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# Evaluation of drinking water quality indices (case study: Bushehr province, Iran)

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**Abstract**

**Background:** Internal corrosion and the formation of scale in water distribution pipes are the most important problems for an urban water distribution system. Physical, chemical, or biological factors can lead to these two processes. Internal corrosion and scale formation can impact health, economy, and aesthetics. This study assessed the physicochemical quality parameters and evaluated the potential for corrosion and scale formation in drinking water at the distribution systems of 5 selected cities in Bushehr province (Kangan, Dashtestan, Dashti, Bushehr, and Ganaveh) from 2009-2012.

**Methods:** This study was carried out based on laboratory data collected from monthly samplings of tap water in the Water and Wastewater Company of Bushehr province during the years 2009-2012. Internal corrosion and scale formation rates were calculated using the Ryznar, Langelier, Aggressive, and Puckorius indices.

**Results:** The results of the Ryznar, Puckorius, Aggressive and Langelier indices indicated that the drinking water in the 5 selected cities of Bushehr province was corrosive. Moreover, the majority of parameters used to determine water quality exceeded Iran's national standards.

**Conclusion:** It is concluded that there is problem of water corrosion and scaling in drinking water of distribution systems in selected cities.

**Keywords:** Bushehr, Water corrosiveness, Scale formation, Saturation index

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## Introduction

A sufficient quantity of drinking water with an appropriate quality is vital for human life. Social, agricultural, and industrial developments have led to the contamination of water resources and reduced water quality. In addition, population growth and increasing living standards in communities have increased the need for water (1). The World Health Organization (WHO) considers the provision of clean water an indicator of health development in developing countries (2). Therefore, an urban water supply system should provide an adequate amount and desirable quality of water (2). The quality of urban drinking water is affected by its chemical stability, which can cause corrosion and scale formation in water pipes.

According to the ISO (8044), corrosion is defined as the chemical and physical interactions between metal and its surrounding environment affecting the characteristics of metal and causing damage to it, its surrounding environment, and its technical system (3). Generally, this environment involves either a liquid medium, such as water flow in pipes, or a solid medium, such as soil contact with buried pipes (4). Water's potential for corrosion is affected by physical, chemical, and biological factors. Physical factors include flow rate and temperature; chemical factors include alkalinity, hardness, conductivity, dissolved oxygen, presence of sulfate and chloride ions, dissolved gases, and pH (5,6). Biological corrosion, which is generally created by iron and sulfate reducing bacteria, is resistant to high amounts of chlorine in a distribution system (6). White et al in 2011 indicated that bio-films grown in the distribution system can impact corrosion in a drinking water distribution system. Moreover, they introduced some other microorganisms influencing corrosion, which can grow in heavy metal-rich environments (7). Scale formation can harm treatment plant equipment and fixtures. Scaling is problematic as it forms inside the pipes and reduces the area available for carrying water. Corrosion can lead to economic, health, and aesthetic problems. Corrosion in distribution pipes can cause perforation, the loss of large volumes of water, and it can reduce the space available for carrying water (8). Water with high corrosion potential can dissolve the initial materials in metal pipes and fittings and cause health problems. Corrosion may also allow heavy metals such as cadmium, copper, lead, and other pollutants to enter the water. Industry spends billions of dollars because of corrosion. According to 2002 reports, the expenses associated with corrosion in Australia, the United Kingdom, Japan, and some other countries were several times greater than the respective country's gross national product (9). There are no exact statistics available regarding the expenses caused by corrosion and scaling in Iran; however, it has been indicated that greater than 30% of the distributed water is lost because of corrosion in the distribution systems (10).

In Iran, similar studies have been conducted to evaluate the stability of drinking water. Ebrahimi et al in 2012 investigated the potential for corrosion and scale formation in the drinking water distribution system of Koohdasht city using indices of corrosion and scale formation. Their results indicated that the drinking water in Koohdasht tends to be corrosive (11). Similarly, Jaafarzadeh et al found that the drinking water in Ahwaz city is corrosive and contains high concentrations of metals (exceeding EPA standards) including lead, iron, cadmium, copper, and manganese (12). Furthermore in 2012, Malakootian and Fatehizadeh evaluated the quality of drinking water in Bardsir city, Iran using the Langelier, Ryzener, and Aggressive indices and found that it is scaling (5). Paseban et al assessed the drinking water distribution system of Bojnoord, Iran in 2012 and found that the drinking water distribution system in Bojnoord had a scaling tendency. They suggested that scaling may lead to reductions in flow and pressure in the water system (13). In another study in 2011, Mokhtari et al indicated that the drinking water in Ardabil city was slightly corrosive (14). Zazouli et al found similar results in Yasooj city (15).

According to the statistics obtained from the Water and Wastewater Company in Bushehr province, the amount of water produced for the province in the first 6 months of 2011 was 1 118 507 cubic meters from underground reservoirs and 37 761 285 cubic meters from surface water, of which the total amount of 23 146 177 cubic meters was consumed. Considering the high levels of water lost from the distribution system, the evaluation of reasons for such losses seems to be essential. The water pipes used in the distribution networks of these cities are galvanized metal with a lifetime of usually about 20 years. One important factor involved in water loss in distribution systems is corrosion. Therefore, it is necessary to study all factors involved in the corrosion potential of water resources and its trend in distribution systems. The potential of water to corrode and scale is characterized by its stability. Instability and low quality water in pipes can lead to corrosion and scaling in them (16,17).

## Methods

This study aimed to determine the corrosion and scaling potential of drinking water in 5 selected cities in Bushehr province (Bushehr, Kangan, Dashtestan, Ganaveh, and Dashti) using the Ryzener, Puckorius, Aggressive, and Langelier water stability indices.

Bushehr has a latitude of 27°14′N and a longitude of 50°6′, 52°58′E from the Greenwich meridian and is surrounded by Khuzestan, Kohkiloye, and Boyer Ahmad provinces from the north, the Persian Gulf and Hormozgan province from the south and west, and Fars province from the east. It has an area of about 27 653 km$^2$ and population of over 886 000 people. According to political divisions, this province consists of nine cities, 5 of which (Kangan, Dashtestan, Dashti, Bushehr, and Ganaveh) were selected for the present study. The geographic location of this province is shown in Figure 1. The main sources of drinking water in this province are rivers, springs, groundwater wells, and the Kowsar Dam reservoir.

Data used in this study was obtained from the Bushehr Water and Wastewater Company and included water quality parameters such as the concentrations of anions (chloride, sulfate, ammonium, nitrate, nitrite, fluoride), cations (calcium, magnesium, iron), total hardness, total alkalinity, pH, and total dissolved solids (TDS) that were determined regularly from drinking water distribution systems in the selected cities. Samples were taken in Bushehr, Dashtestan, and Dashti from 2010 to 2011, in Kangan from 2008 to 2012, and in Ganaveh from late 2007 to late 2010. The total number of samples used in this study was 228. Processes including sterilization of containers, sampling, and transportation and storage of samples in the lab were performed according to standard procedures (18).

Statistical analysis was performed using SPSS software (version 16), and the mean results were compared with Iranian National and EPA standards. A single sample

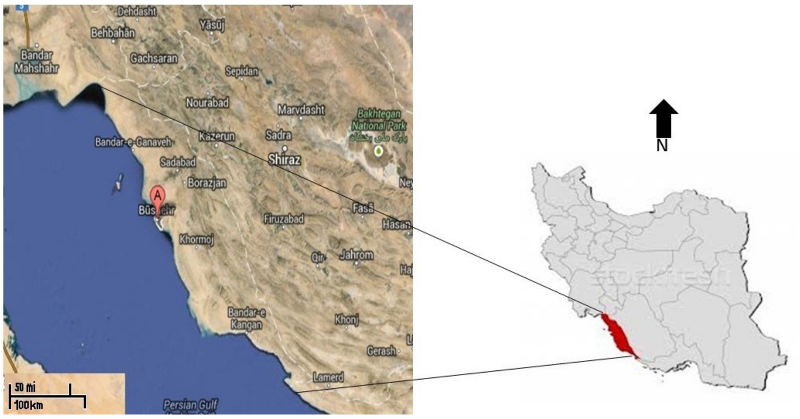


**Figure 1.** Geographical situation of Bushehr province.

$t$ test was used to compare the means of water quality parameters with the standard limitations, applying $P < 0.05$ as the minimum level of significance.

To determine the corrosion and scaling potential of the water distribution systems in the 5 selected cities, the Langelier (LI), Ryzener (RI), Puckorius (PI) and corrosivity (AI) indices were used with equations 1 to 6.

*pHs = 9.3 + A + B – (C + D)* (11) Eq. 1

*A = (Log10 (TDS)-1)/10* (14)

*B = -13/12Log10 (°C + 273) + 34.5* (14)

*C = Log10 (Ca2+ as CaCO3)- 0.4* (14)

*D = Log10 (Total Alkalinity as CaCO3 )* Eq. 2

*RI = 2 pHs – pH* (11) Eq. 3

*LI= pHs – pH* (11) Eq. 4

*PI = 2 pHs - pHeq* (11) Eq. 5

*pHeq = 1.465 Log (Total Alkalinity as mg/l)+ 4.54* (11) Eq. 6

## Results

The results (Tables 1 and 2) of the Langelier saturation index showed that the drinking water in Ganaveh (0.38) and Bushehr (0.18) was unstable and had a slight scaling tendency. The drinking water of Dashtestan (-0.062), Dashti (-0.23), and Kangan (-1.09) was shown to be corrosive. In comparison, the water of Ganaveh had the highest potential for scaling, and that of Kangan and Dashtestan had the maximum and minimum corrosion potential, respectively.

**Table 1.** The interpretation of indices (11)

| Saturation Index | Ranges | Interpretation |
|---|---|---|
| LI | > 0 | Water is scale forming (non-aggressive) |
| | < 0 | Water is not scale forming (aggressive) |
| | = 0 | Water is balanced |
| RI | < 4 | Water is scale forming (non-aggressive) |
| | 5-6 | Water is relatively scale forming |
| | 6-6.5 | Water is stable |
| | 6.5 -7 | Water is aggressive |
| | > 8 | Water is aggressive strongly |
| AI | <10 | Water is aggressive strongly |
| | 10-12 | Water is aggressive |
| | >12 | Water is non-aggressive |
| PI | <6 | Water is aggressive |
| | >6 | Water is scale forming (non-aggressive) |

The results of Aggressive index indicated that the water quality of Bushehr (12.21) and Ganaveh (12.3) cities were sever aggressive and Dashti (11.75), Dashtestan (11.91), and Kangan (10.96) were low aggressive.

Results of the Ryznar stability index indicated that the aggressiveness of the drinking water was low in Bushehr (7.01) and Ganaveh (7.04), medium in Dashtestan (7.51) and Dashti (7.78), and severe in Kangan (9.78).

According to the Puckorius Scaling Index (PSI), the 5 selected cities had a tendency for corrosion. The highest tendency was observed in Kangan (11.21).

Table 3 summarizes the results of the water quality parameter analysis. The results showed that the mean concentrations of water quality parameters in some cases were higher than Iran's national allowable limits. In Kangan, there were no significant differences between mean concentrations of $No^{-2}$ and $SO^{-4}$ and the Iranian national standard. TDS, total hardness, $Mg^{+2}$, and $Cl^{-}$ concentrations showed positive significant differences with Iranian national standards, because they exceeded the national allowable limitations. The parameters of $F^{-}$, $NO^{-3}$, $NH_3$, $Ca^{+2}$, $Fe^{+2}$, and pH had no significant differences with national standards.

Assessing the water quality parameters in the selected cities revealed that the mean concentration of TDS in Kanghan and Dashtestan exceeded the national allowable limits. Total hardness of water in Kanghan, Dashtestan, Dashti, and Bushehr also exceeded national limits. The water in Kangan had the highest chloride concentration among the selected cities which was significantly different from national standards in that it exceeded national limits. The results in Kangan and Dashti revealed that the mean concentrations of total hardness and $Mg^{+2}$ had positive significant differences with Iranian national standards. The evaluation of total water hardness in Bushehr and Ganaveh cities showed a positive significant difference with national standards. $Ca^{+2}$ concentration in Ganaveh had no significant difference with national standards. The rest of the assessed data showed no significant differences

**Table 2.** Interpretation of water quality Indices in selected cities

| Index | Selected city | Kangan | Dashtestan | Dashti | Bushehr | Genaveh |
|---|---|---|---|---|---|---|
| | n | 110 | 57 | 14 | 20 | 27 |
| LSI | Mean± SD<br>(min-max) | -1.09±0.7<br>(-3.14-0.39) | -0.062±0.9<br>(-4.89-1.30) | -0.23±0.99<br>(-2.56-.58) | 0.18±0.44<br>(-.82-0.9) | 0.38±1.25<br>(-2.4-2.9) |
| | Interpretation | Aggressive | Aggressive | Aggressive | Scale formation | Scale formation |
| AI | Mean± SD<br>(min-max) | 10.96±0.78<br>(8.7-12.4) | 11.91±0.92<br>(6.98-13.3) | 11.75±1.03<br>(9.31-12.6) | 12.21±0.45<br>(11.18-12.94) | 12.3±1.2<br>(9.57-14.94) |
| | Interpretation | Median aggressive | Low aggressive | Low aggressive | Not aggressive | Not Aggressive |
| RI | Mean± SD<br>(min-max) | 9.78±1.27<br>(7.41-13.77) | 7.51±1.7<br>(5.41-16.98) | 7.78±1.70<br>(6.64-11.93) | 7.01±0.77<br>(5.7-9.16) | 7.04±1.74<br>(4.12-11.26) |
| | Interpretation | Median aggressive | Median aggressive | Median aggressive | Low aggressive | Low aggressive |
| PSI | Mean± SD<br>(min-max) | 11.21±1.4<br>(9.02-16.29) | 7.23±2.1<br>(5.32-18.5) | 7.63±1.8<br>(5.82-11.84) | 6.62±1.3<br>()4.75-10.56 | 7.39±1.46<br>(5.37-11.46) |
| | Interpretation | Sever aggressive | Aggressive | Aggressive | Aggressive | Aggressive |

**Table 3.** Analysis of physicochemical quality of drinking water in 5 selected cities in Bushehr province

| Parameter | City | | | | | Iranian national standard[b] (19) | EPA (19) | Unit |
|---|---|---|---|---|---|---|---|---|
| | Kanghan<br>n = 110 | Dashtestan<br>n =57 | Dashtie<br>n =14 | Bushehr<br>n =20 | Ghenaveh<br>n =27 | | | |
| TDS | 2170.32±745.9<br>(55-9260) | 2785.9±369.2<br>(9-1538) | 951.79±525.9<br>(50-1797) | 1438.95±1514.8<br>(220-7650) | 552.85±344.6<br>(100-1080) | 1500 | 500 | mg/L |
| *P* value | 0.013[a] | 0.000[a] | 0.002[a] | 0.859[a] | 0.000[a] | _ | _ | _ |
| Total hardness | 915.87±944.3<br>(12-3812) | 587.6±315.9<br>(4-1600) | 579.1±315.94<br>(4-1600) | 583±163.3<br>(220-1100) | 454.1±218.84<br>(60-720) | 500 | 350 | mg/L as $CaCO_3$ |
| *P* value | 0.000[a] | 0.041 | 0.375 | 0.035 | 0.286 | _ | _ | _ |
| Total Alkalinity | 1.00±0.16<br>(1-1) | 2.11±0.345<br>(1-2) | 2.05±0.250<br>(2-2) | 2.18±0.367<br>(1-3) | 1.99±0.63<br>(1-2) | _ | _ | mg/L as $CaCO_3$ |
| *P* value | - | - | - | - | - | _ | _ | _ |
| Fluoride | 0.86±0.74<br>(0-6) | 0.81±0.6<br>(0-3) | 0.57±0.5<br>(0-1) | 0.53±0.31<br>(0-1) | 0.56±0.353<br>(0-1) | 1.7 | 2 | mg/L |
| *P* value | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | _ | _ | _ |
| Chloride | 883.33±1678.5<br>(25-7460) | 206.55±138<br>(11-994) | 207.76±91.7<br>(40-390) | 193.96±95.9<br>(89-532) | 193.96±95.8<br>(4-216) | 400 | 250 | mg/L |
| *P* value | 0.003[a] | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | _ | _ | _ |
| Sulfate | 370.12±307.4<br>(8-2350) | 240.63±186.6<br>(0-1360) | 130.25±63.6<br>(20-260) | 194.08±143.4<br>(72-464) | 294.35±173.8<br>(25-672) | 400 | 250 | mg/L |
| *P* value | 0.310 | 0.000 | 0.0000 | 0.000 | 0.004 | _ | _ | _ |
| Nitrite | 2.62±3.95<br>(0-24) | 0.01±0.38<br>(0-0) | 0.1±0.021<br>(0-0) | 0.02±0.089<br>(0-0) | 0.0±0.004<br>(0-0) | 3 | 1 | mg/L |
| *P* value | 0.312 | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | _ | _ | _ |
| Nitrate | 6.09±7<br>(0.67-) | 38.11±26.8<br>(0-32) | 24.7±87.6<br>(0-329) | 1.65±2.73<br>(0-10) | 2.06±4.28<br>(0-21) | 50 | 10 | mg/L |
| *P* value | 0.000[a] | 0.739 | 0.299 | 0.000[a] | 0.000[a] | _ | _ | _ |
| Ammonium | 0.22±0.1<br>(0-0) | 0.01±0.024<br>(0-0) | 0.03±0.05<br>(0-0) | 0.6±0.223<br>(0-1) | 0.13±0.47<br>(0-176) | 1.5 | _ | mg/L |
| *P* value | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | _ | _ | _ |
| Calcium | 114.3±102.8<br>(3-401) | 131.95±69<br>(0-321) | 154.24±91.75<br>(3-361) | 183.1±189.2<br>(22-1041) | 134.45±108.2<br>(0-1041) | 250 | _ | mg/L |
| P Value | 0.000[a] | 0.00[0a] | 0.02[a] | 0.00[0a] | 0.77 | _ | _ | _ |
| Magnesium | 156.63±183.3<br>(1-720) | 65.77±52.42<br>(0-249) | 84.97±120.04<br>(2-478) | 37.78±20<br>(13-102) | 32.45±19.95<br>(13-102) | 50 | _ | mg/L |
| *P* value | 0.000 | 0.027 | 0.295 | 0.013 | 0.000 | _ | _ | _ |
| Iron | 0.13±0.280<br>(0-2) | 0.04±0.088<br>(0-0) | 0.05±0.116<br>(0-1) | 0.07±0.2<br>(0-1) | 0.05±0.14<br>(0-1) | 0.3 | 0.3 | mg/L |
| *P* value | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | _ | _ | _ |
| pH | 7.19±1.51<br>(6-8) | 7.39±0.280<br>(7-8) | 7.34±0.314<br>(7-8) | 7.38±0.317<br>(7-8) | 7.80±0.852<br>(6-10) | 8.5 | 9 | _ |
| *P* value | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | 0.000[a] | _ | _ | _ |

[a] One sample test used to mean comparison between cities data and Iranian national standards, applying $P < 0.05$ as the minimum level of significance.
[b] Maximum allowable limits: the maximum ions concentrations in the water that Its continued consumption will not be hazardous for human health with weight of 76 kg and daily water consumption of 2 L.

with national standards.

## Discussion

The present study has shown that the drinking water of distribution systems in 4 of the studied cities had a tendency to corrode, and in Bushehr the tendency of scale formation was predominant. pH is an important parameter for predicting corrosion. Normally, a higher pH indicates a lower corrosion rate. A high pH contributes to protective film formation by reducing the film-free corrosion rate and increasing the precipitation rate. pH influences $FeCO_3$, and, under certain circumstances, increasing pH decreases $FeCO_3$ solubility and increases super saturation (20). According to the current findings, the concentrations of totally dissolved solids, chloride, and sulfate ions in drinking water are high in most of the cities studied, and this can lead to increased corrosion tendency in water. pH and total alkalinity can determine the distribution of $CO_2$, $HCO_3$, and $CO_3^{2-}$ fractions in water. Species distribution depends on pH value, temperature, and ionic strength. This finding is consistent with the findings of other similar studies (21, 22).

Some studies have found that low pH (23) and high concentrations of chloride and sulfate ions (24) can lead to water being more aggressive. Husband et al showed that perforation of a copper pipe is related to cold and chlorinated waters with high pH and sulfate and low alkalinity (25). Moreover, a high correlation was found between the severity of corrosion in metal pipes and the ratio of sulfate and chloride ions to bicarbonate (26,27). These results suggest that high metal concentrations associated with low bicarbonate concentrations in water may increase its corrosion tendency. Furthermore, a low concentration of bicarbonate ions can increase the corrosivity of water, and high concentrations of dissolved solids and oxygen can increase the severity of corrosion. Dissolved solids may lead to increased water conductivity and result in increasing corrosion potential, which would be intensified with the predominance of sulfate and chloride ions and would be reduced with the predominance of bicarbonate ions (23).

In the present study, Kanghan had the most aggressive water among all the studied cities, followed by Dashtestan, Dashti, and Ganaveh. According to the results (Tables 1 and 3), the drinking water in Kanghan had the highest concentrations of chloride, sulfate, nitrite, ammonium, iron, magnesium, fluoride, and total hardness. Moreover, the lowest pH and alkalinity and the highest concentration of TDS which may contribute to causing severe corrosivity of drinking water were observed in this city. Ammonia is responsible for the rapid consumption of oxygen and chlorine in water (28). Furthermore, low alkalinity and high ionic concentrations of sulfate, chloride, iron, magnesium, and total hardness could accelerate the corrosivity of water (29). It has been suggested that high concentrations of iron in drinking water may result in a severe corrosion potential for the water distribution network of Kangan (17,30). A high TDS concentration is usually associated with high concentrations of ions which increases the conductivity of water. The water's ability to conduct a corrosive current has a direct relationship with conductivity (31). In contrast, the water quality indices showed that Bushehr had the best water quality parameters and a mild tendency to scaling formation. Compared with Iran's national standards, the parameter values were in accordance with allowable limits, suggesting a more desirable water quality. It is suggested that the intensity of a lower corrosion potential can be attributed to a better quality of water in the pipes of a distribution system. Similarly, the other cities which have a higher water quality may have less aggressive drinking water. According to the findings of this study and other similar studies, the drinking water in some provinces of Iran does not have appropriate chemical stability; it seems that there are corrosion and scale formation problems in the distribution systems of these provinces. Other studies have been carried out in Shahroud (32), Kian (33), Kerman (2), Shahrood (34), Zanjan (3), Ahvaz (35), Kashan (36) and other cities to assess the quality of drinking water using aggressive and scaling indices. According to these studies, the drinking water in Shahroud, Kian, Ardebil, Zanjan, Ahvaz, and Kashan has a tendency to be aggressive, and in Kerman, there is a scaling potential. Selvam et al (37) evaluated the water quality index of groundwater resources around the coastal city of Tuticorin in southern India and concluded that the groundwater quality was impaired by man-made activities. Ravikumar et al studied the water quality index to determine the quality of surface water of Mallathahalli Lake in India and showed that the lake water fell into the poor water category (38).

## Conclusion

According to the findings of the present study, the majority of water quality parameters of the drinking water in distribution pipes of the 5 studied cities exceeded Iranian national and EPA standards. Therefore, it seems there is a problem with the usage of water in some specific industries. Moreover, the drinking water in the selected cities was not chemically stable, and thus it seems there is a problem of water corrosion and scaling in the drinking water distribution systems. Corrosion byproducts and leakage of heavy metals and iron in drinking water pipes are common results of aggressive waters. Therefore, it is recommended that corrosion and scaling indices be used in future studies to attain the information needed by water operators to predict the extent of corrosion and metal leakage in water distribution networks and to enable the continuous monitoring of water quality.

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## Ethical issues

The authors certify that all data collected during the study is presented in this manuscript, and no data from the study has been or will be published separately.

## Competing interests

The authors declare that they have no competing interests.

## Authors' contributions

All authors contributed equally and were involved in designing the study, data collection, and article approval.

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