Journal of the Nigerian Association of Mathematical Physics
Volume34,(March, 2016), pp133 – 140

Trend Analysis of Mean Global Temperature: Implications on Bio-Climatic Conditions and the Need for Mitigation

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Abstract

This study examines the trend of change ofmean global surface temperature records spanning over a period of 135 years and then projects ahead, using the resulting trend, for a period of 76 years. The study is motivated by the increase in thermal stress experienced by living things arising from increase in environmentaltemperature and attendant effect on economy status of the nations. The nonparametric Mann-Kendall technique which detects monotonic trend and Sen's method which quantifies the magnitude of the trend were used.TheS Statistic of Mann-Kendall technique yield no result because n is above 9 but the Z statistic gives positive values for each of the monthsof the years with a minimum of 10.26 in December and the maximum 11.70 in June. At a significant level of 0.001,$Z_{(1-\alpha)/2} = 3.31$and therefore the null hypothesis of no trend is rejected. The Sen's estimate $Q(°C/$year) ranges between 0.778 in January and 0.605 in July, which is less than $1°C/$year but reveals a gradual increase in the record of each month of the 135 years. An examination of Sen's estimate for each year yields -52.33 in 1880 and 51.89 in 2014 with an gradient of 0.777, which implies a graduate increase in mean surface temperature over the years.The linear model projected ahead reveals that by 2090, the mean global temperature will be between $86°C$ in October and $150°C$ in January while the Sen's estimate for 2090 is $120°C$. This requires urgent attention of the relevant stakeholders at all levels to put in place measures to mitigate the present trend of increase inmean global temperature.

Key words: Mean global temperature, monotonic trend,Mann-Kendall test, Sen's estimate

1.0 Introduction

Weather and climate have profound impacts on living organisms. Greenhouse gases, principally water vapor, carbon dioxide, nitrous oxideand ozone are naturally present in the atmosphere and absorb thermal infrared radiation emitted from the surface of the earth and the atmosphere[1]. The atmosphere is warmed by this mechanism and, in turn, emits thermal infrared radiation, with a significant portion warming the earth's surface and the lower atmosphere. Consequence, themean of the earth has increased over the years than it would be without the effects of the greenhouse gasses [2]. The continue production of greenhouse gases from both natural and artificial sources makes the mechanism of global warming to continue and thus the mean global surface temperature of the earth is increasing.It also causes anuplift of water level in the sea due to melting of mountain glaciers and expansion of the oceans[3] as well as uncomfortable bio-climatic conditions for human.

Human body is a constant-temperature device. The body metabolism produces and dissipates heat energy continuously and by this maintains the body temperature despite heat lost to the environment through body surface and changing ambient thermal conditions [4]. There is a balance between the heat gain and heat lost that keep the body functioning properly. When the thermal ambient conditions is higher than the optimum, the heat gains and retains by the body is greater than the heat loss to the environment. Therefore the human health becomes complicated by the heat imbalance thus forcing the body to continue functioning as it tries to return normal temperature. This physiological condition is referred to as thermal stress. If this condition persists without relief then human health is at risk. Plants suffer wilting which result in reduced or total loss of yield. Animals also go through some level of discomfort which may lead to death in some cases. According to [5]temperature

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variation has negative impact on the national economic performance, though some other factors are playing some roles. The threat of climate have a substantial impact on agricultural production worldwide as heat waves cause significant yield losses with great risks for future global food security [6]. Projections to 2050 suggest both an increase in global mean temperatures and increased weather variability, with implications for the type and distribution of agricultural production worldwide. Projections based on population growth and food consumption patterns indicate that agricultural production will need to increase by at least 70 percent to meet demands by 2050[7].In this study, the linear trend of the increase in global surface temperature is examined from 1860 to 2090. This is to reveal what the average global temperature will be in year to 2090 and consequently the attendant bio-climatic conditions as well as the need for early mitigation.

2.0 Materials and Methods

The methods used in this study includethe nonparametric Mann-Kendall and Sen's tests which are contained in MAKESENS excel template. Mann-Kendall test detectsmonotonic trend in time series data while Sen's test quantifies the magnitude of the trend. The sensitivity of these tests to inhomogeneous patterns in time series data is low but they are suitable formonotonoustrends with no seasonal or other cycle in the data. Other advantage is the data need not conform to any particulardistribution [8,9]. It has therefore served as an excellent reference for other trend test techniques [10].

2.1 Mann-Kendall Test

Mann-Kendall test has been widelyused to test for trend inmany applications where time series dataare in use [11,12]. Itindicates the direction but not the magnitude of significant trends. In this study, thenull hypothesis is the data are independent and randomly ordered. The Mann-Kendall test is applicable in cases when the data values *xi* of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i. \quad (1)$$

where$f(t_i)$is a continuous monotonic increasing or decreasing function of time and the residuals $\varepsilon_i$can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time.

The Mann-Kendall statistic (S) is given as [8, 13]:

$$S = \sum_{k=1}^{n-i} \sum_{j=k+1}^{n} sgn(x_j - x_k), \ (2)$$

where x_j and x_j are the annual values in years j and k , $j > k,$ and

$$sgn(x_j - x_k) = \begin{cases} 1 & if x_j - x_k > 0 \\ 0 & if x_j - x_k = 0 \\ -1 & if x_j - x_k < 0\,. \end{cases} \quad (3)$$

A positive value of S indicates an increasing trend while negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, *n*, to statistically quantify the significance of the trend. [14,15] estimated the variance of S as

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} p_t(p_t - 1)(2t_p + 5)\right], (4)$$

where *n* is the number of data points, q is the number of tied groups (a tied group is a set of sample data havingthe same value), and t_p is the number of data points in the p^{th} group. Statistic Swill yield result if *n* is less than 10 otherwise statistic Z replaces it. The values of *S* and *VAR(S)*are used to compute the Z statistics. The normalized test statistic Z can beestimated using

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if S > 0 \\ 0 & if S = 0 \ (5) \\ \frac{S+1}{\sqrt{VAR(S)}} & if S < 0\,. \end{cases}$$

A positive value of Z indicates an increasing trend while negative value indicates a decreasing trend. To test for either an upward or downward monotone trend (a two-tailed test) at α level ofsignificance, the nullis rejected if the $|Z| > Z_{(1-\alpha)/2}$ where $Z_{(1-\alpha)/2}$is obtained from the standard normal cumulative distribution tables.The tested level of significance (α)0.001, 0.01, 0.05 and 0.1 are available in MAKESENS.

2.2 Sen's Method

For a linear trend is present in a time series, the true slope (change per unit time) can be estimatedby using a simple nonparametric proceduredeveloped in [18]. The linear model $f(t_i)$is described as [19]:

$f(t_i) = Qt + B, (6)$

where Q are the slopesof all data pairs and are calculated as

$Q_i = \frac{x_j - x_k}{j - k}, i = 1,2, \ldots n, j > k (7)$

and B is a constant, which represent the value at the beginning of observation and t is time in year.

The Sen's estimator of slope is the median of these n values of Q_i. The n values of $Q_i$areranked from the smallest to the largest and the Sen's estimator is

$Q = Q_{\frac{n+1}{2}}, if n is odd (8a)$

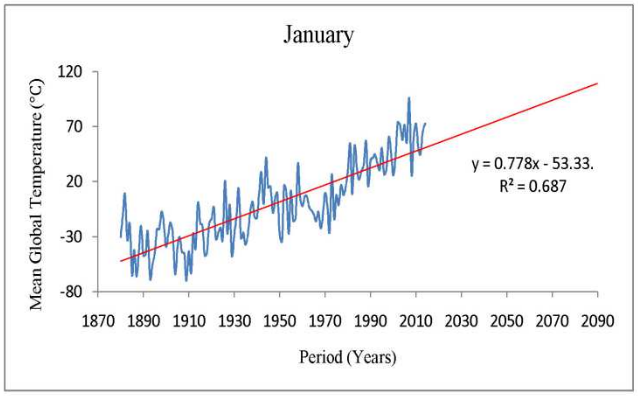
$Q = \frac{1}{2}(Q_{\frac{n}{2}} + Q_{\frac{n+2}{2}}), if n is even (8b)$

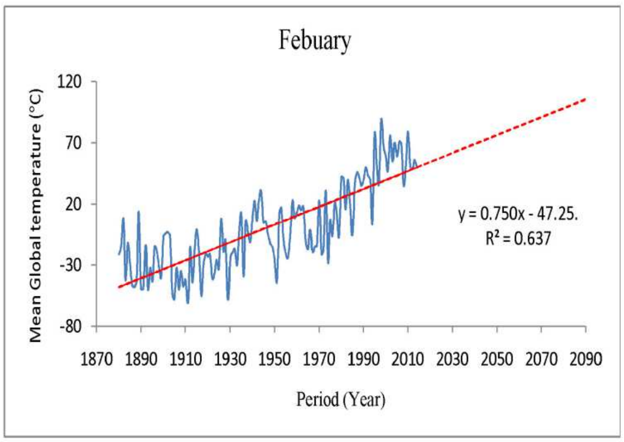
A $100(1-\alpha)\%$ two-sided confidence intervalabout the slope estimate is obtained by the nonparametrictechnique based on the normal distribution.The method is valid for *n* as small as
10 unless there are many ties [9].

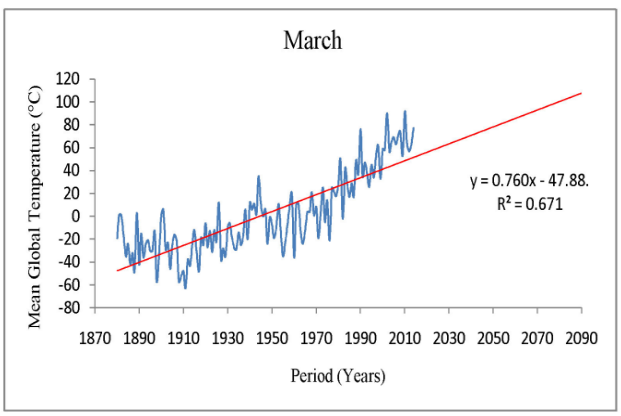
3.0 Results and Discussion

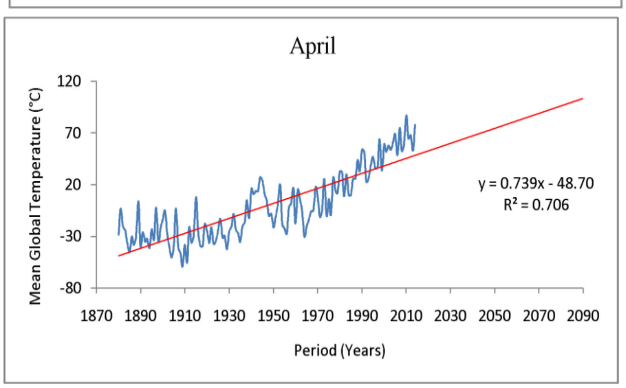
The data set used for this study spanned over a period of 135 years. The analysis wasfirst conducted to reflect the trend within each month of the years.R-square is a measure of how close the fitted regression line is to the plotted data. It is the percentage of the variables explained by the linear model. As shown in Table 1, the value of R-square ranges between 63.0% in December and 74.8% in June. Therefore a larger percentage of the data followed the linear model.The Mann-Kendall statistic (S) has no result because$n$ is more than 9 but produces result for Z at 0.001 level of significant. The value of statistic$Z$ is positive for all the months of the years. This implies upward trend; the value of mean global temperature increases over the period of 135 years. The range of value of Z is between 10.26 in December and 11.70 in June (Table 1). $|Z| > Z_{(1-\alpha)/2}$ holds for all values of statistic Z in this study.From the standard normal cumulative distribution tables,$Z_{(1-\alpha)/2} = 3.31$ [20], therefore the null hypothesis of no trend is rejected at$\alpha = 0.001$ level of significant.

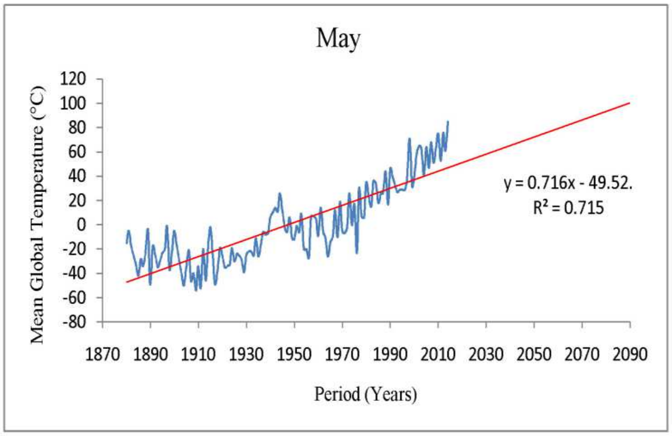
As presented in Table 1 and also in Figures 1 and 2, the slope Q represents the change per unit time ($°C$/year) and its value ranges between 0.778 in January and 0.605 in July. The increase within each month is less than $1°C$.An examination of Sen's estimate for each year yields -52.33 in 1880 and 51.89 in 2014 with an gradient of 0.777 (Figure 4), which implies a graduate increase in meanglobal temperature over the years. The constant $B(°C)$represents the value of the variable at the beginning of the observation while Y ($°C$) reveals what the temperature will be by year 2090 and Y-B ($°C$) show the differences within each month for a period of 210 years.The linear model reveals that by 2090, the mean global temperature will be between $86°C$ in October and $150°C$ in Januarywhile the Sen's estimate for 2090 is $120°C$.The result of the analysis of yearly average of the data is presented in Table 1 and Figure 3, which indicates R Square value of 75.2%, statistic$Z$ value of 11.88 and Q value of 0.692.This trending analysis reveals that the mean global temperature of earth surface is increasing gradually at a rate that is less than a centigrade per year. This value seems too small to be noticed but the cumulated effect of such increase over many years constitute hazard to life. It is also obvious that the period of exposure to elevated temperature will vary depending of regions. The entire thermal stress indexes used to estimate the effect of elevated temperature on human have direct proportional relationship with temperature. Therefore as temperature is increasing, the adverse effect of elevated temperature will also be increasing. The adverse effect includes reduction in the ability to concentration on things, increased mortality rate, general reduction in rate healing rate and many others.It will also bring about more natural disasters like increased in the occurrence of tsunami, raining fall accompanying with heavy storms over long period of time, flooding in many places to mention a few. Reduction in agricultural produce because excessive evapotranspiration and wilting which may lead to farming.Therefore, stakeholders at all levels are employed to take proactive measure that can either slow down the increasing trend or bring about a reverser for the safety of all. There nations of the world must adopt methods of energy generation devoid of emission of greenhouse gases. The task of reducing the production of greenhouse gases and global is a collective one. Awareness program must be put in place to ensure it effectiveness as well as policy by offender can be sanctioned.


January
Mean Global Temperature (°C)
120
70
20
-30
-80
1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
Period (Years)
y = 0.778x - 53.33.
R² = 0.687


Febuary
Mean Global temperature (°C)
120
70
20
-30
-80
1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
Period (Year)
y = 0.750x - 47.25.
R² = 0.637


March
Mean Global Temperature (°C)
120
100
80
60
40
20
0
-20
-40
-60
-80
1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
Period (Years)
y = 0.760x - 47.88.
R² = 0.671


April
Mean Global Temperature (°C)
120
70
20
-30
-80
1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
Period (Years)
y = 0.739x - 48.70
R² = 0.706



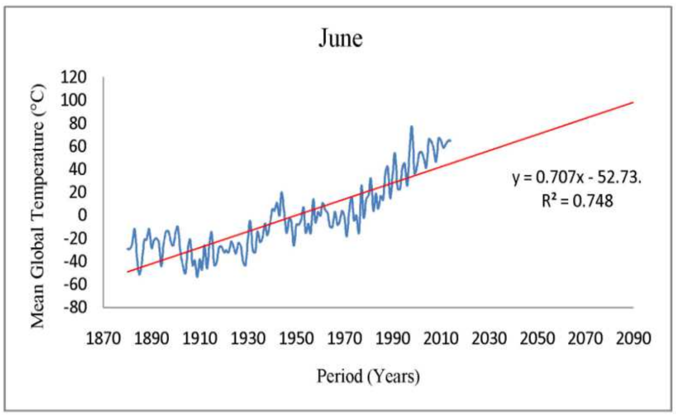
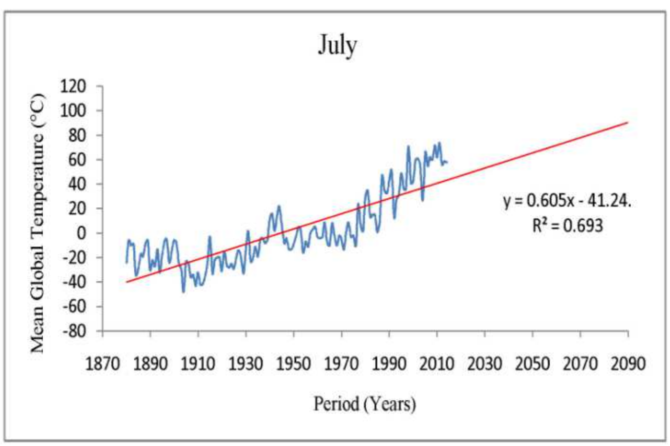
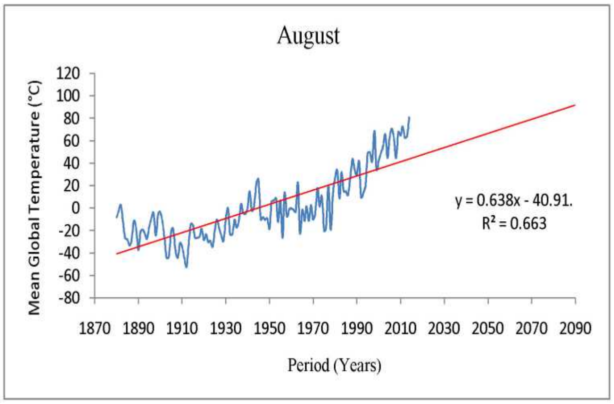
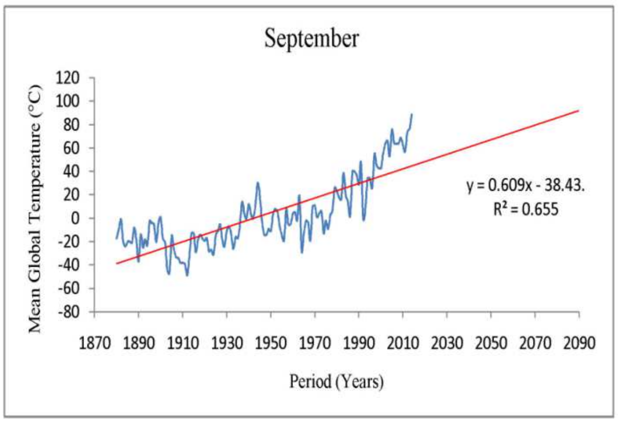
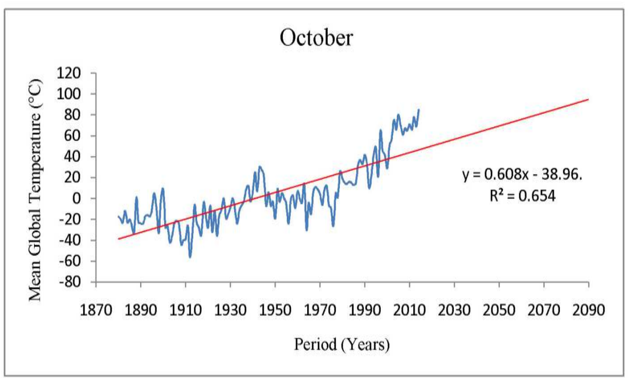


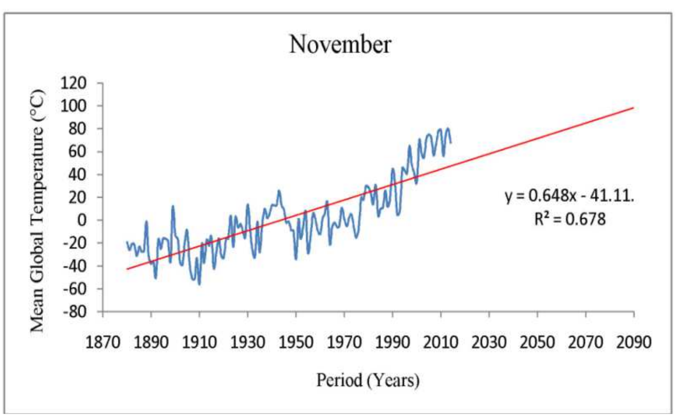
Figure1: Graphical Result of Trend Analysis of Mean Global Temperature for January to July




August
Mean Global Temperature (°C)
120
100
80
60
40
20
0
-20
-40
-60
-80
1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
Period (Years)
y = 0.638x - 40.91.
R² = 0.663


September
Mean Global Temperature (°C)
120
100
80
60
40
20
0
-20
-40
-60
-80
1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
Period (Years)
y = 0.609x - 38.43.
R² = 0.655


October
Mean Global Temperature (°C)
120
100
80
60
40
20
0
-20
-40
-60
-80
1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
Period (Years)
y = 0.608x - 38.96.
R² = 0.654


November
Mean Global Temperature (°C)
120
100
80
60
40
20
0
-20
-40
-60
-80
1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090
Period (Years)
y = 0.648x - 41.11.
R² = 0.678

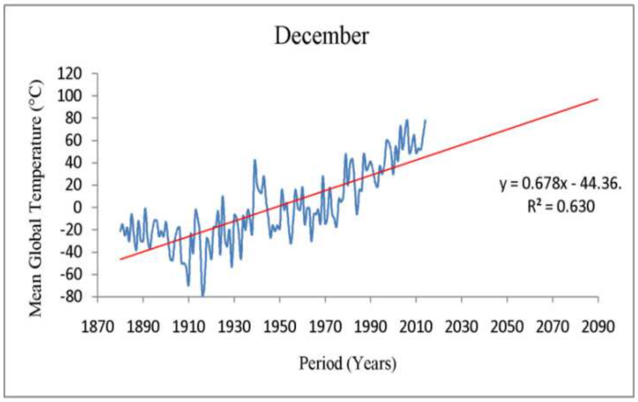


Figure2:Graphical Result of Trend Analysis of Mean Global Temperaturefor July to December

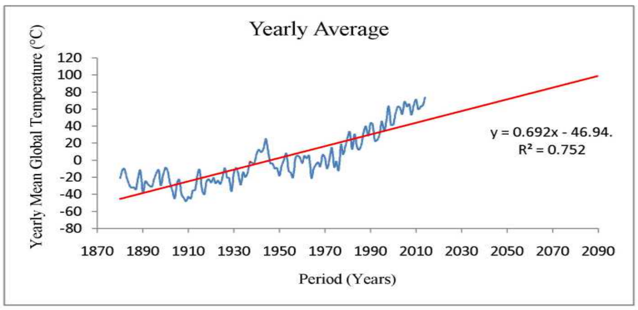


Figure 3: Graphical Result of Trend Analysis of Annual Mean Global Temperature.

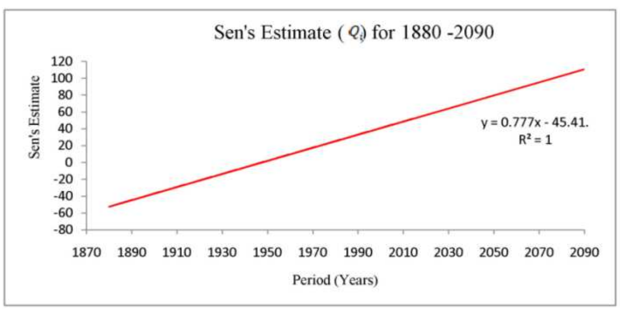


Figure 4: Graphical Result of Trend Analysis of Sen's Estimate

Table 1: Result of Trend Analysis of Mean Global Temperature

Time Series	**First Year**	**Last Year**	**n**	**Test Z**	**Significant**	**Q** $(°C/y)$	**B** $(°C)$	**R Square (%)**	**Y at 2090** $(°C)$	**Y-B** $(°C)$
January	1880	2014	135	10.86	***	0.778	-52.33	68.7	150	202.33
February	1880	2014	135	10.09	***	0.750	-47.25	63.7	120	167.25
March	1880	2014	135	10.69	***	0.760	-47.88	67.1	140	187.88
April	1880	2014	135	11.18	***	0.739	-48.70	70.6	110	158.70
May	1880	2014	135	11.20	***	0.716	-49.52	71.5	100	149.52
June	1880	2014	135	11.70	***	0.707	-52.73	74.8	100	152.73
July	1880	2014	135	11.17	***	0.605	-41.24	69.3	160	201.24
August	1880	2014	135	10.67	***	0.638	-40.91	66.3	170	210.91
September	1880	2014	135	10.75	***	0.609	-38.43	65.5	86	124.43
October	1880	2014	135	10.76	***	0.608	-38.96	65.4	88	126.96
November	1880	2014	135	10.95	***	0.648	-41.111	67.8	100	141.11
December	1880	2014	135	10.26	***	0.678	-44.356	63.0	99	143.36
Yearly Average	1880	2014	135	11.88	***	0.692	-46.94	75.2	115	146.94

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