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Variation of Soil Temperature and Its Relationship with the Environment in Nagqu, Tibet

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Abstract: Based on soil temperature data of 0–60 cm at 10 cm interval monitored by the IST (IST. Hrgc-16s), the vertical variation characteristics of soil temperature were analyzed. and Then meteorological factors, including air temperature, humidity, atmosphere pressure, wind speed, rainfall, cumulative solar radiation and other indicators obtained by the Tianqi weather station (WS00G10A) from June 2017 to November 2019, were used to explore its relationship between soil temperature using the correlation method. The results showed that: (1) the soil temperature fluctuated between −15 °C and 17.5 °C in Nagqu region, Tibet, and the soil surface temperature changed significantly compared with the deep layer. (2) The diurnal variation of soil temperature in 0−30 cm was obvious, and had a distinct period of oscillation. However, the soil temperature in the 30−60 cm layer had little change, peak and valley value lagged behind by about 1 h with each 10-cm soil depth increased. The fluctuation of day and night temperature showed the greatest difference in special months, and the largest difference was in winter. (3) The annual average value of soil temperature and accumulated soil temperature showed an increasing trend firstly, then decreased with the increase of soil depth, and reached the maximum value of 4.27 °C and 1,557 °C at the soil depth of 30 cm. (4) Soil temperature (0 cm) had a significant response to the changes of air temperature, humidity, atmospheric pressure, rainfall and cumulative solar radiation intensity, with correlation coefficient of 98%, 91%, 84%, 75%, 72%, respectively. The experimental results revealed the law of soil temperature variation in Nagqu region, which laying a foundation for discussing plant growth and the relationship between soil and environment in the northern Tibetan plateau.

Keywords: soil temperature; meteorological factors; correlation analysis; Nagqu region

Dataset Available Statement:

The dataset supporting this paper was published at: Yang, H. B., Yu, X. D., Fu, H. M., et al. Dataset on soil temperature, meteorological factors and their correlation coefficients in Nagqu, Tibet, China (2017–2019) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2020. DOI: 10.3974/geodb.2020.03.03.V1.

1 Introduction

Tibetan Plateau, the highest plateau in the world, has different climatic conditions from other

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regions. The climate in this region is strong solar radiation, and long sunshine hours, low air temperature and large temperature difference between day and night, cold and dry in winter, cool and rainy in summer[1]. Tibet's unique and stable "micro" environment has also been altered as global climate keeps on changing, climate change is more severe[2–3], The average annual temperature of the Tibetan Plateau increases 0.026 ℃ per year in recent years[4], and it is far higher than the global air temperature growth rate. Soil temperature is one of the key variables affecting many important physical, chemical and biochemical processes in the soil[5–6], which determines soil quality and affects the nutrient utilization rate and plant growth[7]. Plant roots are sensitive to extreme changes in soil temperature due to its narrow comfort zone[8], The heat transfer in the atmosphere and on the ground and the increase of soil temperature in different degrees can change the balance of soil carbon bank reserves and nutrients (NPK, etc.), and affect soil fertility[9–10]. Therefore, research on soil temperature is the basic premise to ensure the heat balance and the normal growth of plant.

As an ecological fragile region in China, Tibet has always attracted much attention. It is necessary to study soil temperature change and its response to environment on different time scales under the trend of climate change in warmth and humidity. It's reported that plant roots growth and soil biological activity mainly depend on soil temperature[7,11–12]. The phenomenon in the Nagqu region such as rain and hail in summer, dry and wind in winter or spring, strong ultraviolet rays uneven exposure lead to great differences in climate and soil properties in different regions or even in the same region. In addition, many variables such as the vast territory and different landform and physiognomy lead to different soil temperature variation patterns. This paper focuses on the central and eastern region of Nagqu, where a weather station and a temperature monitoring station were established. Based on previous studies, the vertical and instantaneous changes of soil temperature in recent years in Nagqu were analyzed on other levels, and to find out the time nodes of soil temperature affected by environmental factors. Therefore, soil temperature and meteorological data in the past two years were usually used to clarify the characteristics of soil temperature variation and determine the correlation of meteorological factors.

2 Metadata of the Dataset

The metadata for the "Dataset on soil temperature, meteorological factors and their correlation coefficients in Nagqu, Tibet, China (2017–2019)"[13] is summarized in table 1. It includes the full name, short name, authors, year, data format, data size, data files, data publisher, data sharing policy, etc.

3 Methods

3.1 Study Area

The experiment site was located in the northwest of Nagqu county in Nagqu region (central coordinates: 31°33′49″N, 116°00′37″E). It is about 30 km away from Nagqu county and close to the Beijing-Tibet highway, with convenient transportation.

Nagqu belongs to the plateau subfrigid zone monsoon sub-humid climate zone and has cold, low oxygen and dry climate. There are about 100 windy days in one year, and it has an average annual temperature of −2.2 ℃, the coldest temperature can reach −40 ℃, the annual sunshine hours are more than 2,886 hours, It receives 400 mm of annual precipitation, and has warm climate from May to September. From October to May of next year is the period of snow and soil freezing. The annual growing season is about 100 days.

Table 1 Metadata summary of the dataset

Items	Description
Dataset full name	Dataset on soil temperature, meteorological factors and their correlation coefficients in Nagqu, Tibet, China (2017–2019)
Dataset short name	SoilTem_MeteoFac_Nagqu_2017-2019
Authors	Yang, H. B., Elion Ecological restoration Co. LTD, 502952735@qq.com Yu, X. D., Elion Ecological restoration Co. LTD, yuxiaodan2018@163.com Fu, H. M. 0000-0002-0245-1134, Beijing center for physical and chemical analysis, dena1988@sina.com Li, H. T., Elion Ecological restoration Co. LTD, lihuiting@elion. com.cn Zhao, J. L., Elion Ecological restoration Co. LTD, zhaojinling@elion. com.cn Xu, W., Elion Ecological restoration Co. LTD, xuweicuc@gmail. com
Geographical region	Nagqu, Tibet Year From June 2017 to September 2019
Data format	.xlsx Data size 2.67 MB (after compression)
Data files	(1) Hourly, daily, and monthly soil temperature data for different soil depths (Tab.1–Tab.3); (2) Soil temperature characteristics at different soil depths (Tab.4) (3) Soil temperature characteristics data of different soil depths hourly, daily and monthly meteorological data (Tab.5–Tab.7) (4) Correlation coefficient data of soil temperature and meteorological elements at different soil depths (Tab.8)
Foundations	Ministry of Science and Technology of P. R. China (2017YFC0506800, 2016YFC0500708); National Natural Science Foundation of China (41807105)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[14]
Communication and searchable system	DOI, DCI, CSCD, WDS/ISC, GEOSS, China GEOSS, Crossref

3.2 Data Collection and Processing

Data observation period: From June 2017 to September 2019.

Soil environment monitoring method: IST. HRGC-16s. Temperature and humidity probes were installed every 10 cm depth. From the surface, and the probes were installed laterally. Monitoring frequency was once per hour. Monitoring depth of soil temperature was 0–60 cm at 10 cm interval.

Atmospheric environment monitoring method: Tianqi meteorological station (WS00G10A) was set at the height of 2 m in the center of the test area on the open space without any obstruction, and monitored once per hour. Monitoring indicators include air temperature, relative humidity, atmospheric pressure, wind speed, wind direction, rainfall, and solar radiation.

Data were analyzed by SAS 8.0 and SPSS 19.0 software system.

4 Results and Analysis

4.1 Characteristics of Annual Variation of Soil Temperature in Different Depth

4.1.1 Vertical Variation of Soil Temperature

Table 2 showed the temperature difference, annual cumulative temperature, average, maximum and minimum values of soil temperature in each layer from June 2017 to September 2019. The temperature difference decreased with the increase of soil depth, which showed significant differences from 0 to 40 cm (P<0.05), and tended to be stable under 40 cm. The mean value increased firstly and decreased with the increase of soil depth, finally tended to balance. The average temperature of 30 cm soil layer was significantly higher than that of 0–20 cm soil (P<0.05). There was no difference from 30 to 60 cm soil layers. With the increase of depth, the accumulated temperature also increased firstly then decreased, and finally tended to be stable, reaching the maximum in the 30 cm soil layer. The fluctuation range of maximum and minimum soil temperature decreased with the increase of soil depth. The results suggested that 30 cm soil layer was a temperature turning point and had a high and stable temperature environment.

4.1.2 Temporal Variation of Soil Temperature

The trend in different layers of soil temperature was similarly (Figure 1). The total fluctuation of soil temperature was similar to the periodic change of sine or cosine, it was high in summer, low in winter, and the amplitude was about 11.3 ℃. The temperature difference in soil layers changed a little and the volatility was low from April to October. However, the fluctuation of all soil layers was severe from October to March of the next year, especially the soil surface, but the fluctuation would decrease with the increase of soil depth. The soil temperature changed suddenly in October, dropping rapidly by about 14 ℃, becoming the month with the greatest variation. From April, the temperature was above 0 ℃ and the soil began to thaw.

Table 2 Analysis of soil temperature differences in different soil depths

Depths (cm)	Temperature difference (℃)	Mean value (℃)	Annual accumulated temperature (℃)	Maximum (℃)	Minimum (℃)
0	22.36a±0.33	1.99d±0.30	724.61	36.38	–24.69
10	8.47b±0.17	2.85c±0.27	1,040.94	29.56	–14.44
20	3.52c±0.09	3.36bc±0.25	1,227.54	22.31	–11.44
30	1.67d±0.04	4.27a±0.24	1,557.02	19.31	–8.94
40	0.89e±0.02	3.68ab±0.24	1,343.79	16.81	–8.44
50	0.44e±0.01	3.60ab±0.23	1,312.32	15.31	–7.63
60	0.27e±0.01	3.66ab±0.21	1,336.59	14.13	–6.69

Note: The temperature difference is the difference between the maximum and minimum daily temperatures. The mean value is the average soil temperature during the monitoring period. The maximum and minimum values are the maximum and minimum daily mean values since the monitoring. Different letters (a, b, c, d, e) following the data indicate significant differences (P<0.05) in the same column. The results are expressed as mean ± standard error.

4.2 Diurnal Variation Characteristics of Soil Temperature in Different Depth

January, April, July, October from 2017 to 2019, taking the months average in different years, were selected to study the diurnal variation of soil temperature. In order to eliminate the sharp variation of soil temperature by different weather, the mean value at the same time every day for a month was calculated. As shown in Figure 2, diurnal variations of soil temperature decreased with soil depth, remained almost in equilibrium until 30–60 cm, and changed significantly and had the same trend in other soil layers. Temperature of the soil surface reached the peak first, the second was that of 10 cm, also showed hysteresis. In special months, the peak value of soil surface appeared at 16:00, the peaks of 10 cm appeared at 17:00, and the peaks of 20 cm all appeared at 19:00. The peak value in soil surface were 2.9, 15.1, 6.3, 12.4 ℃, the peak value in 10 cm layer were 19.2, 8.8, –4.8, 4.3 ℃, and the peak value in 20 cm layer were 15.5, 5.0, –6.0, 1.9 ℃, respectively, in the four selected months.

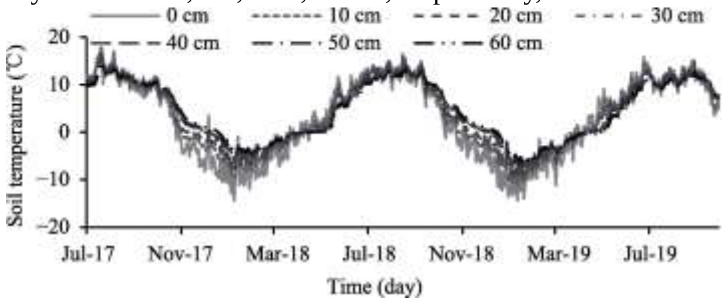

Figure 1 Variation trend of soil temperature with time in each layer

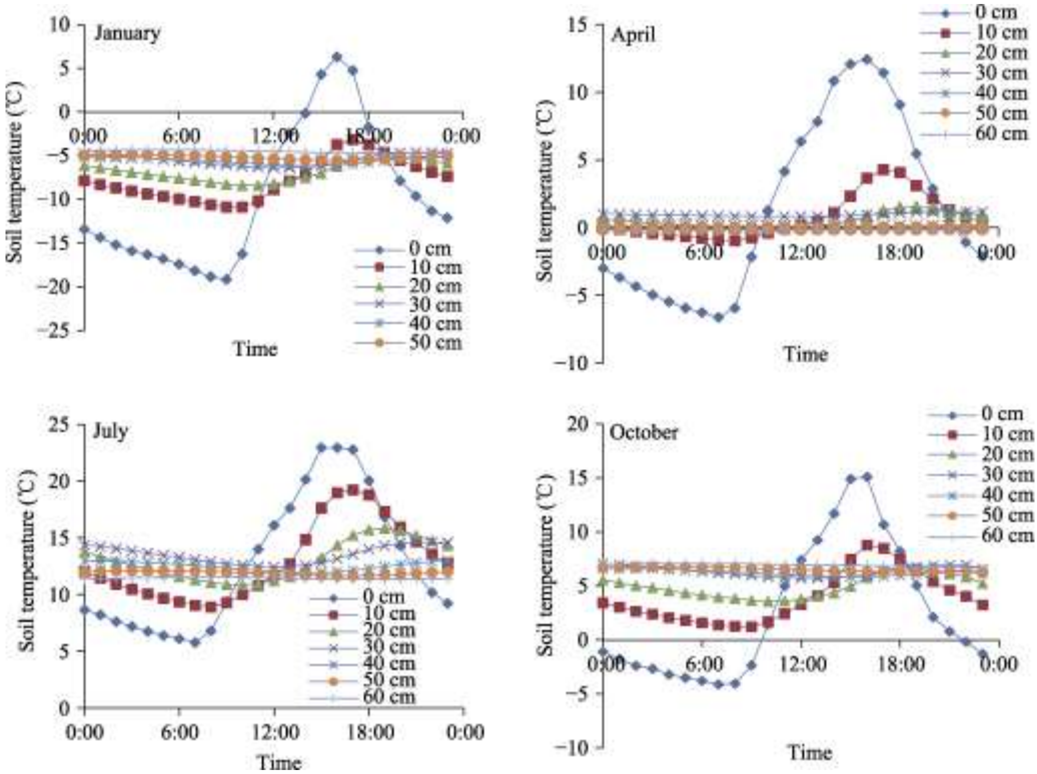

Figure 2 Diurnal variation of soil temperature at different depths

The soil surface temperature also reached the valley value first, which was the same as the peak value rule. In special months, the valley values of 0 cm layer appeared at 7:00 in April, July and October, but the valley value appeared at 9:00 in January. Compared with 0 cm layer, the occurrence time of peaks in 10 cm layer was delayed by one hour, and the valley value in 20 cm layer was delayed by two hours. In special months, the valley value in 0 cm layer were 6.1, –5.4 , –18.7, –6.9 ℃, the valley value in 10 cm layer were 9.1, 0.4, –11.6, –1.1 ℃, and the valley value in 20 cm layer were 10.8, 2.6, –9.4, 0.1 ℃, respectively.

4.3 Relationship Between Soil Temperature and Meteorological Factors

4.3.1 Soil Surface Temperature and Air Temperature

Surface temperature is an important parameter for the interaction between atmosphere and soil, and can characterize the surface heat source. As shown in Figure 3, the fluctuation of the soil and air temperature was consistent with time, showing a similar trend of sine and cosine. Soil temperature was slightly higher than air temperature, and the temperature difference was 1.0–5.5 ℃. From December 2017 to September 2018, the difference between soil and air temperature was large, in the range of 2.5–5.5 ℃, and the difference in other months was within 2.5 ℃. By fitting the soil temperature and air temperature variation curves, the air and soil temperature amplitude were 12.5 ℃ and 10.8 ℃, respectively. Air temperature changes more significantly than soil temperature. The reason may be that the dense grass on the surface increases the heat capacity of the soil, or the surface and deep soil temperature transfer each other, so that led to the result.

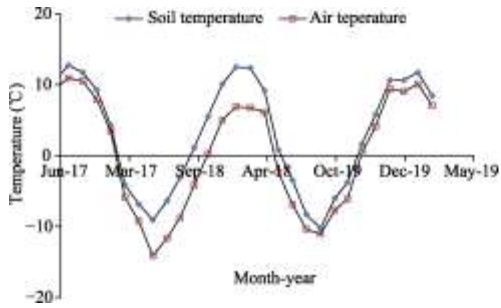

Figure 3 Dynamics of soil surface temperature and air temperature

4.3.2 Soil Surface Temperature and Air Humidity

According to Figure 4, air humidity corresponded to soil temperature. The air humidity was the highest in the summer, which could reach more than 80%, and the lowest in the winter, about 20%. However, the air humidity in the winter of 2018 was higher than that the same period in other years, which may be due to the measures of regular spray. The purpose of this measure was to investigate the winter survival of the plant.

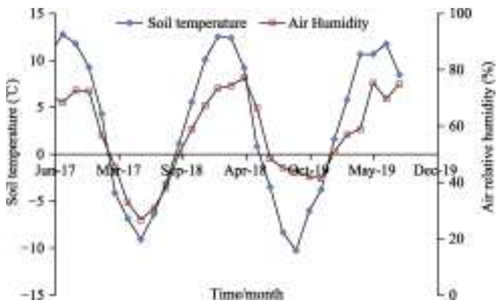

Figure 4 Dynamics of soil surface temperature and air humidity

4.3.3 Soil Surface Temperature and Cumulative Solar Radiation

Figure 5 showed the variations of solar radiation and daily soil temperature over time. It can be seen that solar radiation and soil temperature showed periodic fluctuation, the variation range of total radiation is large. Compared with the soil temperature, the total radiation had some advance, which indicated the change of soil temperature caused by a certain amount of solar radiation.

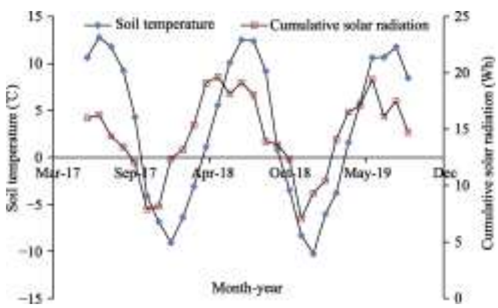

Figure 5 Dynamics of soil surface temperature and cumulative solar radiation

4.3.4 Soil Surface Temperature and Precipitation

It can be seen from Figure 6 that the rainfall mainly occurred from May to October. During that period, the fluctuation of monthly rainfall and soil temperature was consistent and tended to be synchronous. From November to April of the following year, the local rainfall was approximately 0 mm, so it was more accurate to consider the relationship between rainfall and soil temperature in the growing period without considering the relationship between rainfall and soil temperature in this period.

4.3.5 Soil Surface Temperature and Wind Speed

Wind speed is a very uncertain factor and varies from season to season. As shown in Figure 7, wind speed and soil temperature fluctuated with time, and the wind speed changed more randomly. However, it can be seen that the soil temperature was high and the wind speed was low in summer, while the soil temperature was low and the wind speed was high in winter. Figure 8 showed the variation of wind speed at different moments in four seasons. The wind speed from 0:00 to 11:00 had no change basically, and maintained at 0.6–1.4 m s^{-1}. From 12:00 to 24:00, the wind speed gradually increased and reached the maximum at 16:00, then gradually decreased with time. The peak wind speed in winter and spring was about 1 m s^{-1} higher than that in summer and autumn. Overall, the changes in soil temperature and wind speed in each season are consistent and synchronous. Therefore, it is reasonable to consider the daily wind speed and soil temperature, to eliminate the rule covering caused by the random variation of daily wind speed.

4.3.6 Soil Surface Temperature and Atmosphere

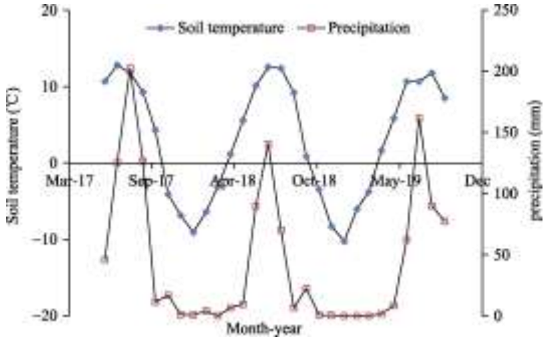

Figure 6 Dynamics of soil surface temperature and precipitation

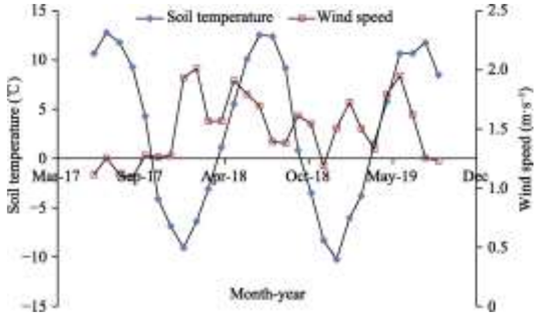

Figure 7 Dynamics of soil surface temperature and wind speed

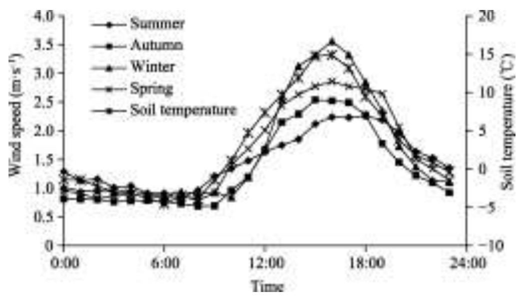

Figure 8 Dynamics of wind speed and soil surface temperature in one day

The daily average maximum pressure in Nagqu region was 594 hPa on October 30, 2018, and the minimum was 571 hPa on January 26, 2018 (Figure 9). The local atmospheric pressure was between 571–594 hPa, and the average pressure value was 585 hPa, which was 58.5% of the standard atmospheric pressure. The air pressure was lower in winter and higher in summer, which was the opposite of inland areas. The change in atmospheric pressure was consistent with the change of soil temperature.

4.4 The Analysis and Test of Correlation Between Meteorological Factors and Soil Temperature

According to correlation analysis (Table 3), air temperature, humidity, cumulative solar radiation, rainfall and atmospheric pressure were significantly correlated with soil temperature, with correlation coefficients of 98%, 91%,72%, 75% and 84%, respectively. Partial correlation analysis reflects the linear correlation between two variables separately. It showed that air temperature, cumulative solar radiation, rainfall and atmospheric pressure were significantly correlated with soil temperature, with partial correlation coefficients of 88%, 71%, 47% and 42% respectively, while wind speed and air humidity were not correlated with soil temperature.

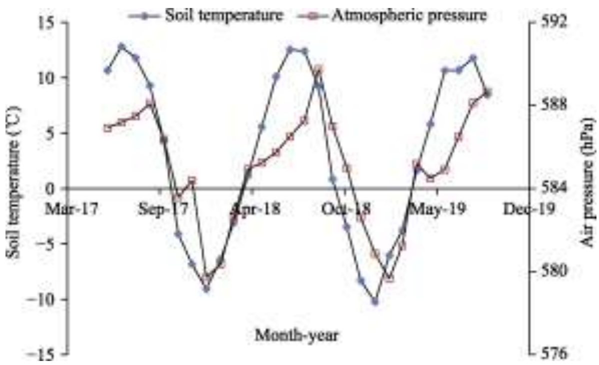

Figure 9 Dynamics of soil surface temperature and atmosphere

Table 3 Correlation coefficients of meteorological factors and soil temperature

Meteorological factors	Correlation coefficients	Partial correlation coefficients
Air temperature	0.98**	0.88**
Air humidity	0.91**	–0.01
Cumulative solar radiation	0.72**	0.71**
rainfall	0.75**	0.47**
Wind speed	–0.21	0.30
Atmosphere	0.84**	0.42*

Note: Df=33; * represents a significant bilateral correlation at the 0.05 level, ** represents a significant bilateral correlation at the 0.01 level.

5 Discussion

5.1 The Variation Trend of Soil Temperature

The results showed that soil temperature in alpine and high-altitude areas had a similar periodic trend of sine and cosine, with a maximum amplitude of 15.7 ℃, which is consistent with the results on soil temperature variation trends in other regions of China[15–18], but slightly different in oscillation period and amplitude. Qi *et al.*[19] monitored 22 stations on the Changtang Plateau, and compared with this paper, the difference in diurnal and monthly changes was 1.2–1.6 ℃. The differences may be caused by different time scales of data monitoring, differences in latitude and longitude or surface vegetation[20]. In January, April, July and October, the soil temperature showed a law of large difference in winter and small difference in summer, the main reason is that the sunshine duration is longer in summer than in winter in Nagqu region, and the energy received by the soil is different. In addition, the soil type is alpine meadow, with more gravel under the soil, and the specific heat capacity of the soil is small, leading to a large change in the day-night temperature. On the spatial scale, the mean temperature of each layer in soil showed a tendency of increasing first and then decreasing with increasing soil depth. In four special months, the temperature amplitude of different soil layers decreased with the increase of depth, and the lag time of peak-valley variation become longer with the increase of depth, the lag time increased by about 1 h for every 10 cm increase of depth.

5.2 The Relationship Between Meteorological Factors and Soil Temperature

The correlation coefficient between soil temperature and air temperature was 98% in Naqu region, In comparison, the correlation coefficient between air temperature and soil surface temperature in China was 93%[21]. In terms of the relationship between air and soil temperature, the response of air temperature was stronger than soil temperature, and the fluctuation was larger, which was consistent with the results on Alxa[22]. However, Yang *et al.*[23] found that the ground temperature change in western China was more intense than the air temperature, which may be due to the unique climate and complex topography in alpine and high-altitude areas, and the different monitoring scales, but the correlation of air and soil was independent of these factors. Therefore, to get a good relationship, more *in situ* monitoring should be set up to study further the relationship between soil and air temperature in different time scales. Many researchers have pointed out that air temperature is the main reason for the rise of soil temperature[24–26]. The air temperature and soil temperature are mutually influenced, and heat is always transferred spontaneously from the side with high temperature to the side with low temperature. So it is untenable to say that air temperature is the most important factor affecting soil temperature[27]. The soil temperature at different depths had a good correlation with air temperature, which becomes more closely related to the increase of soil depth[28].

In general, the more precipitation, the higher the air humidity. In this study, the correlation coefficients of precipitation, air humidity and soil temperature were 75% and 91% respectively, showing a significant positive correlation. This result is supported by some studies, such as Zhao *et al.*[29], who concluded that soil temperature and precipitation were significantly positively correlated at the level of 0.01 in the study of hilly red soil region. It showed that precipitation was one of the important factors affecting soil temperature, but the influence level varies in different regions. However, Luo *et al.*[30] found that precipitation was not correlated with a ground temperature of 5 cm in the study of Ulan Buh Desert. It may be that the desert has a large temperature difference between day and night, with intense light and little precipitation, thus masking the correlation between precipitation and soil temperature. The results of Meng *et al.*[31] showed that the influence of precipitation in Yunnan on soil temperature was mainly manifested in summer, showing a significant negative correlation. Except for summer, precipitation in other seasons had little correlation with soil temperature. Zhang *et a*l.[32] continuously measured the soil temperature in different microhabitats of the dominant sand-fixing shrub *Caragana* community in arid regions, and the results showed that the soil temperature was mainly affected by precipitation, which significantly reduced the soil temperature. Because precipitation is an unstable factor, and this paper was studied on the scale of the whole year, avoiding the result deviation caused by a short period of research, and need continue to study.

Solar radiation is the primary source of soil heat[26], which directly affects soil temperature. The correlation between soil temperature and solar radiation intensity in Nagqu was 72% (P<0.01). An *et al.*[33] studied the mechanism of water and heat transfer and its relationship with meteorological factors at the soil-gas interface in xi'an arid region, and the positive correlation was confirmed by the analysis model. Wei *et a*l.[34] conducted a solar radiation simulation experiment in Fujian province, and also obtained a significant relationship between solar radiation and soil temperature, with a correlation coefficient of 62.2%. Therefore, solar radiation has an essential influence on soil temperature in Tibet.

There are few studies on the relationship between atmospheric pressure and soil temperature, especially in the environment of low pressure and high wind in Nagqu. In this study, the correlation coefficient between atmospheric pressure and soil temperature was 84%, showing a positive correlation. The main reason was the height of the underlying surface in Tibet (about 4,500 m). The atmosphere was the same as the upper air in the inland region, The thin air made the higher the pressure, the higher the temperature will be[35]. The partial correlation coefficient of the two was 42%, indicating that atmospheric pressure and soil temperature in the Nagqu area also reached a significant level without considering other environmental factors. The temperature increased, and the pressure increased. The correlation between wind speed and soil temperature is not significant, contrary to the research results of Zhao[29] in Jiangxi province and Yu *et al.*[36] in Xilinhot, which may be caused by the special environment of Tibet.

6 Conclusion

Based on the analysis of monitoring data from June 2017 to September 2019, the conclusions are drawn as follows:

In terms of time distribution, the soil temperature presented periodic changes in the form of sine and cosine between −15 ℃ and 17.5 ℃, and it changed abruptly in October, with a rapid decrease of 13.9 ℃. The change of day-night temperature of soil also showed the change of sine and cosine. Different soil layers had different peak-valley values at different times. With every 10 cm increase in soil depth, the lag time increased by about 1 h. January was the month with the greatest variation in temperature between day and night. In terms of spatial distribution, the annual mean temperature and cumulative temperature of soil first increased then decreased with the increase of depth, and the turning depth was 30 cm. The variation coefficient of temperature in different soil layers decreased with the increase of depth.

The order of the influence of meteorological index on soil temperature was air temperature > air humidity > atmospheric pressure > cumulative solar radiation > rainfall > wind speed. Among them, air temperature, rainfall, air humidity, solar radiation and atmospheric pressure were significantly positively correlated. The correlation coefficients of air temperature, air humidity, cumulative solar radiation, rainfall and atmospheric pressure were 98%, 91%, 72%, 75% and 84%, respectively.

Author Contributions

Yang, H. B. and Yu, X. D. collated and analyzed soil and meteorological data. Yang, H. B. wrote the data paper. Li, H. T. and Zhao, J. L. provided guidance on data analysis verification and article writing. Fu, H. M., Yu, X. D. and Xu, W. revised and reviewed the draft.

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