INVESTIGATING CLIMATE CHANGE IMPACTS ON SURFACE SOIL PROFILE TEMPERATURE (CASE STUDY: AHWAZ – SW OF IRAN)

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ABSTRACT

In arid and semi-arid regions, warming of soil surface sets in a high thermal gradient which causes intense moisture flow. In recent years, researchers have noticed ascending trend of temperature at watershed level. The present study proved the occurrence of ascending trend in time series of temperature through both non-parametric and Mann Kendall parametric tests as well as linear regression in synoptic station in Ahwaz province, Iran. While the degree of trend was determined, the relations of Soil-Medium temperature were obtained for the depths of 5 and 30 cm. Applying the relations of ascending air temperature with the relations of soil-medium temperature, a new relation was developed which can express the ascending trend of soil temperature based on medium temperature. These relations indicated that, at depths of 5 and 30 cm, the soil temperature is higher, respectively, by 2 and 1 ˚C than medium temperature. Furthermore, the ascending trend of temperature gradient of soil surface profile in depths of 5 and 30 cm is respectively 0.038 and 0.030 ˚C per year. Although the increase of soil temperature is small, these low soil temperature changes are effective on plant growth and soil properties like moisture profile of soil structure alteration, thermal conductivity, heat capacity and heat diffusion coefficient.

Keywords: Climate Change; Medium Temperature; Soil Temperature; Time series; Trend.

1. INTRODUCTION

Temperature and precipitation are the most important climatic parameters, which affect the hydrologic cycle, the crop production cycle, soil, water use (especially agriculture), human activities and environment. Soil temperature, in turn, is one of the major features in the cycle of crop production and heat and humidity transfer. Plant growth and development and processes of soil development are affected by soil temperature. Various plant species require different temperatures; and their production and efficiency are optimized for different temperature ranges. Soil heat spatially and temporally fluctuates from horizon to horizon and throughout the day and year. Soil temperature controls the growth type and root growth; and along its volatility, it has powerful effects on the soil-forming processes and agricultural productions. There are usually concerns over low temperature whereby biological activities, seed germination, root development of most productions face serious trouble, but Summer crops such as maize, sorghum and cotton which need essentially hot climates are directly affected by an increase temperature and climate change.

The industrialization of societies has led to an increase in greenhouse gases especially CO2; if these gases are not reduced, the average global temperature could increase around 1.1 to 4.6 °C by 2100 (IPCC., 2007). Issues of climate change and in particular increasing the temperature in Iran have been a concern of researchers.

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In this context, it can be mentioned the presence of trend component in a time series of temperature in Tabriz by Rasoli (2002), Jask by Asakereh and Kheradmand (2002), Ahwaz by Hemadi et al. (2011). In addition to the mentioned cities, the issue of climate change has been considered by other researches on the watersheds' level. Masah-Bavani and Morid (2004) by analyzing meteorological variables related to General Circulation Model (GCM) in the future periods for the upstream stations of Zayandehrud dam with definition of two scenarios showed that the increase in average annual temperature has increased 2.3 and 5.4 °C compared to the average base period (10 °C)(Massah Bavani & Morid (2004)). Also for the two scenarios, the decrease in the average annual rainfall would be 149 and 234 mm, respectively in upstream Zayandehrud compared to base value (1458 mm). Ashofteh and Masah-Bavani (2009), with uncertainties of AOGCM model, showed that the temperature of Aidoghmoush Basin in the of East Azerbaijan will increase during 2069-2040 between 1 and 6 °C compared to the base period. The increase is between 1 to 5.4 °C for the winter and spring and between 2 to 6 °C for summer and autumn. They showed the increase of rainfall mainly for autumn and winter and its decrease for other seasons in the same period.

Climatic changes in addition to temperature have also been reported in precipitation and river flow. Smadi and Zeghul (2006) studied the sudden change of precipitation attributes (amount and number of rainy days) in Amman, Jordan to two synoptic stations during 81-year-old period; they achieved a down trend in rainfall and shifts in rainfall days by using different statistical tests including Mann-Kendall. Downtrend of precipitation mentioned with an average annual rainfall of 165 mm equal to -5.0 mm per year in Mefrak synoptic station (Smadi, & Zghoul., 2006). Ma et al. (2008) analyzed the climate changes and its effect on the flow regime in the river basins in the arid region of North West China. In the above study, the average annual flow hydrometric data were used in 8 catchment basins. Literature review on climate change indicates that the studies on the effects of climate on soil are few, so they are addressed in the present study. Soil temperature has a major role in the emergence and development of soil and soil heat determines many soil reactions. Soil temperature is used as a criterion in soils' identification in their classification. Changes in soil temperature is slow from the surface to the depth. It varies highly at the soil surface and it is stable and uniform at the depth of 9 m. Annual mean of soil temperature is usually 1 °C more than the average annual air temperature; and temperature gradient or temperature change with depth about 5 °C per 10 cm of soil depth (Bay Bordi, 1994). As mentioned, temperature in the soil surface layer is higher than the surrounding air, but daily fluctuations decrease in the lower depths of the soil. Daily temperature fluctuation does not take place at a depth of 50 cm and temperature is constant at a depth of 1 to 3 m of soil throughout the year. High temperature amplifies chemical weathering processes, which occur in short periods, so that the speed of chemical reactions nearly doubles with every 10°C increase in temperature (Anon,.1989). Since the soil temperature influences plant growth and soil microorganisms, this study intends to assess the impacts of climate change in temperature in Ahwaz synoptic station on the soil surface and at 5 and 30 cm depths.

2. METHODS

In this study, monthly and annual temperature data were received and analyzed from 1957 to 2014 in Ahwaz city for nearly 60 years from the Meteorological Organization of Khuzestan province. Spreadsheet Excel and statistical hydrology software Trend are used in order to save of analyzing data. Ahwaz synoptic station is the oldest station in Khuzestan province, which has a better maintained climatological data compared to other stations. This station is located at 48º 40'E latitude and 31º 20'N longitude and is 18 m amsl. In this station, in addition to air temperature, wind,

relative humidity and other common meteorological parameters; the soil temperature is recorded at depths of 5 to 100 cm with environment temperature at the same time. In this study, the recorded soil temperature was used at the depths of 5 and 30 cm. First, the annual time series of ambient temperature was plotted and preliminary analysis was performed on it. In time series analysis of temperature, the graphical indices such as the raw data index, smoothed, the moving average and variability, trend component (Trend), cycling (Cyclical), seasonal (Seasonal) and irregular or random (Irregular) are extractable from the original data. Displayed temperature time series suggests that it has an increasing trend. In order to clarify the situation of existence of trend in the time series, we used non-parametric and parametric tests of Mann-Kendall and linear regression. Mann-Kendall test is along with free distribution that it has many applications to prove the existence of trend in time-series data. This method replaces time series values (x_1, x_2, x_3 ..... x_n, with the rating values (R_1, R_2, R_3, ... R_n) (starting from the lowest rank 1 to rank n). The statistic of this test, s, will be expressed as follows:

$$s = \sum_{i=1}^{n=1}\left[\sum_{j=i+1}^{n} sgn(R_j - R_i)\right] \qquad \text{... (1)}$$

Where:

$$sgn(x) = 1 \quad \text{for} \quad x > 0$$
$$sgn(x) = 0 \quad \text{for} \quad x = 0 \qquad \text{... (2)}$$
$$sgn(x) = -1 \quad \text{for} \quad x < 0$$

If the null hypothesis (H_0) is true, then S is calculated from normal distribution with mean zero ($\mu = 0$) and variance $\sigma = n(n-1)(2n+5)/18$. Z-statistic is estimated as follows:

$$Z = |s|/\sigma^{0.5} \qquad \text{... (3)}$$

S-statistic positive value indicates increasing trend in time series and vice versa. Linear regression analysis is a parametric test that is applied for normally distributed data and clarifies the linear trend of relationship between time (x) and variable (y). Regression parameters (a) and (b) were estimated by the following equations:

$$b = \sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})/\sum_{i=1}^{n}(x_i - \bar{x})^2 \quad , \quad a = \bar{y} - b\bar{x} \qquad \text{...(4)}$$

S-statistic is calculated as: $s = b/\sigma$ in which σ is equal to:

$$\sigma = \left((12\sum_{i=1}^{n}(y_i - a - bx_i))/(n(n-2)(n^2-1))\right)^{0.5} \qquad \text{...(5)}$$

S test statistic follows t-Student distribution with (n-2) degree of freedom under the null hypothesis. Normally distributed data and independent errors (deviation from trend) are the assumptions of linear regression test which is the same normal distribution with a mean of zero. After a clear trend in time series, its quantity value was calculated from the least square method of time series. By determining the trend component of temperature in the environment, the possibility of transferring it to a pile of soil is been possible by soil temperature-environment relationships. For this reason, couples environment and soil temperature recorded at the same time were considered and the relationships between them were extracted. At the end, results graphically will be expressed and discussed.

3. RESULTS AND DISCUSSION

As mentioned in the previous section, in this study, the recorded temperature data were used in Ahwaz synoptic stations. In this station, in addition to the air temperature, soil temperature at depths of 5 to 100 cm, the environment temperature is recorded at the same time. Table 1 shows mean annual temperature in Ahwaz station during the 60-year-old observations. As can be seen in the table bellow, annual mean temperature is 5.25 and its changes are between at least 4.23 up to 9.27 °C. Annual series changes range 5.4 °C and its standard deviation is less than 1°C; taking this into account, coefficient of variation (CV) of series is equal to 4%.

Table 1. Statistical parameters of annual series of temperature, environment and soil temperature in Ahwaz synoptic stations (°C)

Statistical parameters	Annual Series	Environment	Soil h = 5 cm	Soil h = 30 cm
The number of observations (sample)	58	183		
Average	25.5	26.0	28.1	27.5
The maximum	27.9	46.2	49.8	38.4
The least	23.4	2.6	4.2	13.4
Range of variations	4.5	43.6	45.6	25.0
SD	0.90	11.4	11.9	8.5
Coefficient of variation	0.04	0.44	0.42	0.31

The highest soil temperature changes occur at the surface; temperature fluctuations become low by moving from the surface to the depth of soil. In this study, the recorded soil temperature was used at depths of 5 and 30 cm. Simultaneous series of ambient and soil temperature consists of 183 observations. Table 1 shows some relevant statistical properties. Mean ambient temperature, and the soil temperature at 5 cm and of 30 cm depth were 26, 28 and 5.27 °C, respectively; their variations' ranges are 44, 46 and 25 °C, respectively. The coefficient of variation (CV) of the ambient temperature was 44%. The same at a depth of 5 cm and 30 cm depth was 42% and 31%, respectively. Figure 1 shows changes in mean annual temperature of Ahwaz synoptic station. In order to reduce this variability, time series was taken from raw data of 5-year moving average (2). As mentioned in the Materials and Methods section, in the temperature time series analysis, the graphical indices of time series i.e. raw data, smoothed; moving average and variability, as well as major indices of time series such as trend component, cyclical, seasonal and randomly are extractable from the original data. Among the above components, the trend component is important in this research. Figures 1 and 2 both apparently show the existence of trend component in time series of annual temperature, but this is not enough. The discussion of existence of trend in time series must be proved or rejected by tests. To clarify the existence of trend in annual temperature time series were used Mann-Kendall parametric and non-parametric tests and linear regression. The results of statistical analysis are reflected in Table 2; these results show the increasing trend in time series and are significant in the statistical level (α = 0.01).
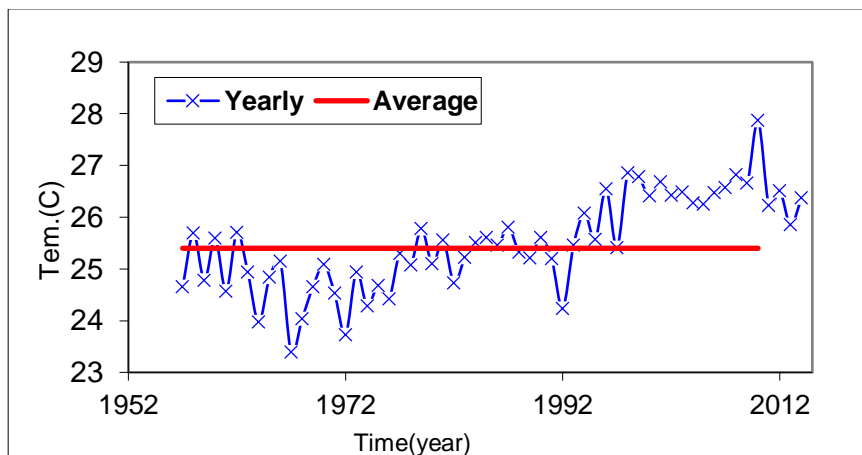
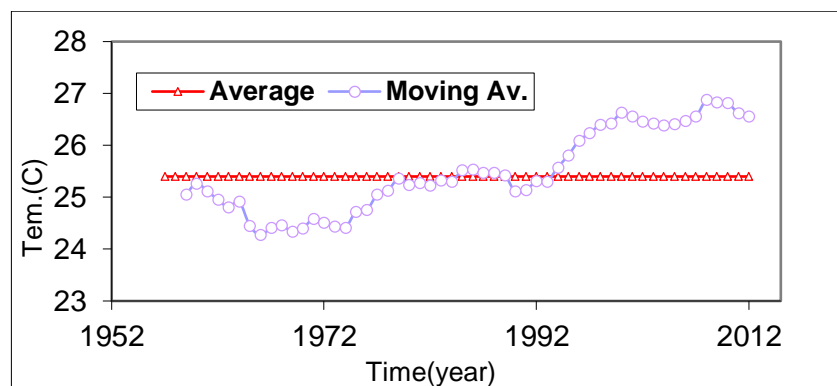**Figure 1.** Changes of mean annual temperature in Ahwaz synoptic station

Figure 2. 5-year moving average of annual temperature time series in Ahwaz

synoptic station

Table 2. Results of statistical analysis to prove or reject the trend component of time series of temperature

Statistic and critical values	Test Statistic	$\alpha = .1$	$\alpha = .05$	$\alpha = .01$	Result
Mann-Kendall test	5.145	1.645	1.96	2.576	S (0.01)
Linear regression test	6.617	1.68	2.01	2.68	S (0.01)

Trend component is calculated using the least squares method of the observed series and is shown in Figure 3. It is observed that the gradient of temperature trend component in the studied synoptic station is 0.040 and the width of origin is 24.3 °C.
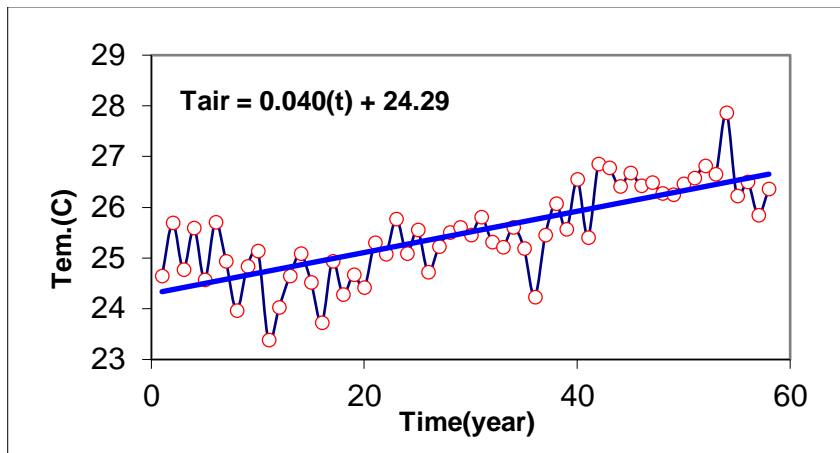
Figure 3. Trend component in time series of annual temperature in Ahwaz synoptic station

The last part of this study was to determine the relationship between simultaneous series of environment air and soil temperature in depths of 5 cm and 30 cm. Daily temperatures of environment and soil were measured three times a day. Soil temperature changes are usually delayed than air that is why before extracting discussed relations of corresponding data, moving average of 3 orders was performed in order to prevent daily fluctuations and then the relations were extracted. This relationship is well observed in Figures (4) and (5); the discussed relations are significant at the statistical level (α = 0.1).
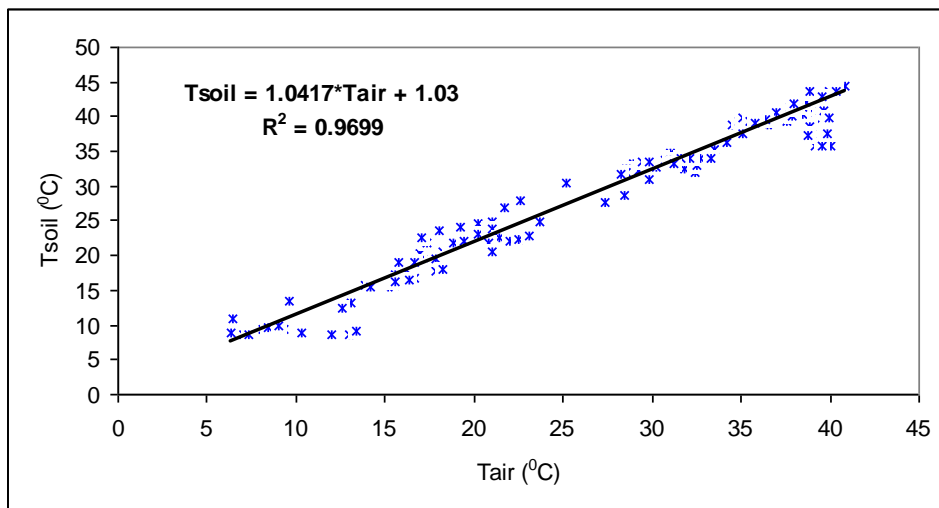

Figure 4. The relationship between ambient and soil temperature at 5 cm depth
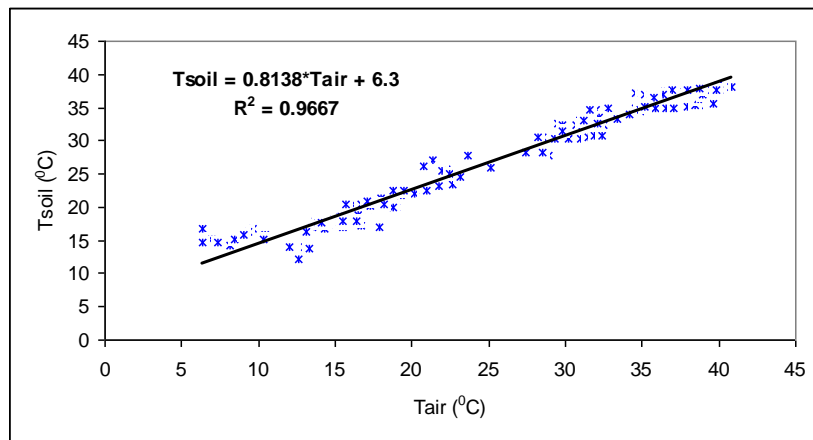
Figure 5. The relationship between ambient and soil temperature at 30 cm depth

With further consideration of Figures 3 to 5, the equation between increasing trend of air temperature and soil-environment temperature equations at depths of 5 and 30 cm, respectively, are expressed in accordance as follows:

$$T_{air} = 0.040 * t + 24.29 \qquad (6)$$

$$T_{soil} = 1.0417 * T_{air} + 1.03 \qquad (7)$$

$$T_{soil} = 0.8138 * T_{air} + 6.3 \qquad (8)$$

Equation (6) shows increased trend of air temperature and equations (7) and (8) show soil-environment temperature at depths of 5 and 30 cm; by substituting equations (7) and (8) in equation (6), the increased trend of temperature of the soil surface layer in depths of 5 and 30 cm is extracted in accordance with equations (9) and (10).

$$T_{soil} = 0.0416 * t + 25.3 \qquad (9)$$

$$T_{soil} = 0.0325 * t + 25.3 \qquad (10)$$

These equations show that the soil temperature at a depth of 5 and 30 cm is respectively 2 and 1 °C higher than the ambient temperature. In addition, the gradient of increasing temperature trend of soil surface profile at depths of 5 and 30 cm is 0.042 and 0.032 °C per year, respectively. Ahwaz area is a semi-arid area, so warming its soil surface is significant and is caused a lot of thermal gradient in which the movement of water becomes more intense as a result of it; soil wetting also produces the heat.

Of course, there is a complex interaction between the soil moisture and temperature because despite the increase in ambient temperature, the dry soil surface is heated earlier, but the transfer of heat in a moist soil is taken more than one dry s. mentioned topics quantitively needs further researches on this area

4. CONCLUSIONS

The studied area is an arid to semi-arid region and its warming the soil surface is considerable and it creates a lot of thermal gradient. The trend in time series of mean annual temperature was confirmed using two Mann-Kendall's non-parametric and parametric tests and linear regression. This was increasing (positive) trend and its amount is equal to 0.040 °C per year. In this study, the soil temperature-environment equations were extracted at depths of 5 and 30 cm. Combined application of equation

of increasing trend of air temperature with soil-environment temperature equations is led to develop another equation that stated increasing trend of soil temperature. In general, these equations suggest that the soil temperature at depths of 5 and 30 cm is higher than the environment, 2 and 1°C, respectively. As well as, the trend gradient of raising the temperature of soil surface profile at a depth of 5 and 30 cm is 0.042 and 0.032 °C per year, respectively. Although the development of soil temperature thought to be restricted, the same bit changes of soil temperature are efficient on future plant growth, soil properties such as alteration moisture profile of soil structure, thermal conductivity, heat capacity and heat diffusion coefficient.

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