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Water Quality Assessment and Pollution Analysis of One of the Major Tributary Rivers of Yamuna in Central India: The Chambal River

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ABSTRACT
Our study was intended to calculate the water quality index of the Chambal river system, an important tributary of the Yamuna River flowing in the north-central Indian subcontinent. The river water is available to all nearby cities for public consumption, tourism, wildlife conservation, hydropower generation, and many other public projects. The Water Quality Index (WQI) is an essential parameter for all policymakers to evaluate, assess, and manage surface water resources. The study tested many samples for quality determination based on water quality index such as pH, electrical conductivity, total dissolved solids, biological oxygen demand (BOD), dissolved oxygen (DO), total alkalinity, calcium, magnesium, sodium, phosphate, sulfate, chloride, fluoride, nitrate, and total hardness, etc. An analysis of various parameters based on the weighted arithmetic water quality index shows that the water quality status of this river is 'good' or comes under grade 'B' according to the prescribed quality standards, which indicates that the river water is substantially safe for human consumption and aquatic ecosystem. The possibility of deterioration in the water quality of this river always remains a serious concern for its stakeholders, as many cities and villages are situated along the banks of this river, and anthropogenic activities are also increasing with time in the river course area. So, through this study, there is the hope of getting valuable information to water policymakers.
Keywords: *Chambal river, water quality index, pollution analysis*

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INTRODUCTION

Water is a very prodigious fluid that is an essential human need for survival on this planet. Without water, we cannot even imagine our existence in this universe [21, 28]. After air, water is the most vital ingredient for the living of life, and that's why it similes as nectar. The availability of safe drinking water is our birthright. Generally, surface water quality is considered a critical issue in recent times due to the expected reduction in the quantity of freshwater available in the future [13]. Water, an exigent commodity of life, is called polluted when harmful, undesirable, or toxic substances are found and become hazardous to health [17]. We all know that about 71% of our globe is surrounded by water. Out of this, 97 % of the water is saline, which is available as ocean water. The remaining about 3 % of freshwater is available in the form of glaciers, groundwater resources, rivers, ponds, and wells [8, 35]. Despite all of this, pure, clean drinking water is not available with ease to people worldwide. The availability of safe drinking water for human beings is a key component of the sixth Sustainable Development Goal–SDG [36]. Without proper water quality monitoring, it would be tough to determine which water bodies or sources are more safe to drink [24]. Furthermore, the adequacy of pure water is constantly falling with an increase in the global population because the imbalance between demand and supply of clean drinking water is set to increase even more shortly. It has been reported by TWAS that, on average, more than 6 million children die every year from water-borne diseases (which is about 20000 children a day) and several more suffer from the use of contaminated water [47]. This is very concerning because more than half of the population in developing nations do not have access to safe drinking water, and 73% lack sanitation; as a result, their wastes eventually contaminate their drinking water supply, causing significant suffering [14, 53]. In most water bodies worldwide, pollution level has obtained their highest level of danger in the last 20-30 years [5].

In India, water contamination has reached an all-time high. Currently, almost all river systems in India are heavily polluted [19]. Scientists at the National Environmental Engineering Research Institute (NEERI) in Nagpur estimate that nearly 70% of India's water is polluted [34]. Throughout India, metropolitan areas generate an estimated 62,000 MLD (million litres per day) of sewage, but the treatment capacity is approximately 23,277 MLD. As a result, at least 70% of sewage produced in urbanized India is discharged into waterways, oceans, lakes, and wells, damaging watersheds and freshwater resources [1, 42]. In many nations, particularly in underdeveloped countries, the quality of drinking water is not good and, hence, many waterborne diseases are caused by poor drinking water quality.[32] The easy access to basic amenities, such as pure drinking water, has become an issue and is garnering renewed focus now [33]. Recently the term 'Day Zero,' referring to the severe water crisis, was born in Cape Town, South Africa, in the year 2018 when the potable water in the entire city was exhausted. According to the World Resource Institute, one-fourth of the world's population faces a severe water crisis. According to this, seventeen countries whose cities may face 'Day Zero' conditions include India. That's why water quality evaluation seems to have become extremely crucial in the current world situation [38]. However, a number of hydrological researches in the field of sustainable water management have been published all over the world, giving enough meaningful inputs to the environmental status of river-based water.

Recently, traditional technologies have been superseded by several advanced technologies that help simplify complex tasks. Over the years, WQI has developed as an important technique for the summary of water quality data into basic words for scientists related to water research [6, 7]. This index combines information from various variables into a mathematical calculation that assigns a number from 1 to 100 to the quality of water bodies, which can be classified into five categories. Each has a separate quality status and consumption domain [18]. The primary aim of the water quality index is to help the general public to understand the use of precise water quality data [15]. In general, the world is now using four different type of water quality indices, i.e., the Canadian council of the ministry of the environment water quality index (CCMEWQI), the Oregon water quality index (OWQI), the National Sanitation Foundation water quality index (NSFWQI) and the weighted arithmetic water quality index (WAWQI). The quality of water is estimated in our analysis by using the weighted water quality index arithmetic approach. The purpose of using the WAWQI approach in this study is that it has a benefit over other methods, such as this system, which incorporates many water quality variables into a numerical formula which evaluates the water body using a number called the health rates of water quality index [41]. The study examines whether surface water supplies are suitable for direct human consumption.

MATERIAL AND METHODS

Study Area

The Chambal basin runs across the Indian subcontinent's north-central region, originating from Mhow town near Indore in Madhya Pradesh, a significant tributary of the Yamuna River [54]. The river has a key role in incorporating, organizing and changing the biological environment of the basin [43]. Dholpur, the city we chose for our sample collection or sampling, is the most eastern city in Rajasthan, located near the downstream of the river. The river flow area passing through the Dholpur district forms the boundary between two Indian states; Rajasthan and Madhya Pradesh [45]. This area of the river, which is included in our study area, comes under the protected National Chambal Sanctuary (NCS) and is part of the Chambal sub-basin catchment area[4]. The River Chambal is a significant source of drinkable water in the area. It is also important in terms of the environment and ecology because it provides a home to diverse wildlife [51]. The Chambal River is the primary source of potable water in Rajasthan and Madhya Pradesh, where a significant portion of the nearby cities and rural population depend on it to fulfill their basic demands for water [16, 26, 39]. When so many people, aquatic flora and fauna directly depend on river water, routine monitoring of the river's environmental health becomes necessary.

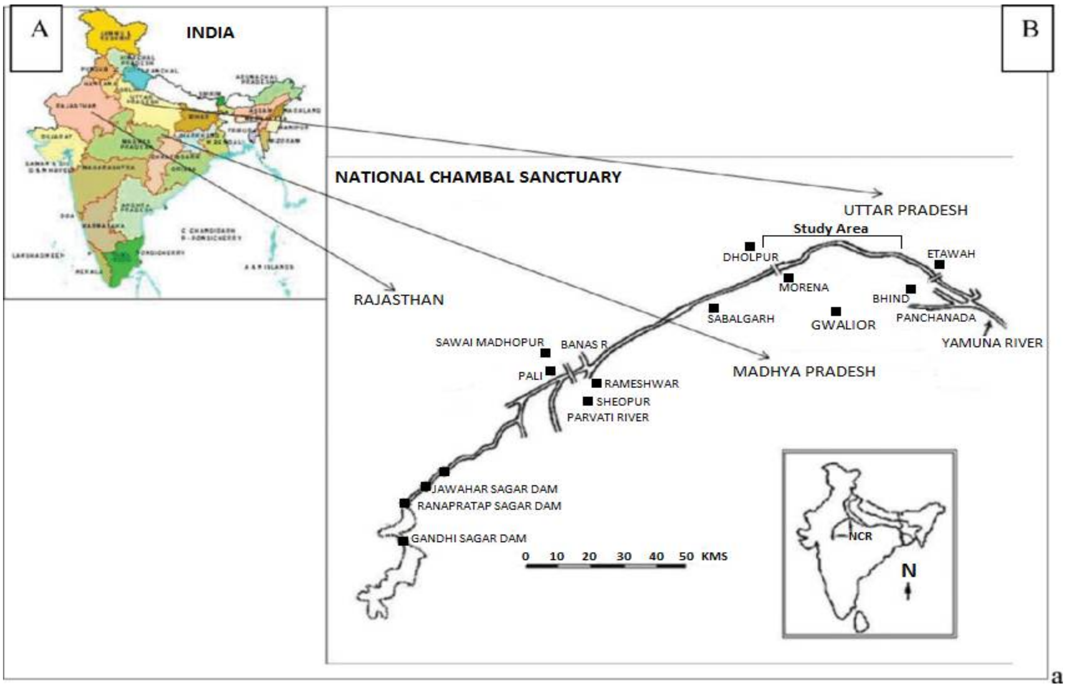

Figure-01: The geographical map of the National Chambal Sanctuary showing the selected sampling stations of river Chambal for this study.

Analytical Procedure

In an attempt to assess the quality of the river's water, we tested about sixteen different water quality standards every month. The average year-round results of all these variables and their respective standard values are listed below in the figure table. In our research area, four sample collection points were fixed, which are located at approximately the same distance from each other along the length of the river. Water samples were picked up from these collection points for twelve consecutive months in almost every season. Collected river water specimens were brought to the research laboratory with all the necessary precautions and following standard handling procedures. Finally, all of the samples that had been collected were examined according to standard procedures for various physico-chemical characters that the Bureau of Indian Standards and the World Health Organization have suggested. In our study, sixteen variables were considered to calculate the WQI. The weighted arithmetic approach to the water quality index, first proposed by Horton [31] and later modified by Brown et al. [9], was used to calculate the WQI. The following formula is used here to calculate the WQI:

$$\mathbf{WQI} = \sum_{i=1}^{n} w_i q_i \ / \ \sum_{i=1}^{n} w_i$$

Where,

n = parameters or variables count
w_i= the i^{th} parameter's unit weight
q_i = the i^{th} parameter's quality ratings

Further, the quality rating (q_i) was calculated using the following formula:

$$q_i = 100\ [(v_i - v_{id}) / (s_i - v_{id})]$$

Here,

v_i = the i^{th} parameter's observed value
s_i = the i^{th} parameter's standard value
v_{id} = the i^{th} parameter's ideal value in pure water

(For all parameters except pH and dissolved oxygen, the ideal value 'v_{id} ' is 0; the ideal value 7.0 and 14.6 mg/l is taken for pH and DO, respectively)

The unit weight or relative weight of particular parameter is that value which is inversely proportional to the recommended standard value 's_i' of particular parameter and is calculated as:

$$w_i = k/s_i$$

Where,

k = the proportionality constant.
And, the following equation was used to calculate '***k***' the constant of proportionality:

$$k = 1 / \sum_{i=1}^{n} (1/s_i)$$

RESULTS AND DISCUSSION

Table-01: Averages of observed values of selected parameters with their standard deviation and recommending agency's standards of drinking water.

S.No.	Parameters	Averages of Observed Values with Std. Deviation (v_i)	Recommended Standard Values According to BIS [11, 12, 40] (s_i)
1.	Turbidity (NTU)	0.0	5
2.	pH	7.89±0.22	6.5-8.5
3.	E.C. (µS/cm)	430.91±69.48	2000
4.	T.D.S. (mg/l)	356.25±45.08	500
5.	T.H. (mg/l)	153.08±24.06	300
6.	B.O.D. (mg/l)	8.5±1.33	5[23]
7.	D.O. (mg/l)	6.2±0.55	5[23]
8.	Calcium (mg/l)	32.32±5.22	75
9.	Magnesium (mg/l)	12.38±2.65	30
10.	Sulphate (mg/l)	41.01±5.33	200
11.	Nitrate (mg/l)	4.69±0.75	45
12.	Chloride (mg/l)	37.52±5.92	250
13.	Fluoride (mg/l)	0.33±0.05	1
14.	Phosphate (mg/l)	0.32±0.22	5[52]
15.	Alkalinity (mg/l)	153.08±36.66	200
16.	Sodium (mg/l)	51.37±9.54	100

Table-02: Selected river water parameters with their unit weights and quality ratings.

S.No.	Parameters	Unit weight (w_i)	Quality rating (q_i)	w_iq_i
1.	Turbidity (NTU)	0.09918863	0	0.0
2.	pH	0.05834625	59.33	3.64168342
3.	E.C. (µS/cm)	0.00024797	21.5455	0.00534267
4.	T.D.S. (mg/l)	0.00099188	71.25	0.07067190
5.	T.H. (mg/l)	0.00165331	51.02	0.08434340
6.	B.O.D. (mg/l)	0.09918863	170	16.8620682
7.	D.O. (mg/l)	0.09918863	87.5	8.67900572
8.	Calcium (mg/l)	0.00661257	43.0933	0.28495771
9.	Magnesium (mg/l)	0.01653143	41.2666	0.68219629
10.	Sulphate (mg/l)	0.00247971	20.505	0.05084657
11.	Nitrate (mg/l)	0.01102095	10.4222	0.11486264
12.	Chloride (mg/l)	0.00198377	15.008	0.02977246
13.	Fluoride (mg/l)	0.49594318	33	16.3661250
14.	Phosphate (mg/l)	0.09918863	6.4	0.63480727
15.	Alkalinity (mg/l)	0.00247971	76.5	0.18969826
16.	Sodium (mg/l)	0.00495943	51.37	0.25460607
		$\sum w_i$=1.00000460		$\sum w_iq_i$=47.77098776

Following that, the Chambal River's water quality index (WQI) was determined employing the weighted arithmetic index formula:

WQI = 47.770987 / 1.000004 = 47.770767

Table-03: Water quality classification grades and statuses according to the WQI results [10, 15, 18].

WQI	***Status***	***Grades***
0-25	Excellent	A
26-50	Good	B
51-75	Poor	C
76-100	Very poor	D
Above 100	Unsuitable for drinking	E

Table-04: Water quality index levels and water quality status accordingly [41].

Description of Water Quality Index levels and status	
<50	Excellent
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Unsuitable or unfit for drinking

The WQI method was applied to combine multiple characteristics and attributes into a single score that depicted the water quality of the river Chambal. The annual WQI value was about 47.77, which can be classified as 'B' grade water or 'good' quality water (Table-03) and 'excellent' quality of water according to Ramakrishniah *et al*. [41] as WQI belongs to the range of 25-50 (Table-04). On the other hand, Table-01 shows descriptive data for all of the water quality measures studied. Selected results from the determination of water quality parameters are described below to better understand the causes of degraded water quality in the Chambal River.

The information on the river's surface water quality is extremely important for the survival and maintenance of aquatic life. Humans are always been reliant on the river in one way or another to meet their daily requirements. In order to maintain this perspective, the present study used WQI approach to assess the surface water quality of the river. To determine the river quality index, twelve months regular monitoring of the river have been done along with its four sampling sites and sixteen physico-chemical parameters were analyzed i.e., pH, turbidity, EC, total hardness, TDS, DO, BOD, calcium, magnesium, sulphate, phosphate, nitrate, chloride, fluoride, alkalinity, sodium. Tables- 01 and 02 show the average values with standard deviation of all these parameters from the Chambal river basin, as well as the findings of water quality data analysis.

Turbidity means that what level of cloudiness or sludge in water and in the monitoring of water quality, it is an important factor. The increased turbidity reduces the penetration of light into the water body.[50] The optimal turbidity limit, according to BIS criteria, is 5 NTU. In the current study, the average turbidity value was found to be zero. Some researchers, such as Gupta *et al*., [3] and Almeida, Gonzalez, Mallea, and Gonzalez, [20], have also recorded increased turbidity values during the monsoon season for certain rivers.

The pH of a water sample indicates its acidic and basic nature in general. The aquatic species that live in water won't be able to survive if the pH of the water is extremely low or high. The dissolvability and toxic effects of chemical substances and heavy metals in water are also affected by the pH factor. In this study, the pH levels on average of 7.89 ± 0.22 were recorded, which shows the slightly basic nature of water. According to BIS regulations, the pH acceptable range is 6.5-8.5.

Electrical conductivity is a measurement of electric current carrying capacity and dissolved ions present in a water sample. The average electrical conductivity value is 430.91±69.48 µS/cm which comes under the BIS recommended limits. Kamboj *et al*., [29] observed that the electrical conductivity of the Ganga River ranged from 258 µS/cm to 290.1 µS/cm, whereas Upadhyay and Chandrakala, [49] discovered that the electrical conductivity of the Kaveri River in Karnataka ranged between 290–320 µS/cm.

Total dissolved solid (TDS) is a measurement of dissolved particles in a water sample taken directly. Throughout the investigation, the average TDS concentration 365.25±45.08 mg/l, was found within the desirable limits of TDS as per BIS and WHO standards. The TDS levels in the Ganga River varied between 172.90 to 187.70 mg/l according to Kamboj et al., [29] and the Sutlej River TDS levels varied between 156 mg/l to 582 mg/l, according to Jindal and Sharma, (2010).

Hardness of water is mainly caused by cations like calcium and magnesium, as well as anions like carbonates, bicarbonates, and chlorides. Water hardness is recognized to have negative consequences. The average value of hardness was found to be 153.08±24.06 mg/l under the BIS and WHO standards. The total hardness of the Bhagirathi River was observed at 85.46 mg/l in summer time, 108.79 mg/l in the monsoon season and 95.62 mg/l in the winter season, according to Pathak, Prasad and Pathak, (2015).

Biological oxygen demand is an estimation of the quantity of oxygen consumed via aerobic bacteria and various microorganisms to decompose organic waste materials which are present in water. The moderate value of BOD in Chambal water, 8.5±1.33 mg/l, was recorded, which was found to be above the ICMR desirable limit of BOD, i.e., 2 mg/l. The range of BOD of 0.35–2.18 mg/l from the Narmada River was detected by Gupta et al., (2017).

Dissolved oxygen is also an important factor in water quality evaluation because it represents the biophysical processes that occur in the water, as well as the extent of pollution in the water. In the current study, the average value of DO was found to be 6.2±0.55 mg/l. According to BIS and ICMR standards, the desired dissolved oxygen limit is 5 mg/l and 5 mg/l, respectively. The DO level variation from 6.5-15 mg/l of the Narmada River was also found by Sharma *et al*., (2008).

Calcium is a necessary component for normal bone development. Because calcium is plentiful in most rocks and has a higher solubility, it is found in all water sources. The average value of calcium in Chambal water samples was observed to be 32.32±5.22 mg/l, and that is under the BIS and WHO prescribed limit of calcium of 75 mg/l. Kamboj and Aswal, [30]) measured the calcium levels in Ganga canal water ranging from 28 mg/l to 31.9 mg/l.

Magnesium is frequently found in lower concentrations than calcium because magnesium-rich rocks dissolve slowly, while calcium is more prevalent in the earth's crust. The average magnesium concentration in water samples was 12.38±2.65 mg/l, although the acceptable limits for magnesium are 30 mg/l and 150 mg/l, respectively, as per BIS and WHO regulations. Thakor et al. (2011) find out the magnesium concentration in Pariyej lake water ranging from 26 to 33 mg/l.

Sulphate ion can be found in all natural water and, when present in excess, has a cathartic effect on humans. Sulphates enter water bodies primarily through rocks, shales, sewage treatment plants, industrial discharges, and fertilized field runoffs. It is also a significant component of water hardness as it contributes to the formation of sulphate compounds. In this investigation, the average of sulphate concentration was 41.01±5.33 mg/l, which was below the BIS and WHO prescribed limit of 200 mg/l and 250 mg/l, respectively.

Nitrate ion content in drinking water is critical because it produces blue baby syndrome (methamoglobinemia) in children if it exceeds 45 mg/l. Agricultural yards runoffs in which fertilizers are used, animal's fecal waste, urban drainage, sewage and many other natural or man-made reasons may lead to high levels of nitrates in the water. During the course of our research, the value of nitrate in the study area was 4.69±0.75 mg/l, which is less than the BIS and WHO specified limit of 45mg/l and 50 mg/l, gradually.

Chlorides are required in small amounts for proper cell functions in both plants and animals, but it can have a laxative effect on humans if present in higher concentrations in water. Anthropogenic activities such as industry effluents, sewage, pesticides runoff, and, in some circumstances, geological factors all contribute to the occurrence of chloride ions in water. The average value observed during this research was 37.52±5.92 mg/l, which was well within the BIS and WHO suggested limit of 250 mg/l.

Fluoride is a prevalent element in the earth's crust that occurs naturally in water sources. Although fluoride has health benefits, but it may be destructive when consumed in excess of the prescribed amount, as it can cause enamel fluorosis and other health complications. During the course of this research, the fluoride ion concentration was found to be 0.33±0.22 mg/l which was also within the specified limit of 1 mg/l in water. Puri *et al*., (2015) observed the fluoride concentration in Ambazari lake water varying from 0.56 mg/l to 1.2 mg/l.

Phosphate ions come in natural water from both point and nonpoint sources. Phosphorus is an essential ingredient for plant and animal development and for the aquatic ecosystems. Often, it is a growth limiting factor of any water body because, as phosphorus levels rise, eutrophication rises, as a consequence, dissolved oxygen levels decline, and ultimately, the water body's whole ecosystem ruins or collapses. In this study an average of 0.32±0.22 mg/l of phosphate content within the specified limit of 5 mg/l was observed.

Alkalinity is the ability of water to defy acidic changes in pH; in other words, alkalinity is the ability of water to neutralize acid. Water has alkalinity due to numerous hydroxides, bicarbonates, carbonates, and, in some cases, silicates, borates, and phosphates also. The average alkalinity value was 153.08±36.66 mg/l, which was also found well within the acceptable limit according to the BIS standards of 200 mg/l and the WHO recommendation of 300 mg/l.

Sodium is found in all natural streams; literally all the compounds of sodium can dissolve easily in water, and it naturally leaches from rocks and soil. In a limited amount, it is an essential element for all fresh water animals, plants and humans. The sodium concentration in this investigation was 51.37±9.54 mg/l, which was well below the BIS's allowed limit of 100 mg/l in water. According to Kamboj *et al*., [29, 30], sodium levels in Ganga River ritual bathing places ranged from 3.5 mg/l to 6.4 mg/l.

WQI analysis

The water quality index enables the overall examination of water quality to be carried out at several levels that impact the hosting capacity of a waterway and whether the overall water quality of water bodies constitutes a risk to diverse water usage [2]. Based on all WQI measurements, the Chambal River's average WQI value throughout the current study was 47.77 observed. The water quality was evaluated as 'B' grade or 'good' quality water according to Chatterjee and Raziuddin, [15], Tyagi *et al*., [48] and 'excellent' quality water according to Ramakrishniah *et al*., [41] quality classification standards as mentioned in Table-03 and 04 respectively.

CONCLUSION

Our study's intention was to establish a water quality index for the Chambal River stream and analyze its water's appropriateness for drinking purposes, as the river is included among a few clean rivers in northern India. Several essential physicochemical indicators were considered and examined to assess the adequacy of water. The weighted arithmetical approach to the water quality index was chosen because it gives us an easy understanding of a system's consolidated water quality. The quality rating of the water based on water samples from the flowing region of the river, which was the prime focus of our study, clearly showed that the water in the river Chambal is not profoundly fit for direct human consumption. In our investigation, the river's water quality index not exceeded the permissible optimum figure. Based on our study and samples, which were taken according to the specified guidelines, a water quality index of 47.77 was obtained. However, many studies published in various research journals indicate that sometimes the results of the quality index are influenced by the ideal agency chosen for the ideal permissible values of various parameters in the calculation.

Nonetheless, the quality index of river water which we have obtained is a strong indication that the river's physico-chemical health is in good state but it always remains the same, it's not possible in today's time. So, when a physico-chemical imbalance occurs, whatever the reasons behind it, the ecological health of the river is directly affected. Although the river's water quality index does not fall into the critical category, the WQI value of 47.77 seems to be tending towards the next level of 51-75 ('poor' quality) and above, which indicates that the river is steadily approaching a critical level of contamination. As a result, if there is no treatment available, direct use of this river water for drinking and other purposes should be avoided. There may be a risk of exposure to water-borne infections, as coliform tests are not done during the investigation. It was also discovered that just a few variables' results were beyond the BIS and WHO recommended limits, which may be due to seasonal variations. Some interrelated parameters influence the water quality of any river and its local and temporal variation, which varies throughout the year depending on the water flow rate.[25] Domestic discharge, urban waste, and other anthropogenic activities were found to be the key sources of contamination in the Chambal river water system. However, frequent water quality monitoring is required to detect regular changes in the river's physico-chemical characteristics in order to ascertain the river's health. It not only helps in providing research-based data to our policymakers, but also makes the public aware.

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