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Analysing Spatial and Temporal Rainfall Variability of Southern Rajasthan using GIS Approach

Vinayak Paradkar, H. K. Mittal

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ABSTRACT

This study focuses on analysing the behavioral patterns of rainfall in southern Rajasthan, particularly in reference to its amount and variation over time. The study made use of Standard Meteorological Weeks (SMW) and historic weekly rainfall records. IDW (Inverse Distance Weighting) interpolation technique within the ArcGIS platform was used for spatial analysis, creating spatial variation maps. It was found that significant rainfall occurred from Standard Meteorological Week (SMW)-22 to SMW-42. The weekly mean rainfall across the study area during the monsoon period ranged from 2.1 to 68.4 mm, with corresponding standard deviations ranging from 9.3 to 79.7 mm. Notably, the standard deviation was often higher than the mean, indicating substantial variability in weekly rainfall. Trend analysis using the Mann-Kendall test revealed that most stations in the study area exhibited no significant trend in annual rainfall data. Similarly, weekly rainfall data showed a trend in SMW-30 for 44 stations, while all other weekly data series did not exhibit significant trends, except for SMW-30. Stationarity was generally accepted for most weekly data series, except for SMW-30 and SMW-32, which showed non-stationary behavior. However, homogeneity tests indicated homogeneity in weekly rainfall data series for almost all selected stations. Overall, the study highlighted the significant variability in rainfall patterns in southern Rajasthan, with no significant trend in annual rainfall, except during the peak monsoon period (SMW-30). These findings contribute to a better understanding of regional rainfall behavior, which is crucial for water resource management and agricultural planning in the region.

Keywords Spatial, Temporal, Rainfall variability, GIS, Southern Rajasthan.

INTRODUCTION

The world's total water resources are around 1.36 × 108 M ha-m, with 97.2% being saline and only 2.8% freshwater. Out of the freshwater, 2.2% is surface water and 0.6% is groundwater. However, only 0.01% of surface water is in fresh water streams, and 0.25% of groundwater can be economically extracted (Sojitra *et al.* 2016). India receives approximately 4000 cubic kilometers of annual precipitation, with monsoon rainfall accounting for about 3000 cubic

Vinayak Paradkar[1]*, H. K. Mittal[2]

[1]Senior Research Fellow, Center for Protected Cultivation Technology, Indian Agricultural Research Institute, New Delhi 110012, India

[2]Professor, Department of Soil and Water Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan 313001, India

Email: paradkarvd@gmail.com
*Corresponding author

kilometers (Jha 2013). Urbanization, industrialization and population growth have increased water demand, causing watershed and river system changes that lead to flooding and damages. Around 67% of India's cultivated land is rainfed, providing 44% of food grains and supporting 40% of the population (Venkateswaralu 2011). Variations in rainfall due to natural climate variability and human-induced changes significantly impact crop yields and the country's economy (Roy and Mazumdar 2013). Extreme rainfall studies are crucial for understanding watershed behavior and flooding (Cronin *et al.* 2014). As water availability doesn't always match demand, large storage reservoirs are essential to redistribute stream flow, although they are usually designed assuming stationary climate conditions (Kumar *et al.* 2013). Global warming induced rainfall changes will require a review of reservoir design and management practices in India. Uneven and erratic rainfall distribution is common in many parts of India (Manoj and Kumar 2013).

Rajasthan heavily relies on rainfall as its main water source. An average annual rainfall of the state is 594.9 mm. Western part sees varying rainfall, from under 100 mm in Jaisalmer to over 400 mm in Sikar, Jhunjhunu, and Pali. In the east, Ajmer receives 550 mm, while Jhalawar gets 1020 mm rainfall. Banswara and Jhalawar in the plains record the most rain. Mount Abu in the southwest receives the highest at 1638 mm (Rathore 2004). Rainfall varies greatly, being erratic in the west with dry spells. Rainy days range from 10 in Jaisalmer to 48 in Mount Abu during the June-September monsoon (Rathore and Verma 2013). In deficit year 2002, the state received 220.4 mm against the average of 518.6 mm monsoon rainfall (Singh *et al.* 2018). About 75-95% of Rajasthan's rain falls during June-September which is crucial for farming. Climate change related monsoon deficiencies lead to frequent droughts which declared Rajasthan as the most drought prone state with high probabilities of rainfall scarcity (Varghese *et al.* 2021).

Limited water resources, erratic rainfall, and repetitive droughts may lead to reduced agricultural and economic conditions (Mundetia and Sharma 2014). Therefore, there is a need to adopt a proactive approach by strengthening the scientific advancement in understanding rainfall distribution using different methods and identify the parts more severe to drought. Worldwide several studies have been conducted regarding the analysis of spatial and temporal variations in rainfall. The quantification of their trends can provide valuable reference data for regional water requirements and water resources planning (Wu *et al.* 2013). Therefore, this study aimed to analyze spatial and temporal rainfall variability of selected stations of southern Rajasthan using GIS technique.

MATERIALS AND METHODS

Study area

The study area includes seven districts viz., Banswara, Dungarpur, Pratapgarh, Udaipur, Chittorgarh, Rajsamand, and Bhilwara. It falls under IV A (Bhilwara, Rajsamand and Chittorgarh) and IV B (Pratapgarh, Udaipur, Dungarpur and Banswara) agro-climatic zones (Hussain 2015). The region bridges the "Humid east" and "Arid west" climates. It spans 23°01'10" to 26°01'15" N latitude and 73°01'10" to 75°43'30" E longitude, covering 50,510 km^2. The average annual rainfall of this region ranges from 400 to 1100 mm (Rathore and Verma 2013). Banswara, Dungarpur, Pratapgarh, Udaipur, Chittorgarh, Rajsamand and Bhilwara occupies an area of 5037, 3770, 4117, 11724, 10856, 4551 and 10455 km^2, respectively. The location map of the study area is shown in Fig. 1.

Spatial variation of rainfall

Spatial distribution of rainfall is crucial for various purposes like water resource management and hydro-

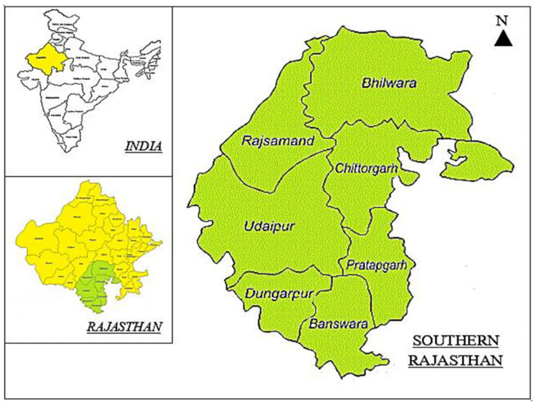

Fig. 1. Location map of the study area.

logical modelling. Rainfall is particularly challenging to predict due to its temporal and spatial variability. Spatial analyses involve describing patterns, exploratory analysis, interpolation, and modelling (Yavuz and Erdogan 2012). Inverse Distance Weighted (IDW) is a standard interpolation method, often default for generating surfaces when attribute values are sparsely sampled (Sahu and Khare 2015). GIS technology has become vital due to its capacity to manage spatial data and employ advanced statistical techniques. Therefore, in this study IDW interpolation technique with ArcGIS was used for spatial analysis of rainfall.

Inverse distance weighting method (IDW method)

The IDW method is a deterministic interpolation method, as it does not exploits the statistical properties of the observation sample. It has been referred as one of the standard spatial interpolation technique in geographic information sciences (Foehn *et al.* 2018). The weights are inversely proportional to the distances between the prediction locations and the sampled locations (Shen *et al.* 2019). The known sample points are implicit to be self-governing from each other (Bhunia *et al.* 2018). The formula for the IDW method is as follows:

$$Z(S_0) = \sum_{i=1}^{n} \lambda_i Z(S_i) \qquad \text{... (2.1)}$$

Where, $Z(S_0)$ represents the interpolated value at point S_0, $Z(S_i)$ represents the observed value at point Si, n is the number of observations, and λ_i is the weight. The IDW method uses the same data processing procedure on all three-time scales (Tao *et al.* 2017).

Temporal variation of rainfall

Most of the parametric methods are based on assumption of normality and are very sensitive to extreme values. Therefore, non-parametric methods, which are distribution free are generally employed. In this study, the non-parametric Mann-Kendall test was used for analysing variation in the time series. The World Meteorological Organization (WMO) has also suggested using the Mann-Kendall method for assessing trends in meteorological data (WMO 1988).

Mann-Kendall test

The Mann Kendall test was applied to determine statistical trends in rainfall. This nonparametric test performs well even with missing values or outliers and widely used in trend analysis of rainfall data (Brath *et al.* 2002). This statistical method is used for studying spatial and temporal trends of hydro climatic series (Swain *et al.* 2015). Mann (1945) formulated this test for trend detection and the test statistic distribution was given by Kendall (1975) for testing non-linear trend and turning point. The Mann Kendall test statistic (S) is calculated by using the formula below:

$$S = \sum_{i=1}^{n-1} \sum_{j=j+1} sig(X_j - X_i) \qquad \text{....(2.2)}$$

$$sig(X_j - X_i) = \begin{cases} +1 \; if\,(X_j - X_i) > 0 \\ 0, \; if\,(X_j - X_i) = 0 \\ - \; if\,(X_j - X_i) < 0 \end{cases} \qquad \text{.... (2.3)}$$

Where X_i and X_j are the sequential data values of the time series in the years i and j, n is the length of the time series, tp is the number of ties for the p^{th} value and q is the number of tried values. The test statistics Z_c is computed as,

$$Z_c = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, \; if\,(S) > 0 \\ 0, \; if\,(S) = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, \; if\,(S) \end{cases}$$

The positive values of Z_c indicates increasing trends, while negative values of Z_c indicates decreasing trends in the time series. The null hypothesis, which assumes that there is no significant trend in the time series, is rejected if $|Z_c| > Z_{1-\alpha/2}$ and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is the critical value of Z from the standard normal table and for the 5% significance level the value of $Z_{1-\alpha/2}$ is ±1.96.

Sen's slope estimator

It computes both the slope (i.e. linear rate of change) and intercept according to Sen's method (Swain *et al*. 2015). First, a set of linear slopes is calculated as follows:

$$d_k = \frac{X_j - X_i}{j - i} \quad .... (2.5)$$

For (1 < i < j < n), where d is the slope, X denotes the variable, n is the number of data, and i, j are indices. Sen's slope is then calculated as the median from all slopes: b = Median d_k. The intercepts are computed for each time step t as given by,

$$a_t = X_t - b * t \quad ... (2.6)$$

This function also computes the upper and lower confidence limits for Sen's slope.

Stationarity tests of rainfall

Dickey Fuller test

Dickey and Fuller (1979) developed this test for identifying a unit root in a time series. An order 1 autoregressive model can be written as follows:

$$X_t = \rho X_{t-1} + \varepsilon_t \quad ...(2.7)$$

Where the εt are independent identically distributed variables that follow an N (0, σ2) normal distribution. The series is stationary if lρl < 1. It is not stationary and corresponds to a random walk if ρ=1. The critical values and p-values are estimated by running a predefined set of Monte Carlo simulations for the considered sample size in XLSTAT software.

KPSS test

Contrary to the Dickey-Fuller test, this test allows testing the null hypothesis that the series is stationary (Kwiatkowski *et al.* (1991). The statistics used for this test is given by,

$$\eta = \frac{1}{n^2} \sum_{t=1}^{n} \frac{S_t^2}{S^2} \quad ....(2.8)$$

Where S_t^2 the mean squared error between is times 1 and t. This statistics along with the critical values and p-values adapted to the size of the sample were computed using Monte Carlo simulations for each new run in XLSTAT software.

Homogeneity tests of rainfall

Pettitt's test

This approach after Pettitt (1979) is commonly applied to detect a single change-point in hydrological series or climate series with continuous data. It tests the null hypothesis H_0: The T variables follow one or more distributions that have the same location parameter (no change), against the alternative hypothesis H_a: A change point exists. The non-parametric statistic is defined as:

$$K_T = \max | U_t, T | \quad ... (2.9)$$

The change-point of the series is located at K_T, provided that the statistic is significant.

***Standard normal homogeneity test* (SNHT)**

The Standard Normal Homogeneity Test (SNHT) was developed by Alexandersson (1986) to detect a change in a series of rainfall data. The test is applied to a series of ratios that compare the observations of a measuring station with the average of several stations. The null and alternative hypotheses are determined by,

H_0 = The T variables Xi follows N (0, 1) distribution.
H_a = between times 1 and v the variables follows N (μ_1, 1) distribution, and between v+1 and T they follows N (μ_2, 1) distribution.

RESULTS AND DISCUSSION

Analysis of spatial variation of rainfall

Analysis of rainfall variability is important from the point of view of proper irrigation scheduling, decision on crop rotation plans, soil water conservation strategies. In this study, the rainfall data of 50 years (1973 to 2022) was analyzed. Considering all the stations,

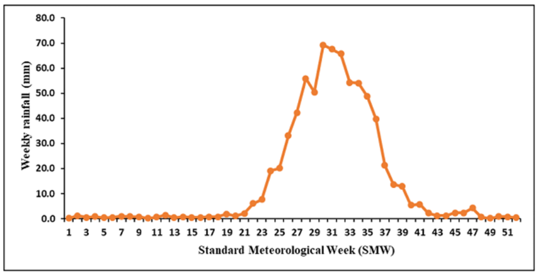

Fig. 2. Average weekly rainfall distribution of southern Rajasthan.

it was observed that, significant rainfall occurred from standard meteorological week 22 (SMW-22) to standard meteorological week 42 (SMW-42). Weekly mean rainfall of the study area over the monsoon period varies from 2.1 to 68.4 mm; with respective standard deviation from 9.3 to 79.7 mm. It was also seen that for most of the weeks standard deviation is more than the mean, indicating the large variability in weekly rainfall. The maximum average weekly rainfall (95.62 mm) of Banswara District was highest among the peak weekly rainfall of seven districts in the study area. The minimum average weekly rainfall (49.13 mm) among districts in the study area was noted in Rajsamand District. The average weekly rainfall distribution of the study area is shown in Fig. 2. The peak rainfall (68.40 mm) was observed in SMW-30 and the minimum rainfall (2.10 mm) was noted in SMW-42.

The mean and standard deviation of weekly rainfall for the study area is shown in Fig. 3. The mean of weekly rainfall for the study area lies between 2.10 mm to 68.40 mm over monsoon period i.e. SMW-22

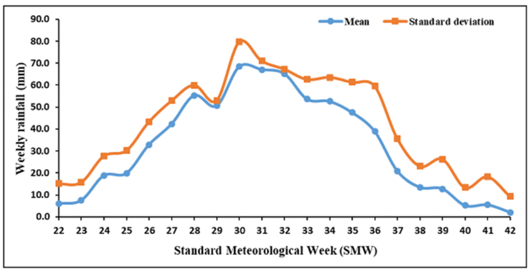

Fig. 3. Comparison of mean and standard deviation of weekly rainfall over monsoon period for southern Rajasthan.

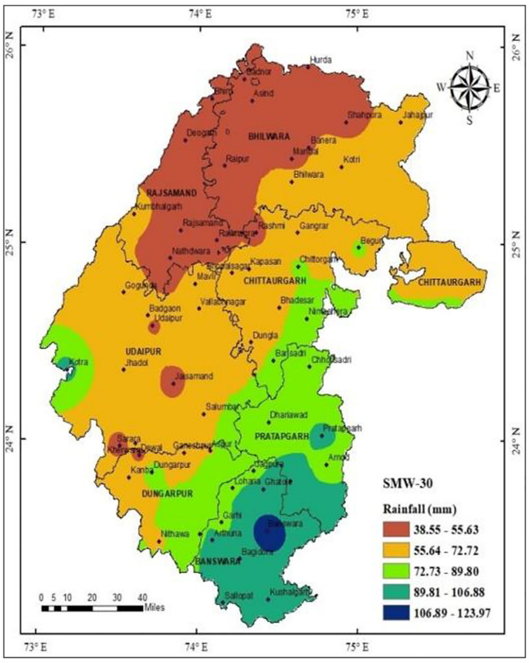

Fig. 4. Spatial variation of weekly rainfall in southern Rajasthan for standard meteorological week 30 (SMW-30).

to SMW-42. The maximum rainfall (68.40 mm) was observed in SMW-30 and the lowest rainfall (2.10 mm) was noted in SMW-42. The standard deviation of weekly rainfall varies between 9.3 mm to 79.7 mm. Similar to the mean weekly rainfall highest standard deviation (79.7 mm) was seen in SMW-30 and it was lowest (9.3 mm) in SMW-42. Furthermore, it was seen that the standard deviation of each week is higher than the mean of corresponding week indicating greater variability of rainfall in southern Rajasthan (Fig. 3). Gupta *et al.* (2016) and Hussain (2015) also reported high rainfall variation in Rajasthan.

Fig. 4 shows the spatial variation of weekly rainfall in southern Rajasthan for standard meteorological week 30 (SMW-30) which was having peak rainfall of 68.40 mm and Fig. 5 shows the spatial variation of annual rainfall in the study area. It can be noted that rainfall of SMW-30 varied from 38.55 mm to 123.97 mm over southern Rajasthan whereas annual rainfall for the study area varied from 407.55 mm to 1091.84 mm.

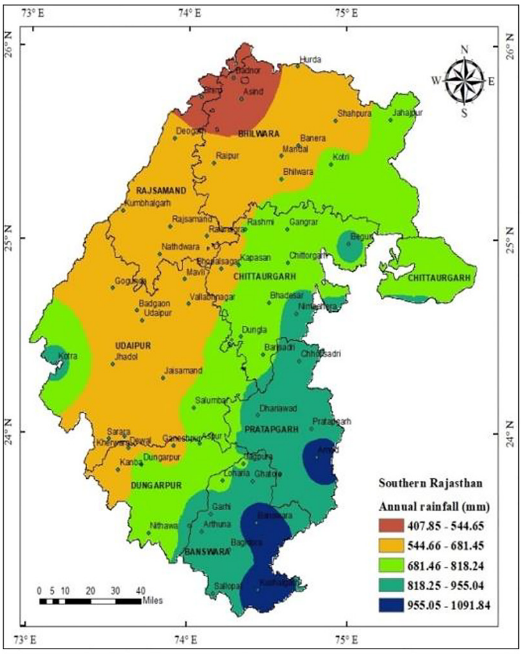

Fig. 5. Spatial variation of annual rainfall in southern Rajasthan.

Analysis of temporal variation of rainfall

Trend analysis of weekly rainfall

Trend analysis of weekly rainfall was carried out in the present study for 50 years rainfall data from 1973 to 2022. It was found that, the trend was present in SMW-30 data series for most of the stations in the study area followed by SMW-32 and SMW-38. No trend was found in other weekly rainfall data series. The results of trend tests for SMW-30, Mann-Kendall test and Sen's slope for different stations in the study area are also summarized in Table 1.

Out of fifty eight selected stations in the study area, the trend was present in forty four stations at SMW-30. The computed p value was less than significance level alpha=0.05 for these stations hence criteria of trend was accepted. The criteria of no trend was accepted for remaining fourteen stations. The Sen's slope values also presented similar results.

Stationarity tests for weekly rainfall

For checking stationarity in the weekly rainfall data sets of selected stations in the study area, Dickey Fuller and KPSS tests were applied. The stationarity was accepted for most of the weekly data series except SMW-30 and SMW-32 when evaluated by both the tests. Such results were observed for all the selected stations in the study area.

Homogeneity tests for weekly rainfall

For checking homogeneity in the weekly rainfall data sets of selected stations in the study area, Pettitt's test and Standard Normal Homogeneity (SNH) tests were applied. It was observed that, both the homogeneity tests were passed for all weekly rainfall data series. These results were observed for almost all the selected stations in the Southern Rajasthan.

Table 1. Results of trend tests (SMW-30) for stations in the study area.

Sl. No.	Station	Mann-Kendall test		Sen's slope		
		τ value	P value	Value	Lower	Upper
1	Garhi	0.199	0.043	1.214	0.007	2.750
2	Ghatole	0.233	0.018	1.341	0.161	3.000
3	Loharia	0.209	0.034	1.005	0.045	2.686
4	Sallopat	0.195	0.048	1.000	0.001	2.200
5	Asind	0.222	0.026	0.384	0.001	1.125
6	Badnor	0.220	0.027	0.538	0.001	1.302
7	Banera	0.212	0.032	0.818	0.001	1.818
8	Hurda	0.216	0.030	0.500	0.001	1.308
9	Kotri	0.232	0.019	0.970	0.111	2.000
10	Mandal	0.220	0.027	0.797	0.001	1.692
11	Shahpura	0.220	0.029	0.891	0.001	1.688
12	Barisadri	0.290	0.003	1.635	0.526	2.829

Table 1. Continued.

Sl. No.	Station	Mann-Kendall test		Sen's slope		
		τ value	P value	Value	Lower	Upper
13	Begun	0.197	0.045	0.884	0.001	2.000
14	Bhadesar	0.315	0.001	1.712	0.500	2.955
15	Bhopalsagar	0.233	0.020	0.850	0.001	1.667
16	Chittorgarh	0.276	0.005	1.463	0.400	2.711
17	Dungla	0.282	0.004	1.410	0.348	2.600
18	Gangrar	0.263	0.008	1.000	0.267	2.087
19	Kapasan	0.234	0.018	0.833	0.065	1.830
20	Nimbahera	0.267	0.007	1.644	0.318	3.287
21	Rashmi	0.200	0.043	0.857	0.001	1.716
22	Aspur	0.303	0.002	1.250	0.317	2.600
23	Dewal	0.294	0.003	1.031	0.182	2.000
24	Dungapur	0.208	0.034	1.203	0.065	2.859
25	Galiakot	0.194	0.050	1.000	0.001	2.515
26	Ganeshpur	0.263	0.008	0.846	0.154	2.250
27	Nithawa	0.281	0.004	1.240	0.300	2.385
28	Arnod	0.275	0.005	1.632	0.327	3.500
29	Chhotisadri	0.221	0.025	1.093	0.029	2.167
30	Dhariawad	0.293	0.003	1.940	0.569	3.232
31	Pipal Khunt	0.219	0.026	1.313	0.077	2.863
32	Pratapgarh	0.310	0.002	1.786	0.667	3.372
33	Nathdwara	0.217	0.029	0.712	0.001	1.633
34	Railmagra	0.249	0.012	1.079	0.167	2.037
35	Badgaon	0.199	0.045	1.167	0.001	2.200
36	Gogunda	0.170	0.086	0.692	0.001	1.904
37	Jhadol	0.200	0.043	1.083	0.001	2.583
38	Kherwara	0.210	0.035	0.889	0.001	2.120
39	Kotra	0.214	0.031	1.333	0.040	2.818
40	Mavli	0.337	0.001	1.880	0.625	2.946
41	Salumber	0.314	0.002	1.780	0.400	3.054
42	Sarara	0.257	0.010	1.136	0.107	2.286
43	Udaipur	0.212	0.031	1.009	0.040	2.286
44	Vallabhnagar	0.272	0.006	1.570	0.200	2.626

CONCLUSION

In this study, the behavioral pattern of rainfall with reference to its amount and variation for each standard meteorological week was evaluated. Using MK test, the annual rainfall data series of all the stations in the study area showed no trend except Badnor, Bhadesar, Aspur, Nithawa and Mavli. The values of Sen' slope were also within limits (bounds) and hypothesis of no trend was accepted for all stations in the study area except these five stations. Similarly, in weekly rainfall data series trend was present in SMW-30 for 44 stations. The stationarity was accepted for most of the weekly data series except SMW-30 and SMW-32 when evaluated by both Dickey Fuller and KPSS tests. It was observed for almost all the selected stations in the study area. Both Pettitt's and SNHT homogeneity tests were passed for all weekly rainfall data series in almost all the selected stations in the Southern Rajasthan. The rainfall distribution study of southern Rajasthan revealed that weekly mean rainfall over monsoon period (SMW-22 to SMW42) varies from 2.1 to 68.4 mm with respective standard deviation of 9.3 to 79.7 mm. In addition, the standard deviation for all weeks is greater than the mean weekly rainfall. The trend analysis of rainfall indicated no significant trend in annual rainfall time series of Southern Rajasthan due to high rainfall variability. Furthermore, the significant trend observed in standard meteorological week 30 (SMW-30) time series due to peak period of monsoon rainfall.

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