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Assessment of Water Quality using Principal Component Analysis and Cluster Analysis for River Markanda, India

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Abstract*: The present study uses several univariate and multivariate statistical techniques to evaluate and interpret a water quality data set obtained from the Markanda River within the states of Himachal Pradesh and Haryana, India. Data was collected from September-November 2015 for eight parameters which are used to evaluate the status of the river water quality, namely pH, electrical conductivity, total dissolved solids, total hardness, chloride, sulfate, biochemical oxygen demand and chemical oxygen demand. Water quality was monitored at 8 sampling locations along the stretch of river Markanda. All the datas were first analysed using univariate statistical tools, followed by principal component analysis and hierarchical cluster analysis that reduced the data dimensions for better interpretation. This study also presents the usefulness of different statistical methods for evaluation and interpretation of river water quality data for the purpose of monitoring the effectiveness of water resource management. Higher values of EC and BOD indicate that river water is not safe for drinking purpose as prescribed by Bureau of Indian Standards (BIS).*

Keywords*: Markanda river, Principal component analysis, Biplot, Cluster analysis, BIS***

I. INTRODUCTION

As water is the most important natural resource for survival of life on earth therefore, water demand is increasing day by day due to growing populations and rapid urbanization. Industrial growth, irrigation and modern lifestyles consumes a lots of freshwater. From the dawn of human civilization, aquatic resources particularly rivers are being used as dumping grounds for domestic sewage, industrial, and agricultural wastes.

The logic behind that rivers having vast column of water can undergo the process of self-purification. The process of self-purification includes dilution and dispersion, aeration, oxidation, reduction and by the action of many micro-organisms would make the toxic agents/substances into nontoxic one. In India, due to the accelerated pace of urbanization and industrialization, the problem of water pollution has assumed an alarming situation, and about 70% rivers in India are polluted [1]. In the last few decades, there has been increasingly more emphasis on the deterioration of water quality of Indian rivers [2,3,4,5].

In general pollution of a river first affects its water quality parameters then systematically destroys the aquatic community, thus disturbing the associated food chain as well as food web and is also harmful to the public health. Diverse uses of rivers are seriously impaired due to increased pollution.

Therefore, it has become important to assess immediate water quality of rivers and to predict future changes in water quality resulting from the developmental activities in the region. As mentioned earlier huge amount of water is required for irrigation which is fulfilled by using river water. Several rivers of northern India like the Markanda, Dishradwati, Ghaggar, Ravi, Yamuna, Saraswati, Satluj and the Ganga rivers as mentioned in the ancient Sanskrit literature, have generated much interest among the research community. In recent past years several studies related to monitoring of Indian rivers have been made by various researchers [6,7,8,9,10,11,12,13,14,15,16,17,18].

Such type of work is being done by limnologists and scientists all over the world, so that proper measures can be taken to improve the water quality for various purposes. These studies also help in giving warning to downstream users about the adverse conditions of the water. Keeping this in view, present investigation have been undertaken to assess the pollution status in the river Markanda from the point of origin up to the plains of Haryana at Markanda Temple, Mullana. An extensive study has also been done on the water quality parameters of river Maranda in the years 2013 & 2014 [18].

II. MATERIALS AND METHODS

A. Description of Study Area

The Markanda river located in the foothills of the Siwalik hills and Gangetic plains of Haryana, is the most well-known stream between the Yamuna and the Ghaggar river systems [19]. The river originates from Nahan in Himachal Pradesh. Its basin spreads between 30° 00′ and 30° 40′ North latitudes and 76° 32′ and 77° 24′ East longitudes in the Siwalik foothills, North West India. The basin covers an area of 1547 km^2. The area falls under subtropical and semi-arid region with the annual average rainfall of 1100 mm in the hilly region and 750 mm in normal areas. The geological strata the basin consists of sedimentary rocks of Tertiary to Quaternary alluvium deposits. Rocks and alluvium deposits belongs to Tertiary and Quaternary age, which occupy the northern and south part of the basin respectively [20]. The sampling was carried out at eight designated sampling stations selected on the basis of accessibility where peoples are using the river water for domestic purposes. The coordinates of sampling locations are as follows: (M1) 30º 30′42.2″ N and 77º 22′ 01.2″ E (M2) 30º 30′50.1″ N and 77º 20′57.4″ E (M3) 30º 31′05.7″ N and 77º 20′01.7″ E (M4) 30º 31′47.4″ N and 77º 18′27.9″ E (M5) 30º 31′00.0″ N and 77º 14′47.4″ E (M6) 30º 30′22.5″ N and 77º 13′18.8″ E (M7) 30º 29′47.2″ N and 77º 12′40.0″ E (M8) 30º 16′33.3″ N and 77º 01′27.1″ E.

B. Statistical Analysis

Principal component analysis (PCA) has been done on the original data set using MATLAB software. The analytical results were compiled using Microsoft Excel, and SPSS 19.0 software was used to perform cluster analysis (CA) on the data. The data were normalized to the Z score (with a mean of "0" and a standard deviation of "1") and then classified using Ward's method [18]. The correlation coefficient distance was used in the CA. The water quality parameters that correlated well were identified and grouped for further analysis. Pearson's correlation matrix has been used to identify the relationship among the water quality parameters to support the results obtained by multivariate analysis [18].

III. ANALYTICAL METHODS

River water samples were collected on monthly basis from 8 selected locations in 1-L airtight sampling bottles. All the water samples were analyzed immediately after collection of the samples. Water quality parameters like pH, EC, TDS, TH, Cl^-, SO_4^{2-}, BOD and COD were analyzed according to the standard methods [21]. The monitoring was made over a period of three months (September, October and November 2015), comprising of one session i.e. post-monsoon. All measurements were done in triplicates. Analytical reagent (AR) grade chemicals were used throughout the study without any further purification. Distilled water was used for experimental purposes. A comparison of water quality parameters of the Markanda river as observed with drinking water quality standards (BIS) was given in Table II.

IV. RESULTS AND DISCUSSIONS

A. pH

The pH values of the river water samples varied from a minimum value of 7.11 at sampling station M1 to a maximum value of 8.46 at sampling station M8 (Tables I & II). The results shows that pH values of the river water collected from eight different sampling locations were found within the desirable permissible limits (6.5-8.5) of drinking water quality standards of BIS (Table I). Almost similar values were observed in studying the effect of dye effluents on pH of river Kshipra, Ujjain City [22]. From the previous study it was observed that the pH values were ranged from 7.09-8.32 and found within the prescribed limits of BIS [18]. Statistical analysis for pH is presented in Table III.

TABLE I WATER QUALITY PARAMETERS (AVERAGE) AT DIFFERENT SAMPLING LOCATIONS OF RIVER MARKANDA

Sample No.	pH	EC	TDS	TH	Cl^-	SO_4^{2-}	BOD	COD
1	7.11	0.32	191	87	12.8	10.0	2	18
2	7.88	0.40	246	269	32.5	18.4	11	35
3	8.28	0.42	260	180	28.6	22.5	9	38
4	8.35	0.35	218	400	39.5	20.6	10	65
5	7.56	0.65	389	311	22.7	17.0	13	54
6	7.67	0.41	255	415	37.3	21.8	18	102
7	8.25	0.39	239	322	43.4	30.3	10	67
8	8.46	0.53	316	374	60.1	25.5	15	52

TABLE II
COMPARISON OF AVERAGE WATER QUALITY PARAMETERS OF RIVER MARKANDA WITH DRINKING WATER QUALITY STANDARD (BUREAU OF INDIAN STANDARDS)

Parameters	Range of Samples		BIS Limits	
	Minimum	Maximum	Desirable	Maximum
pH	7.11	8.46	6.5-8.5	No Relaxation
EC (mS/cm)	0.32	0.65	-	0.3
TDS (mg/l)	191.0	389.0	500	2000
TH (mg/l)	87.0	415.0	300	600
Cl^- (mg/l)	12.8	60.1	250	1000
SO_4^{2-} (mg/l)	10.0	30.3	200	400
BOD (mg/l)	2.0	18.0	<2	<2
COD (mg/l)	18.0	102.0	-	-

TABLE III
STATISTICAL ANALYSIS OF WATER QUALITY PARAMETERS OF MARKANDA RIVER

	pH	EC	TDS	TH	Cl^-	SO_4^{2-}	BOD	COD
N	8	8	8	8	8	8	8	8
Min.	7.11	0.32	191.0	87.0	12.8	10.0	2.0	18.0
Max.	8.46	0.65	389	415	60.1	30.3	18.0	102.0
Mean	7.945	0.434	264.25	294.75	34.61	20.76	11.0	53.87
Std. error	0.167	0.038	21.88	40.04	5.02	2.12	1.67	8.97
Variance	0.222	0.011	3831.35	12830.79	202.32	36.15	22.28	644.41
Stand. dev.	0.472	0.106	61.897	113.27	14.223	6.013	4.72	25.38
25 percentile	8.065	0.405	250.5	316.50	34.90	21.20	10.50	53.0
75 percentile	7.587	0.36	223.25	202.25	24.175	17.35	9.25	35.75
Skewness	8.332	0.502	302	393.5	42.425	24.75	14.5	66.5
Kurtosis	-0.708	1.378	1.256	-0.926	0.336	-0.291	-0.586	0.677
Coeff. var	-0.533	1.683	1.715	0.116	0.765	0.984	1.487	1.09

B. Electrical Conductivity (EC)

The EC values of the river water samples varied from a minimum value of 0.32 mS/cm at sampling station M1 to a maximum value of 0.65 mS/cm at sampling station M5 (Tables I & II). The results shows that EC values of the river water collected from 8 different sampling stations were not satisfying the maximum permissible limits (0.3 mS/cm) of drinking water quality standards of BIS (Table II). From the previous study almost similar EC values (0.30-0.60 mS/cm) were observed while assessing the water quality parameters for Markanda river, India [18]. Comparatively higher values of EC (1.05-1.29 mS/cm) was observed for Yamuna river at Agra region of Uttar Pradesh, India [23]. Statistical analysis for EC is presented in Table III.

C. Total Dissolved Solids (TDS)

The TDS content of the analyzed river water samples varied from a minimum value of 191 mg/l at sampling station M1 to a maximum value of 389 mg/l at sampling station M5 (Tables I & II). More the content of dissolved solids can affects the density of water, influences osmoregulation of freshwater organisms, hence reduces solubility of oxygen, and utility of water for drinking purpose [24]. The results shows that TDS content of river water collected from eight different sampling stations were satisfying the prescribed limits (500 and 2000 mg/l) of drinking water quality standards of BIS (Table II). Almost similar TDS values (183-330 mg/l) were observed while assessing the water quality parameters for the river Markanda18. Statistical summary for TDS is presented in Table III.

D. Total Hardness (TH)

The total hardness content of river water samples varied from a minimum value of 87 mg/l at sampling station M1 to a maximum value of 415 mg/l at sampling station M6 (Tables I & II). The results shows that total hardness content of river water collected from eight different sampling stations were within the prescribed maximum permissible limit (600 mg/l) of drinking water quality standards of BIS (Table II). Almost similar values (80-375 mg/l) were observed while assessing the water quality parameters for Markanda river, India [18]. However, comparatively lower values of TH (80.5-104.9 mg/l) were observed for Yamuna river at Yamunanagar region of Haryana, India [7]. Statistical summary for total hardness is presented in Table III.

E. Chloride (Cl^-)

The chloride content of the analysed river water samples varied from a minimum value of 12.8 mg/l at sampling station M1 to a maximum value of 60.1 mg/l at sampling station M8 (Tables I & II). The results shows that chloride content of river water collected from eight different sampling stations were within the prescribed limits (250 and 1000 mg/l) of drinking water quality standards of BIS (Table II). Almost similar Cl^- values (7.9-55.8 mg/l) were observed while assessing the water quality parameters for the river Markanda, India [18]. In an earlier study lower values of Cl^- (24.5-88.63 mg/l) were observed for Yamuna river at Yamunanagar region of Haryana, India and found within the prescribed limits of BIS [7]. Statistical summary for Cl^- is presented in Table III.

F. Sulfate (SO_4^{2-})

The sulfate content of the analysed river water samples varied from a minimum value of 10 mg/l at sampling station M1 to a maximum value of 30.3 mg/l at sampling station M7 (Tables I & II). The results shows that sulfate content of river water collected from eight different sampling stations were within the prescribed permissible limit (200 and 400 mg/l) of drinking water quality standards of BIS (Table II). Lower values of sulfate (7.0-16.5 mg/l) were obtained while assessing the water quality parameters of Markanda river, India [18]. However comparatively higher values of SO_4^{2-} (97.75-114.0 mg/l) were observed for Yamuna river at Yamunanagar region of Haryana, India and were found below the prescribe limits of BIS [25]. Statistical analysis for SO_4^{2-} is presented in Table III.

G. Biological Oxygen Demand (BOD)

The biological oxygen demand of the analysed river water samples varied from a minimum value of 2 mg/l at sampling station M1 to a maximum value of 18 mg/l at sampling station M6 (Tables I & II). The results shows that BOD content of river water collected from eight different sampling stations were exceeding the prescribed limits (<2 mg/l) of drinking water quality standards of BIS (Table II). Similar results were obtained in studying the BOD of river Ghataprabha, Belgaum, Karnataka [26]. From the earlier study almost similar BOD values (2-13) were observed while assessing the water quality parameters for the river Markanda, India [18]. Comparatively higher values of BOD (10.31-23.83 mg/l) were also observed for Yamuna river in rural and semi-urban setting of Agra region of Uttar Pradesh, India [17]. Statistical analysis for BOD is presented in Table III.

H. Chemical Oxygen Demand (COD)

The COD of the analyzed river water samples varied from a minimum value of 18 mg/l at sampling station M1 to a maximum value of 102 mg/l at sampling station M6 (Tables I & II). This indicate that pollution load in the river is due to untreated industrial effluents, agricultural runoff and sewage water entering into it from the neighbouring areas. Increase in COD could be attributed to an increase in the addition of both organic and inorganic contaminant [27]. The results show that COD content of river water collected from seven different sampling stations were exceeding the maximum limit (20 mg/l) of drinking water quality standards of WHO. Almost similar results (COD values) were observed while assessing water quality parameters for Markanda river, India [18]. Comparatively lower values of COD (5.8-11.7 mg/l) were observed for Yamuna river at Yamunanagar region of Haryana, India [7]. Statistical analysis for COD is presented in Table III.

I. Principal Component Analysis

PCA was performed on covariance correlation matrix data, such that the considered data set can be explained. Analyzing the results (Table IV), the cumulative percent variance of PC1 and PC2 is more than 98% and from the third component the cumulative percentage variance is more than 99% therefore, PC1 and PC2 has taken for consideration. The loading values >0.75 signifies "strong", the loading with values in between 0.5-0.75 indicate "moderate" while loading values between 0.3-0.50 denote as "weak" [28]. Using the above classification, two variables in each component (I & II) have strong positive loading. Considering the first two components, higher coefficient is observed for TH, BOD, Cl^- and SO_4^{2-} with 0.903, 0.886, 0.847 & 0.800 in PC1, and electrical conductivity (EC) and total dissolved solids (TDS) with 0.855 & 0.844 in PC2. The coefficient for COD with 0.749 and

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pH with 0.685 in PC1 having moderate loading. The coefficients for other parameters are less i.e. in between 0.3-0.5. Biplots of all the physico-chemical parameters are shown in Figure 1. The three biplots of EC, TDS and BOD are falling in the first i.e. positive coordinate (Figure 1) which indicates similar trend will follow between them and the other five biplots i.e. pH, TH, Cl^-, SO_4^{2-} and COD are falling in the second coordinate (Figure 1), which indicates similar trend will also follow between them. The group of water quality parameters (EC, TDS and BOD) which are falling in the first coordinate will not affected by the parameters of second coordinate (pH, TH, Cl^-, SO_4^{2-} and COD) and vice-versa. Hence the quality of river water can be well differentiated by taking the three parameters having higher coefficients (TH, BOD and EC). Variables, with higher PC1 and PC2 values indicating that concerned parameters are responsible for development of poor water quality along all the sampling locations of river Markanda. The reason for poor water quality is probably due to disposal sewage and industrial effluents into the river without any treatment.

TABLE IV FACTOR LOADING FOR MARKANDA RIVER WATER QUALITY

	Components							
Variables	1	2	3	4	5	6	7	8
pH	0.685	0.446	0.516	0.037	0.216	0.128	0.034	0
EC	0.450	0.855	0.251	0.030	0.011	0.054	0.020	0
TDS	0.480	0.844	0.232	0.050	0.037	0.015	0.007	0
TH	0.903	0.048	0.311	0.198	0.166	0.119	0.074	0
Cl^-	0.847	0.332	0.245	0.239	0.207	0.099	0.051	0
SO_4^{2-}	0.800	0.383	0.264	0.361	0.087	0.054	0.059	0
BOD	0.886	0.244	0.284	0.070	0.135	0.224	0.034	0
COD	0.749	0.092	0.619	0.191	0.058	0.027	0.087	0
Eigenvalue	13927.6	3344.16	204.68	80.96	7.954	2.103	0.033	0
% Variance	79.281	19.036	1.1651	0.46087	0.045	0.012	0.0002	0
Cumulative % Var.	79.281	98.317	99.4821	99.94297	100	100	100	100

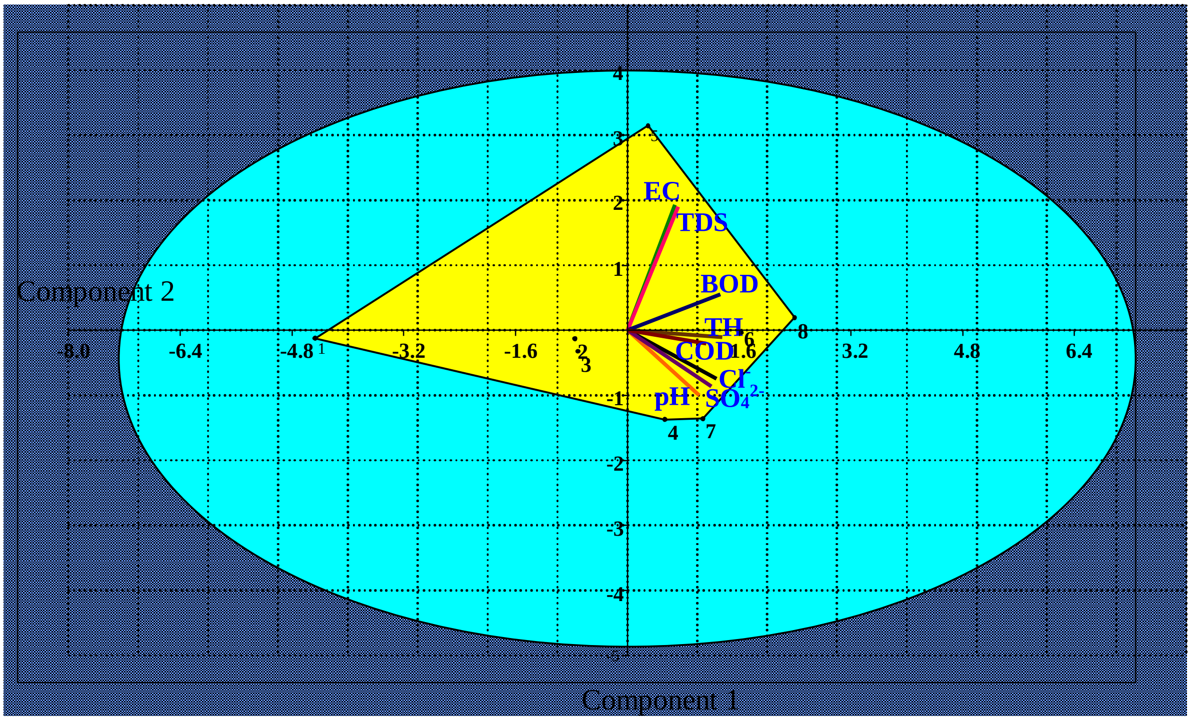

Fig. 1 Scatter plots of the principal component analysis of river water

J. Cluster Analysis Results

The cluster analysis results are illustrated in the hierarchical clustering dendrograms shown in Figure 2. The cluster analysis results for the river water indicate that the physico-chemical parameters could be split into three main groups. The first group (cluster I) included EC and TDS; the second group (cluster II) included TH, BOD and COD; and the third group (cluster III) included pH, Cl^- and SO_4^{2-} (Figure 2). The cluster results indicate that three different factors were responsible for the development of the water quality in the Markanda river. EC and TDS (cluster I) have one source; TH, BOD and COD (cluster II) are derived from another source; and pH, Cl^- and SO_4^{2-} (cluster III) are associated with other sources.

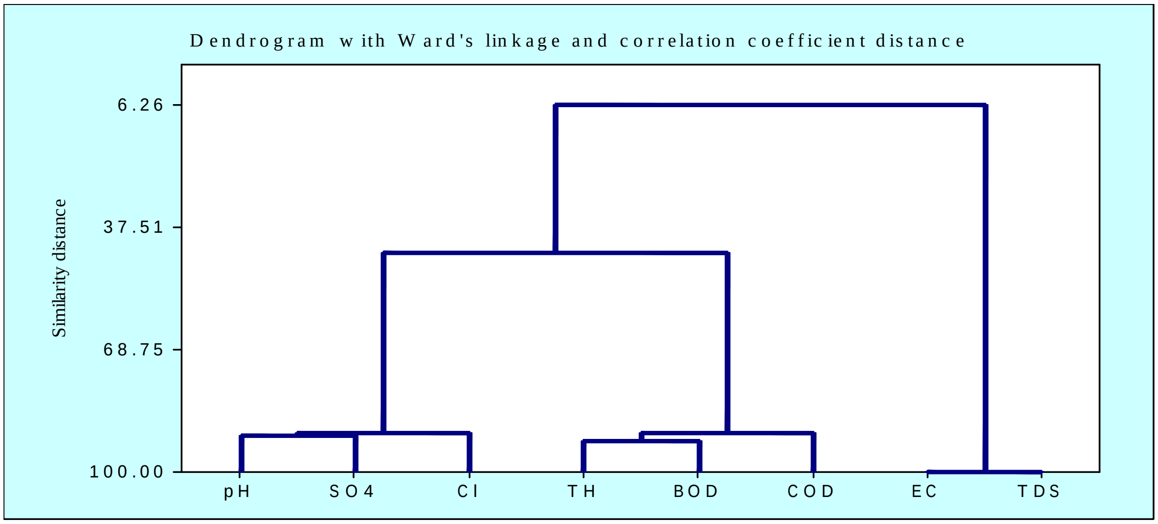

Fig. 2 Cluster analysis based on water quality parameters of river water

K. Correlation Matrix Analysis

Water samples collected from river Markanda and correlation matrix was used to know the relationship between water quality parameters [18,29]. Correlation matrix was prepared between eight different water quality parameters and is presented in Table V. The highest positive correlation is observed between electrical conductivity (EC) and total dissolved solids (TDS) with 0.998. There is also strong positive correlation exists between BOD and TH (0.844), COD and TH (0.841), pH and sulfate (0.814), pH and chloride (0.808), sulfate and chloride (0.803), BOD and COD (0.787), chloride and TH (0.725) and so on. Moderate to insignificant positive correlation was observed in between other physico-chemical parameters (Table V).

TABLE V CORRELATION MATRIXES AMONG THE WATER QUALITY PARAMETERS OF RIVER WATER

	pH	EC	TDS	TH	Cl^-	SO_4^{2-}	BOD	COD
pH	1							
EC	0.051	1						
TDS	0.077	0.998	1					
TH	0.505	0.288	0.319	1				
Cl^-	0.808	0.156	0.166	0.725	1			
SO_4^{2-}	0.814	0.110	0.137	0.583	0.803	1		
BOD	0.353	0.519	0.553	0.844	0.620	0.517	1	
COD	0.240	0.112	0.152	0.841	0.462	0.531	0.787	1

V. CONCLUSIONS

This study assessed some physico-chemical properties of Markanda River from eight different locations, during the months of August to November 2013 and 2014. Based on the eight environmental parameters such as pH, electrical conductivity, total dissolved solids, total hardness, chloride, sulfate, biological oxygen demand and chemical oxygen demand for water quality, it was able to identify three main sources which are responsible for deteriorating the water quality of Markanda River at all the sampling stations. Water quality parameters like BOD and COD were exceeding the level of pollution. Therefore it is concluded that River

Markanda is polluted and unsafe for human consumption. Overall, this study recommends identifying the pollution sources and monitoring the water quality parameters from time to time so that will help researcher to interpret data and implementation of remediation actions to protect the quality of the river water from deterioration.

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