Tropical Climate Constructed Wetlands as an Urban Stormwater Quality Improvement

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ABSTRACT: The rapid development in an urban area can drastically change the land use and deteriorate the quality of source water. The contribution of higher intensity of rainfall will also worsen the problem and affect the quality of water. Constructed wetland is an essential component in improving the quality of stormwater and as an alternative method to reduce flood in urban area. It has been widely used in developed countries and temperate climate for the stormwater quality improvement. However, in Malaysia it can be considered as a new innovation and has not been widely implemented nationwide. The aim of this paper is to evaluate the function of constructed wetland in tropical climate as stormwater quality improvement with the experience from three constructed wetlands situated in Penang, Selangor and Kuala Lumpur in Malaysia. The data collected from these wetland systems used to treat stormwater runoff or runoff-impacted surface waters were examined and compared in order to identify any obvious trends that may aid future stormwater treatment wetland design efforts. The parameters measured and discussed in this paper are Total Phosphorus (TP), Biological Oxygen Demand (BOD), Total Nitrogen (TN), Total Suspended Solid (TSS) and Chemical Oxygen Demand (COD). The results indicate that the mean pollutant removal for BOD ranged from 8.73% to 39.03%, COD ranged from 11.74% to 27.66%, TSS ranged from -72.70% to 73.64%, TP ranged from 1.32% to 57.69% and TN ranged from 3.50% to 70.56%. The findings also indicate that the mean outlet concentrations for BOD, COD and TSS comply with the Water Quality Index Class II, thus far, partially fulfil the government's policies. Findings from this study can be used significantly to enhance the knowledge in constructed wetland under tropical climate where it can serve effectively for managing urban runoff using control at source approach.

KEYWORDS: Constructed wetland; Water quality; Tropical climate; stormwater; urban runoff

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INTRODUCTION

Stormwater management has evolved dramatically throughout Malaysia since its first adoption and application in Malaysia as early as 2000. The original management manual, Manual Saliran Mesra Alam (MSMA) was intended to provide guidance in planning and designing effective stormwater best management practices (BMPs) to developer/owner developing properties subject to Drainage and Irrigation Department of Malaysia and Local Government compliance (DID, 2000). This manual effectively manages the impacts of stormwater and prevents adverse impacts to stormwater quality, habitat and flood storage capacity as well as meets the requirements set by the Malaysian government. The Drainage Irrigation Department (DID) has updated the original manual (1st Manual) to reflect the current engineering practice based on the local data and experience concerning stormwater management and to incorporate the Manual Saliran Mesra Alam (MSMA) methods. The revised manual, (MSMA 2nd Edition) provides appropriate guidance for stormwater management on new development and redevelopment projects and most importantly, incorporates MSMA as the "industry standard" for all sites, representing a fundamental shift in how development projects are planned and designed (DID, 2011). The concept in MSMA 2nd edition is to control the stormwater at source quantitatively and qualitatively and provide amenity to the new developed area.

Constructed wetland is one of the elements in MSMA Manual, incorporating the natural function of wetland to aid pollutant removal from stormwater with the advantage of control over location, design and management to optimize the water quality function (DID, 2012). It is commonly used as a practice to reduce non-point source pollutants and as a stormwater treatment system. It is part of sustainable urban drainage system and has a main function as water quality improvement, thus, contributing towards environmental friendly effort and can be one part of the green technology concept. Constructed wetland can be defined as an engineered system that is designed to imitate natural wetland to exploit the water purification functional value for humans (Kivaisi, 2001). It can be clearly designed to aid in pollutant removal from stormwater through sedimentation, filtration of fines and biological uptake (Donald, 2001; Mitch & Gosselink, 2000).

Constructed wetlands are widely used in temperate climate countries compared to tropical climate countries as water quality improvement. The success of constructed wetlands application for wastewater has led to the exploration of the treatment for different sources such as stormwater, industrial, agricultural, urban, airport runoff and acid mine drainage (Scholz *et al.*, 2007; Kadlec & Wallace, 2009; Asmaliza *et al.*,2013). However, the constructed wetlands have evolved recently to the hybrid system with the application to treat various industrial wastewater (Oovel *et al.*, 2007; Serrano *et al.*, 2011; Kato *et al.*, 2011). Water quality issues have become increasingly important and this forms the main goal in constructed wetland (Kadlec, 2005). The information on water quality for constructed wetland is very important to ensure that the constructed wetland has an ability to remove the contaminants from stormwater runoff. Therefore, the aim of this paper is to evaluate the function of constructed wetland in tropical climate as stormwater quality improvement with the experience from three constructed wetlands in Malaysia.

METHODOLOGY

Study Area

i) Putrajaya Wetland

Putrajaya has been developed by the Federal Government and functions as the Federal Administrative Centre of Malaysia. It is strategically located with the coordinate 2^0 57′ 43″N and 101^0 41′ 47″E, at the south of the popular Klang Valley area. The Putrajaya lake catchment, which is also known as the Sg. Chuau catchment, is located about 25 km south of Kuala Lumpur and it extends about 12 kilometres in a north to south direction and about 4.5 km from east to west (**Figure 1**). The surface area of the whole lake is about 400 hectares with a total volume of about 23.5 million cubic meters. The water depth ranges from 3 to 14 metres with the average depth of 6.6 metres. The lake has a 20 m width promenade that acts as a buffer feature along the lake shorelines and stretches at a total length of 34.0 km. The Putrajaya catchment covers an area of 52.4 km^2 and eight major sub-catchments of the Putrajaya lake catchment are the Upper-North, Upper-West, Upper-East, Lower East, Bisa, Central, Lower and Limau Manis.

ii) USM Engineering Campus

The USM Engineering Campus project is located at Sri Ampangan, Nibong Tebal Pulau Pinang with the coordinate 100^0 30.3′N and 5^0 9.4′ E, about 2 km South East of the town of Nibong Tebal, about 1.5km North East of the town of Parit Buntar Perak and about 1.5km North West of the town of Bandar Baharu (**Figure 1**). The area of the campus is about 320 acres and is made up of mainly oil palm plantation land. It is fairly flat. The project includes a series of components such as ecological swales, online sub surface detentions and dry ponds that contribute to the treatment of the stormwater before it leaves the campus. This system, known as Bioecological Drainage System

(BIOECODS), was designed to combine infiltration, delayed flow, storage and purification as pre-treatment of stormwater before discharging to a constructed wetland. The concept of BIOECODS is to integrate the drainage components with the ecological pond components for further treatment of the stormwater runoff.

iii) Humid Tropic Center

The site of the constructed wetland is located at Humid Tropic Centre (HTC) Jalan Redang, Kuala Lumpur with coordinate 3^0 10′ N and 101^0 42′ E, near to the Drainage Irrigation Department (DID) Headquarters, Kuala Lumpur (**Figure 1**). The constructed wetland is a part of the Manual Saliran Mesra Alam Stormwater Management Ecohydrology (MSMA SME) components at Humid Tropic Centre. The components comprise of constructed wetland, bio-retention, grass swale, rain water harvesting, green roof, porous pavement and greywater reuse system. Stormwater will convey to the constructed wetland through the grass swale and bio retention before discharging to the water course.

Data collection and Analysis

Water quality data from the respective study area were collected at the inlet and the outlet points of the constructed wetland during rainfall events from April 2011 until December 2012 using grab sampling method. The parameters measured and discussed in this paper were Total Suspended Solids, Total Phosphorus, Total Nitrogen, Biological Oxygen Demand and Chemical Oxygen Demand. However, other parameters such as temperature, heavy metals, dissolved oxygen and Total Coliform were also measured and analysed concurrently. The testing procedures conducted were in accordance to the *Standard Method for Examination of Water and Wastewater (20th Edition)*. After that, the statistical analysis using Wilcoxon Signed Teat was carried out to determine the significant conditions between water quality parameter at the inlet and outlet points, hence, evaluating the performance of the constructed wetland.

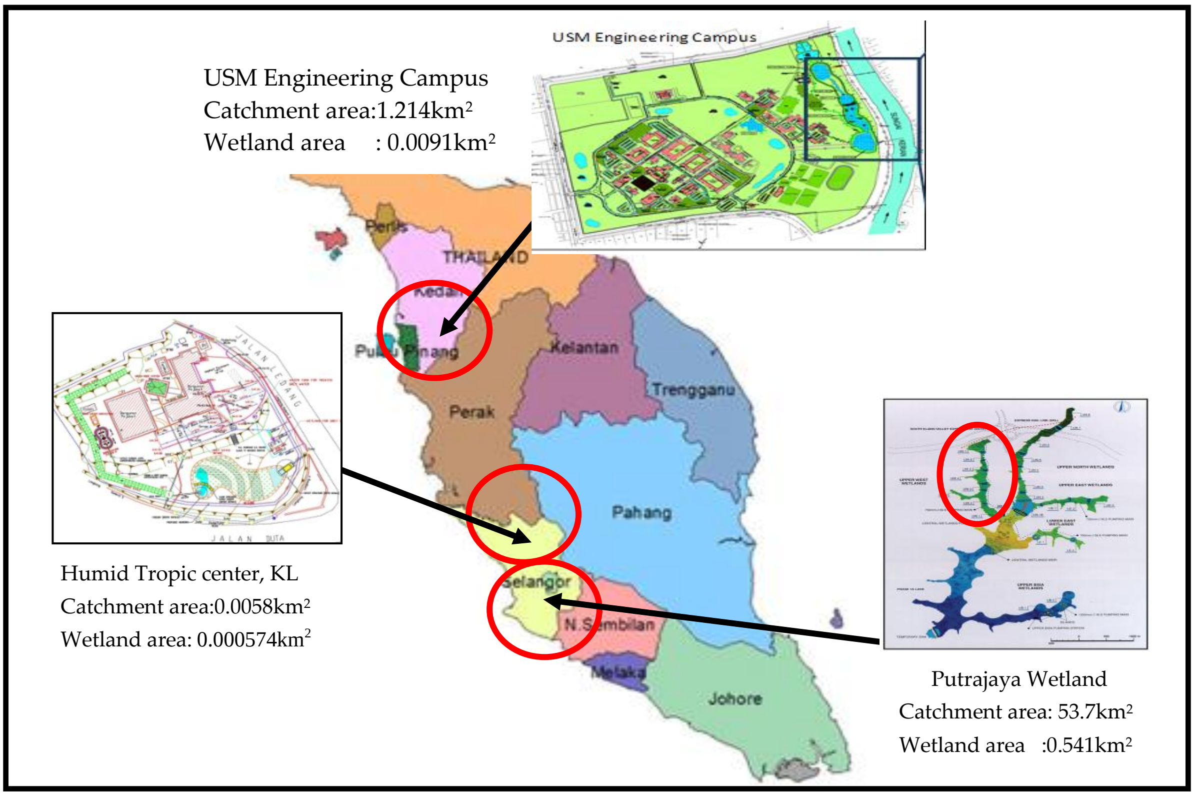

Figure 1. Location of study sites

RESULT AND DISCUSSION

Water Quality Standard

The water quality standards which is commonly practised in Malaysia is National Water Quality Standard (NWQS) provided by the Department of Environment (DOE) with 6 classes of water quality (I, II, III, IV, and V) (**Table 1**). Currently, the Malaysian government upholds the policy that all water quality shall be maintained in class II and deemed as suitable for recreational use with body contact. Consequently, the concentrations at the outlet point of the constructed wetland must comply with Class II NWQS in order to fulfill the requirement.

Table 1. National Water Quality Standard (DOE, 2006)

Parameters	Class				
	I	II	III	IV	V
BOD(mg/l)	<1	1-3	3-6	6-12	>12
COD(mg/l)	<10	10-25	25-50	50-100	>100
TSS (mg/l)	<25	25-50	50-150	150-300	>300
DO (mg/l)	>7	5-7	3-5	1-3	<1
pH	>7	6-7	5-6	<5	>5
AN (mg/l)	<0.1	0.1-0.3	0.3-0.9	0.9-2.7	>2.7
Water Quality Index (WQI)	<92.7	76.5-92.7	51.9-76.5	31.0-51.9	<31.0

Biochemical Oxygen Demand

Table 2 shows the data for Putrajaya. The mean concentration at the inlet was 2.104 mg/l and outlet was 1.840 mg/l while the mean percentage of removal efficiency was calculated around 8.73%. Meanwhile, the mean BOD concentration for the Humid Tropic Centre at the inlet was 3.938 mg/l and outlet was 2.148 mg/l and the mean removal efficiency for HTC was calculated at around 39.03%. As for the USM Engineering Campus, the mean concentration at the inlet was 1.335 mg/l and outlet was 1.098 mg/l and the mean percentage of removal efficiency for USM Engineering Campus was 9.34%. Thus, the mean concentration for both outlets (inlet and outlet) for Putrajaya and the USM Engineering Campus recorded below NWQS. HTC, on the other hand, recorded a little higher concentration compared to NWQS which was 3 mg/l (**Table 1**) for inlet but slightly lower for the outlet.

The results obtained from the study sites are similar to the other researchers' findings across the world where constructed wetland has an ability to remove BOD. Mustafa *et al.* (2009) assessed the long term performance of representative integrated constructed wetlands in treating farmyard runoff and the results indicated that the percentage of BOD removal was around 97.6%. Another study conducted by Babatunde *et al*. (2011) in Ireland showed that the percentage of removal efficiency for BOD was around 18% to 88%. In the present study, HTC showed the highest removal efficiency of BOD compared to the other selected locations; Putrajaya and the USM Engineering Campus. The removal efficiency depends on system type, design, retention time, hydraulic, nutrient mass loading rate, climate, vegetation and microbial communities (EPA, 2000). Other factors that may contribute to the good performance of constructed wetlands as a BOD removal is filtration/ sediment of suspended solids and bacteria oxidation (Babatunde *et al*., 2008).

Table 2. BOD concentrations at the inlet and outlet points and percentage removal for respective study sites

Study site	Mean BOD concentration (inlet)	Mean BOD concentration (Outlet)	Mean Percentage removal
HTC	3.938±0.37	2.148±0.25	39.03
USM	1.335±0.17	1.098±0.16	9.340
Putrajaya	2.104±0.11	1.84±0.10	8.73

Chemical Oxygen Demand

The mean COD concentration at the inlet and outlet points of the constructed wetland and the percentage of removal efficiency for study areas are shown in **Table 3**. As for Putrajaya, the mean inlet concentration recorded 14.08 mg/l and 12.71 mg/l respectively. The Humid Tropic Center's mean inlet concentration recorded 20.66mg/l while the mean outlet concentration recorded 16.39 mg/l. The performance between inlet and outlet concentrations can be calculated as the mean percentage of removal efficiency with the value of 17.67%. COD concentration at the inlet and outlet points for the USM Engineering Campus pointed out that the mean concentration was 16.87mg/l and 12.35 mg/l respectively. The calculated mean removal efficiency for this site was 27.68%. Both inlet and outlet points for the study sites indicated lower value compared to NWQS which was 25 mg/l (**Table 1**). Therefore, the USM Engineering Campus showed the highest percentage of removal efficiency compared to the other two selected areas (HTC and Putrajaya) when comparison between the mean percentage of removal efficiency were made.

Previous studies conducted by Jing *et al.* (2008) and Dong *et al.* (2011) recorded that the removal efficiency for COD was around 51%-92%. The COD removal within the wetland system depends on vegetation type and water level due to root oxygen and carbon release (Sun *et al*., 2009; Dong *et al*., 2011). The existence of the macrophytes in the constructed wetlands system is important to remove the organic material from polluted water (Jing *et al*., 2008). The highest COD removal performance might be due to good growth of vegetation resulting in a high concentration of dissolved oxygen (Dong *et al*., 2011).

Table 3. COD concentrations at the inlet and outlet points and percentage removal for respective study sites

Study site	Mean COD concentration (inlet)	Mean COD concentration (Outlet)	Mean Percentage removal
HTC	20.66±2.45	16.39±1.72	17.67
USM	16.87±1.49	12.35±1.60	27.68
Putrajaya	14.08±0.98	12.71±0.79	11.74

Total Suspended Solid

Table 4 highlights the mean TSS concentration at the inlet and outlet points and the mean percentage removal efficiency for study areas respectively. The mean concentration for Putrajaya at the inlet and outlet points was 25.55mg/l and 18.66 mg/l respectively while the mean for the percentage of pollutant removal was around 1.42%. Meanwhile, the Humid Tropic Center mean concentration at the inlet was 28.02 mg/l and at the outlet was 45.69 mg/l, while the mean percentage of pollutant removal efficiency is -72.70%. The negative percentage means that higher TSS concentrations at the outlet on certain storm events was due to a nearby construction process, thus, contributing a lot of sediment flows into the outlet zone. As for the USM Engineering Campus, the mean concentration at the inlet was recorded at 24.48 mg/l while the outlet concentration was recorded at 6.17 mg/l. The mean percentage of removal efficiency was 73.64%. The main factor that contributes to the lower inlet concentration at the USM Engineering Campus is that the stormwater is already conveyed through the swale and detention pond before entering the constructed wetlands. NWQS for TSS in order to achieve Class II is 50 mg/l (**Table 1**) and all the mean concentrations for the study sites were below the NWQS value. Meanwhile, Humid Tropic Center recorded relatively the highest pollutant removal efficiency amongst other selected study sites.

The results from these study sites are supported by the previous study in the Czech Republic indicated that the percentage of removal efficiency was around 93.2% and 88.5% during the stabilization periods in 2007 and 2008 respectively (Vymazal & Kropfrlova, 2011). Along the same line, Mustafa *et al.* (2009) conducted a continuous study to evaluate the performance of the integrated constructed wetlands and found that the percentage of pollutant removal efficiency for TSS was around 93.7%. In addition, Shutes *et al.* (2004) conducted a study on the constructed wetlands in the United Kingdom and recorded that the percentage of pollutant removal efficiency for TSS at around 36% to 95% with an average of 76%. The results might have been due to the suspended solid that usually happens in the physical process where the major removal mechanisms are sedimentation aggregation and surface adhesion. The mechanisms are involved when the largest and heaviest particle settle in the inlet and open water zone while slightly smaller and lighter particles may only settle after flowing into wetlands vegetation (USEPA, 1999). The function of wetlands vegetation is to enhance the sedimentation by reducing water column mixing and re suspension of particles from the sediment surface (USEPA, 1999).

Table 4. TSS concentrations at the inlet and outlet points and percentage removal for respective study sites

Study site	Mean TSS concentration (inlet)	Mean TSS concentration (Outlet)	Mean Percentage removal
HTC	28.02±4.15	45.69±9.12	-72.70
USM	24.48±1.97	6.17±0.69	73.64
Putrajaya	25.55±3.62	18.66±3.50	1.42

Another Parameters Analysis

i) Total Phosphorus

Table 5 shows the mean concentrations of Total Phosphorus at the inlet and outlet points of the study sites and the percentage of pollutants removal for the study sites respectively. The result for Putrajaya wetland recorded the inlet and outlet concentration at 0.061 mg/l and 0.06 mg/l respectively while the mean percentage of removal efficiency was calculated around 1.32%. The HTC wetland result showed that the mean inlet concentration and outlet concentration was around 0.954 mg/l and 0.324 mg/l respectively, while the mean percentage of pollutant removal efficiency was at 57.69%. As for the USM Engineering Campus, the mean inlet concentration was 0.205 mg/l while the mean outlet concentration was 0.123 mg/l. The mean percentage of removal efficiency was 33.04%. The finding amongst these study sites indicate that the HTC wetland has a good percentage of removal efficiency compared to the other two locations.

The findings from the current study sites are supported by Kadlec *et al.* (2012) study on the performance of constructed wetlands to improve water quality at Brighton Wetlands. It was found that the percentage of removal efficiencies for TP was around 33%. Other similar supportive studies include those conducted in Taiwan and Queensland, Australia with pollutant removal around 50% to 80% and -48% to 13% respectively (Greenway & Woolley, 1999; Jing *et al*., 2001). Similarly, the percentage of pollutant removal efficiencies for Ireland, Czech Republic, Denmark, United Kingdom, North America, Germany, Poland and Sweden were 88.2%, 51.0%, 26.7%,26.7%, 32.7%,65%, 46.4% and 58.3% respectively (O'Hogain, 2003; Vymazal, 2003; Babatunde *et al*., 2008). Generally, the removal efficiency of water quality parameters in the current study sites were influenced through the hydraulic retention time, size of constructed wetlands, condition of macrophytes and the location of watersheds either in flat or steep areas. The factor that influenced the removal efficiency in the current study sites concurs with the condition of macrophytes where a dense stand of emergent aquatic vegetation were intentionally used to reduce pollutants, where macrophytes also provided places for algae to grow and decrease the flow resistance during rainfall events (Jadhav & Buchberger, 1995).

Table 5: TP concentrations at the inlet and outlet points and percentage removal for respective study sites

Study site	Mean TP concentration (inlet)	Mean TP concentration (Outlet)	Mean Percentage removal
HTC	0.954±0.089	0.324±0.03	57.69
USM	0.205±0.03	0.123±0.02	33.04
Putrajaya	0.061±0.015	0.060±0.20	1.32

ii) Total Nitrogen

The mean concentration of TN at the inlet and outlet points of the constructed wetland for the study areas and the mean percentage of removal efficiency are shown in **Table 6.** The recorded mean concentration at the inlet of Putrajaya constructed wetlands was 1.06 mg/l while the mean concentration for the outlet was 0.97 mg/l. Therefore, the calculated mean TN percentage removal efficiency for the Putrajaya Wetlands was 3.50%. The results for HTC show that the mean concentration at the inlet and outlet was 3.06 mg/l and 1.31 mg/l respectively and the mean percentage of removal efficiency for TN at HTC was 51.85 %. As for the USM Engineering Campus, the mean concentration at the inlet and outlet was 3.34 mg/l and 0.898 mg/l respectively while the mean percentage of removal efficiency was 70.56%. The findings indicate that the USM Engineering Campus has a good performance of pollutant removal efficiency for TN amongst the three study sites.

Table 6. TN concentrations at the inlet and outlet points and percentage removal for respective study sites

Study Site	Mean TN concentration (inlet)	Mean TN concentration (Outlet)	Mean Percentage removal
HTC	3.056±0.30	1.31±0.11	51.85
USM	3.34±0.22	0.898±0.08	70.56
Putrajaya	1.060±0.58	0.97±0.38	3.50

The results obtained in these study sites are similar to the study conducted by other researchers across the world. Masi & Martinuzzi (2007) reported that the percentage of removal efficiency for TN was around 60% for constructed wetlands in Italy and the factors that might influence this percentage were high evapotranspiration rate and the shortest Hydraulic Retention Time (HRT).

Zurita *et al.* (2009) conducted a similar study to evaluate the performance of constructed wetlands and reported that the removal rate was moderately high at around 52.7% to 49.3%.

Statistical Analysis

A statistical analysis was carried out on the inlet and outlet points of the constructed wetlands of the Humid Tropic Center, Putrajaya and the USM Engineering Campus to evaluate the performance of the constructed wetlands. The significant values indicate the significant condition between the inlet and outlet points of the constructed wetland. **Table 7** shows the significant value (P) for water quality parameter according to the respective study sites.

Table 7. The Significant Value (P) value for water quality parameter based on the study sites

Parameter	P value		
	USM	HTC	Putrajaya
BOD	0.028	0.001	0.021
COD	0.005	0.066	0.224
TSS	0.001	0.308	0.041
TP	0.001	0.001	0.414
TN	0.001	0.001	0.039

As can be seen from the table, for BOD values, all the sites show a significant value (P) is less than 0.05 and where the obtained values are 0.028, 0.001 and 0.021 for the USM, HTC and Putrajaya sites respectively. For the COD parameter, the P value is less than 0.05 for USM. However, for other study areas, the P value is more than 0.05. The P values for USM and Putrajaya indicate the values of more than 0.05 compared to HTC which indicate P value as more than 0.05. The P value for TP indicate less than 0.05 for the study areas of USM and HTC, while for Putrajaya the P value is more than 0.414. TN indicates that P values are less than 0.05 for these study areas.

The results concur with studies conducted abroad. Ansola *et al.* (2003) study recorded significant difference between the inlets and the outlets of constructed wetlands for the parameters, such as Total Nitrogen and Total phosphorus. Similar results were also obtained in a study by El Sheikh *et al.* (2010) on the constructed wetlands in Egypt.

CONCLUSION

The findings indicate that the mean outlet concentrations for BOD, COD and TSS comply with National Water Quality Standard Class II, thus far, partially fulfill the government's policies. Meanwhile, the statistical findings for most of water quality parameters indicate the significant condition ($p<0.05$) between the inlet and outlet points of the constructed wetland. Therefore, the findings also demonstrate the efficacy of constructed wetland to treat stormwater and improve water quality.

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