

Temporal Variation of Tropical Karst Groundwater Suitability for Irrigation in Gremeng Resurgence, Gunungsewu Karst Area, Indonesia

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Abstract. Analysis of groundwater availability for irrigation purposes pertains to not only quantity but also quality. The characteristics of groundwater quality essentially define crop productivity and determine whether or not crops can grow. This research was designed to identify the suitability of karst groundwater for irrigation temporally (in one year), with an example of Gremeng Resurgence in Gunungsewu Karst Region, Indonesia. It drew on data on electrical conductivity and several major ions, such as potassium, magnesium, sodium, and calcium, by analyzing % sodium content (Na%), Sodium Adsorption Ratio (SAR), and groundwater suitability for irrigation using the Wilcox and USSS diagrams. These analyses revealed that the water quality observed varied by seasons owing to the effects of dilution by rain and water-rock interaction in the karst region. However, this temporal variation was not substantial so that the classes of groundwater suitability only ranged between good and excellent, and the salinity hazard levels differentiated into low until medium.

1 Introduction

Pressure on natural resources is currently intensifying as population size grows and climate change impacts accentuate [1]. Multiplying population size must be balanced with an increase in food production [2], but, on the other hand, agricultural areas abutting urban regions continue to shrink as they have been constantly converted into built-up land. Another concerning factor associated with food production is climate change impact, including shifts in seasons, changes in rainfall intensity, and intensifying occurrences of extreme climatic phenomena.

Agricultural land with an irrigation system is among the areas on Earth that can produce food. Although it only accounts for 17% of the total agricultural land worldwide [3], the yields can reach, on average, 40% of the global foodstuff [4]. Nevertheless, this farming practice is also responsible for 70% of the total water used by humans [5], especially in arid areas where irrigation water and groundwater are the main conditions for agriculture.

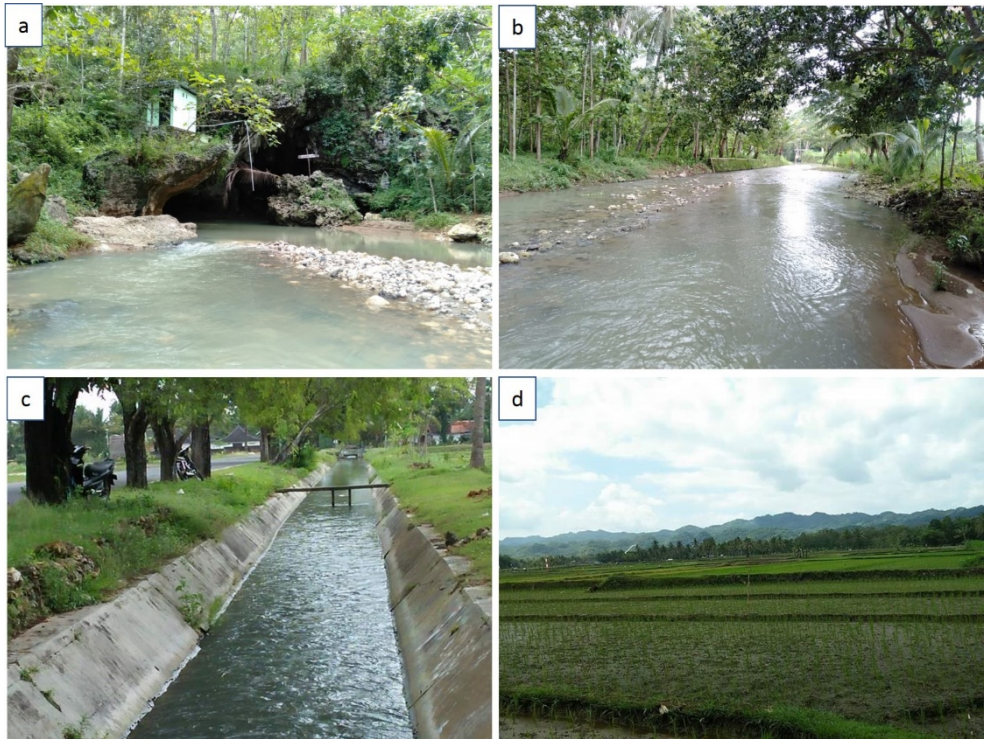
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Sources of water for agricultural irrigation can be classified into three. (1) Green water includes all irrigation water coming from rainwater that is stored temporarily as soil moisture. (2) Blue water is irrigation water sourced from renewable groundwater and surface water, such as rivers, lakes, reservoirs, and wetlands. (3) Non-renewable groundwater and non-local water resources comprise all irrigation water extracted by seawater desalination installations and pumping of fossil groundwater or transported from areas with a great distance, even crossing different groundwater basins and watersheds [6]. Fossil groundwater intake for irrigation is typical in arid regions with little to no precipitation. This source is termed non-renewable groundwater because its extraction exceeds the groundwater recharge in the region or it is not an active part of the hydrological cycle currently taking place in said region.

Groundwater is one of the main sources of irrigation water, especially in arid regions and areas with access to springs producing large discharge. Analysis of groundwater availability for irrigation, however, comprises not only quantity but also quality analysis [7]. In this context, characteristics of groundwater quality strongly determine crop productivity and the ability of crops to live and grow [8]. Besides, a full understanding of these properties is likely to encourage proper groundwater resources management for an accurate, optimum, and efficient allocation. Hydrogeochemical characteristics, which define the state of water quality, include major components in water, soil-water interaction, water-rock interaction in aquifers, dissolved minerals, and influencing anthropogenic activities and interaction time [9, 10, 11, 12,13]. This is possible considering that groundwater quality characteristics are shaped by many factors, such as rainwater or precipitation chemistry, soil properties where infiltration occurs, types of cover or land use, rock constituents of the aquifer, landform genesis (prevailing geomorphological processes), the water residence time in the aquifer, and influencing human activities [14, 15, 16].

Karst groundwater is among the water sources that agricultural irrigation can use. It especially flows from karst springs that have a relatively large discharge and fall into the category of blue water because water utilization and extraction from karst springs are unlikely to exceed the groundwater recharge in the area. However, a study in the tropical karst region in Mexico shows that from a quality standpoint, not all karst groundwater is suitable for irrigation [17]. Also, due to the development of dissolution channels, karst regions have a more dynamic groundwater quality than other landforms. In a highly developed karst area, recharge water flows into the underground river systems rapidly through ponors, sinkholes, and fissure-sized dissolution channels. Therefore, karst groundwater quality analysis needs to incorporate a multi-temporal approach for optimal groundwater utilization [18].

This study was intended to assess the multi-temporal suitability of karst groundwater, with an example of Gremeng Resurgence (Figure 1)—a spring in the Gunungsewu Karst Area. Gremeng Karst Drainage Basin plays a crucial part in irrigating rice fields in Ponjong and Karangmojo Districts, Gunungkidul Regency, the Special Region of Yogyakarta, Indonesia. As for Gremeng Resurgence, it provides water to half of the Beton-Gremeng irrigation system that covers 800 hectares of agricultural land.



Gambar 1. (a.) Gremeng Resurgence, (b.) The River that Flow from Gremeng Resurgence, (c.) Irrigation Channels in the Beton-Gremeng Irrigation System (d.) Irrigated Rice Field in the Beton-Gremeng Irrigation System

2 Methods

2.1 Research Location

The study was conducted at Gremeng Resurgence, one of the largest springs in the Ponjong Sub-system in the Northern-Central Section of the Gunungsewu Karst Area [19] (Figure 2). Administratively, this sub-system is located on the border of the Gunungsewu Karst Area that is adjacent to the Wonosari Basin. Gremeng Resurgence, together with Concrete Resurgence, fulfills the irrigation water needs of all agricultural practices in the Beton-Gremeng irrigation system [20]. It receives water from an allogenic recharge area, approximately 13.25 km, in the ancient volcanic region in the northern part of the Gunungsewu Karst Area.

2.2 Materials and Methods

Based on their focus of measurements and considerations, methods of water suitability analysis for irrigation can be broadly differentiated into four, namely (1) total dissolved salts (salinity hazard), (2) proportion of sodium ions in water to other cations, including the level of sodium hazard and its relation to soil permeability effects, (3) total alkalinity, which is generally highly associated to alkalinity concentration (calcium is combined with magnesium), and (4) concentrations of toxic elements or ions (toxicity) [21]. However, an analysis that factors in several ions, instead of just one, is more advisable [22]. Using more than one method is also suggested to produce better research outcomes and avoid errors in the measurement or content analysis that relies on just one ion.

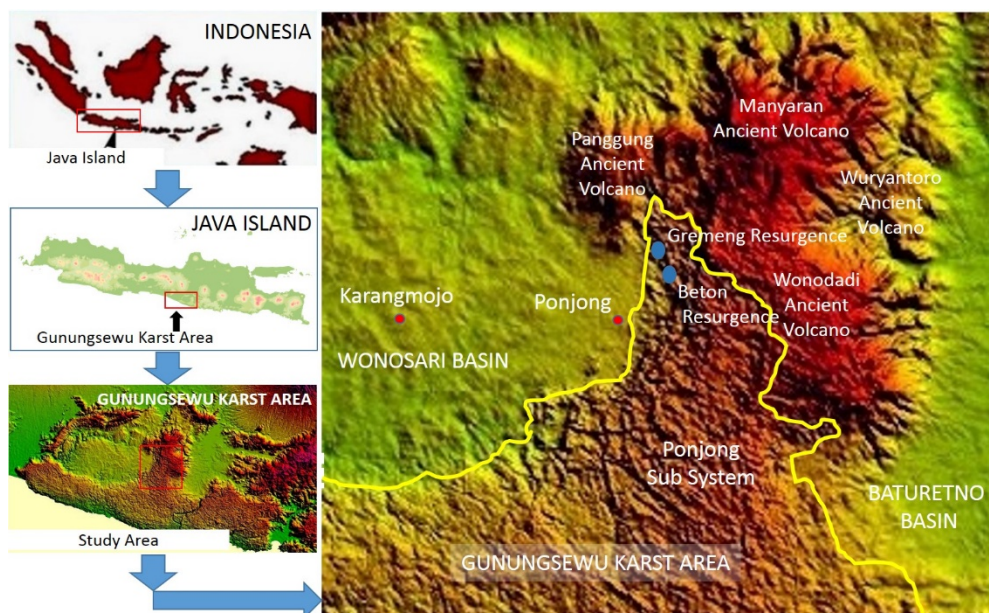


Figure 1. The Location of Gremeng Resurgence

This paper discusses the results of research that used four methods, namely (1) percentage of sodium content (Na%), (2) Sodium Adsorption Ratio (SAR), (3) Groundwater suitability analysis for irrigation with Wilcox Diagram, and (4) Groundwater suitability analysis for irrigation with USSL Diagram. Data collection was carried out temporarily for 13 times, from February 2019 to January 2020. The parameters observed were electrical conductivity (EC, measured directly in the field using EC meters) and several major elements, i.e., Ca²⁺, Mg²⁺, Na⁺, and K⁺, which were analyzed in the laboratory.

Percent sodium content was calculated using equation 1. It represents the percent sodium content in groundwater compared to other cations and is expressed in meq/l. The calculation results were then grouped into five classes (Table 1) to determine the suitability of water for irrigation purposes.

$$Na\% = \frac{(Na+K)100}{(Ca+Mg+Na+K)} \dots \dots \dots (1)$$

Table 1. Classification of Groundwater Suitability Level for Irrigation Based on Percent Sodium Content (Na%)

Classification	Na%	Class of Water
S1	<20	Excellent
S2	20-40	Good
S3	40-60	Permissible
S4	60-80	Doubtful
S5	>80	Unsuitable

Source: Wilcox (1955) [23]

Sodium Adsorption Ratio (SAR) was computed using equation 2. All cations used in this calculation are presented in meq/liter. The calculation results were then classified according to the provision listed in Table 2.

$$SAR = \frac{Na}{\sqrt{\frac{1}{2}(Ca+Mg)}} \dots\dots\dots(2)$$

Table 2. Classification of Groundwater Suitability Level for Irrigation Based on SAR Values

Classification	SAR	Class of Water
S1	<10	Excellent
S2	10-18	Good
S3	18-26	Fair
S4	>26	Poor

Source: Bhat et al. (2018) [7]

Groundwater suitability for irrigation using the Wilcox diagram was determined by connecting two parameters, namely electrical conductivity and sodium level in groundwater. The Wilcox diagram divides the suitability into five classes, namely excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable, and unsuitable [7]. Meanwhile, groundwater suitability analysis for irrigation using the USSL diagram was carried out with the same principles as plotting the data on the Wilcox Diagram, only salinity hazard and sodium hazard were the parameters used here. The results of data plotting on the USSL diagram were classified into several suitability classes according to the conditions described in Table 3.

Table 3. Classification of Groundwater Adjustable for Irrigation Based on the USSL Diagram

C/S	S1	S2	S3	S4
C1	Good	Moderate to good	Moderate	Moderate to poor
C2	Moderate to good	Moderate	Moderate to poor	Poor
C3	Moderate	Moderate to poor	Poor	Very poor
C4	Moderate to poor	Poor	Very poor	Unusable

Source: USSL (1954) [24]

3 Results and Discussion

The electrical conductivity, as measured directly in the field, showed a somewhat widely temporal variation (Table 4) between the rainy season and the dry season. Electrical conductivity tended to be higher in the dry season (April 2019-October 2019) than in the rainy season. This is possible because, in the dry season, Gremeng Resurgence receives recharge water only from groundwater as allogenic recharge and diffuse flow as autogenic recharge [20]. Meanwhile, in the rainy season, dilution by rain reduces dissolved solids in groundwater; hence, a relatively low electrical conductivity.

Table 4. The Measurement Results of Water Suitability Parameters for Irrigation in Gremeng Resurgence

Date	Major Ion (meq/L)				EC (µS)
	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	
02/22/2019	1.95	0.36	0.43	0.08	215

03/12/2019	1.50	0.32	0.43	0.05	213
03/25/2019	1.65	0.52	0.39	0.05	234
03/25/2019	2.00	0.72	0.39	0.05	249
04/07/2019	2.40	0.72	0.52	0.05	247
05/07/2019	3.19	0.72	0.43	0.05	268
07/13/2019	3.29	0.68	0.70	0.05	280
08/04/2019	3.74	0.28	0.30	0.03	373
09/20/2019	2.91	1.48	0.83	0.05	339
10/22/2019	1.80	1.20	0.78	0.05	359
11/25/2019	2.51	1.62	0.89	0.02	387
12/29/2019	1.88	0.72	0.65	0.08	265
01/27/2020	1.99	0.56	0.65	0.03	270

Source: Field Survey and Laboratory Analysis

Table 4 also shows that not every major ion content in Gremeng Resurgence had a wide temporal fluctuation, for example, magnesium, sodium, and potassium. A high variation was only found in calcium ions, which is inevitable because calcium and bicarbonate are the primary ions composing karst regions. Calcium was found to be higher in the dry season, indicating the absence of dilution process but prevailing water-rock interaction.

Relatively small fluctuations in major ion content were also apparent in groundwater suitability levels for irrigation that did not fluctuate drastically and tended to be relatively stable (Table 5). Classification by SAR proved that the groundwater suitability levels for irrigation fell into the category of Excellent throughout the year. A different condition was detected in Na%, which classified groundwater suitability as *good* to *excellent*. Nevertheless, the percent sodium in *good* was only slightly higher than 20%, i.e., 21%. A decline in suitability class came about during the rainy season (Figure 3). A low sodium concentration (less than 20%) indicates that the threat of soil damages due to sodium is also low. Sodium can damage soil structure, which consequently decreases infiltration capacity, forms hard soil crust, and inhibits crop growth [25, 26].

Table 5. The Calculation Results of Na% and SAR of Gremeng Resurgence

Date	Na%	Classification of Na% for Irrigation	SAR	Classification of SAR for Irrigation
02/22/2019	18.18	Excellent	0.41	Excellent
03/12/2019	21.12	Good	0.46	Excellent
03/25/2019	16.98	Excellent	0.38	Excellent
03/25/2019	14.03	Excellent	0.34	Excellent
4/7/2019	15.52	Excellent	0.42	Excellent
05/07/2019	11.06	Excellent	0.31	Excellent
07/13/2019	15.83	Excellent	0.49	Excellent
08/04/2019	7.58	Excellent	0.21	Excellent
09/20/2019	16.65	Excellent	0.56	Excellent
10/22/2019	21.78	Good	0.64	Excellent
11/25/2019	17.96	Excellent	0.62	Excellent
12/29/2019	21.95	Good	0.57	Excellent
01/27/2020	21.05	Good	0.58	Excellent

Source: Data Analysis Results (2020)

The results showed by two previous methods and the Wilcox Diagram were similar (Figure 4). The Wilcox diagram analysis revealed that the suitability of karst groundwater in Gremeng Resurgence for irrigation fell into the category of excellent to good. In other words, hazards that originate from sodium presence and electrical conductivity in the study area are relatively low. Such low electrical conductivity is attributable to the relatively long distance

to seawater sources (little to no possibility of intrusion), relatively small catchment (13.25 km²), allogenic recharge that responds quickly to rain (allowing short contact of water to rocks), and relatively developed dissolution channels [27, 28, 29]. High electrical conductivity has the same impact as high sodium content. Both can lead to the deaths of crops or non-optimum crop growth in agricultural land.

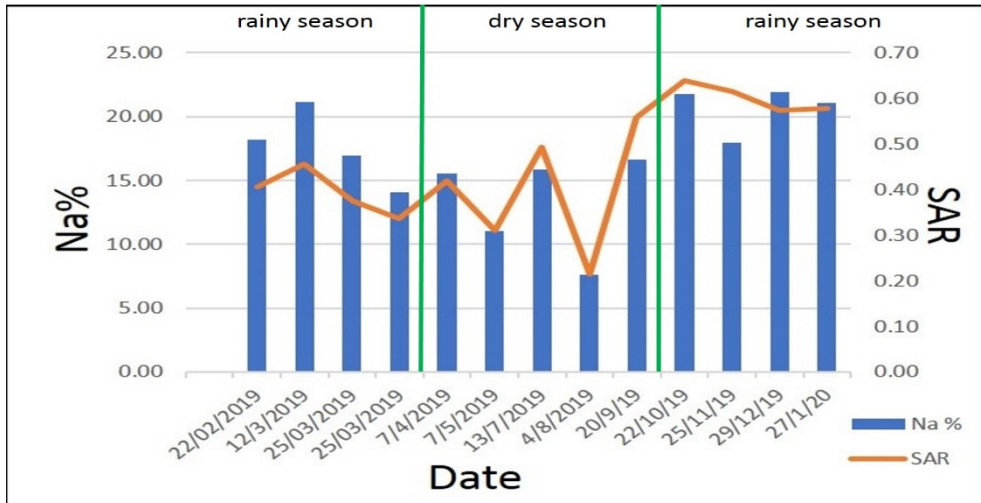


Figure 3. Temporal Variation of Na% and SAR in Gremeng Resurgence

Although both Wilcox and USSL diagrams of Gremeng Resurgence (Figures 4 and 5) showed that the danger level of sodium was low (Figure 3), the salinity hazards detected were different. These results are possible because the classification of salinity hazards in the USSL diagram has a shorter range than that of the Wilcox diagram. In the USSL diagram, the classes are limited to 250 $\mu\text{S}/\text{cm}$, 750 $\mu\text{S}/\text{cm}$, and 2250 $\mu\text{S}/\text{cm}$ electrical conductivities, whereas in the Wilcox diagram, the ranges of electrical conductivities in every class are much wider, namely 1000 $\mu\text{S}/\text{cm}$, 2000 $\mu\text{S}/\text{cm}$, 3000 $\mu\text{S}/\text{cm}$, and 5000 $\mu\text{S}/\text{cm}$.

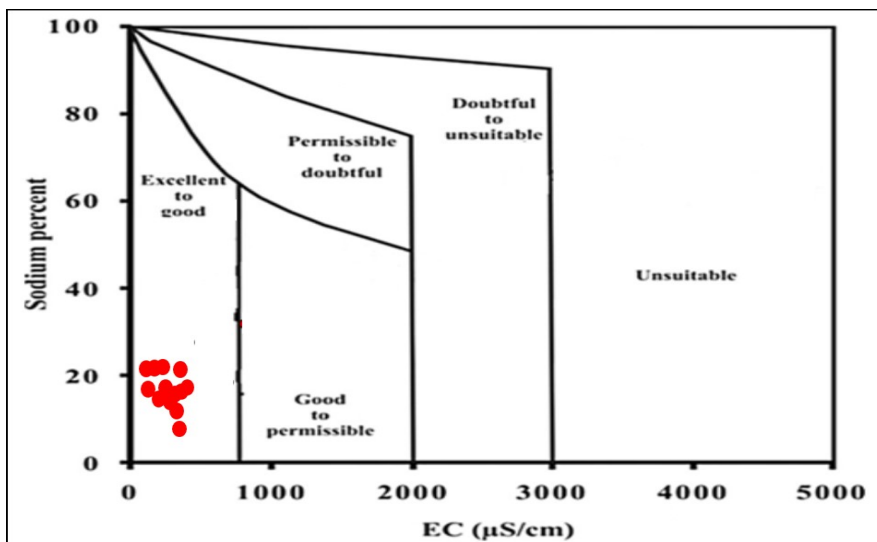


Figure 4. The Suitability of Gremeng Resurgence Water for Irrigation Based on the Wilcox Diagram

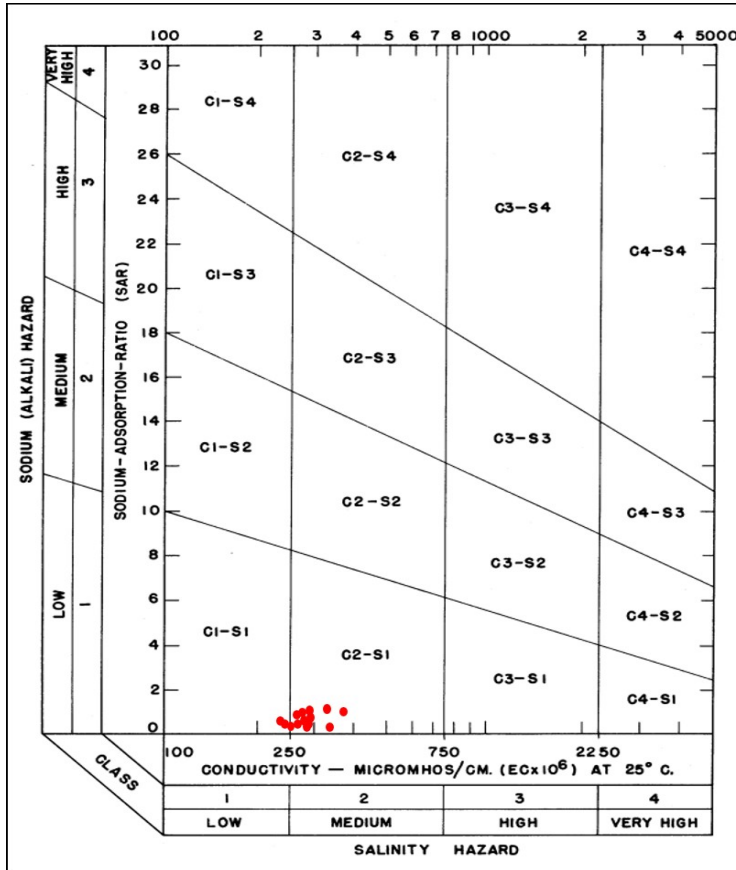


Figure 5. The Suitability of Gremeng Resurgence Water for Irrigation Based on the USSL Diagram

4 Conclusion

The season is a factor of groundwater quality characteristics and, consequently, temporal variation of groundwater quality in Gremeng Resurgence. During the rainy season, dilution by rainwater that enters the groundwater through allogenic recharge and flows through dissolution conduits reduces the water quality slightly. On the contrary, during the dry season, the water-rock interaction process becomes dominant. Nevertheless, the groundwater quality parameters in the study area do not vary widely so that the class of groundwater suitability for irrigation does not change significantly. Such temporal variations show that groundwater suitability for irrigation changes only between good and excellent classes, while the salinity hazard levels range from low to medium. Overall, the groundwater in Gremeng Resurgence is suitable for irrigation purposes throughout the year.

5 Acknowledgment

This research uses some of the data analyzed and presented in the first author's dissertation. It received funding from Universitas Gadjah Mada through the Grant Scheme for Final Assignment Recognition Program (*Hibah Program Rekognisi Tugas Akhir*) in 2020, with the contract number 2607/UN1/DITLIT/DIT-LIT/PT/2020.

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