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Assessment of the Effects of Temperature and Rainfall Variability on Reservoir Level at Zaria Dam, Kaduna State, Nigeria

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ABSTRACT

The study assessed the effects of temperature and rainfall variability on reservoir level at Zaria dam. Zaria reservoir is located in the region of high climatic variation which may affect the level of water in the reservoir. The study evaluates the impacts of rainfall and temperature variability on the reservoir level at Zaria dam. Rainfall, temperatures data were analyzed using multiple regression analysis to examining the relationship and effects on reservoir level. The study made use of the variables for the period of 20 years (2001-2020). Reservoir level (dependent variable) was regressed on the rainfall and temperature (independent variables) to determine the effects. The results revealed that maximum and average temperatures had p-values 0.164 and 0.340 which were greater than $\alpha = 0.05$, implying that maximum temperature and average temperature were statistically insignificant. Rainfall and minimum temperature had P-values 0.0163 and 0.015 which were less than $\alpha = 0.05$, implying that rainfall and minimum temperature were statistically significant. The coefficient of determination (R^2) value obtained from the first regression shows that 33.4% of the variation in reservoir level is attributed to rainfall and average temperature. The R^2 value obtained from the second regression shows 32.6% of the variation in reservoir level was accounted for by maximum and minimum temperatures. This implies that 66% variation in reservoir level could be as a result of the changes in rainfall and temperatures. Kaduna State Government should plan for relocating settlements within the flood plains downstream of the Zaria dam.

Keywords: Rainfall, Temperatures, Reservoir level, Zaria Dam and Regression analysis

INTRODUCTION

Although Warning notifications on the consequences of future climate variability were somehow ignored, observable conditions indicated that water resource may be greatly affected (Dong and Sutton, 2015). In recent years, the major threat to water resources is climate variability particularly rainfall and temperature. Temperature fluctuations, rainfall patterns, floods, and droughts are all major signs of climate change that have strong effects on river systems (Mohammad and Guido, 2018). The variation in climate may cause low or extreme changes on streams within various river basins. This may have serious implication on the design and control of water management structures (IPCC, 2001). Evidence of climate change or variability is around and therefore, observation of the recent hydro-meteorological information is

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required to reduce environmental consequences such as flooding, drought, loss of living organisms (Singh and Woolhiser, 2009). The outcome of the changes in stream measurements may cause positive or negative effects on rivers, water resources, seasonal water provision and storage. Climate variability may increase the available water which may cause or increase the dangers of flooding (Barnett et al., 2005).

Indications of monitored climatic variability in Africa shows continuous increase in temperature of 0.7^0C over the last century and 0.05^0C increase in the last decade (Akinsola and Ogunjobi, 2001). Therefore, increase in temperature causes stronger water evaporation in both land surfaces and water bodies. This implies that loss of water from surfaces of rivers within basins is a function of temperature. Rainfall, Evaporation and Relative Humidity have been described as important indices on which water level depends (Dammo et al., 2017). The most noticeable meteorological variation in West Africa over the last four (4) decades was repeated decrease (downward sloping) of rainfall (Akinsola and Ogunjobi, 2014). The changes in global distribution of water will have impacts on regional water resources. Increasing incidence of dryness of streams along basins at intervals is usually affected by variation in temperature and rainfall (Reynolds et al., 2015). Identifying trends in hydro-meteorological data is critical for climate change and variability impact assessments particularly for understanding changes in hydrological regimes at both regional and catchments levels (Meresa et al., 2017). Therefore, in light of basin-level water resources management, an assessment of changes in reservoirs, rainfall and temperature is necessary as these variables influence the available water and its quality for various uses (Meshram et al., 2017).

Bates et al. (2008) ascertained that there is evidence of consistent change in river basins at global scale, with some areas particularly higher latitudes experiencing an increase while a decrease in some parts of West Africa, Southern Europe and Southern Latin America. The report revealed that there was 4% increase in global total reservoir level per 1^0C rise in temperature during the last century, with regional variation following the same trend. Higher water temperatures have been reported in lakes and river basins in response to global warming (Bates et al., 2008). Africa is the most susceptible continent to dangers of climate variability particularly water resources retreats (Schlenker and Lobell, 2010). Nigeria will not be an exception. As discussed by Mustapha et al. (2018) argued that sediment load deposition, rainfall variability, temperature increase, irrigation agriculture, increased population, and grazing cause loss of stored water within a river basin, increasing the risk of shortage of water for drinking, irrigation and fishing. Recent studies on climate variability and its effect on water resources are very rare in Africa particularly in the sub regions of West Africa. Considering the nature of Nigeria, hydro-meteorological assessments are needed in various regions of the country for proper understanding of the characteristics of meteorology and hydrology (Odjugo, 2011).

MATERIALS AND METHODS

The Study Area

The reservoir across River Shika is officially known as Zaria dam (popularly called Shika dam) was constructed in 1975. It has its head waters near the north western edge of the Jos Plateau and falls near the Magami village into Kaduna plains. The Zaria dam is located between Latitudes 11^{0}8'6.14" N and Longitudes 7^{0}45'33.39" E, that is the point where the reservoir water is measured as shown in Table 1. The Zaria dam is the main source of available water (pipe- borne) to the numerous residents in urban Zaria. The reservoir water is used for irrigation, fishing and other domestic uses (Nnaji et al., 2011). The dam has the following characteristics (Water and Power Development Company, 1991);

Dam catchment area = 3200km^2.

Length of the Dam Crest = 640m.

Gross storage capacity = 16.0 × 10^{6}m^3.

Hectares of land = 18.8 hectares.

Length of the Lake = 35 Km at maximum flood water level.

Maximum Dam height = 14.9m.

Water Supply Capacity = 872 million liters.

The reservoir water is been discharged to River Galma, located between Latitudes 11^0.0'00" N to 11^{0}13'20" N and Longitudes 7^{0}36"0 E to 7^{0}54"0 E as shown in Figure 1. The Galma River is one of the main tributaries of River Kaduna. River Galma is the principal natural or artificial removal of surface and sub-surface water in Zaria because Rivers Saye, Kubanni, Likarbu, Gilmo drain into it, which is known as "Galma River basin" and belongs to the north eastern part of Kaduna River basin which borders the Chad basin to the north (Nnaji et al., 2007).

Hydro-meteorological Stations Used for the Study

Hydro-meteorological stations used for the study were described in Latitudes, Minutes and Seconds; Longitudes, Minutes and Seconds as shown in Table 1. The meteorological station and Zaria dam were shown in the map of Galma River basin (Figure 1).

Table 1: Hydro-meteorological Stations in the Study Area

Stations	Type	Latitude	Longitude
Monitoring and Evaluations, IAR, ABU, Zaria.	Met. Station	N 11^{0}9'54.05"	E 7^{0}38'2.55"
Zaria Dam/Reservoir (Shika Dam)	Gauge Station	N 11^{0}8'6.14"	E 7^{0}45'33.39"

Source: Field Work, 2021

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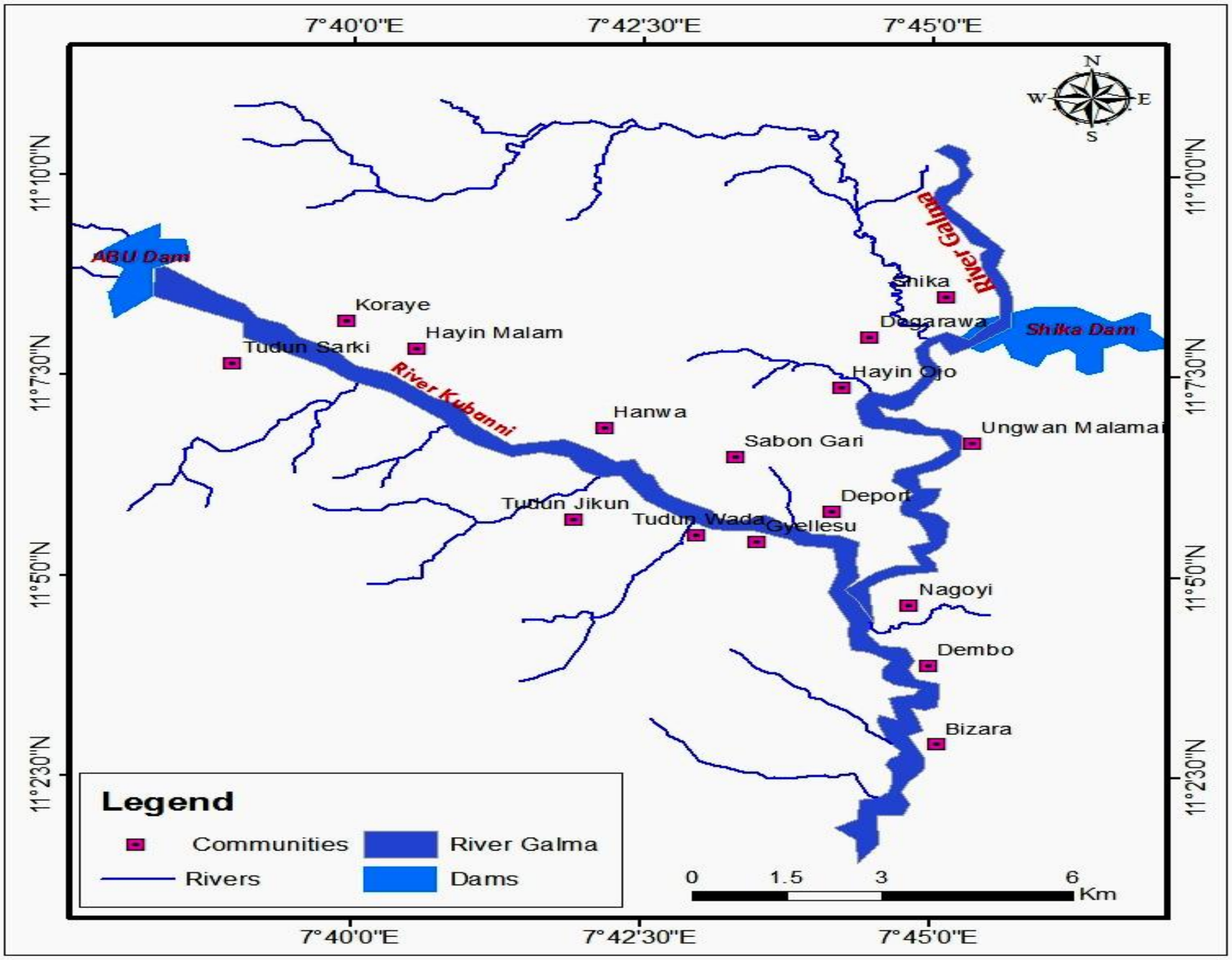

Figure 1: The Study Area showing Zaria Reservoir/Shika dam

Source: Modified Zaria Topo Sheet 102 S.W

Sources of Data

The data used in this study were obtained from secondary sources. Rainfall and temperatures data used for the study were obtained from the Institute for Agricultural Research (I.A.R) Ahmadu Bello University, Zaria. Hydrological data (reservoir level) was obtained from Zaria reservoir with the permission from the Hydrology Unit, Kaduna State Water Board (KSWB) Kaduna, Nigeria.

Methodology

Multiple regression analysis was conducted to evaluate the relationship (effects) between meteorological parameters and reservoir level. The first multiple regression analysis described effects of the two independent variables (rainfall and annual temperature) as predictors while dependent variable (reservoir level) as response. The second multiple regression analysis described effects or relationship of dependent variable (reservoir level) as response while the independent variables (maximum and minimum temperatures) as predictors. Multiple regression analysis equation is presented as in equation 1 below;

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n + \varepsilon_i \quad (1)$$

Where y is the dependent variable (response), β_0 is the intercept, X_1, X_2 and X_n are the independent variables (predictors), β_1, β_2 and β_n are the coefficients of X_1, X_2 and X_n, respectively and ε_i is the error that has normal distribution with mean of zero.

For multiple linear regressions with only two independent variables, equation 2.1 is reduced to equation 2 as shown:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon_i \quad (2)$$

All terms were previously defined in equation 1.

However, the coefficient of determination (R^2) explained the percentage or proportion of the variation in the response variable that can be accounted for by the two predictors in the multiple regression models (Kingsley et al., 2020; Attah, 2013).

RESULTS AND DICUSSION

Relationship between Rainfall, Average Temperature and Reservoir Level

The annual rainfall and temperatures data for the study period (2001-2020) is presented in Table 2 while the mean monthly reservoir level raw data for the period of study (2001-2020) is presented in Table 3.

Table 2: Annual Rainfall and Temperatures (2001-2020)

Years	Rainfall(mm)	Max. temp.(^{0}C)	Min. temp.(^{0}C)	Average temp.(^{0}C)
2001	1322.3	32.0	20.3	26.2
2002	1007.6	32.6	21.0	26.8
2003	1135.4	33.4	21.0	27.2
2004	1074.9	33.9	20.3	26.6
2005	863.7	33.4	19.2	26.3
2006	1088.5	33.2	18.9	26.1
2007	1093.1	33.0	18.6	25.85
2008	1175.5	32.9	18.7	25.35
2009	1278	33.8	18.9	26.4
2010	1127.3	33.6	20.0	26.8
2011	1208.29	33.5	19.7	27.95
2012	1333.3	33.2	19.0	26.45
2013	1075.3	36.0	21.8	28.9
2014	1067.9	33.4	21.0	27.2
2015	1454.9	33.6	19.7	26.65
2016	1378.3	33.2	19.0	26.1
2017	1397.6	34.4	18.0	26.25
2018	889.7	31.9	18.2	25.05
2019	1039.5	33.1	20.8	27.0
2020	1000.2	31.9	19.4	26.6

Source: Institute for Agricultural Research, ABU Zaria

Table 4 presents the relationship between rainfall, average temperature and reservoir level for the period of 20 years (2001-2020). Table showed the regression line; Reservoir Level=15.7+ 0.006mm* Rainfall - 0.43℃*Average temperature. In other words, for each unit of increase in rainfall, reservoir level increases while for each unit of increase in average temperature, reservoir level decreases.

Table 4: Relationship between Rainfall, Average Temperature and Reservoir Level

Regression Equation	R^2	Multiple R
Reservoir Level=15.7+0.006$_{\text{Rainfall (mm)}}$-0.43$_{\text{Average Temperature}}$	33.4	0.577
Adjusted R^2 25		
Observation 20		

Source: Authors’ Computation, 2021

Multiple R (0.577) is the correlation coefficient, and it explained the moderate positive relationship between reservoir level, rainfall and average temperature. Multiple R (0.577) shows that as rainfall and average temperature increases, reservoir level also increases.

Coefficient of determination (R2) is 33.4%, this implies that about 33.4% of the variation of reservoir level is caused by rainfall and average temperature.

Table 3: Mean Monthly Reservoir Level m/yr (2001-2020)

Years	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2001	0.19	0.068	0.004	0.10	0.356	0.728	1.61	3.363	3.298	1.141	0.311	0.22	11.389
2002	0.184	0.0525	0.001	0.096	0.49	0.63	0.735	1.979	2.279	0.937	0.24	0.20	7.583
2003	0.319	0.288	0.00	0.00	0.131	0.69	1.032	2.620	2.588	0.25	0.343	0.03	8.291
2004	0.00	0.00	0.00	0.433	0.499	0.538	1.455	3.445	3.463	0.943	0.467	0.00	11.243
2005	0.200	0.107	0.00	0.433	0.35	0.894	1.635	1.643	1.510	0.478	0.249	0.329	7.828
2006	0.293	0.184	0.263	0.340	0.989	0.989	0.765	1.75	2.266	1.494	0.405	0.455	9.788
2007	0.309	0.430	0.098	0.673	0.963	0.340	1.193	3.232	2.631	1.513	0.395	0.530	12.307
2008	0.321	0.358	0.315	0.253	0.24	0.963	0.991	3.71	2.568	0.748	0.563	0.259	11.289
2009	0.308	0.240	0.00	0.556	0.791	2.194	2.041	1.637	1.771	0.597	0.474	0.332	10.94
2010	0.272	0.226	0.182	0.212	0.410	0.67	1.187	2.88	2.232	2.087	0.33	0.186	10.874
2011	0.139	0.076	0.249	0.226	0.348	1.033	1.28	3.254	3.629	1.129	0.969	0.651	12.983
2012	0.177	0.426	0.420	0.319	0.356	1.195	3.377	3.363	2.411	1.141	0.311	0.22	13.716
2013	0.313	0.336	0.195	0.197	0.092	1.30	1.703	1.656	3.175	1.582	0.406	0.368	11.323

2014	0.00	0.00	0.00	0.109	0.325	0.513	0.975	2.919	2.823	2.013	0.954	0.660	11.291
2015	0.394	0.107	0.00	0.666	0.935	0.871	2.896	2.224	2.461	1.065	1.160	0.402	13.181
2016	0.328	0.321	0.334	0.506	0.569	1.041	2.096	3.488	2.929	1.153	0.690	0.529	13.984
2017	0.189	0.133	0.00	0.156	1.080	1.655	1.633	2.324	3.355	1.236	0.442	0.282	13.721
2018	0.135	0.102	0.00	0.607	1.525	0.907	2.163	3.283	2.718	1.645	0.49	0.187	13.762
2019	0.161	0.073	0.000	0.117	0.622	0.777	1.02	1.677	2.83	2.05	1.153	0.277	10.01
2020	0.265	0.082	0.00	0.00	0.864	1.203	1.474	1.936	2.632	1.979	1.630	0.432	12.497

Source: Kaduna State Water Board (KSWB, 2021)

The R^2 value revealed that the variation in reservoir level does not necessarily rely on the variables as other hydrological variables and human activities affects the reservoir level. The remaining 66.6% that could not be accounted for by the regression model could be attributed to other climatic variables, hydrological variables and human activities. Awotwi et al. (2015b) suggested that increase in rainfall and temperature is the major cause of increase in stream flow and evapotranspiration in the Upper Volta River Basin, West Africa. Dammo et al. (2017) shows the effects of rainfall on water level were positive over the 3 decades with variations over each decade in North-eastern Nigeria. Rainfall in these specific sites contributed to increase in water levels in the rivers across the decades.

Significant Relationship between Rainfall, Average Temperature and Reservoir Level

Table 4 presents the significance of relationship between rainfall, average temperature and reservoir level for the period of 20 years (2001-2020).

Table 4: Significance of Relationship between Rainfall, Average Temperature and Reservoir Level

Variables	P-Values	Significance F
Rainfall (mm)	0.0163	0.038
Average Temperature (℃)	0.34	

Source: Authors' Computation, 2021

Table 4 described the statistical significance of relationship between rainfall and average temperature on reservoir level of Zaria dam. The Table further revealed the results from test of statistical significance or relationship using $\alpha = 0.05$. Rainfall had p-value of 0.0163 which is less than $\alpha = 0.05$ level of significance ($P < \alpha = 0.05$). Therefore, null hypothesis was rejected. This showed that rainfall is statistically significant to variations in reservoir level of Zaria dam at $\alpha = 0.05$ level of significance. The result conforms with Awotwi et al. (2017) which shows stream flow increase at a rate of 9.98×107m3 yr-1 with rainfall variation influencing 17.4% in the Lower Pra River Basin of Ghana. The result corresponds to findings of Garbrecht and Schneider (2008) that the highest pool elevation drops of 2 meters from top of the conservation pool in Fotcobb reservoir, Central Oklahoma was highly significant to decadal variations of precipitation.

Average temperature had the p-value of 0.340 is greater than 0.05 level of significance ($P > \alpha = 0.05$), null hypothesis is accepted. Therefore, average temperature is statistically insignificant to reservoir level at $\alpha = 0.05$ level of significance. There is no significance of relationship between average temperature and reservoir level of Zaria dam at $\alpha = 0.05$ level of significance. Adeyeri et al. (2017) revealed meteorological variability and the withdrawal of water in the basin are the major causes of the unsteadiness of water level in the Lake Chad basin.

Relationship between Maximum, Minimum Temperature and Reservoir Level

Table 5 presents the relationship between maximum, minimum temperature and Reservoir Level for the period of 20 years (2001-2020).

Table 5: Relationship between Maximum, Minimum Temperature and Reservoir Level

Regression Equation	R^2	Multiple R
Reservoir Level= 14.2+ $0.52_{max\ temp} - 1.03_{min\ temp}$	32.6	0.571
Adjusted R^2 24.7%		
Observation 20		

Source: Authors' Computation, 2021

Table 5 shows the regression line is: Reservoir Level=14.2+0.52 ℃ * maximum temperature-103 ℃ * minimum temperature. Therefore, for each unit increase in maximum temperature, reservoir level increases with 0.52m. For each unit increase in minimum temperature, reservoir level decreases. However, Dammo et al. (2017) revealed temperature impacted negatively on water level of rivers in North Eastern Nigeria. Each rise in temperature of 45.4, 43.1 and 45.9 ℃ led to a reduction in water level by 0.4 m in the respective sites for the 3 decades.

Multiple R (0.571) is the correlation coefficient, and it explained that there is moderate relationship between maximum, minimum temperatures and reservoir level Zaria dam. The Table further revealed that maximum and minimum temperature (independent variables) accounted for the variations of reservoir level (dependent variable). Since the R^2 value is 32.6%, this implies that about 32.6% variability in reservoir level of Zaria dam can be accounted for by maximum and minimum temperatures. On the contrary, Butu et al. (2019) revealed lake level is positively related with temperature and rainfall with coefficient values of 0.69 and 0.45 with R^2 values of 45% (temperature) and Rainfall (35%) at 0.05 significance levels. This implies that Lake level of Kainji dam is sensitive to temperature by 45% and 35% sensitivity to changes in rainfall pattern. The R^2 value also revealed that the variation in reservoir level do not rely on temperature (maximum and minimum) because other non-climatic factors also affect water in reservoirs (Ma et al., 2010).

Significance of Relationship between Maximum, Minimum Temperature and Reservoir Level

Table 6 presents the significance of relationship between maximum, minimum temperature and reservoir level for the period of 20 years (2001-2020). Table 6 shows the statistical significance of maximum, minimum temperatures and reservoir level.

Maximum temperature had the P-value of 0.164, therefore statistically insignificant as the p-value (0.164) is greater than 0.05 ($P > \alpha = 0.05$).

Table 6: Significant Relationship between Maximum, Minimum Temp. and Reservoir Level

Variables	P-Value	Significance F
Maximum Temperature (℃)	0.164	0.039
Minimum Temperature (℃)	0.015	

Source: Authors' Computation (2021)

Minimum temperature had the P-value of 0.015, therefore statistically significant as the P-value (0.015) is less than 0.05 ($P < \alpha=0.05$). However, maximum temperature is statistically insignificant to variations in reservoir level at $\alpha=0.05$ significant level while minimum temperature is statistically significant to the variations in reservoir level of Zaria dam at $\alpha = 0.05$ level of significance. This implies that temperatures increase have positive effect on the water resources of Zaria reservoir. The findings corroborate Salami et al., (2010) which concluded that there is positive effect of climate change on water resources of Jebba hydropower dam due to the reservoir inflow and outflow.

CONCLUSION

Furthermore, the hydro-meteorological variables (rainfall, temperatures and reservoir level) revealed R^2=33.4% in the first analysis, and R^2=32.6% in the second analysis. This implies that 66% variations in reservoir level could be as a result of rainfall and temperature variability. The remaining 34% can be attributed to anthropogenic and hydrological factors and other climatic variables that go beyond the reach of this study. Generally, the result agrees with the findings of Burn and Hag (2002) which stated that in recent years, climate variability particularly in rainfall and temperature is the major threat to water resources in many rivers. And also result from this research corroborates Awotwi et al. (2015a) which showed rainfall and temperatures as the major causes of increase in stream discharge/reservoir level in Upper Volta River Basin, West Africa.

Recommendation

From the findings of this research, the following recommendations are made or derived:

1. The study recommended that Kaduna State Government should plan for reinforcement of the Zaria dam.
2. Kaduna State Water Board under the Kaduna State Government should increase the spillway of the Zaria dam.
3. The Kaduna State Government should plan for relocating settlements within the flood plains downstream of the Zaria dam.
4. The Kaduna State Government should provide early warning system for communities downstream of the Zaria dam. This may help to forecast the occurrence of floods and or droughts

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