the earth's surface with 10% efficiency, which is more than five times the global electricity consumption in 2016 [3].

Information on solar radiation variations and the availability of solar energy is vital for atmospheric and climate change analysis. The amount of sunlight reaching the earth's surface is an important metrological parameter used in a number of socio-economic applications. Sunshine duration is a measure of available light sources for the earth that is estimated on the basis of the time during which the sun irradiates the earth's surface above the threshold level. Although the threshold level of the sun's illumination varies widely, the World Meteorological Organization accepted the threshold level at 120 W m^{-2} (Vuerich et al., 2012). WMO (2003) defines sunshine duration as the sum of that sub-period for which the direct solar irradiance exceeds 120 W m^{-2} (World Meteorological Organization (WMO), 2017). The duration of sunshine is related to the operation and management of atmospheric energy balance, evaporation estimation, agricultural production assessment etc. [6].

The duration of sunshine can be measured by a variety of methods, such as using sunshine duration recorders for direct measurements; getting the irradiance data from a pyrheliometer and so on. [7], [8]. Ground stations covering a specific area are the most reliable and accurate sources of available radiation. A large number of stations are required to measure the trend and availability of radiation, which is both costly and time-consuming. Using satellite data is also a recommended method for analyzing sunshine duration on a regional scale.

To investigate the trend detection of observed metro-hydrological time series data, many popular statistical methods, for instance, linear regression, Spearman's rho tests, cumulative sum, the Mann-Kendall trend test [9]–[11], Şen's slope [12] have used. There are certain assumptions that limit the use of these classical approaches, such as the sequence independence of data series; assessing the monotonic trend and so on. As part of trend detection of metro-hydrological time series data, Şen proposed an innovative trend analysis (ITA) method [9]. ITA has some advantages over classical methods as shown in comparisons between them.

The purpose of this paper is to investigate sunshine duration in Saudi Arabia from geostationary meteorological satellite data. We also assessed variation in sunshine duration among different regions in the country and their pattern over the last few decades. The estimated sunshine duration values are classified into clusters to assess their spatial distribution in the country. The paper is organized as follows. The geography of the study area is described in the next section which is followed by the temporal and spatial distribution of sunshine duration in different regions of the country. Discussion and conclusion on the results are presented in the next section.

2. MATERIALS AND METHODS

2.1. Study Area

Saudi Arabia occupies almost 80% of the Arabian Peninsula, with the Persian Gulf to the east, Yemen to the south and the Gulf of Aqaba & the Red Sea to the west. Geographically the country lies between latitudes $16^{\circ}21'58''\text{N}$ - $32^{\circ}9'57''\text{N}$ and longitudes $34^{\circ}33'48''\text{E}$ - $55^{\circ}41'29''\text{E}$ as shown in Figure 01. There are thirteen administrative regions in the country. In the Asir region, the elevations of inland mountains rise to more than 2,700 m [13]. The Eastern Province stretches along the Persian Gulf. According to the Food and Agriculture Organization (FAO), the northern regions of the country are subtropical while the southern side falls tropical. Al-Rub al-Khali, the world's largest continuous sand desert is in the southern region. Except for the western coast of Asir province, in most of the region, the climate is generally dry and extremely hot during the day and the temperature drops rapidly at night. The average temperature during summer is about 45°C . In the winter, the temperature rarely drops below 0°C in some parts of the northern region. Generally, dry winds blow over the country and consequently, almost all of the area is arid. Under the influence of subtropical high-pressure systems and relatively very little cloud cover, daily temperatures are largely varied between regions and as well as in seasons [13]. In contrast, between October and March 60 percent of the annual precipitation occurs in the Asir region due to the Indian Ocean monsoons with about 300 millimetres of rainfall [14]. Rainfall in other parts of the country is very low and erratic. However, geographically Saudi Arabia is located in the Sun Belt and has widespread desert land and clear skies around the year. Therefore it is one of the largest solar photovoltaic (PV) energy producers [15].

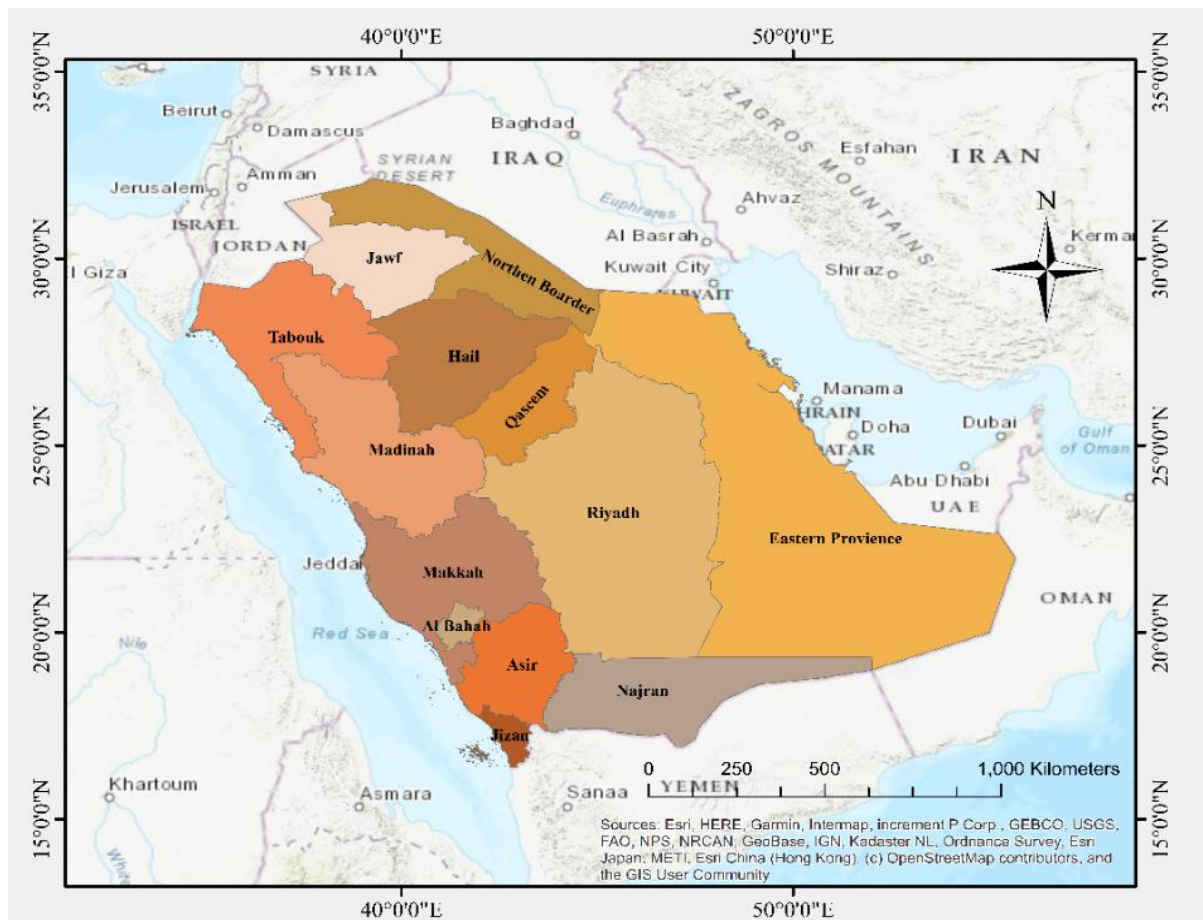


Figure 01. Maps of Saudi Arabia

Spring, summer, autumn and winter are the four distinct seasons of the country, ranging from chilly winter breezes in January to high desert temperatures in August. It is the spring season that begins in March and lasts until April. A summer season lasts almost four months, starting in May and ending in August. The autumn season begins after the summer season and extends up to October, and the winter ends before the spring.

2.2. Data

EUMETSAT provides the SARA-2.1 climate data record for solar surface radiation. The data includes parameters related to cloud, radiation, irradiance and sunshine duration [16]. Satellite-based Sunshine Duration (SDU) is derived from SARA-2-1 30-minute instantaneous DNI by extracting the period during which DNI exceeds 120 W m⁻² [16], [17]. The monthly means of SDU in Saudi Arabia are extracted from the data set between 1983 and 2022.

2.3. Methodology

The data acquired for the monthly mean Sunshine Duration (SDU) was used to compute the seasonal and annual mean of SDU at different administrative regions of Saudi Arabia. And, spatiotemporal distribution in the availability of SDU across the country was analysed. Furthermore, robust statistical methods were used to identify the variability and the trend of SDU in the country.

The **coefficient of variation (COV)** is a statistical approach used to identify the level of dispersion around the mean of a time series [18]. Using the following mathematical equation is used to compute the COV.

$$COV = \frac{\sigma}{\bar{x}} \times 100\% \quad (1)$$

Where, σ = standard deviation of a time series data set

$\bar{x}$ = mean of a data set

The **autocorrelation function (ACF)** was developed to identify the randomness of a data set in a time series [19]. The presence of autocorrelation in a time series causes a problem in the trend detection approach. The autocorrelation coefficient at lag j (where $j \geq 0$) is computed by the following mathematical equation

$$r_j = \frac{\sum_{t=j+1}^n (x_t - \bar{x})(x_{t-j} - \bar{x})}{\sum_{t=1}^n (x_t - \bar{x})^2} \quad (2)$$

Where, r_j = autocorrelation function at lag- j

x_t = data point at a time t

$\bar{x}$ = mean of a data set

j = lag no

x_{t-j} = data point at a time $(t-j)$

For this study, it was checked whether the data in the time series are serially correlated, the autocorrelation function $r_{(1)}$ for lag(1) at the 95% confidence interval. If $r_{(1)}$ falls within the upper and lower limit of the confidence interval, then the time series is considered to be serially correlated.

For the present study, the following statistical approaches were adopted for trend detection of SDU across the kingdom

- Mann-Kendall (MK) test
- Modified Mann-Kendall (mMK) test
- Sen's Slope
- Innovative Trend Analysis (ITA)

A brief description of the aforementioned methods is given in the following section

The **Mann-Kendall (MK)** test is a non-parametric test to detect whether there is enough statistical evidence of the presence of a monotonic trend in a time series[10], [11]. When there is sufficient statistical evidence, the MK test rejects the null hypothesis, which is the absence of monotonic trends in the data set. The sign of the difference between the earlier and later points of the data is computed from a given time series data $\{x_k\}_{k=1}^n$.

$$sgn(\varphi) = \begin{cases} 1 & \text{if } (x_{k+1} - x_k) > 0 \\ 0 & \text{if } (x_{k+1} - x_k) = 0 \\ -1 & \text{if } (x_{k+1} - x_k) < 0 \end{cases} \quad (3)$$

The Mann-Kendall Test statistics parameter, S is computed by the following equation

$$S = \sum_{k=1}^{n-1} \sum_{k+1}^n (x_{k+1} - x_k) \quad (4)$$

Where x_k and x_{k+1} are the data at k_{th} and $(k+1)_{th}$ timestamp respectively.

The variance of the Mann-Kendall test statistics (S) is given below

$$\sigma^2 = \frac{[n(n-1)(2n+5) - \sum_{i=1}^q t_i(t_i-1)(2t_i+5)]}{18} \quad (5)$$

Where n is the length of the data set, q is the number of tied groups in the data set and t_i is the no of data points in the i_{th} tied group.

The standardized Mann-Kendall test statistics Z_c is computed as follows

$$Z_c = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \quad (6)$$

Kendall's τ is given by the following equation

$$\tau = \frac{\sqrt{2}S}{\sqrt{[n(n-1) - \sum_{i=1}^q t_i(t_i-1)][n(n-1)]}} \quad (7)$$

A negative value of Mann-Kendall test statistics (Z_c) indicates the presence of a downward trend over time and vice-versa. There is a statistically significant indication of the existence of a trend at a 90% confidence interval when the absolute value of Z_c is more than 1.65 but less than 1.96 [20]. For the case of $2.58 > |Z_c| > 1.96$, there is a significant trend present in the data series at the 95% confidence interval [20]. If the absolute value of the test statistics (Z_c) is greater than 2.58, there will be a 99% probability to have a significant trend in the temporal data set [20].

Time series data are often not random and influenced by autocorrelation, Yue and Wang (2004) have proposed a variance correction approach in the Mann-Kendall tests known as the modified Mann-Kendall tests, which may be used for trend detection to address the issue of serial correlation in the data set. After detrending the data, lag-1 autocorrelation coefficients are used to calculate the effective sample size.

$$\sigma^2 = \frac{1}{18} [n(n-1)(2n+5)]\varepsilon \quad (8)$$

Where ε = correction factor to adjust the autocorrelated data

$$\varepsilon = 1 + \frac{2}{n(n^2-3n+2)} \sum_{e=1}^{n-1} (n-e)(n-e-1)(n-e-2)\zeta \quad (9)$$

ζ = the autocorrelation function between ranks of observation.

$$\zeta = 2 \sin\left(\frac{\pi}{6} \zeta\right) \quad (10)$$

Sen's Slope is a simple non-parametric approach used to determine the magnitude of the trend slope of a time series [12].

$$d_k = \text{median} \left\{ \frac{y_j - y_i}{x_j - x_i} \right\} \quad (11)$$

Where d_k = Sen's slope

i and j are the timestamp of the data series, and i is less than j .

Innovative Trend Analysis (ITA) by **Zekai Sen** is a modern, effective method of interpreting hydrometeorological trends that is easy to interpret [9]. The data set is divided into two halves, the first part is sorted ascendingly, followed by the ascending order in the second part. A two-dimensional Cartesian coordinate system is used to plot the first and second subseries according to the horizontal X-axis and vertical Y-axis, respectively. At 45° , a diagonal line is plotted on the scatter plot as a trendless line. Data points fall on the 1:1 line indicating there is no trend. If the data points are gathered in the triangular zone above the 45° line, the time series exhibits an increasing trend and vice versa. [20], [21]. When the positioning of points in the scatter plot indicates the presence of a single monotonic trend, a grouping of data point zone, such as "low"; "medium" or "high", is not necessary. Otherwise, the scatter points that don't match monotonic increasing or decreasing trends are identified into low, medium and high groups. Points in the first half of the data series below the 30th percentile are considered to be in the low group zone, whereas those points of the first part are exceeded the value of the 70th percentile and are identified to be felled in the high group arena. And the zone between low and high is defined as the medium zone [21].

In the ITA method, the trend line's slope is computed by the following equation

$$Slope = \frac{2(\bar{x}_j - \bar{x}_i)}{n} \quad (12)$$

Where, $\bar{x}_i$ & $\bar{x}_j$ are the mean of the first half & Second half of the time series data set. And σ_x is the standard deviation of the first half of the data set.

In a standard normal distribution with zero mean and standard deviation, the confidence limits (CL) are calculated by the following equation

$$CL_\alpha = 0 \pm x_\alpha \sigma_s \quad (13)$$

Where, α = Significance level; the value of x_α will be 1.65 and 1.96 for CL90 and CL95 respectively, and σ_s is the standard deviation of the trend slope.

$$\sigma_s = \frac{2\sqrt{2}\sigma}{n\sqrt{n}} \sqrt{(1 - cor(\bar{x}_i, \bar{x}_j))} \quad (14)$$

Where, σ = Standard Deviation of the data set; n = length of the data set; $cor(\bar{x}_i, \bar{x}_j)$ = coefficient of correlation between mean values of the two halves of the data set.

The negative value of the slope implies a downward trend and vice-versa. When the slope value is fallen within the confidence limit, it indicates that there are no trend exists, otherwise, there is significant evidence for the existence of a trend in the time series data set.

2.4. Results and Analysis

Monthly sunshine duration data for different regions in Saudi Arabia were extracted from EUMETSAT satellite imagery for the last three decades (1983-2022). This section describes spatial distribution, seasonal and annual variation and trend of sunshine duration in different regions of the country.

2.4.1. Spatial Distribution of Sunshine Duration in Saudi Arabia

Based on the analysis of data from 1983 to 2022 the monthly mean sunshine duration in Saudi Arabia was 283 ± 18 hours. The monthly mean maximum and minimum sunshine duration were in the southwest region and northern part of the country with 368 ± 18 hours and 162 ± 46 hours respectively. The distribution of sunshine hours in Saudi Arabia is shown in Figure 02. From the spatiotemporal analysis, it appears that from the middle part to the northern side of the country experienced monthly mean SDU over 285 h on average every year over the past forty years. However, on average per year, the minimum monthly mean SDU observed on the southwest corner of the country with a range of 261.33-280 h.

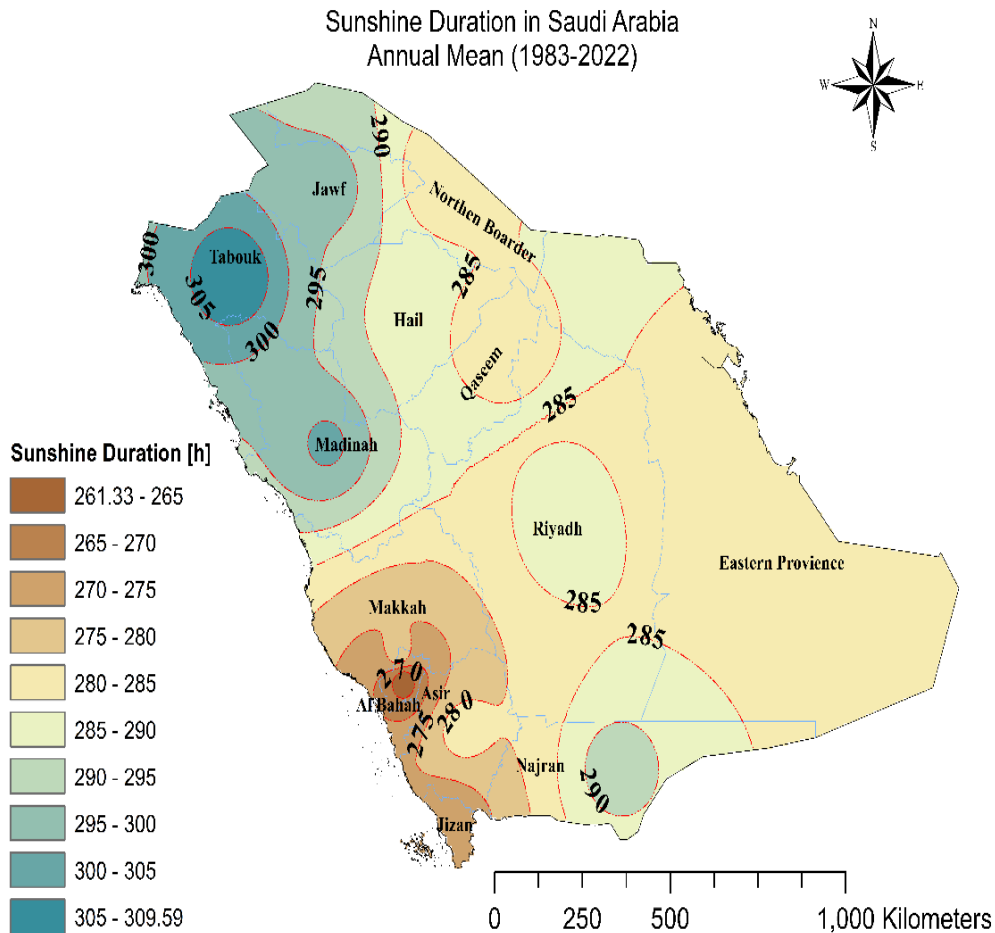


Figure 02. Spatial Distribution of Sunshine Duration in Hours in Saudi Arabia.

2.4.2. Variability Sunshine duration in Saudi Arabia

The SDU at the Earth's surface is significantly varied by geographical and astronomical factors, such as the Earth-Sun distance, geographical location of the point of interest, positioning of the Sun's location, weather and atmospheric conditions. Table 01 presents a Summary of the COV test's results and illustrates the seasonal and annual variation of sunshine duration in different parts of the kingdom. It is seen from the table that the maximum level of SDU variation occurred during the spring season, followed by the autumn and winter season. Whereas, the least variability of SDU across the country was found in the summer season. During the spring season, the regions which fall in the southern part of the country, for instance, Eastern province, Albahah, Asir, Najran and the other regions, experienced a considerable level of sunshine duration, with over six percent, while in the other part of the country, the variation of SDU was just under 4%. However, over the past forty years, the variation of SDU in most parts of the country were just under three percent during the summer season, some hilly areas, such as Asir, Al Bahah, Makkah and Madinah, where the variation of SDU was over four and a half percent. Overall, from the COV test result, it appears that the annual variation of sunshine duration in Saudi Arabia was around two percent, but in the Al Bahah region, the variation was about 3.5%.

Table 01: Seasonal and Annual Variability of Sunshine Duration in Saudi Arabia

Region	Latitude	Longitude	Altitude (m)	Coefficient of Variation (COV in percent)				
				Spring	Summer	Autumn	Winter	Annual
Al Bahah	20°09'00"	41°27'00"	1744	7.03	5.19	6.30	7.67	3.53
Asir	19°09'00"	42°57'00"	1168	7.27	5.21	3.67	2.73	2.53
Eastern Province	24°00'00"	49°45'00"	329	8.06	3.04	2.83	4.99	2.61
Hail	27°24'00"	41°27'00"	936	4.78	3.64	7.03	4.66	2.39
Jawf	30°03'00"	39°36'00"	746	4.81	2.13	4.49	4.14	1.83
Jizan	17°21'00"	42°39'00"	604	5.74	4.75	4.48	4.95	2.62
Madinah	24°54'00"	39°30'00"	692	4.45	3.65	4.68	3.64	2.05
Makkah	20°39'00"	41°21'00"	785	4.85	4.86	5.51	3.63	2.37
Najran	18°24'00"	46°54'00"	846	6.69	3.71	2.91	2.92	1.83
Northern Boarder	30°15'00"	42°24'00"	514	4.91	3.08	5.94	4.43	2.37
Qassim	27°06'00"	43°27'00"	767	4.67	3.15	5.32	5.65	2.42
Riyadh	23°03'00"	45°33'00"	578	5.54	3.36	3.11	4.05	2.11
Tabuk	28°15'00"	37°09'00"	695	4.48	2.21	4.02	3.04	1.74

2.4.3. The trend of Sunshine Duration in Saudi Arabia by the Mann-Kendall/ Modified Mann-Kendall test

The autocorrelation function (ACF) was used to identify the serially correlated data set from the seasonal as well as annual spatiotemporal time series data set. The Modified Mann-Kendall test was applied for detecting whether the monotonic trend was present in the serially correlated data set, otherwise, the Mann-Kendall test was used for trend detection. An analytical summary of the trend analysis of sunshine duration in Saudi Arabia is presented in Table 02. From the MK/MMK test results, it appears that there is an upward trend in sunshine duration across the country during the spring season. In the autumn and winter season, the non-parametric trend test indicates an increasing but statistically nonsignificant trend of SDU, except in some regions, such as Jizan, Madinah and Tabuk, sunshine duration decreases in the autumn season but that is not significant from the statistical point of view.

However, the availability of SDU in the summer season decreases during the past four decades, but the Tabuk, Northern Border and Qassim regions experienced a statistically nonsignificant increasing trend. Overall, it appears from the MK/MMK test results which are shown in Table 02 that the availability of SDU in Saudi Arabia increased between 1983 and 2022, but in some regions, for instance, Riyadh and southwestern regions, the increasing trend isn't statistically very significant.

Table 02: Analytical Summary of Trend Analysis of Sunshine Duration in Saudi Arabia by the Mann-Kendall/ Modified Mann-Kendall test

Region	Season	Mean	σ	Leg1-AC	τ	p-value	Zc	Sen's Slope	Trend	α
Al Bahah	Spring	271.8	19.1	0.183	0.351	0.0014	3.18	0.996	Up	99%
	Summer	266.1	13.82	0.499	-0.302	0.0622*	-1.864*	-0.456	Down	90%
	Autumn	271.9	17.12	0.011	0.017	0.8796	0.151	0.026	Up**	
	Winter	246	18.87	0.415	0.31	0.0351*	2.106*	0.601	Up	95%
	Annual	261.3	9.23	0.463	0.215	0.2197*	1.227*	0.262	Up**	
Asir	Spring	267.2	19.41	0.183	0.294	0.0076	2.668	0.734	Up	99%
	Summer	285.1	14.85	0.377	-0.258	0.0623*	-1.863*	-0.493	Down	90%
	Autumn	300.3	11.01	0.235	0.051	0.6495	0.454	0.057	Up**	
	Winter	278.4	7.61	0.108	0.274	0.013	2.481	0.263	Up	95%
	Annual	282.4	7.14	0.189	0.048	0.6664	0.431	0.024	Up**	
Eastern Province	Spring	254.4	20.51	0.388	0.241	0.1119*	1.589*	0.629	Up**	
	Summer	320.6	9.74	0.119	-0.053	0.6329	-0.477	-0.085	Down**	
	Autumn	302.6	8.56	0.018	0.125	0.2584	1.13	0.175	Up**	
	Winter	243.4	12.15	0.071	0.258	0.0191	2.341	0.337	Up	95%
	Annual	280.8	7.32	0.337	0.287	0.0426*	2.026*	0.245	Up	95%
Hail	Spring	281.6	13.47	0.288	0.369	0.0008	3.343	0.641	Up	99%
	Summer	335.4	12.21	-0.076	-0.058	0.6001	-0.524	-0.098	Down**	
	Autumn	293.5	20.64	-0.068	0.035	0.7531	0.314	0.083	Up**	
	Winter	243.5	11.34	0.171	0.202	0.0673	1.829	0.313	Up	90%
	Annual	288.8	6.89	0.133	0.217	0.0489	1.969	0.227	Up	95%
Jawf	Spring	290.8	13.97	0.029	0.315	0.0043	2.854	0.532	Up	99%
	Summer	356.4	7.57	-0.073	-0.028	0.8067	-0.244	-0.028	Down**	
	Autumn	304.1	13.64	-0.073	0.071	0.5216	0.64	0.104	Up**	
	Winter	237.2	9.83	0.07	0.197	0.0746	1.782	0.278	Up	90%
	Annual	297	5.44	0.278	0.251	0.023	2.272	0.198	Up	95%
Jizan	Spring	292.6	16.79	0.113	0.335	0.0023	3.04	0.7	Up	99%
	Summer	265.7	12.62	0.355	-0.248	0.0845*	-1.725*	-0.436	Down	90%
	Autumn	274.5	12.31	0.118	-0.005	0.9721	-0.034	-0.019	Down**	
	Winter	261.8	12.95	0.079	0.205	0.0639	1.852	0.3	Up	90%
	Annual	270.3	7.07	0.096	0.082	0.4629	0.734	0.08	Up**	
Madinah	Spring	303.1	13.5	0.333	0.282	0.0428*	2.024*	0.501	Up	95%
	Summer	334.6	12.21	0.001	-0.143	0.1959	-1.293	-0.181	Down**	
	Autumn	301.5	14.1	-0.063	-0.035	0.7531	-0.314	-0.06	Down**	
	Winter	266.8	9.71	0.287	0.269	0.0148	2.435	0.363	Up	95%
	Annual	301.2	6.16	0.133	0.12	0.2786	1.083	0.103	Up**	
Makkah	Spring	287.6	13.94	0.232	0.282	0.0107	2.551	0.511	Up	95%
	Summer	277	13.47	0.401	-0.317	0.0212*	-2.303*	-0.499	Down	95%
	Autumn	283.8	15.62	0.066	0.023	0.843	0.198	0.032	Up**	
	Winter	270.7	9.83	0.287	0.243	0.0276	2.202	0.298	Up	95%
	Annual	277.8	6.58	0.245	0.002	0.9907	0.011	0.002	Up**	
Najran	Spring	287.7	19.23	0.295	0.307	0.0053	2.784	0.792	Up	99%
	Summer	300.6	11.16	0.206	-0.225	0.0414	-2.038	-0.331	Down	95%
	Autumn	306.3	8.92	0.201	0.033	0.7708	0.291	0.022	Up**	
	Winter	280.2	8.17	-0.138	0.23	0.037	2.085	0.224	Up	95%
	Annual	292.6	5.36	0.331	0.12	0.4268*	0.794*	0.095	Up**	
Northern Boarder	Spring	270.8	13.29	0.337	0.358	0.0053*	2.782*	0.611	Up	99%
	Summer	342.2	10.52	0.096	0.092	0.4081	0.827	0.134	Up**	
	Autumn	293.3	17.42	-0.066	0.048	0.6664	0.431	0.063	Up**	
	Winter	217.2	9.62	0.152	0.115	0.2998	1.036	0.181	Up**	
	Annual	280.5	6.65	0.27	0.256	0.0204	2.318	0.214	Up	95%
Qassim	Spring	268	12.51	0.238	0.371	0.0007	3.367	0.606	Up	99%
	Summer	333.3	10.51	0.098	0.002	0.9907	0.011	0.002	Up**	
	Autumn	298.2	15.87	-0.077	0.061	0.584	0.547	0.113	Up**	
	Winter	231	13.04	0.117	0.1	0.3696	0.897	0.146	Up**	
	Annual	282.5	6.83	0.018	0.23	0.037	2.085	0.19	Up	95%
Riyadh	Spring	268.8	14.88	0.316	0.343	0.0107*	2.551*	0.525	Up	95%
	Summer	315.2	10.58	0.152	-0.212	0.0545	-1.922	-0.252	Down	90%
	Autumn	307.3	9.55	0.017	0.082	0.4629	0.734	0.117	Up**	
	Winter	259.6	10.51	-0.016	0.194	0.0785	1.759	0.277	Up	90%
	Annual	287.6	6.07	0.244	0.171	0.1212	1.549	0.137	Up**	
Tabuk	Spring	306.4	13.74	0.119	0.315	0.0043	2.854	0.463	Up	99%
	Summer	360	7.96	-0.336	0.033	0.6826*	0.408*	0.033	Up**	
	Autumn	310	12.46	-0.053	-0.028	0.8067	-0.244	-0.037	Down**	
	Winter	260.7	7.91	0.196	0.161	0.1453	1.456	0.183	Up**	
	Annual	309.6	5.38	0.281	0.271	0.0139	2.458	0.212	Up	95%

Note: σ = Standard Deviation; CV = Coefficient of Variation; α = Confidence Interval; Up = Upward trend; Down= Downward Trend; * = Corrected by Modified Mann-Kendall method; ** = Statistically Non Significant Trend; AC-Leg1 = τ ; τ = Kendall's τ ; Zc = standardized Mann-Kendall test statistics;

2.4.4. The Trend of Sunshine Duration in Saudi Arabia by the Innovative Trend Analysis

The Innovative Trend Analysis (ITA) is a modern, effective trend interpretation method for hydrometeorological time series data sets and the graphical representation makes it easy to interpret. Trend analysis of SDU by the ITA approach for different regions of Saudi Arabia is presented in Figure 03. From the figure, it is seen that there is an upward trend in the availability of SDU in the northern regions, for example, Northern Border; Qassim; Tabuk; Jawf; Hail and Madinah. Whereas the other regions have a mixed pattern in the availability of SDU.

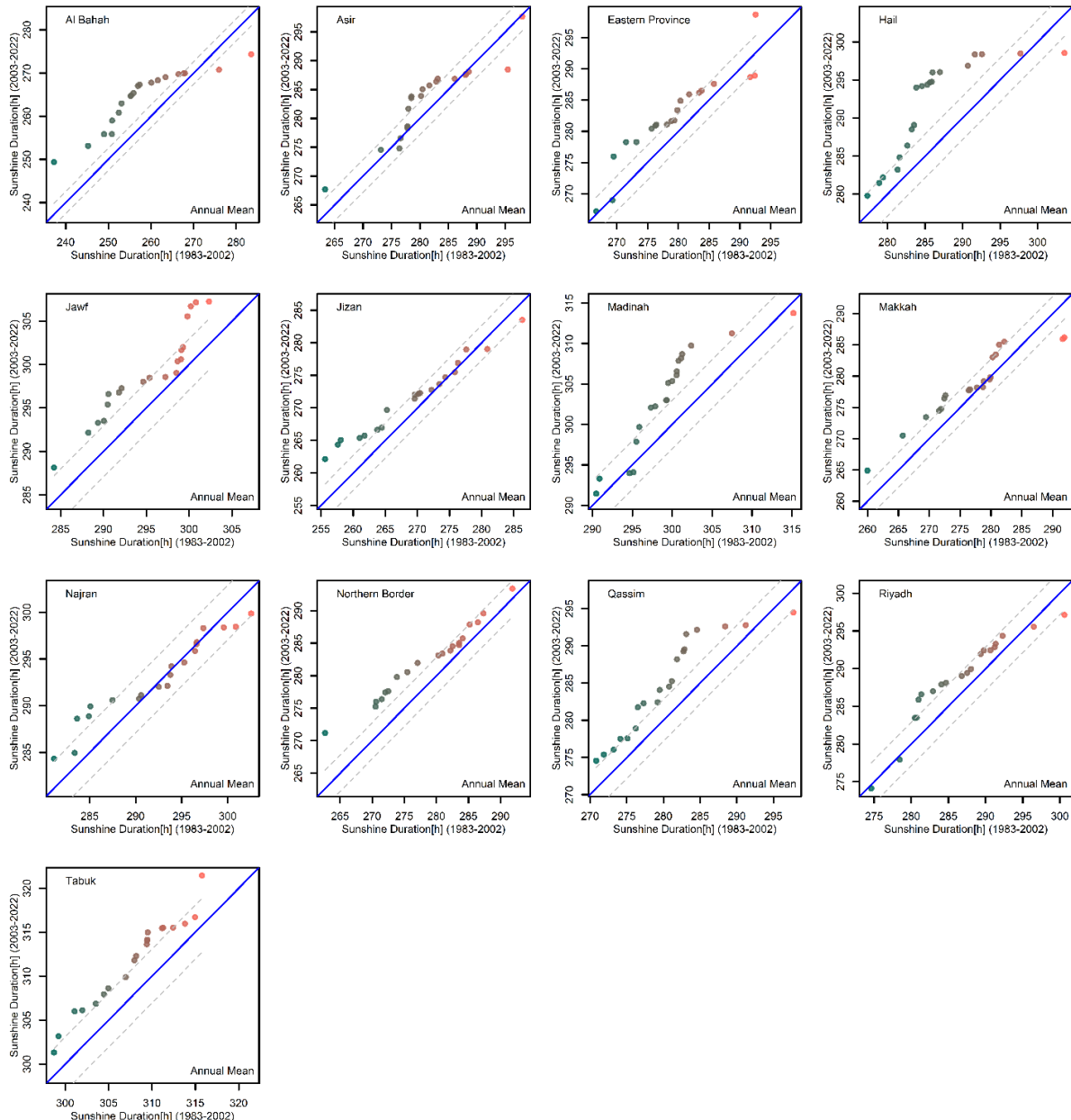


Figure 03: ITA results of Sunshine Duration [h] at different Regions in Saudi Arabia

The seasonal and annual trend of sunshine duration in different regions of Saudi Arabia is evaluated by the ITA approach and presented in Table 03.

Table 03: Analytical Summary of Trend Analysis of Sunshine Duration in Saudi Arabia by Innovative Trend Analysis Method

Region	Season	D	Slope	SD	LL	UL	low	medium	high	Trend	α
Al .Bahah	Spring	0.6793	0.893	0.055	-0.1424	0.1424	2.616	2.886	2.176	Up	99%
	Summer	-0.4611	-0.63	0.027	-0.0704	0.0704	-1.077	-1.515	-3.204	Down	99%
	Autumn	0.2616	0.351	0.04	-0.1046	0.1046	3.19	0.448	-0.085	Up	99%
	Winter	0.76	0.9	0.029	-0.0761	0.0761	4.625	1.953	1.907	Up	99%
	Annual	0.2309	0.298	0.03	-0.0786	0.0786	1.339	1.132	-0.04	Up	99%
Asir	Spring	0.5533	0.719	0.057	-0.1485	0.1485	1.691	2.366	2.093	Up	99%
	Summer	-0.4073	-0.59	0.044	-0.1142	0.1142	-0.983	-1.701	-2.576	Down	99%
	Autumn	0.1578	0.235	0.023	-0.0604	0.0604	1.817	0.554	-0.19	Up	99%
	Winter	0.2523	0.346	0.016	-0.0425	0.0425	1.603	0.848	0.741	Up	99%
	Annual	0.0548	0.077	0.021	-0.0562	0.0562	0.148	0.523	-0.222	Up	99%
Eastern Province	Spring	0.5507	0.681	0.031	-0.0808	0.0808	2.227	1.734	2.262	Up	99%
	Summer	-0.1671	-0.27	0.018	-0.0477	0.0477	-0.482	-0.545	-1.55	Down	99%
	Autumn	0.1246	0.187	0.03	-0.0785	0.0785	1.469	0.648	-0.539	Up	99%
	Winter	0.2354	0.283	0.028	-0.0737	0.0737	0.821	0.629	1.205	Up	99%
	Annual	0.1067	0.149	0.022	-0.0569	0.0569	0.644	0.461	0.192	Up	99%
Hail	Spring	0.5633	0.771	0.046	-0.1204	0.1204	1.349	2.498	2.78	Up	99%
	Summer	-0.0774	-0.13	0.019	-0.0514	0.0514	-0.235	-0.124	-0.992	Down	99%
	Autumn	0.1864	0.271	0.047	-0.1228	0.1228	2.014	0.9	-0.602	Up	99%
	Winter	0.3457	0.413	0.019	-0.0513	0.0513	1.595	1.027	1.175	Up	99%
	Annual	0.1874	0.268	0.033	-0.0853	0.0853	0.46	1.052	0.648	Up	99%
Jawf	Spring	0.3602	0.514	0.028	-0.074	0.074	2.346	1.224	1.194	Up	99%
	Summer	-0.0808	-0.14	0.019	-0.0498	0.0498	0.268	-0.548	-0.902	Down	99%
	Autumn	0.11	0.166	0.025	-0.0654	0.0654	2.175	0.204	-0.689	Up	99%
	Winter	0.3232	0.377	0.021	-0.0555	0.0555	0.721	0.997	1.695	Up	99%
	Annual	0.1294	0.19	0.014	-0.0375	0.0375	0.724	0.337	0.797	Up	99%
Jizan	Spring	0.4933	0.704	0.028	-0.0722	0.0722	3.368	1.735	1.373	Up	99%
	Summer	-0.3568	-0.48	0.026	-0.0691	0.0691	-1.613	-1.106	-1.781	Down	99%
	Autumn	0.0754	0.103	0.041	-0.0815	0.0815	0.16	0.89	-0.596	Up	95%
	Winter	0.3207	0.413	0.06	-0.1564	0.1564	2.799	0.428	1.029	Up	99%
	Annual	0.0827	0.111	0.007	-0.0198	0.0198	0.873	0.247	-0.075	Up	99%
Madinah	Spring	0.3796	0.564	0.019	-0.0513	0.0513	0.954	1.666	2.357	Up	99%
	Summer	-0.1095	-0.18	0.036	-0.0937	0.0937	-0.731	-0.203	-0.953	Down	99%
	Autumn	0.0838	0.125	0.05	-0.0992	0.0992	0.341	0.854	-0.46	Up	95%
	Winter	0.3231	0.424	0.014	-0.0361	0.0361	1.282	1.137	1.407	Up	99%
	Annual	0.1303	0.195	0.021	-0.0555	0.0555	0.215	0.609	0.868	Up	99%
Makkah	Spring	0.3403	0.481	0.039	-0.1017	0.1017	0.636	1.628	1.815	Up	99%
	Summer	-0.4189	-0.59	0.034	-0.0896	0.0896	-0.895	-1.63	-2.79	Down	99%
	Autumn	0.2149	0.301	0.019	-0.0506	0.0506	2.582	0.843	-0.728	Up	99%
	Winter	0.327	0.435	0.027	-0.0709	0.0709	2.123	1.067	0.816	Up	99%
	Annual	0.0563	0.078	0.017	-0.0442	0.0442	0.65	0.107	0.027	Up	99%
Najran	Spring	0.5568	0.779	0.035	-0.0916	0.0916	3.28	1.672	2.405	Up	99%
	Summer	-0.3118	-0.48	0.027	-0.0696	0.0696	-0.669	-1.412	-2.111	Down	99%
	Autumn	0.0287	0.044	0.022	-0.0375	0.0375	0.668	0.311	-0.732	Up	90%
	Winter	0.122	0.169	0.016	-0.0435	0.0435	1.032	0.319	0.287	Up	99%
	Annual	0.024	0.035	0.01	-0.0274	0.0274	0.6	-0.037	-0.144	Up	99%
Northern Boarder	Spring	0.3306	0.44	0.03	-0.0774	0.0774	1.203	1.296	1.384	Up	99%
	Summer	-0.0161	-0.03	0.029	-0.0484	0.0484	0.99	-0.449	-0.499	No	**
	Autumn	0.0951	0.138	0.051	-0.1336	0.1336	1.832	0.215	-0.673	Up	99%
	Winter	0.2527	0.271	0.025	-0.0666	0.0666	0.664	0.716	1.073	Up	99%
	Annual	0.1274	0.177	0.007	-0.0195	0.0195	0.943	0.404	0.311	Up	99%
Qassim	Spring	0.4718	0.617	0.039	-0.1017	0.1017	0.537	2.019	2.736	Up	99%
	Summer	-0.0715	-0.12	0.02	-0.0531	0.0531	-0.111	-0.389	-0.525	Down	99%
	Autumn	0.2387	0.351	0.03	-0.0789	0.0789	2.43	1.029	-0.352	Up	99%
	Winter	0.223	0.254	0.022	-0.0581	0.0581	1.448	0.647	0.232	Up	99%
	Annual	0.1473	0.206	0.02	-0.0528	0.0528	0.516	0.605	0.702	Up	99%
Riyadh	Spring	0.4302	0.565	0.053	-0.1376	0.1376	1.676	1.436	2.057	Up	99%
	Summer	-0.2462	-0.39	0.038	-0.1002	0.1002	-0.423	-1.488	-1.297	Down	99%
	Autumn	0.135	0.206	0.011	-0.0289	0.0289	1.396	0.556	-0.094	Up	99%
	Winter	0.241	0.309	0.019	-0.0497	0.0497	1.49	0.787	0.545	Up	99%
	Annual	0.0702	0.1	0.015	-0.0406	0.0406	0.409	0.352	0.082	Up	99%
Tabuk	Spring	0.3299	0.497	0.022	-0.0591	0.0591	2.719	1.117	0.819	Up	99%
	Summer	0.0121	0.021	0.014	-0.0239	0.0239	0.247	-0.039	0.065	No	**
	Autumn	0.0395	0.061	0.031	-0.0521	0.0521	1.119	-0.073	-0.309	Up	90%
	Winter	0.2134	0.275	0.015	-0.0394	0.0394	0.692	0.639	1.229	Up	99%
	Annual	0.1248	0.192	0.008	-0.0218	0.0218	0.62	0.521	0.586	Up	99%

Note: D = Trend Detector; Slope = Trend slope; SD= Slope Standard Deviation; α = Confidence Interval; Up = Upward trend; Down= Downward Trend; LL = Lower Limit at confidence interval; UL = Upper Limit at confidence interval; low = Slope at low clustering zone; medium = Slope at medium clustering zone; high = Slope at high clustering zone;

From the table, it is seen that there is a clear indication of an increasing trend of sunshine duration in spring, autumn and winter seasons across the kingdom from the spatiotemporal trend analysis by the ITA method. However, SDU is decreasing in most parts of the country during the summer season, except the Northern Border and Tabuk regions where the trend slope isn't statistically significant because the values fall within the 10% significant level.

3. DISCUSSION

It is important to understand the variability and trend of sunshine duration since it is an important design parameter for renewable energy systems and air-conditioning systems. With an average monthly sunshine duration was 283 hours, Saudi Arabia enjoys longer sunshine hours compared to most of the other countries.

Changing patterns of SDU, which are evaluated by Sen's Slope and Innovative Trend Analysis Method, in Saudi Arabia at different seasons are shown in Figure 04. From the figure, it appears that the spatial distribution of the trend slope evaluated by the aforementioned methods shows quite a similar pattern in spring. For instance, sunshine duration in the southwest region increased at a rate of 0.7-0.8 hours per year (h/yr) from the statistical analysis of the past forty years' data. Whereas in the northern part of the country, there was an upward trend of SDU, with a rate of 0.5-0.6 h/yr. Results (trend slope) obtained from the two statistical methods selected for this study indicate that in the summer season, there was a downward trend of SDU in most parts of the country. On the northern side of the country, the availability of SDU was

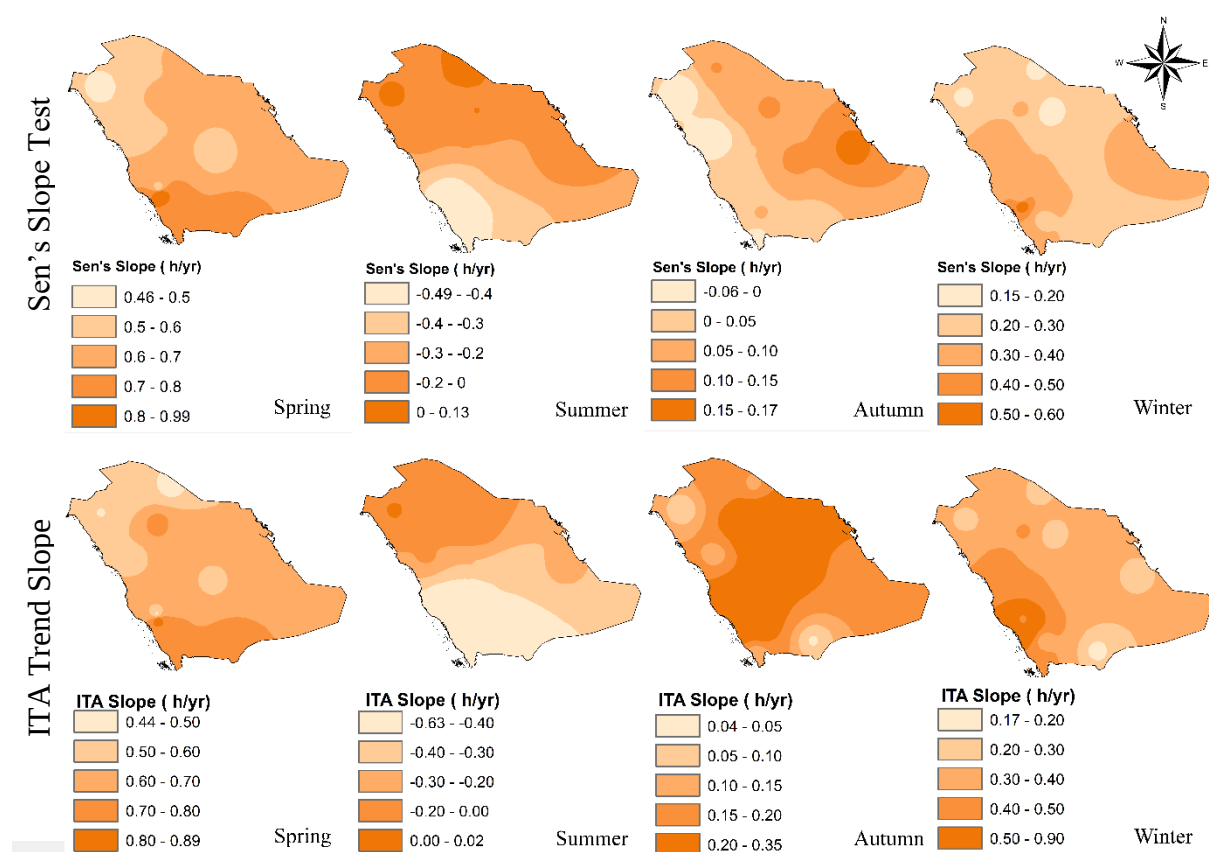


Figure 04: Spatial Distribution of Sunshine Duration Trend Slope at Different Seasons

decreasing at a rate of 0 to -0.2 h/year which is not statistically significant according to the MK/MMK nonparametric trend test. The opposite side (northwest) experienced the highest level of a downward trend of SDU, with a range of -0.63 to -0.40 h/year in the summer season.

Between 1983 and 2022, there was an upward trend in sunshine duration in Saudi Arabia during the winter season, with a range of 0.17-0.5 hours per year. Interestingly, the spatial distribution of the trend slope of SDU estimated by these statistical methods is quite different during the autumn season. More specifically, on the western side of the country the trend of SDU is statistically quite insignificant according to Sen's slope estimator, whereas, in the middle part of the country, it is estimated that the trend slope reached the maximum level with a range of 0.2- 0.35 h/year according to the calculation of ITA method.

The increasing rate of sunshine duration for the last forty years is closely related to the trends of increasing temperature in the region. Almazroui et al. (2013) reported an increasing pattern of average annual temperature in Saudi Arabia [22]. The authors also revealed that the warm days are increasing and the cool days are reducing in the region. According to the authors, the Warm Spell Duration Indicator (WSDI) is significantly increasing at the rate of 3.65 d decade⁻¹ and the Cold Spell Duration Indicator (CSDI) is reducing at the rate of 2.42 d decade⁻¹. Sunshine duration is increasing at the rate of 1.78 hr decade⁻¹ [22].

4. CONCLUSION

The present study explored the spatiotemporal variations in the availability of sunshine duration (SDU) radiation at different seasons in Saudi Arabia over the past forty years. Between 1983 and 2022, EUMETSAT satellite imagery was used to extract data on the sunshine duration for different regions in Saudi Arabia. In investigating the trend hypothesis on time series data, classical and robust statistical methods, such as the Mann-Kendall (MK) trend test; the Modified Mann-Kendall (MMK) trend test and Sen's slope, and the recently proposed Innovative Trend Analysis (ITA) by Şen used for trend detection for the present study. From the results obtained from the Coefficient of Variation (COV) test, it appears that the variation of SDU in Saudi Arabia was around two percent, except in the Al Bahah region where the variation was 3.5%. As per the MK/MMK trend test, there are 34 out of 65 case scenarios where statistically significant trends (either upward or downward) existed. On the other hand, statistically significant trends exist in about ninety-seven percent (63 out of 65) cases according to the ITA method.

Despite technological advances over the past fifty years to improve accuracy, weather satellite data accuracy remains a concern. Eventually, it is possible to eliminate the difficulties and problems associated with remote sensing by improving the sensor and data interpretation methods as well as by incorporating more ground-based observations. Due to the necessity of more efficiently utilizing solar energy technology, it will remain a significant topic in remote sensing.

5. DECLARATION

This is to certify that the authors of the above-listed paper have no conflict of interest. The authors declare that they have no competing interests and that the work is original.

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