Soil Temperature and Moisture Forecasting Using Exponential Smoothing Method Based on Mean Absolute Percentage Error

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Abstract

Soil is an essential medium for almost all plants. Temperature and moisture in the soil become one of the factors that affect plant growth. Unbalanced or unfavorable soil conditions will adversely affect the plant. Therefore, soil conditions, including temperature and moisture, must be monitored to maintain plant health. Forecasting can be used to find out the soil condition in the future so that strategies can be prepared to deal with these conditions. This forecasting is carried out based on existing soil temperature and moisture data, which is then processed using the single exponential smoothing method and mean absolute percentage error as a reference for the error rate or accuracy of the forecasting. The application of these methods succeeded in producing forecasting with very good overall accuracy.

1. INTRODUCTION

Soil serves as a vital substrate for plant growth due to its provision of essential nutrients required for the process of photosynthesis, including minerals, organic matter, water, and air [1, 2]. Plants exhibit optimal growth and productivity when cultivated in suitable soil conditions [3]. Soil quality can be affected by various physical parameters, including temperature and moisture. Soil temperature can affect soil moisture, enzymes in the soil, and the availability of nutrients in the soil [4]. Soil temperature is influenced by several factors, such as climate, soil surface slope, soil color, and geographical location [5]. Putri in [6] explained that temperature is an essential factor in the life of organisms, and temperature changes strongly influence physiological and biological processes. Another no less critical parameter is soil moisture. Soil moisture can affect the distribution of plant roots, the rate of photosynthesis, and the growth of these plants [7, 8]. Good soil moisture and temperature give the soil enough pore space so air circulation can run well [9]. Optimum soil moisture and temperature are essential to increase crop production and water productivity [10], affect the microbial activity and soil biota [11], affect high and low soil pH [9] and decomposition of organic matter [12]. In the early and vegetative phases, plants require high moisture because they need enough water to grow roots, stems, and leaves. While in the end-of-season growth phase, plants need dry-level moisture so that water saving can be done [10]. The lack of soil moisture level can cause wilting in plants. The importance of temperature and soil moisture requires farmers to take appropriate steps to maintain plant health.

The importance of soil moisture and temperature results in the need to monitor both aspects. The process of manual measurement might be intricate and lacking in efficiency. Conventional techniques, such as visual observation, periodic measurement using traditional measuring devices, or checking manually by putting a finger into the soil to a depth of up to 0.4 cm [13] require substantial investments of time, labour, and personnel. Furthermore, the manual approach lacks the capability to offer real-time monitoring, which is crucial for quick decision-making [14]. In addition to manual monitoring, the integration of Internet of Things (IoT) technology offers an alternative approach. The Internet of Things (IoT) is a technical innovation that encompasses several components of intelligent systems, frameworks, smart devices, and sensors [15]. It offers a notable benefit in the form of facilitating remote monitoring and control operations [16-19]. Prior studies have demonstrated the utilization of Internet of Things (IoT) technology for the purpose of monitoring soil temperature and moisture levels. Marcos and Muzaki [3] conduct soil temperature and moisture monitoring using NodeMCU microcontroller that are equipped with temperature sensor, soil moisture sensor, and a water pump that activates when the soil reaches a certain level of dryness. Other research conducted by Fitrianto and Sari [20] employs the Arduino Uno microcontroller alongside the DS18B20 temperature sensor and YL-69 soil moisture sensor to effectively monitor soil temperature and moisture levels. Another study that uses DS18B20 sensor is a study conducted by Thoriq, et al. [21], where the difference is that they use ESP32 microcontroller. All of these previous studies have consistently demonstrated the beneficial outcomes related with the use of Internet of Things (IoT) technology in monitoring soil temperature and moisture levels. This technological approach holds significant potential in assisting farmers with the crucial task of preserving optimal plant health.

This research involves the forecasting of temperature and soil moisture conditions using data collected from a soil monitoring instrument based on the Internet of Things (IoT). The tool uses a NodeMCU microcontroller, which is accompanied by a DS18B20 temperature sensor, and a YL-69 soil moisture sensor. Data obtained from the sensor is sent by the microcontroller to the database so that it can be processed. The DS18B20 sensor is used because its comparatively low error rate of about 0.35% when compared to the actual temperature [22].

2. RESEARCH METHOD

This study used an IoT-based soil monitoring method to collect soil temperature and moisture data at Campus V JPTK UNS. The data was collected throughout a 12-hour period on July 4, 2022, specifically from 13:00 to 24:00, and subsequently stored in a database.

Figure 1. IoT-based soil monitoring tool

Data processing and forecasting are carried out using the Exponential Smoothing method. Makridakis in [23] explained that the Exponential Smoothing method is a procedure for continuous improvement in forecasting the latest observation objects. This forecasting method focuses on decreasing priority exponentially in older objects of observation. There are one or more explicitly defined smoothing parameters in exponential smoothing, and these results determine the weight imposed on the observed value. In other words, recent observations will be given higher priority to forecasting than older observations. The exponential smoothing method is further divided into several methods, one of them is Single Exponential Smoothing. As explained by Astuti in [24], the Single Exponential Smoothing method is a predictive analysis method where the data used is considered to be constantly changing around a fixed mean with a consistent growth pattern. The equation used in the Single Exponential Smoothing method can be seen in equation (1).

$$F_t = aX_t + (1 - a)F_{t-1} \quad (1)$$

Where:
F_t = forecast value in data t
X_t = actual value at time t-1
F_{t-1} = forecast value at time t-1
α = smoothing constant

This study also used the Mean Absolute Percentage Error (MAPE) method to calculate the level of forecasting accuracy. According to Kim and Kim [25], Mean Absolute Percentage Error (MAPE) is the mean value of absolute differentiation between forecast and actual value. It is used to determine the forecasting error rate. Chang in [24] states that MAPE is expressed as a percentage value. The equation used to calculate MAPE can be seen in equation (2), and the criteria can be seen in Table 1.

$$MAPE = \frac{100}{n}\,\Sigma\,\frac{|A_t - F_t|}{A_t} \quad (2)$$

Where:
A_t = actual value in data t
F_t = forecast value in t
N = data periods quantity

Table 1. MAPE criteria [24]

MAPE	Criteria
> 50%	Bad
20% - 50%	Enough
10% - 20%	Good
< 10%	Very Good

3. RESULT AND DISCUSSION

Data processing and forecasting are carried out using Single Exponential Smoothing with two smoothing constants of 0.3 and 0.5. Additionally, the Mean Absolute Percentage Error (MAPE) is employed to evaluate the accuracy of the forecasting level.

Table 2. Soil temperature and moisture dataset

Time	Soil Temperature (°C)	Soil Moisture (%)
13.00	26,44	10,74
14.00	26,31	9,96
15.00	26,25	9,57
16.00	26,06	9,08
17.00	25,88	8,01
18.00	25,69	8,01
19.00	25,56	7,62
20.00	25,63	7,03
21.00	25,5	7,71
22.00	25,44	7,13
23.00	25,44	7,32
24.00	25,75	6,84

The results of dataset processing using the Single Exponential Smoothing method with smoothing constants of 0.3 and 0.5 can be seen in Table 3 for temperature and Table 4 for moisture. Additionally, the comparative visualization of actual data and forecast data is shown in Figure 2 for temperature and Figure 3 for moisture.

Table 3. Temperature data processing result

Time	Temperature (°C)		
	Actual Value	Forecast Value, Ft + 1	
		α = 0,3	α = 0,5
13.00	26.44		
14.00	26.31	26.44	26.44
15.00	26.25	26.40	26.38
16.00	26.06	26.36	26.31
17.00	25.88	26.27	26.19
18.00	25.69	26.15	26.03
19.00	25.56	26.01	25.86
20.00	25.63	25.88	25.71
21.00	25.50	25.80	25.67
22.00	25.44	25.71	25.59
23.00	25.44	25.63	25.51
24.00	25.75	25.57	25.48
01.00		25.63	25.61

Table 4. Moisture data processing result

Time	Moisture (%)		
	Actual Value	Forecast Value, Ft + 1	
		α = 0,3	α = 0,5
13.00	10.74		
14.00	9.96	10.74	10.74
15.00	9.57	10.51	10.35
16.00	9.08	10.23	9.96
17.00	8.01	9.88	9.52
18.00	8.01	9.32	8.77
19.00	7.62	8.93	8.39
20.00	7.03	8.53	8.00
21.00	7.71	8.08	7.52
22.00	7.13	7.97	7.61
23.00	7.32	7.72	7.37
24.00	6.84	7.60	7.35
01.00		7.37	7.09

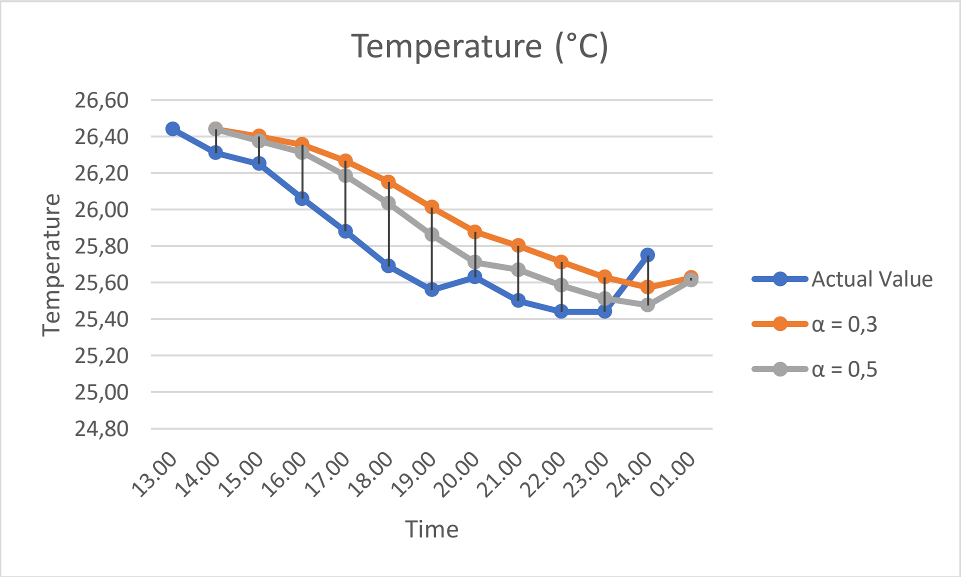

Figure 2. Actual and forecast temperature value comparison

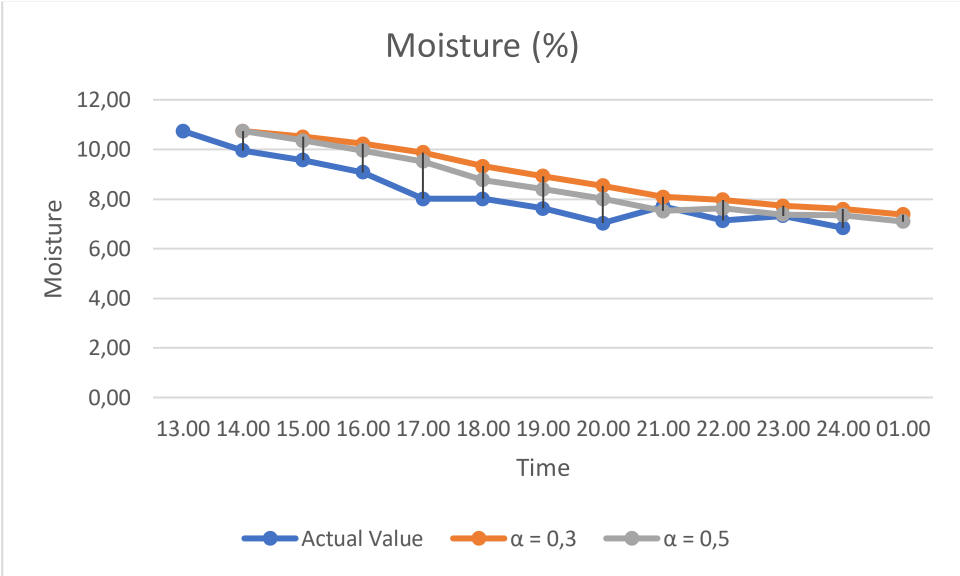

Figure 3. Actual and forecast moisture value comparison

In the following step, the calculation of the Mean Absolute Percentage Error (MAPE) is conducted to determine the degree of accuracy in forecasting. The findings regarding temperature are presented in Tables 5 and 6, while Tables 7 and 8 show the data related to moisture.

Table 5. MAPE for temperature forecast with α = 0,3

Time	Error	Absolute Error	Absolute Error/Actual Value
13.00			
14.00	-0.13	0.13	0.005
15.00	-0.151	0.151	0.006
16.00	-0.296	0.296	0.011
17.00	-0.387	0.387	0.015
18.00	-0.461	0.461	0.018
19.00	-0.453	0.453	0.018
20.00	-0.247	0.247	0.01
21.00	-0.303	0.303	0.012
22.00	-0.272	0.272	0.011
23.00	-0.19	0.19	0.007
24.00	0.177	0.177	0.007
Total			0.119
n			11
MAPE (%)			1.083490231

Table 6. MAPE for temperature forecast with α = 0,5

Time	Error	Absolute Error	Absolute Error/Actual Value
13.00			
14.00	-0.13	0.13	0.005
15.00	-0.125	0.125	0.005
16.00	-0.253	0.253	0.01
17.00	-0.306	0.306	0.012
18.00	-0.343	0.343	0.013
19.00	-0.302	0.302	0.012
20.00	-0.081	0.081	0.003
21.00	-0.17	0.17	0.007
22.00	-0.145	0.145	0.006
23.00	-0.073	0.073	0.003
24.00	0.274	0.274	0.011
Total			0.085
n			11
MAPE (%)			0.776402204

Table 7. MAPE for moisture forecast with α = 0,3

Time	Error	Absolute Error	Absolute Error/Actual Value
13.00			
14.00	-0.78	0.78	0.078
15.00	-0.936	0.936	0.098
16.00	-1.145	1.145	0.126
17.00	-1.872	1.872	0.234
18.00	-1.31	1.31	0.164
19.00	-1.307	1.307	0.172
20.00	-1.505	1.505	0.214
21.00	-0.373	0.373	0.048
22.00	-0.841	0.841	0.118
23.00	-0.399	0.399	0.055
24.00	-0.759	0.759	0.111
Total			1.417
n			11
MAPE (%)			12.88233304

Table 8. MAPE for moisture forecast with α = 0,5

Time	Error	Absolute Error	Absolute Error/Actual Value
13.00			
14.00	-0.78	0.78	0.078
15.00	-0.78	0.78	0.082
16.00	-0.88	0.88	0.097
17.00	-1.51	1.51	0.189
18.00	-0.755	0.755	0.094
19.00	-0.767	0.767	0.101
20.00	-0.974	0.974	0.139
21.00	0.193	0.193	0.025
22.00	-0.483	0.483	0.068
23.00	-0.052	0.052	0.007
24.00	-0.506	0.506	0.074
Total			0.953
n			11
MAPE (%)			8.660131588

The use of Single Exponential Smoothing and Mean Absolute Percentage Error (MAPE) in the forecasting process reveals that temperature forecasting with α values of 0.3 and 0.5 achieves MAPE values of 1.08% and 0.77% respectively. These results are considered very good based on the MAPE criteria. Whereas the moisture forecasting models with α values of 0.3 and 0.5 show Mean Absolute Percentage Error (MAPE) values of 12.88% and 8.66%, respectively. These values are considered to be good and very good forecasting accuracy. Among the two employed smoothing constant values, it was shown that utilising α = 0.5 produced better forecasting outcomes as indicated by the derived Mean Absolute Percentage Error (MAPE) values. This finding shows a similar outcome with the study conducted by Anggraeni and Maulina [26], indicating that larger values of the smoothing constant lead to lower MAPE values, hence indicating improved accuracy in forecasting. However, these findings contradict the research conducted by Sarbaini and Safitri [27], as their study revealed that the use of greater values for the smoothing constant resulted in a proportionally higher MAPE value. In general, the Single Exponential Smoothing method is considered to be a reliable approach for forecasting [26-30].

4. CONCLUSION

This research demonstrates the utilization of Exponential Smoothing, specifically Single Exponential Smoothing, as a technique to forecast soil temperature and moisture. The Mean Absolute Percentage Error (MAPE) is employed to evaluate the accuracy of the forecasts. The implementation of these methodologies proved to be effective in generating forecasts with a high level of accuracy across several metrics. The acquired MAPE values indicate that the soil temperature forecast produced tiny values of 1.08% and 0.77%, while the soil moisture forecasting resulted in values of 12.88% and 8.66%. These forecasts were conducted twice, using smoothing constants (α) of 0.3 and 0.5. The findings of the forecast indicate a decrease in both temperature and moisture levels at the designated time compared to the initial values. The model has the capability to provide future predictions outside the scope of the available dataset. In this particular instance, the forecast indicates a temperature of 26.63°C and a moisture level of 7.37% (α = 0.3) or a temperature of 25.61°C and a moisture level of 7.09% (α = 0.5) in the 1 a.m. time period. This study has the potential to assist farmers in developing strategies for maintaining plant health.

This study primarily employed the simple exponential smoothing (SES) method, utilising different smoothing constants (α) values. Therefore, it is advisable for future research to explore alternative methods in order to identify the optimal approach.

REFERENCES

[1] R. Syofiani, S. D. Putri, and N. Karjunita, "Karakteristik sifat tanah sebagai faktor penentu potensi pertanian di Nagari Silokek Kawasan Geopark Nasional," *Jurnal Agrium,* vol. 17, no. 1, 2020, doi: 10.29103/agrium.v17i1.2349.

[2] E. Handayanto, N. Muddarisna, A. Fiqri, U. B. Press, U. Media, and Z. Kusuma, *Pengelolaan Kesuburan Tanah*. Universitas Brawijaya Press, 2017.

[3] H. Marcos and H. Muzaki, "Monitoring Suhu Udara Dan Kelembaban Tanah Pada Budidaya Tanaman Pepaya," *Jurnal Teknologi dan Sistem Tertanam,* vol. 3, no. 2, 2022, doi: 10.33365/jtst.v3i2.2200.

[4] L. Lutfiyana, N. Hudallah, and A. Suryanto, "Rancang Bangun Alat Ukur Suhu Tanah, Kelembaban Tanah, dan Resistansi," *2017,* vol. 9, no. 2, p. 7, 2017-12-31 2017, doi: 10.15294/jte.v9i2.11087.

[5] G. D. Winarno, S. P. Harianto, and R. Santoso, *Klimatologi Pertanian*. Pusaka Media, 2019, p. xii + 134.

[6] R. Hasibuan, H. Irawan, and T. Yulianto, "The effect of temperature on hatched of seabass egg. Intek Akuakultur, 2 (2): 49-57," ed, 2018.

[7] W. Shi, S. Zhang, M. Wang, and W. Zheng, "Design and performance analysis of soil temperature and humidity sensor," *IFAC-PapersOnLine,* vol. 51, no. 17, pp. 586-590, 2018, doi: 10.1016/j.ifacol.2018.08.134.

[8] L. Scheberl, B. C. Scharenbroch, L. P. Werner, J. R. Prater, and K. L. Fite, "Evaluation of soil pH and soil moisture with different field sensors: Case study urban soil," *Urban Forestry & Urban Greening,* vol. 38, pp. 267-279, 2019, doi: 10.1016/j.ufug.2019.01.001.

[9] H. Karamina, W. Fikrinda, and A. Murti, "Kompleksitas pengaruh temperatur dan kelembaban tanah terhadap nilai pH tanah di perkebunan jambu biji varietas kristal (Psidium guajava l.) Bumiaji, Kota Batu," *Kultivasi,* vol. 16, no. 3, 2017, doi: 10.24198/kltv.v16i3.13225.

[10] C. Arif, B. I. Setiawan, and M. Mizoguchi, "Penentuan kelembaban tanah optimum untuk budidaya padi sawah SRI (System of Rice Intensification) menggunakan algoritma genetika," *Jurnal Irigasi,* vol. 9, no. 1, pp. 29-40, 2014, doi: 10.31028/ji.v9.i1.29-40.

[11] S. Pathan, L. Aylmore, and T. Colmer, "Reduced leaching of nitrate, ammonium, and phosphorus in a sandy soil by fly ash amendment," *Soil Research,* vol. 40, no. 7, pp. 1201-1211, 2002, doi: 10.1071/SR02019.

[12] A. Astuti, "Aktivitas proses dekomposisi berbagai bahan organik dengan aktivator alami dan buatan," *Jurnal Ilmu Pertanian,* vol. 13, no. 2, pp. 92-104, 2005.

[13] A. I. Wicaksono, "PENERAPAN TEKNOLOGI GARDEN BONSAI UNTUK MENDETEKSI KELEMBABAN TANAH DALAM PENYIRAMAN OTOMATIS, SENSOR GERAK MALING DAN CCTV BERBASIS IoT (INTERNET OF THINGS) MENGGUNAKAN ENERGI ALTERNATIF PANEL SURYA," *Jurnal Aplikasi Teknologi Informasi dan Manajemen (JATIM),* vol. 3, no. 2, pp. 165-177, 2022, doi: 10.31102/jatim.v3i2.1704.

[14] M. R. Firmansyah and F. Tasqia, "Pengukuran Kelembapan Tanah Berbasis IoT pada Greenhouse," *Prosiding Patriot Mengabdi,* vol. 2, no. 01, pp. 331-346, 2023.

[15] S. Kumar, P. Tiwari, and M. Zymbler, "Internet of Things is a revolutionary approach for future technology enhancement: a review," *Journal of Big Data,* vol. 6, no. 1, pp. 1-21, 2019/12// 2019, doi: 10.1186/S40537-019-0268-2.

[16] V. Ahmed and S. A. Ladhake, "Innovative cost effective approach for cell phone based remote controlled embedded system for irrigation," *Proceedings - 2011 International Conference on Communication Systems and Network Technologies, CSNT 2011,* pp. 419-422, 2011, doi: 10.1109/CSNT.2011.93.

[17] M. S. Hossain, M. Rahman, M. T. Sarker, M. E. Haque, and A. Jahid, "A smart IoT based system for monitoring and controlling the sub-station equipment," *Internet of Things,* vol. 7, 2019/9// 2019, doi: 10.1016/j.iot.2019.100085.

[18] R. Raja Singh *et al.*, "IoT embedded cloud-based intelligent power quality monitoring system for industrial drive application," *Future Generation Computer Systems,* vol. 112, pp. 884-898, 2020/11// 2020, doi: 10.1016/j.future.2020.06.032.

[19] R. T. Ugale and K. B. Chavhan, "Web-based Automated Electric Machine Test-bench with Data Acquisition and Remote Control," presented at the IEEE International Conference on Power Electronics, Drives and Energy Systems, PEDES 2016, India, 14-17 December 2016, 2017.

[20] D. Fitrianto and C. Sari, "Rancang Bangun Alat Ukur Suhu Dan Kelembaban Tanah Menggunakan Arduino Uno Dengan Perhitungan Mape (Mean Absolute Percentage Error) Pada Lahan Perkebunan," *ELECTRA: Electrical Engineering Articles,* vol. 3, no. 01, pp. 19-27, 2022, doi: 10.25273/electra.v3i01.13642.

[21] A. Thoriq, L. H. Pratopo, R. M. Sampurno, and S. H. Shafiyullah, "Rancang Bangun Sistem Monitoring Suhu dan Kelembaban Tanah Berbasis Internet of Things," *Jurnal Keteknikan Pertanian,* vol. 10, no. 3, pp. 268-280, 2022, doi: 10.19028/jtep.010.3.268-280.

[22] W. D. Meilianto, W. Indrasari, and E. Budi, "Karakterisasi Sensor Suhu dan Kelembaban Tanah untuk Aplikasi Sistem Pengukuran Kualitas Tanah," in *PROSIDING SEMINAR NASIONAL FISIKA (E-JOURNAL)*, 2022, vol. 10.

[23] A. Raharja and W. Angraeni, "Penerapan Metode Exponential Smoothing Untuk Peramalan Penggunaan Waktu Telepon Di PT. Telkomsel Divre3 Surabaya," 2010.

[24] K. J. Atmaja and I. B. G. Anandita, "Sales forecasting system using single exponential smoothing," *Jurnal Mantik,* vol. 4, no. 4, pp. 2552-2557, 2021.

[25] S. Kim and H. Kim, "A new metric of absolute percentage error for intermittent demand forecasts," *International Journal of Forecasting,* vol. 32, no. 3, pp. 669-679, 2016/07/01/ 2016, doi: 10.1016/j.ijforecast.2015.12.003.

[26] D. P. Anggraeni and R. Maulina, "Metode Single Exponential Smoothing (SES) pada Peramalan Tingkat pengangguran terbuka Terbuka di Indonesia," *Evolusi: Journal of Mathematics and Sciences,* vol. 6, no. 2, pp. 111-120, 2022.

[27] S. Sarbaini and E. Safitri, "Penerapan Metode Single Exponential Smoothing dalam Memprediksi Jumlah Peserta Pelatihan Masyarakat," *Lattice Journal: Journal of Mathematics Education and Applied,* vol. 2, no. 2, pp. 103-117, 2022, doi: 10.30983/lattice.v2i2.5937.

[28] J. N. A. Aziza, "Perbandingan Metode Moving Average, Single Exponential Smoothing, dan Double Exponential Smoothing Pada Peramalan Permintaan Tabung Gas LPG PT Petrogas Prima Services," *Jurnal Teknologi dan Manajemen Industri Terapan,* vol. 1, no. I, pp. 35-41, 2022, doi: 10.55826/tmit.v1iI.8.

[29] M. Anshori and D. Widyaningrum, "Peramalan Permintaan Produk Cepat Rusak Dengan Metode Moving Average dan Single Exponential Smoothing," *Jurnal Serambi Engineering,* vol. 7, no. 4, 2022, doi: 10.32672/jse.v7i4.4701.

[30] R. N. Putra, A. Aziz, and A. Zaini, "Implementasi Metode Simple Regresi Linear dan Single Exponential Smoothing untuk Memprediksi Produksi Padi Jawa Timur," *RAINSTEK: Jurnal Terapan Sains & Teknologi,* vol. 5, no. 2, pp. 95-102, 2023.