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Contents

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Comparing Methods of Temperature Trend Analysis: A case study of Bernam River Basin, Malaysia

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Abstract

The topic of climate change has necessitated the diversion of strong attention of hydrologists and other scientists to the topic of temperature trends in recent times. This is because decline or rise in surface temperature is taken as attributes of climate change. This study, therefore, intends to examine the pattern of surface temperature trend in order to detect any anomalies and how this is closely associated with El-Nino episodes in the region. Annual mean temperatures from 11 stations in Bernam river basin were obtained from the Malaysia Meteorological Department (MMD) and the Department of Irrigation and Drainage (DID) Malaysia. Non-parametric statistical techniques such as Mann-Kendall test and Spearman's Rho method and parametric techniques such as Linear regression and student's t test were adopted to detect any abrupt climate change. The analytical results indicated that when there were increasing and decreasing trends in the annual and seasonal temperature, only the increasing trends were significant at both the 90% and 95% confidence levels. The interannual variability of Malaysian temperature was observed to be largely dominated by the El Ni-no-Southern Oscillation (ENSO) as the rise in temperature was seen to be largely related to the El Nino pattern. Regardless of the warming trends, all the stations used in the study experienced uniform warming during an El Nino event for the study periods. El-Nino and UHI are observed as the major contributors to the rise in surface temperature and out of the two techniques used in the trend detection, Mann-Kendall test and Spearman's Rho have been adjudged as most suitable for abrupt trend detection in climate change.

Keywords: *Trend analysis, Surface Temperature, Bernam river basin, El-Nino*

Introduction

The recent emphasis on climate change and the study of its adverse effects on the environment in recent time by the researchers has been attributed to the rise and decline in global temperature and rainfall trends in recent times. According to Stocker *et al.*, (2013), climate change has been described as the statistically significant variations of the climate or that of its variability for decades or a longer period. In spite of the fact that climate change happens globally, its adverse effects, however, is deterministic which depends on the region of study. The major two measures that indicate the signs of climate change are temperature and precipitation variables. According to the IPCC (2007), the average global surface temperature has increased by 0.074°C per year from 1906 to 2000. And this was further buttressed by Stocker et al., (2013) which reported that increases in mean temperature will continue for the next couple of decades (2016–2035). Various factors have been observed as contributors to the spatial and temporal variability of surface temperature warming in a particular region or continent as the case may be. These factors include regional scale features and those associated with atmosphere-ocean interface variabilities such as the Pacific Decadal Oscillation (PDO), the El Nino-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO) and the Indian Ocean Dipole (IOD) (Tangang *et al.* 2007). Apart from these natural variabilities,

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anthropogenic activities and changes such as the urban heat island (UHI) effect (Philandras *et al.*, 1999, Li *et al.*, 2004) and deforestation (Voldoire and Royer, 2004) are also responsible for alteration in local temperature patterns. If the environment is to be safe in terms of mitigating the effects of climate change and making the world a better place, there is need to check the trends in these climate variables so as to relate their variations with past events like El Nino for better understanding of our environment. Longobardi and Villani (2010) has defined a trend as a significant change over time exhibited by a random variable, detectable by statistical parametric and non-parametric procedures. They listed two main procedures in analyzing the rainfall, temperature and streamflow trends.

Many trend analyses using various methods have been carried out globally on meteorological data, most importantly, temperature, precipitation and streamflow. Two basic methods have been used in such analyses; they are parametric and non-parametric methods of analysis. Nonparametric Mann-Kendall method in the detection of trend in hydrologic variables is the most commonly used methods among the researchers (Tabari *et al.* 2011) for being found to be an excellent tool for trend detection (Gan and Kwong, 1992). According to Gocic and Trajkovic (2013), the Mann-Kendall rank statistics test and Theil-Sen's slope method, both of which are non-parametric methods, are generally used to declare trends and magnitude changes in the climate variables in annual and seasonal time scales. On the other hand, the simplest type of parametric method of trend analysis is student's *t*-test. According to Shahin *et al.*, (1993) and Hameed *et al.*, (1997), student's *t*-test has been adjudged as the simplest form of linear models commonly used in examining the trend in hydrologic time series. And according to Longobardi and Villani, (2010), the parametric *t* -test assesses whether the slope coefficient of the fitted linear regression is significantly different from zero, indicating the presence of a linear trend in this case. Onoz and Bayazit (2003) also reported that the parametric *t* -test has less power than the non-parametric Mann–Kendall test when the probability distribution is skewed, but that, in practical applications, they can be used interchangeably, with same results in most cases. The study further reported that the slope coefficient sign would then indicate whether it is a positive or a negative trend. The Mann–Kendall non-parametric test would additionally confirm the existence of a positive or negative trend for a given confidence level.

Using these methods of trend detection in hydrologic time series, many studies have been carried out in the past with results showing the prevailing effects of rise or decline in surface temperature depending on the study locations. Abdullah *et al.* (2015), while studying the variation of sea level and tidal behavior in coastal Malaysian Coastline, attributed these adverse effects of climate change caused by El Nino Southern Oscillation (ENSO) to changes in the temperature and air pressure at the Pacific Ocean. Many other studies have been carried out in Malaysia to check the trends in climate variables. The trend of regional warming in Malaysia using mean annual temperature time series of approximately 50 years was studied by Meng *et al.*, (2005). Their results agreed with the reports of the IPCC for Malaysia which reported the temperature increment of 0.99 to 3.44°C per 100 years. Tangang *et al.*, (2012) also applied the Mann-Kendall test for 32 stations over Malaysia Peninsula for the period of 1974–2004. Their studies concluded the mean surface temperature over Malaysia would increase by 3-5°C by the end of the 21st century. And from their findings, the Mann-Kendall test for mean, variability, and persistence of wet spells showed positive and negative trends in the stations located in east of the peninsula during the northeast monsoon and southwest monsoon seasons, respectively. Their conclusion also included an existence of a wide gap in the knowledge of climate change throughout the Peninsula Malaysia.

The primary objective of this study is to examine the long-term trends of the mean seasonal surface temperature time series for eight stations in Upper Bernam River Basin in Malaysia, for the 42-year period (1962–2002). The secondary objective of this study was to compare the trend detection methods in the

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analysis of surface temperature and to see which of the methods is better in detecting the monotonic trend in surface temperature time series. Trend software (Trend 10.1) that is capable of comparing different trend detection techniques was used in this study. The study, therefore, analyzed and examined the signs of change in the annual surface temperature and compare with El-Nino data specific to Upper Bernam River Basin in Malaysia.

Materials and Methods

The Upper Bernam River Basin is located in Southeast Perak and Northeast Selangor, Malaysia (Fig..1). The total area of the Bernam River Basin is 1097 km^2 which is located between 30° 36' 23" to 30° 47' 55" North and 101° 30' 53" to 101° 39' 33" East. Approximately 60 % of the basin in area is steep mountainous country extending to 1830 m in height above the mean sea level in the northern and eastern direction. The Bernam river has a humid tropical climate having relative humidity of 77 %. The minimum and maximum temperatures of the basin vary between 26°C and 32°C respectively. The average annual rainfall is 1800 mm and gradually increases toward the mountainous part of the basin to 3500 mm and the mean annual runoff ranges from 800 mm to 1950 mm. The climate of Malaysia is connected with many global and regional phenomena, among which are monsoons, El Nino, and the Indian Ocean Dipole (IOD) (Amirabadizadeh *et al.* 2015; Lee *et al.* 2016). These phenomena, according to these past studies could affect the severity of extreme events in the country. According to Nurmohamed and Naipal (2004), global warming, as a result of climate change, directly affects systems such as hydrological cycles and El Nino. The surface climate in Malaysia is influenced by two monsoon regimes: namely, the southwest (SW) monsoon and northeast (NE) monsoon patterns. The Southwest season begins in May and lasts through August and is dominated by the low-level southwesterly winds. On the other hand, according to Taubenheim, (1989), the Northeast monsoon season, being controlled by the northeast wind begins in November and ends in February of the following year.

The surface air temperature dataset in the present study was the annual and daily mean temperature values from eight stations distributed widely in the Upper Bernam River Basin (Fig. 1). The eight stations include FELDA Trolak 4335, Hospital KK Baru 44322 and six (6) stations of HAD-1 to HAD-6. The dataset for the two (2) stations FELDA Trolak 4335 and Hospital KK Baru 44322 were obtained from the Malaysian Meteorological Department while remaining six (6) stations of HAD-1 to HAD-6 were obtained from National Hydraulic Research Institute of Malaysia (NAHRIM) using Providing REgional Climates for Impacts Studies (PRECIS) which was developed at the Hadley Centre at the UK Met Office.

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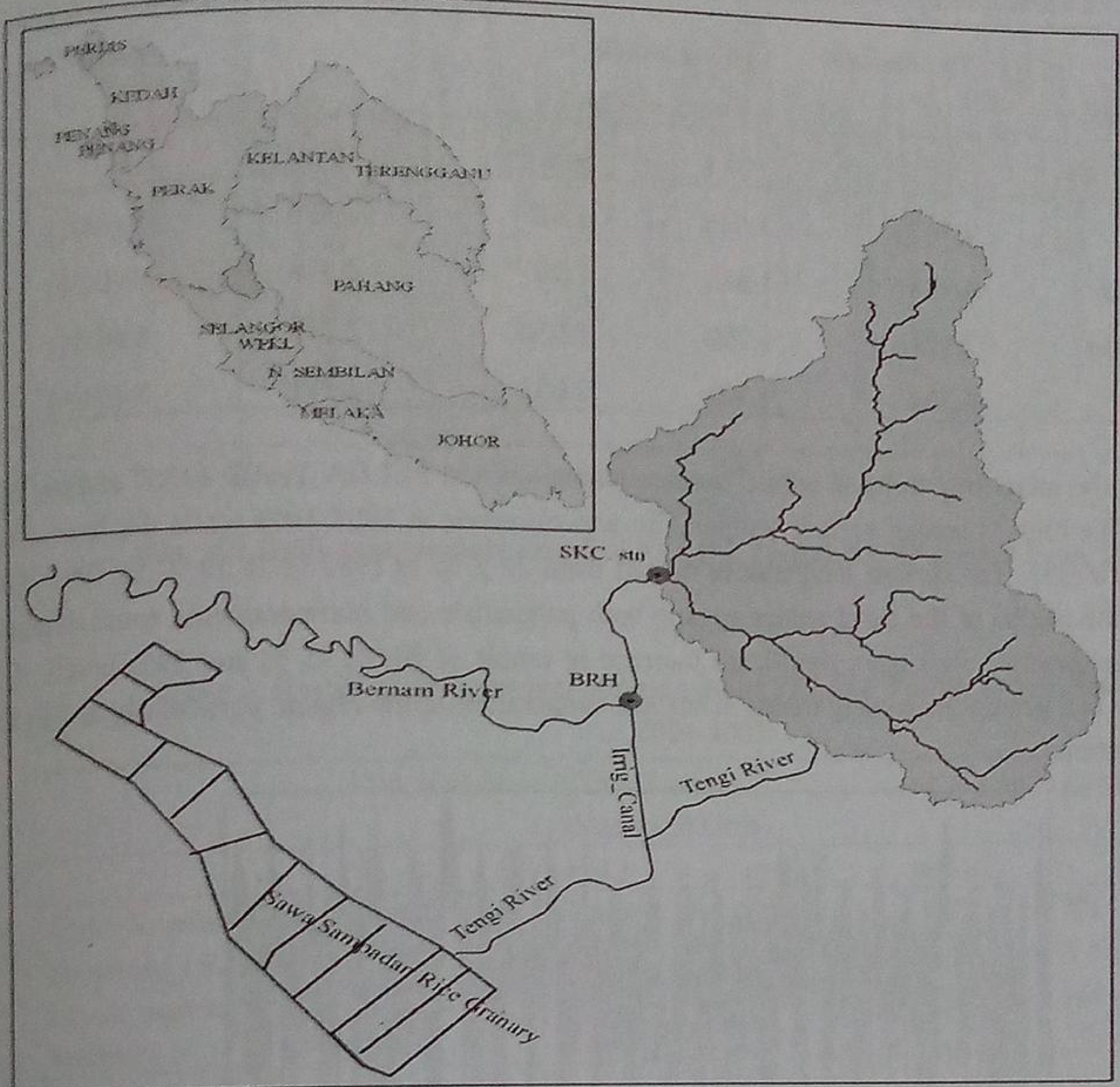

Fig. 1: Location of study area showing Bernam River Basin

Results and discussions

The results of the trend analysis for the non-parametric and parametric methods comprising Mann Kendall, Spearman's Rho, Linear regression and Student's *t* test are presented. The analysis covers the period of 1970 to 2007. The results presented both the annual and daily average surface temperature with varied changes in temperature trends as shown in Fig 2.

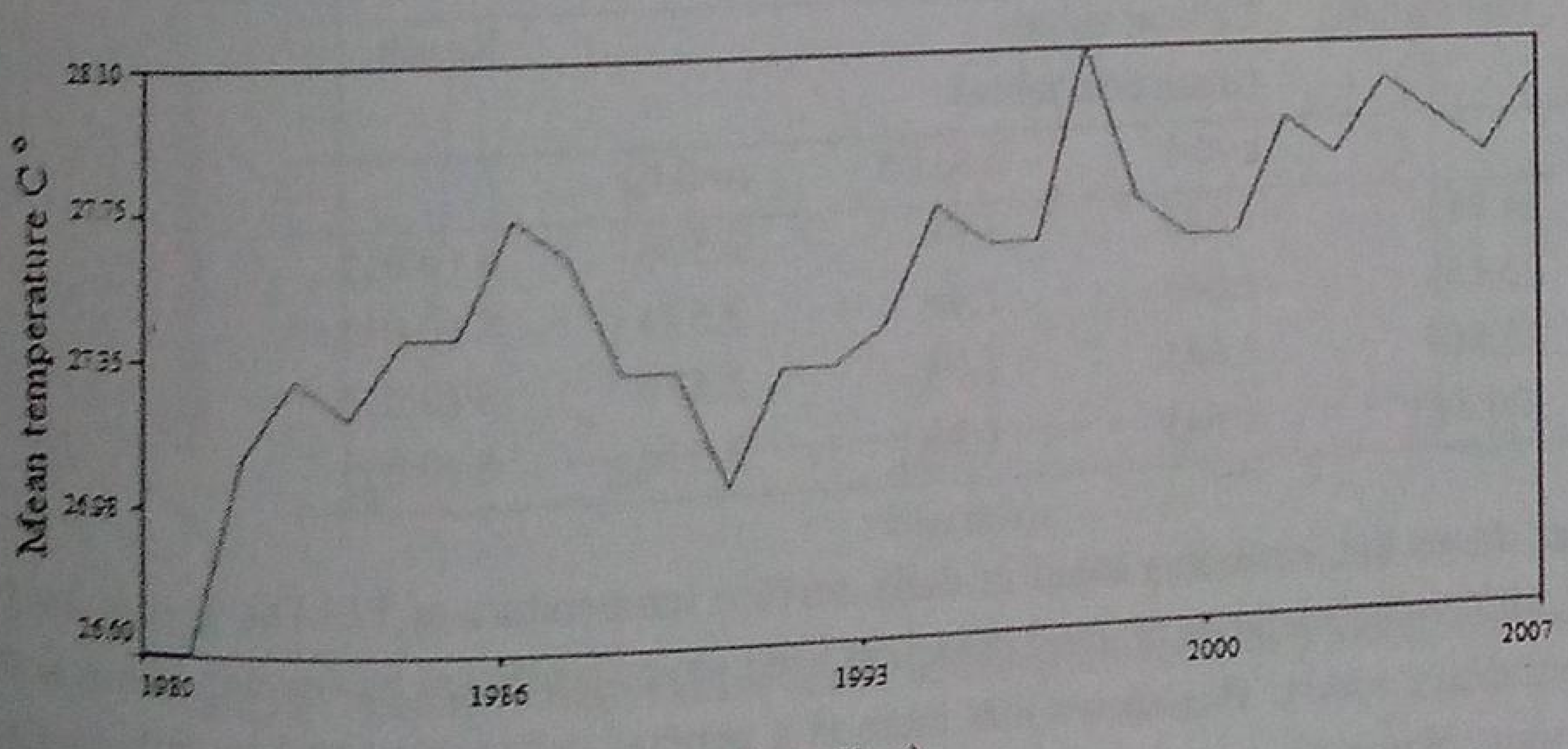

Fig. 2. Annual mean temperature trend of FELDA Trolak 43357 station from 1980-2007

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Table 1. Result of annual temperature trend of FELDA Trolak 43357 station from 1980-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	4.761	1.645	1.96	2.576	S (0.01)
Spearman's Rho	4.488	1.645	1.96	2.576	S (0.01)
Linear regression	7.17	1.706	2.056	2.779	S (0.01)
Student's t	6.234	1.703	2.052	2.771	S (0.01)

Figure 2 shows the increasing trend in annual surface temperature at FELDA Trolak 43357 station from 1980 to 2007. The highest annual surface temperature was observed in 1997/1998 while the lowest was observed in 1981/1982. The surface temperature ranged from 26.5 °C in 1982 to 28.10 °C in 1997/1998. Table 1 shows the results of the trend analysis using both parametric and non-parametric trend detection methods. All the methods used gave significant increase in trends at 90 %, 95 % and 99% levels. This shows that there is a general increasing trends in surface temperature in the region, particularly at FELDA Trolak 43357 station.

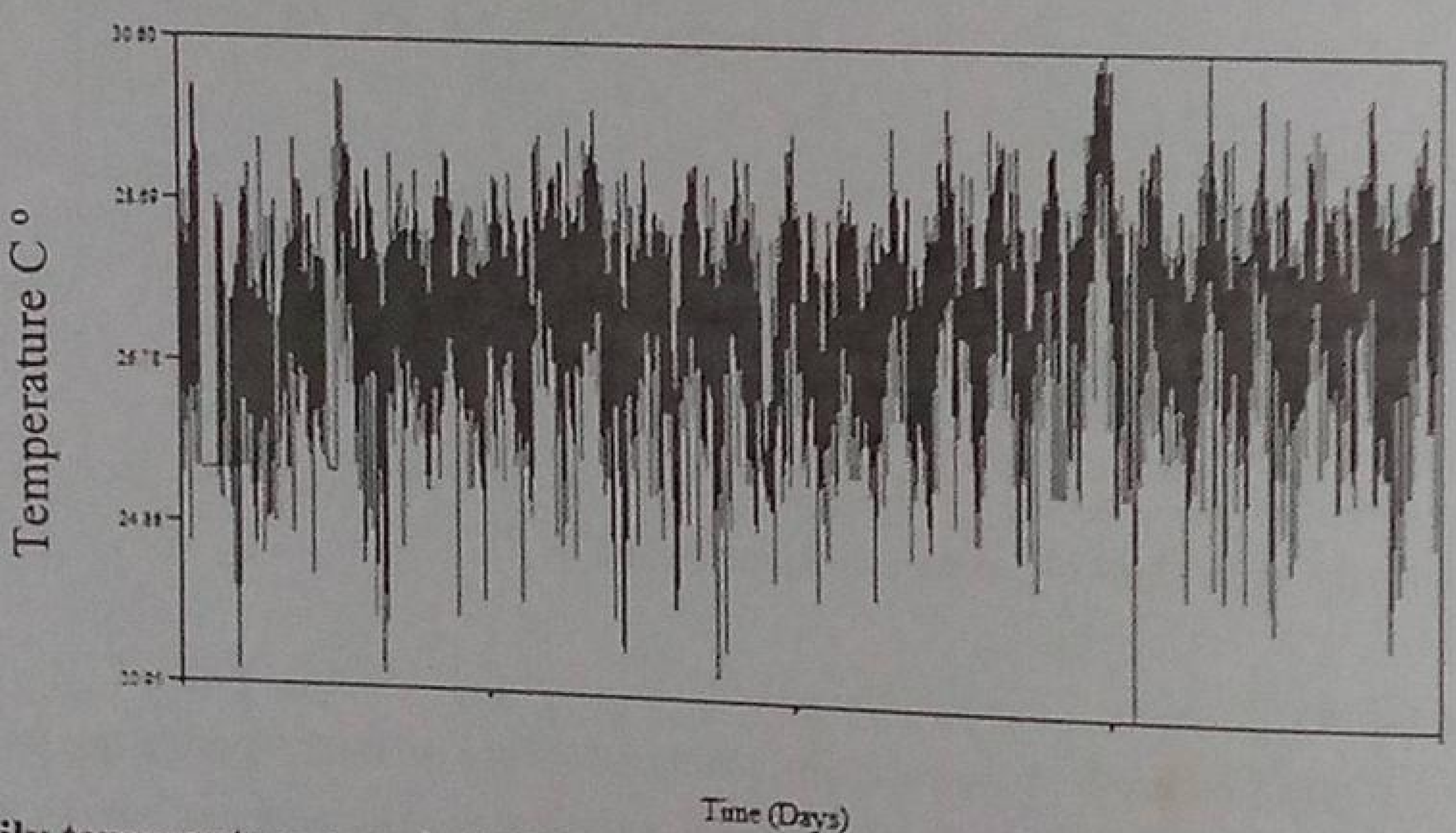

Fig. 3a: Daily temperature trend of FELDA Trolak 43357 station from 1980-2004

Table 2. Result of daily temperature trend of FELDA Trolak 43357 station from 1980-2004

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	24.881	1.645	1.96	2.576	S (0.01)
Spearman's Rho	25.15	1.645	1.96	2.576	S (0.01)
Linear regression	25.867	1.645	1.96	2.576	S (0.01)
Student's t	-20.843	1.645	1.96	2.576	S (0.01)

Unlike Fig. 2, Fig. 3a: shows the increasing trend in daily surface temperature at FELDA Trolak 43357 station. From Table 2, all the four methods of trend detection used gave significant increase in trends at 90 %, 95 % and 99% confidence levels. This shows that there is a general increasing trend in daily surface temperature in the region. However, a negative but significant trend was observed with student's t test parametric technique unlike other methods.

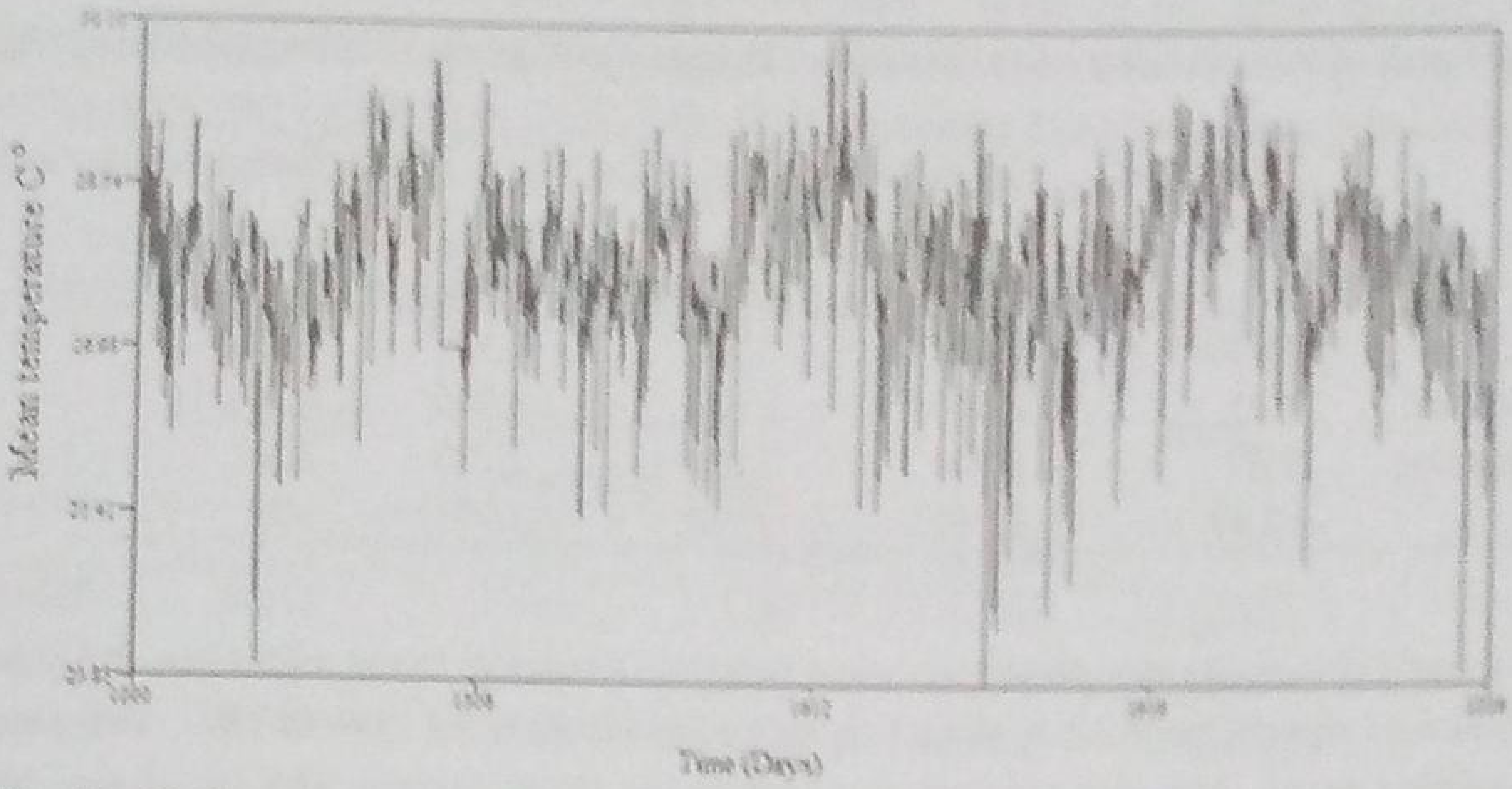

Fig. 3b: Daily temperature trend of FELDA Trolak 43357 station from 2004-2007

Table 3. Result of daily temperature trend of FELDA Trolak 43357 station from 2004-2007

	Test statistic	Critical values (Statistical table).			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	1.464	1.645	1.96	2.576	NS
Spearman's Rho	2.112	1.645	1.96	2.576	S (0.05)
Linear regression	0.917	1.645	1.96	2.576	NS
Student's t	-0.734	1.645	1.96	2.576	NS

Figure 3b shows both the increasing and decreasing trends in daily surface temperature at FELDA Trolak 43357 station for four year period from 2004 to 2007. From Table 3, all the four methods of trend detection used gave no significant increase in trends at 90 %, 95 % and 99% levels except Spearman's Rho method which showed significant trend at 99 % confidence level. This shows that there is no significant trend observed in the daily temperature measurement within the region.

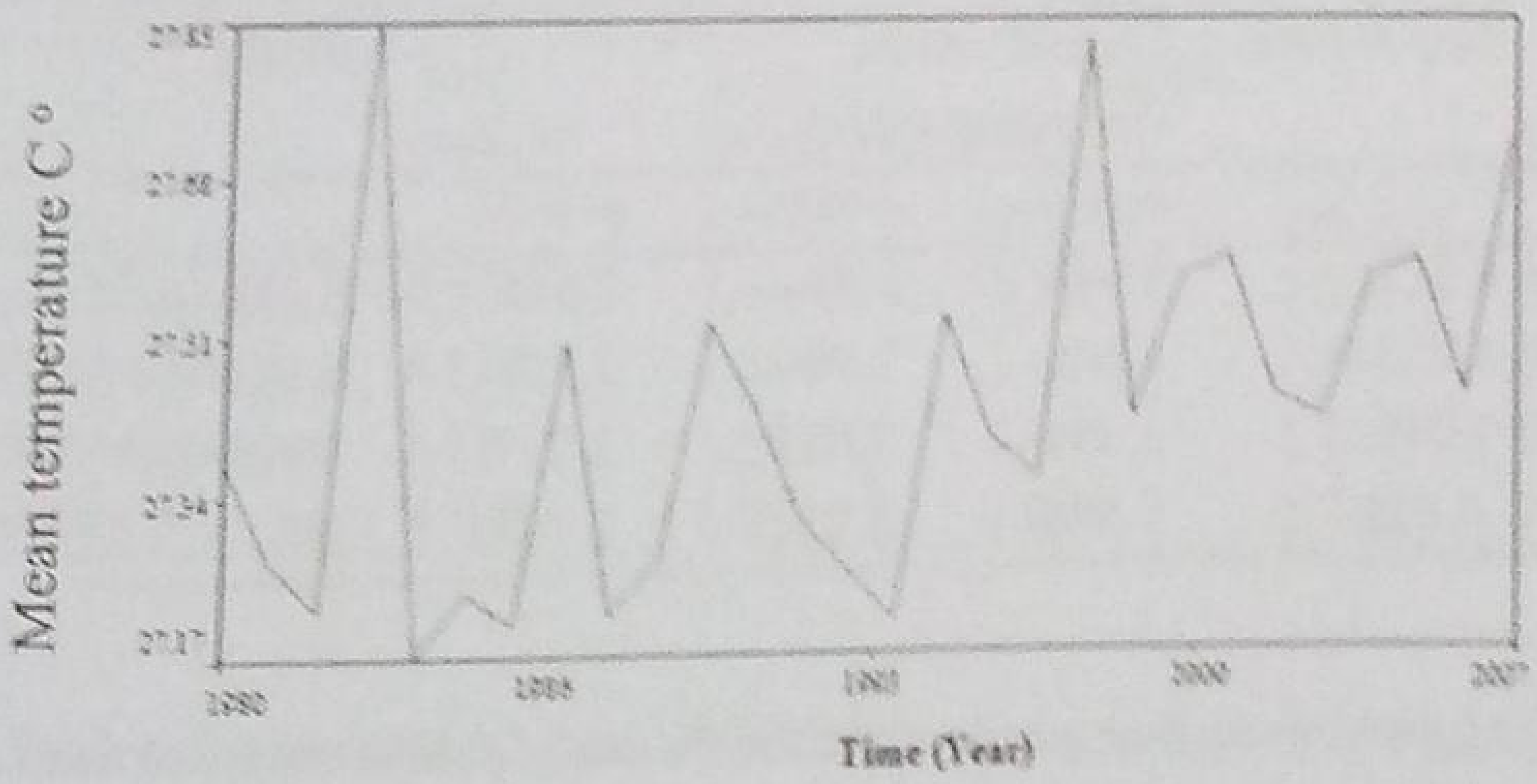

Fig. 4: Annual temperature trend of Hospital KK Baru 44322 station from 1980-2007

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Table 4. Result of annual temperature trend of Hospital KK Baru 44322 station from 1980-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	3.023	1.645	1.96	2.576	S (0.01)
Spearman's Rho	2.85	1.645	1.96	2.576	S (0.01)
Linear regression	2.57	1.706	2.056	2.779	NS
Student's t	-2.37	1.703	2.052	2.771	NS

From Fig. 4 and Table 4, the two parametric trend detection methods: linear regression and student's t test methods shows no significant trend in annual surface temperature from 1980 to 2007, with student's t test showing negative trend. The two non-parametric methods show positive and significant trend but no significant trend between the period 1970-1988 and 1989-2007. The highest annual surface temperature was observed in 1982/1983 while the lowest was observed in 1984/1985. The surface temperature ranged from 27.17 °C in 1983/84 to 27.85 °C in 1981/1982.

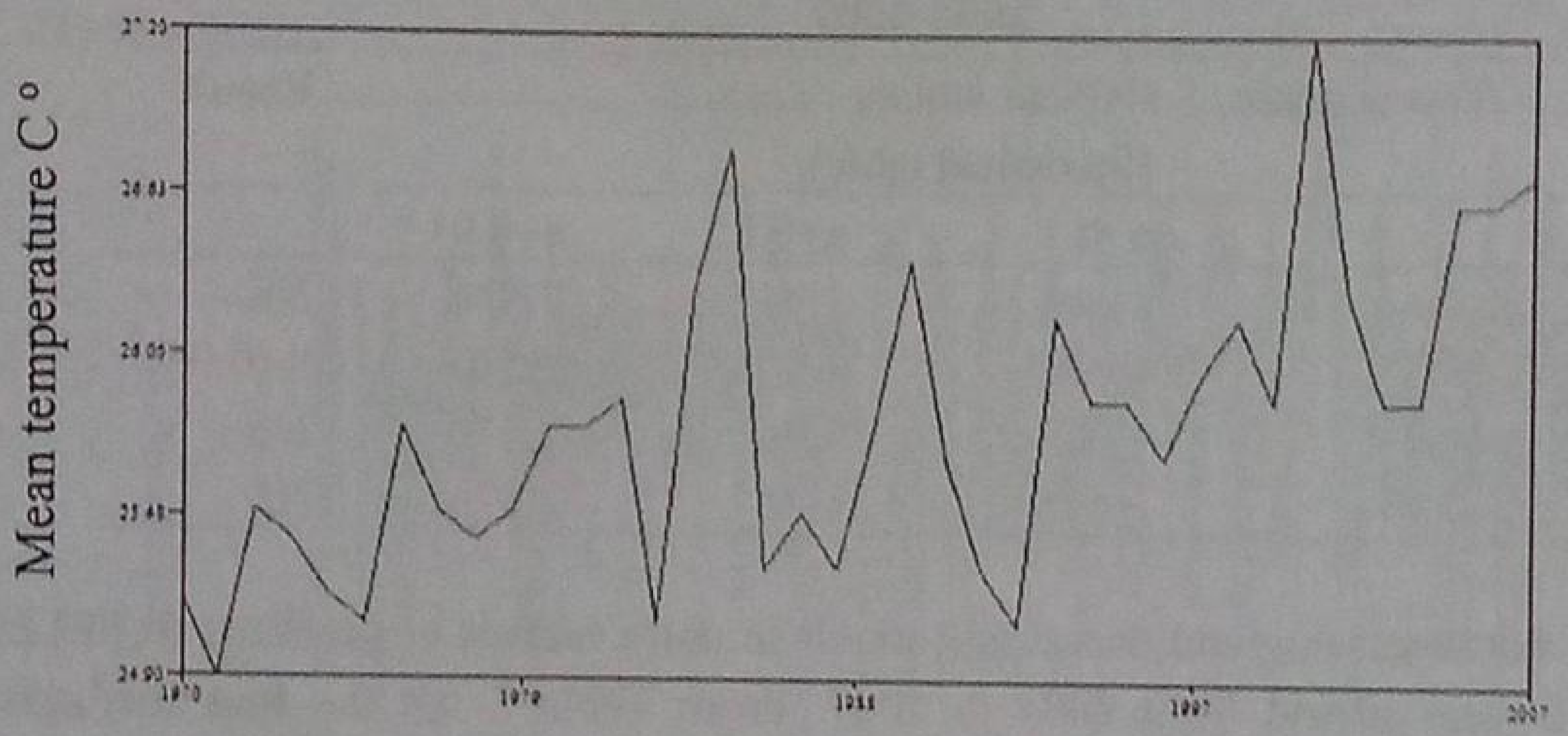

Fig. 5: Annual temperature trend of station Had-1 from 1970-2007

Table 5. Result of annual temperature trend of station Had-1 from 1970-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	4.312	1.645	1.96	2.576	S (0.01)
Spearman's Rho	4.272	1.645	1.96	2.576	S (0.01)
Linear regression	5.049	1.689	2.029	2.722	S (0.01)
Student's t	-1.622	1.688	2.027	2.718	NS

Figures 5 to 10 show an increasing trend in surface temperature for the study period observed from dataset of 1970 to 2007 in all the stations. Tables 5 to 10 also revealed a similar pattern in the temperature trend in the study area, with regards to all the techniques used in the trend detection. Student's t shows negative but no significant trend between the period 1970-1988 and 1989-2007 in all the stations whereas other parametric trend analysis method, Linear regression shows a positive significant trend (99 %) between the two periods of 1970-1993 and 1994-2007 as shown. The two non-parametric methods of Mann-Kendall and Spearman's Rho show positive and significant trend at 90 %, 95 % and 99% levels. The same trend

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was observed in Table 5 (Station Had-1 from 1970-2007) where all the methods used show positive significant trend except student's t test with negative non-significant trend. From Fig. 5, the highest annual surface temperature was observed in 2002/2003 while the lowest was observed in 1970/1971. The surface temperature ranged from 24.9 °C in 1971 to 27.20 °C in 2002/2003.

Table 5. Result of annual temperature trend of station Had-1 from 1970-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	4.312	1.645	1.96	2.576	S (0.01)
Spearman's Rho	4.272	1.645	1.96	2.576	S (0.01)
Linear regression	5.049	1.689	2.029	2.722	S (0.01)
Student's t	-1.853	1.688	2.027	2.718	NS

From Fig. 6, like Fig. 5, the highest annual surface temperature was observed in 2002/2003 while the lowest was observed in 1970/1971. But the surface temperature ranged from 22.63 °C in 1971 to 24.77 °C in 2002/2003, unlike Fig. 5.

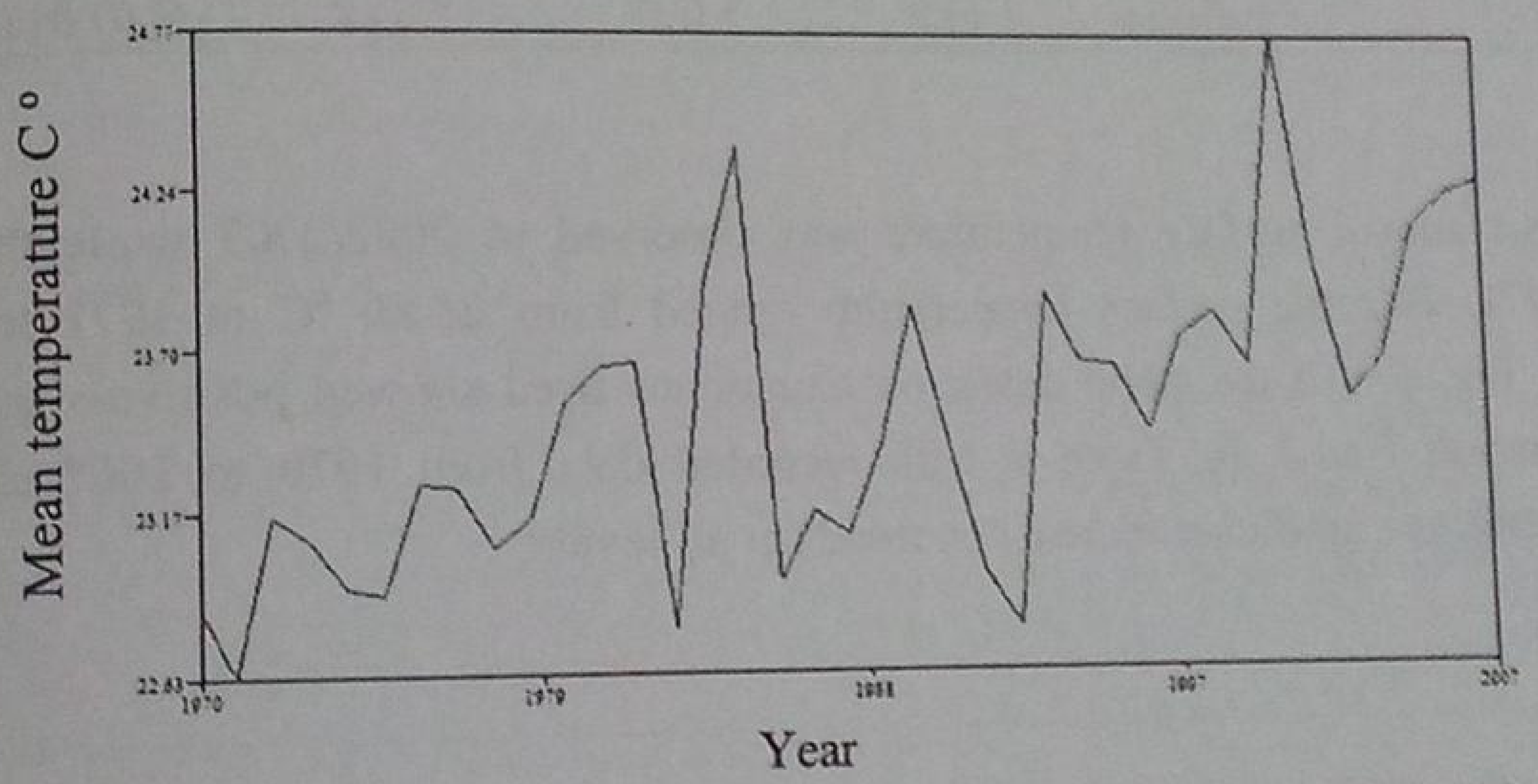

Fig. 6: Annual temperature trend of station Had-2 from 1970-2007

Table 6. Result of annual temperature trend of station Had-2 from 1970-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	4.501	1.645	1.96	2.576	S (0.01)
Spearman's Rho	4.137	1.645	1.96	2.576	S (0.01)
Linear regression	5.33	1.689	2.029	2.722	S (0.01)
Student's t	-1.959	1.688	2.027	2.718	NS

From Table 6 (Station Had-2 from 1970-2007) all the methods used show positive significant trend except student's t test with negative non-significant trend just as observed in Table 5.

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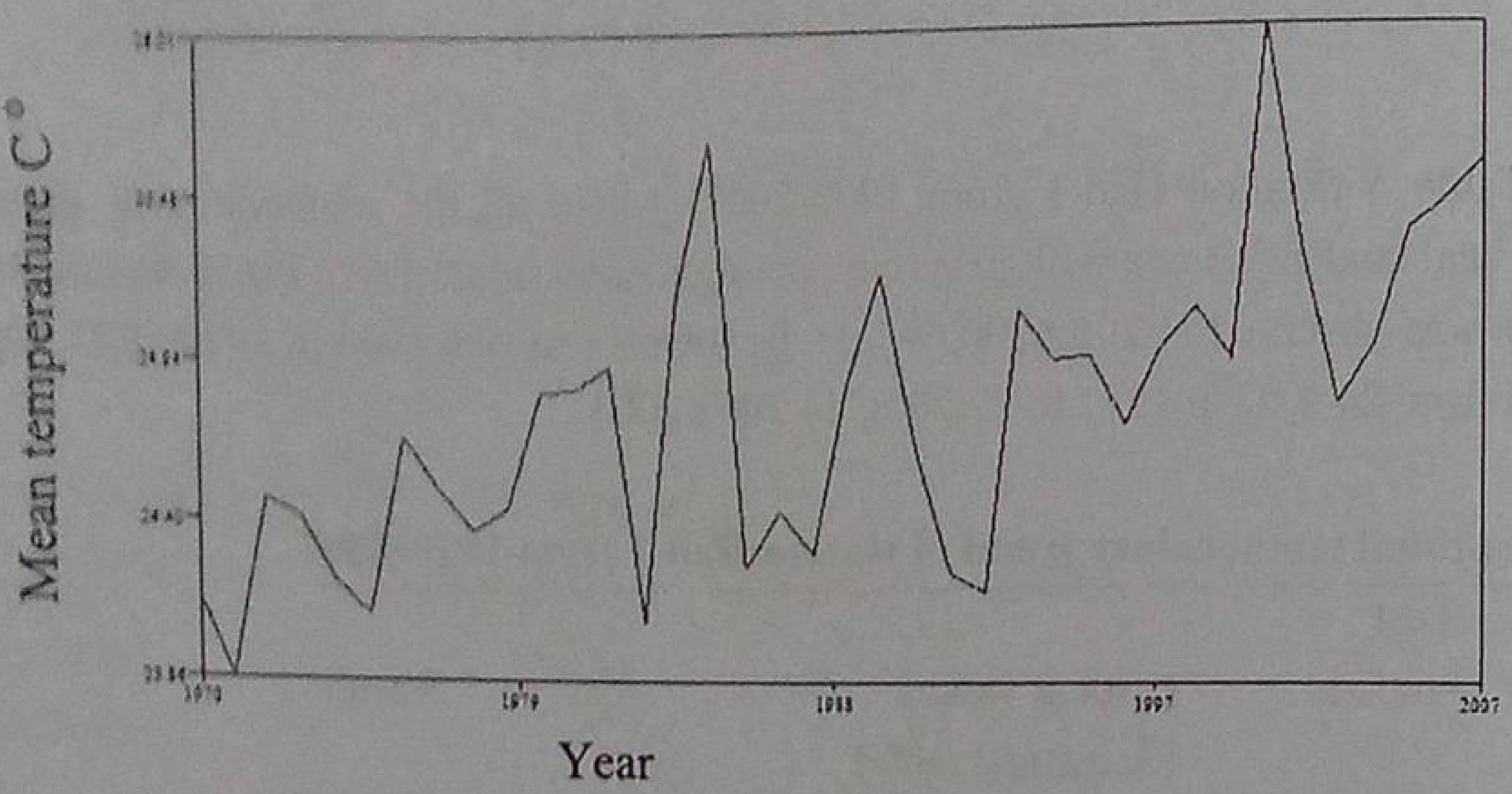

Fig. 7: Annual temperature trend of station Had-3 from 1970-2007

Table 7. Result of annual temperature trend of station Had-3 from 1970-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	4.476	1.645	1.96	2.576	S (0.01)
Spearman's Rho	4.133	1.645	1.96	2.576	S (0.01)
Linear regression	5.226	1.689	2.029	2.722	S (0.01)
Student's t	Infinity	1.688	2.027	2.718	S (0.01)

In Fig. 7, the highest annual surface temperature was observed in 2002/2003 while the lowest was observed in 1970/1971. But the surface temperature ranged from 23.86 °C in 1971 to 26.01 °C in 2002/2003, unlike in Fig. 6. All the trend detection techniques used showed positive significance at all confidence levels. Station Had-3 in Table 7 with recorded data from 1970 to 2007 showed all the techniques showing positive significant increase in trends at all levels.

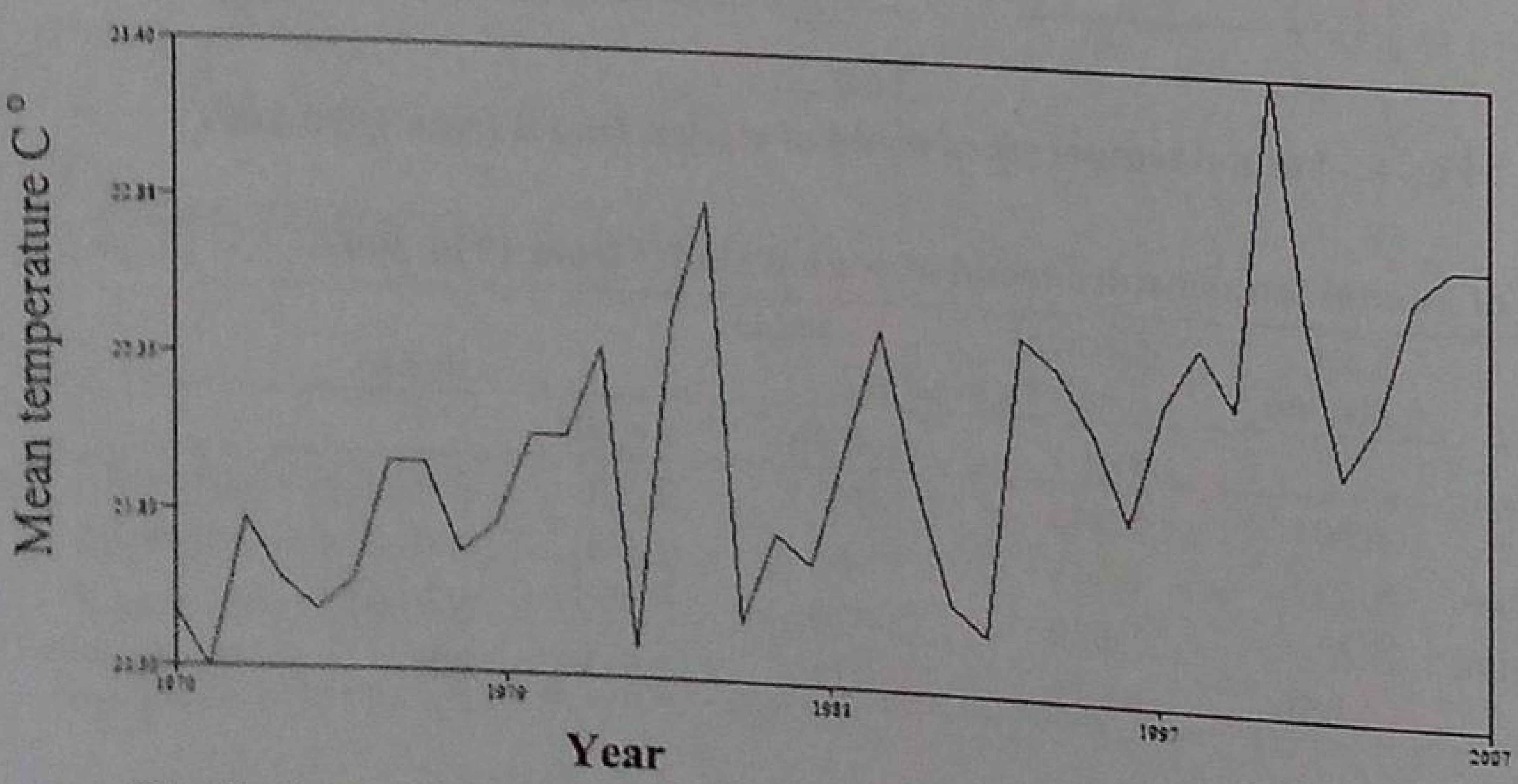

Fig. 8: Annual temperature trend of station Had-4 from 1970-2007

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Table 8. Result of annual temperature trend of station Had-4 from 1970-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	4.337	1.645	1.96	2.576	S (0.01)
Spearman's Rho	4.231	1.645	1.96	2.576	S (0.01)
Linear regression	5.141	1.689	2.029	2.722	S (0.01)
Student's t	Infinity	1.688	2.027	2.718	S (0.01)

Highest annual surface temperature was observed in 2002/2003 in Figure 8 while the lowest was observed in 1970/1971. But the surface temperature ranged from 21.3 °C in 1971 to 23.4 °C in 2002/2003. Table 8 also showed that the trend detections techniques gave positive significant increase in trends at all levels considered.

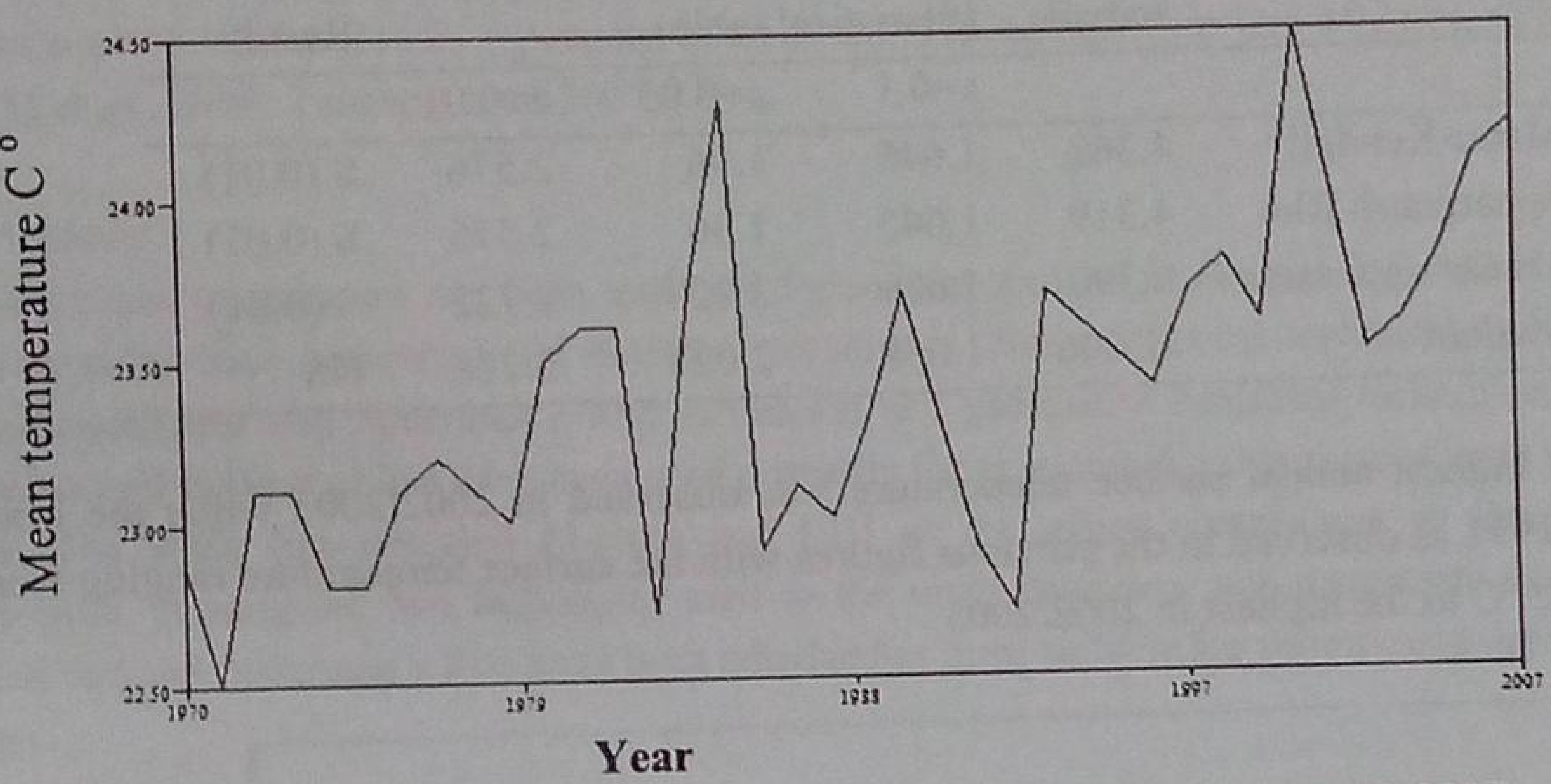

Fig. 9: Annual temperature trend of station Had-5 from 1970-2007

Table 9. Result of annual temperature trend of station Had-5 from 1970-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	4.45	1.645	1.96	2.576	S (0.01)
Spearman's Rho	4.142	1.645	1.96	2.576	S (0.01)
Linear regression	5.415	1.689	2.029	2.722	S (0.01)
Student's t	-3.081	1.688	2.027	2.718	S (0.01)

From Fig. 9, the highest annual surface temperature was observed in 2002/2003 while the lowest was observed in 1970/1971. But the surface temperature ranged from 22.63 °C in 1971 to 24.77 °C in 2002/2003, unlike Fig. 5. Positive significant increase in trends was also observed at station (Had-5) with data set from 1970 – 2007, except negative trend using student's t test (Table 9).

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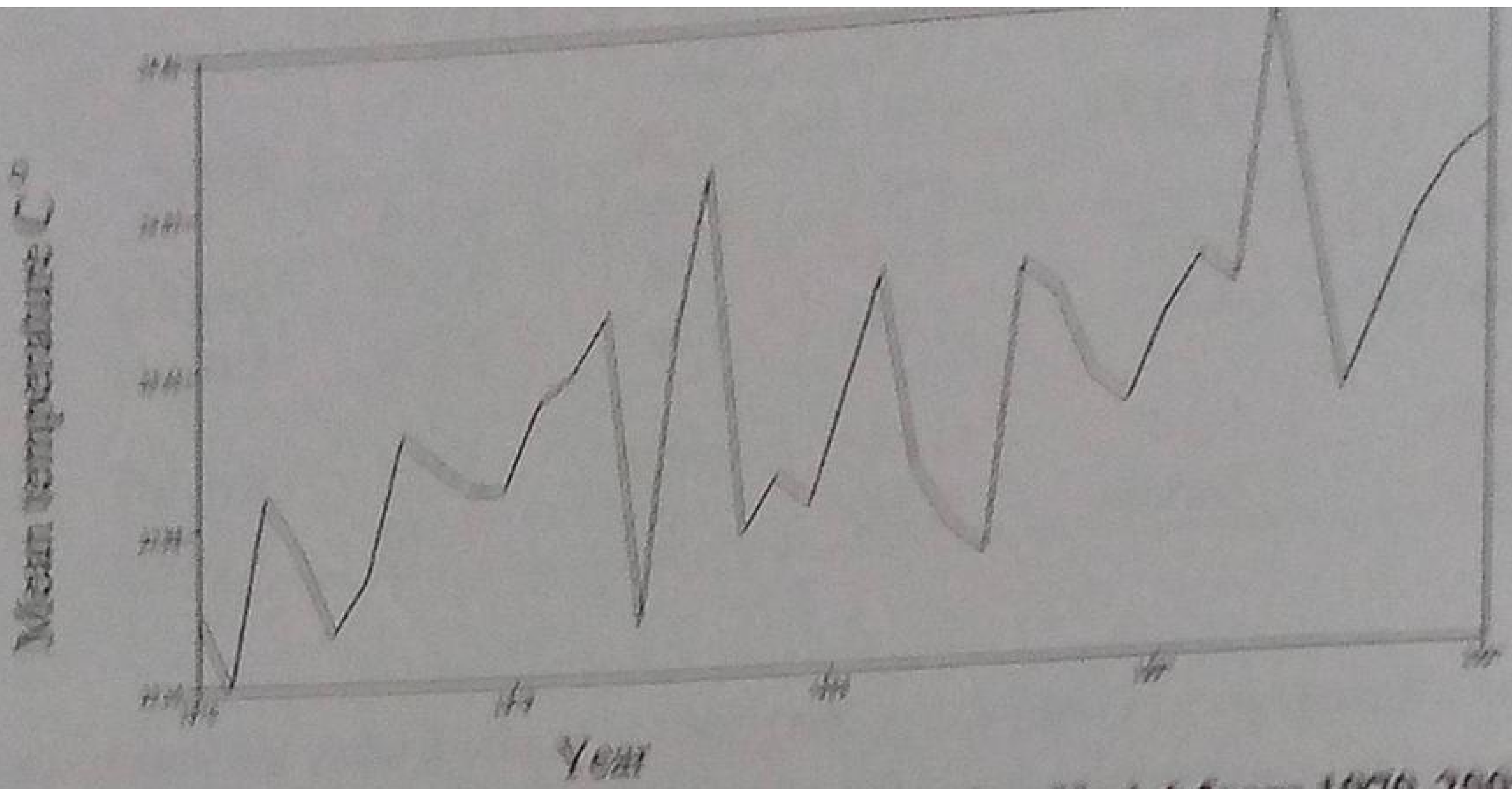

Fig. 10: Annual temperature trend of station Had-6 from 1970-2007

Table 10. Result of annual temperature trend of station Had-6 from 1970-2007

	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	4.362	1.645	1.96	2.576	S (0.01)
Spearman's Rho	4.319	1.645	1.96	2.576	S (0.01)
Linear regression	5.396	1.689	2.029	2.722	S (0.01)
Student's t	-1.606	1.688	2.027	2.718	NS

From Fig. 10, the highest annual surface temperature was observed in 2002/2003 while the lowest was observed in 1970/1971 as observed in the previous figures with the surface temperature ranging from 22.63 °C in 1971 to 24.77 °C to the highest in 2002/2003.

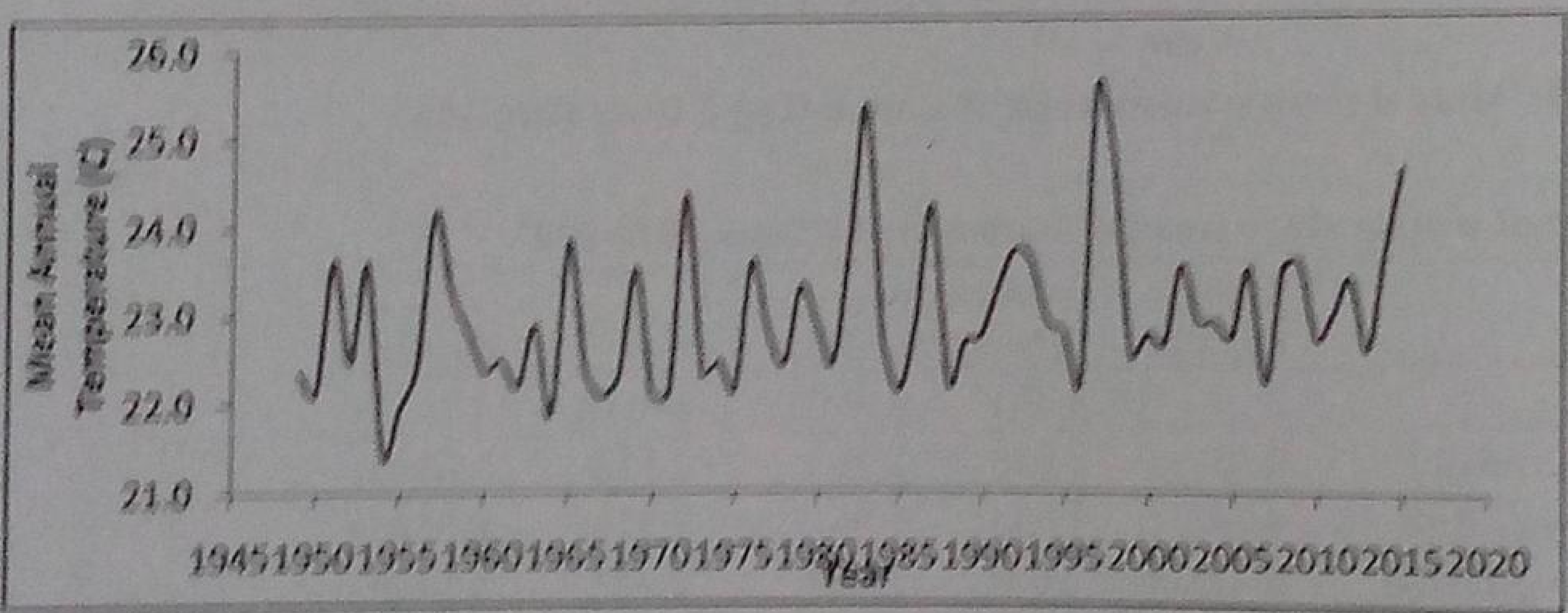

Fig. 11: Variation in Mean Annual Temperature (El-Nino values)

Discussion

Figures 2 to 11 show the various trends in surface temperature in Bernam River Basin from different meteorological stations used in the study. Increasing trend in surface temperature was observed with the lowest in 1980 and highest in 1997/1998 which is in agreement with El-Nino observed during the period (Fig. 11). Figure represents the increasing trend observed in FELDA Trolak 43357 station for the period of 1980 to 2007. The trend shows that the highest temperature was observed in 2001/2002 with the lowest in 1981 and 1990. The same trends were observed in all other stations of Hospital KK Baru (1980-2007), Had-1 to Had-6 (1970-2007) with all the trends revealing an increasing trend in all the stations. The peak for El Nino in 1957, 1971/1972 and 1997/1998 are selected as sample periods for this research as reflected

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in Fig. 11. Daily and annual analysis were carried out and analyzed. Trend detection software with reference to two trend detection of parametric and non-parametric techniques was used. This is to identify accurately the tidal constituents for different time periods. A comparative analysis using different time periods was plotted for easy graphical representation as shown in Figures 1-10. The results showed the compatibility with El Nino effect in years observed (1957, 1971/1972 and 1997/1998) (Xu *et al.* 2004; Demarcq 2009). The peak of the El-Nino was observed in 1997/1998 in all the stations which were consistent with surface temperature measured in all the stations considered in the respective periods except in Hospital KK Baru 44322 station from 1980-2007where the peak temperature was recorded in 1982/1983 followed by 1997/1998. Tables 1 to 10 showed the result of the trend detection analyses using the four detection techniques. Majorly, the results of the detection from the tables showed positive significance using non-parametric techniques as against parametric techniques of linear regression and student's t test. Apart from El-Nino which is said to be responsible for high rise in surface temperature, human induced changes such as the Urban Heat Island effect (UHI) has also been considered as a significant factor in the enhancement of warming rates especially in many developing countries like Malaysia (Philandras *et al.*, 1999; Li *et al.*, 2004; Tangang *et al.* 2007).

Conclusions

Seasonal mean temperature has been analyzed for several stations in Bernam River Basin in Peninsular Malaysia using four different trend detection techniques. Non-parametric statistical techniques such as Mann-Kendall test and Spearman's Rho estimation and parametric statistical techniques such as linear regression and student's t test have been used primarily for assessing the significance level and detection of trends. The study has revealed El-Nino and UHI as the major contributors to the rise in surface temperature. Among the two techniques used in the trend detection, non-parametric, especially Mann-Kendall test and Spearman's Rho have been adjudged as most suitable for abrupt trend detection in climate change.

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