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Study of Spatio –Temporal Variation of Groundwater Drought In Bearma Basin

Dinesh Kumar[1] , T. Thomas[2] , R. M. Singh[3]

[1, 3]Department of Farm Engineering, IAS BHU, Varanasi-221005, UP, India
[2]NIH Ganga Plains South Regional Centre, WALMI CAMPUS, Bhopal-462016, MP, India

Abstract : Drought is an important phenomenon in recent years which caused a lot of problems for most of areas in Bundelkhand region in Central India. Drought lead to water scarcity for people and this problem becomes one of the important challenges for the central zone of India. Bearma basin is one of the considerable groundwater resource fields in South portion of Bundelkhand in Madhya Pradesh, which is Sub-basin of Ken River. In the present study the Bearma basin has been selected with the objective to study of the spatio-temporal variation of groundwater drought. The quarterly ground water levels of 86 observation wells falling in Bearma basin have been used. The spatial-temporal variation of the groundwater drought characteristics in Bearma basin have been studied based on the drought severity classification of Groundwater Drought Index for the selected 86 observation wells in the basin falling in Sagar and Damoh districts during various months of the identified drought years 2002-03 and 2007-08. This spatio-temporal analysis of groundwater droughts has help to understand the variation of groundwater drought and its areal influence during various seasons of a drought years. The study reveals that each groundwater drought event is unique in its characteristics and has varying degree of influence in different zones of the basin. The groundwater drought distribution and pattern is completely different in two of the meteorological drought years of 2002-03 and 2007-08 with the southern portion of the basin facing worse drought scenario during 2002-03 whereas in 2007-08 the northern portions of the basin faced more severe drought conditions.

Keywords: Groundwater drought, Groundwater drought index, Bearma, Bundelkhand, Spatio-temporal variation, Sagar and Damoh

1. INTRODUCTION

Much of the recent public concern over climate change tends to focus on rising global mean temperatures. However, climate varies significantly on a regional scale and changing precipitation patterns can be particularly damaging (IPCC, 2007). In fact, drought is estimated to be the most pricey natural disaster in the world (Witt, 1997) and the most complex and least understood of all natural hazards, affecting more people than any other hazard (Wilhite, 2000). A drought is an extended period when a region notes a deficiency in its water supply (Beran and Rodier, 1985). Different types of drought are meteorological, hydrological, agricultural and socio-economic (Hisdal and Tallaksen 2000; Mishra and Singh 2010; van Loon and van Lanen 2012; Liu *et al.*, 2012 and Choi *et al.*, 2013). Among the different types of drought, investigation of the hydrological drought is most important due to dependence of most of the activities (including industrial, water and power plants) to surface water resources (Vasilides *et al.*, 2011). In this research mainly groundwater drought is investigated. Groundwater is an important source of water; van Lanen & Peters, 2000, defined that a groundwater drought occurs if the groundwater heads in an aquifer have fallen below a critical level over a certain period of time, which results in adverse effects. The critical level can be defined as some percentile of the groundwater hydrograph or based on the standardized ground water levels or based on the long-term seasonal mean and standard deviation.The groundwater drought is defined as a natural decline in the ground water levels that may result in dewatering of the aquifer completely or partly, or to a point where it could cause serious water supply problems. The groundwater drought characteristics can be evaluated using the percentile approach or an appropriate drought index. In this study, an attempt has been made to evaluate the groundwater drought characteristics by developing a Groundwater Drought Index (GDI) in Bundelkhand region. The Bearma basin has been selected as a pilot basin and the study has been carried out to mainly characterize the spatial and temporal variation of groundwater drought.

2. MATERIAL AND METHODS

2.1 Study area

The river Bearma is one of the important tributaries of Ken river passing through the heartland of Bundelkhand in the State of Madhya Pradesh and is located between north latitudes of 23° 07′ and 24° 18′ and east longitudes of 78° 54′ and 80° 00′ Fig.1.

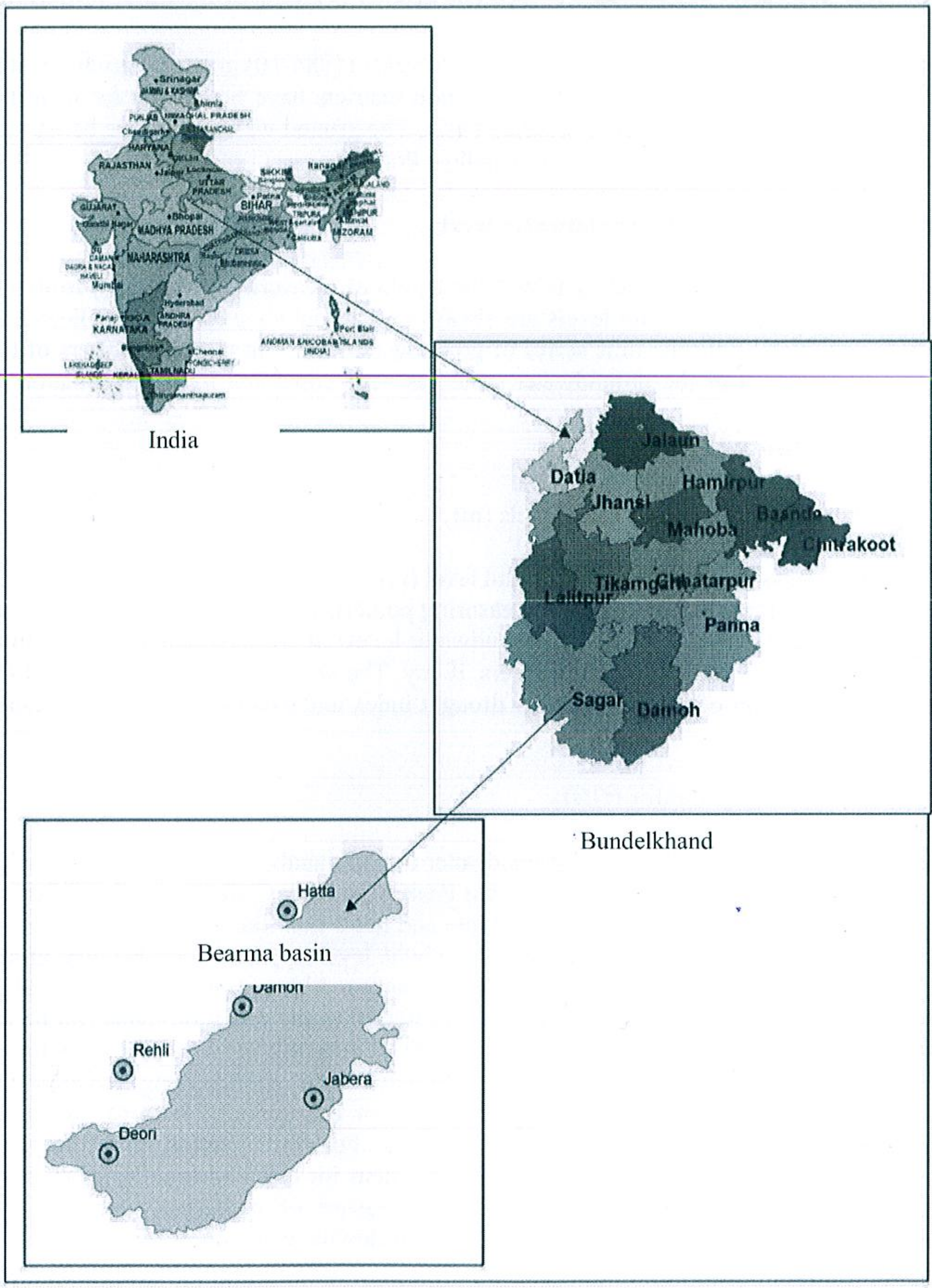

Figure 1. Index map of the Bearma basin

2.2 Hydrological data

To investigate the groundwater drought, there are 26 years (1984-10) quarterly ground water levels of 86 observation wells falling in Sagar and Damoh districts have been used for identifying the groundwater drought characteristics in Bearma basin. The ground water levels are being monitored by the State Ground Water Survey, Govt. of Madhya Pradesh.

2.3 Processing and analysis of groundwater levels

The reduced level of the ground (RL_G) as well the height of measuring point (H_{MP}) from where the measurements for the groundwater levels are always carried out have also been collected for each observation well along with the time series of groundwater levels in all four quarters of the water year. The reduced level of the groundwater table has been computed from the equation as given below:

$$RL_{GWL} = RL_G + H_{MP} - D_{GWL} \tag{1}$$

Where,

RL_{GWL} = Reduced level of groundwater levels (m)

RL_G = Reduced level of ground (m)

H_{MP} = Height of measuring point above ground level (m)

D_{GWL} = Depth of groundwater level below measuring point (m)

After obtaining the time series of RL of groundwater levels, it was compared with the time series of adjacent locations for finding out the outliers, if any. The processed data have been subsequently used in the development of the groundwater drought index and evaluation of groundwater drought characteristics.

2.4 Groundwater drought index (GDI)

The most well-known methods used in groundwater drought analysis from ground water level data are the threshold level approach and the Sequent Peak Algorithm (Tallaksen and van Lanen 2004). However, as ground water level is a state variable and not a flux like recharge, rainfall and stream flow, the deficit volume calculated with the threshold level approach can identify groundwater droughts or scarcities better compared to other approaches. Although the fixed threshold provides quite acceptable results, the cumulative deficit is preferred as the major droughts can be identified more clearly. The best results can be obtained for a fixed threshold level and the cumulative deficit (van Lanen and Peters 2000). The GDI is computed by normalizing quarterly/seasonal groundwater levels and dividing the difference between the quarterly/seasonal water level and its long-term seasonal mean by its standard deviation. For normalization, an incomplete gamma function was used for water level data before using them for calculating GDI. The GDI is an indicator of water-table decline and an indirect measure of recharge, and thus an indirect reference to drought. The GDI is computed as per the following equation given below.

$$GDI = \left\{\frac{GWL_{ij} - GWL_{im}}{\sigma}\right\} \tag{2}$$

Where,
GWL_{ij} = seasonal water level for the ith well and jth observation,

GWL_{im}= seasonal mean,

σ = is the standard deviation.

Even though the groundwater levels are being measured from a measuring point above the ground surface, the water levels have been converted to reduced levels based on the reduced level of the ground surface at the observation. Hence negative anomalies correspond to '*water stress*' while positive anomalies represent a '*no drought*' condition. The cumulative deficit of the summation of negative anomalies of groundwater level below a threshold level over a time period indicates the severity of the ground water drought in that region which can be visualized through spatial interpolation.

2.5 Groundwater drought characteristics

Based on the base map of the Bearma basin, the observation wells falling in and around the basin have been selected using the GIS operations and a map prepared considering all the wells identified for the analysis. 86 observation wells falling in the study area were selected. Thereafter the reduced ground water levels have been computed based on the reduced level of ground and height of measuring point above the ground level at each of these 86 observation wells for years 2002-03 and 2007-08. The classification used for identifying the groundwater drought characteristics based on GDI is given in Table 1.

Table 1: Standard ranges of GDI values and their classification

S. No.	GDI range	Classification
1.	0.0 to -0.99	Mild drought
2.	-1.0 to -1.49	Moderate drought
3.	-1.5 to-1.99	Severe drought
4.	-2.0 ≤	Extreme drought

The negative GDI values indicate a drought condition whereas positive GDI values are indicative of normal and wet conditions. Based on the standard classification, GDI ranging between 0.00 to -0.99 are considered as mild groundwater drought; -1.00 to -1.49 as moderate groundwater drought; -1.50 to -1.99 as severe drought and GDI equal to or less than -2.00 is considered as a severe drought condition. The GDI has been used for identifying the groundwater drought characteristics including the groundwater drought severity, duration and intensity. The duration of the groundwater drought is supposed to begin when the GDI becomes negative and continues till the time when GDI becomes positive again. The sum of the negative GDI values during this duration is defined as the groundwater drought severity and the severity divided by the duration gives the intensity of groundwater drought for that particular event.

3. RESULTS AND ANALYSIS

The spatial-temporal variation of the groundwater drought characteristics in Bearma basin have been studied based on the drought severity classification of GDI for the selected 86 observation wells in the basin falling in Sagar and Damoh districts during various months of the identified drought years 2002-03 and 2007-08. The spatial variation of the ground water drought in the basin has been studied using ILWIS 3.0. A GIS layer (point map) has been created comprising of GDI values at all the wells and subsequently the spatial interpolation using the inverse distance technique is performed. The interpolated map has been classified on the basis of the GDI classification scheme given by (van Lanen and Peters 2000) for categorizing the areas into different drought classes. The spatial and temporal variation of drought classes in the Bearma basin for the various seasons during for the drought year of 2002-03 is given in Fig. 2. The percentage area in basin falling under the various groundwater drought severity classes during 2002-03 is given in Table 2.

In August 2002, more than 70% of the basin area was under normal conditions and only 28.57% area was under mild droughts. Mild groundwater drought conditions were experienced at Ghana, Kesli, Chandpur, Pura, Gunjhora, Devron and Damoh along the western boundaries of the basin adjoining Sonar basin. Mild groundwater drought was also felts at few pockets along Gaisabad, Muhari and Kumhari during August 2002. However with the shortage of rainfall due to failing monsoon, the groundwater drought progressed quite steadily, the drought conditions became more severe and widespread and the area under various drought classes increased, with 4.2% under extreme drought, 6.83% under severe drought, 13.10% under moderate drought and 27.18% under mild drought. This indicates that during November 2002, the combined area under all groundwater drought categories increased from 29.11% in August 2002 to 52.31%. Moderate to extreme groundwater drought conditions were felt towards the southern portion of the basin, with Reechai facing extreme droughts and Taradehi and Titarpani facing severe drought conditions. Moderate drought conditions were felt at Chandpur, Sarra, Singhpur, Ghana and Kesli and few pockets at Hathani and Sanga. However during January 2000, more than 89% of the area was under normal conditions due to favorable water availability scenario ass can be seen from the graphs and only some areas influenced by Taradehi, Reechai and Titarpani experienced mild drought conditions. Moderate to severe drought was experienced in the observation well at Singhpur only. However during May 2003, the area under droughts increased with 28.78% under mild droughts which was prominent at area under influence of Titarpani, Bamhori, Banwar, Hinota, Muhari and Gaisabad. Mild drought was also felt at Damoh, Palar and Bilai during May 2003. This analysis of the ground water drought conditions helps to identify the areas/regions where the drought is predominant and expanding in the subsequent months.

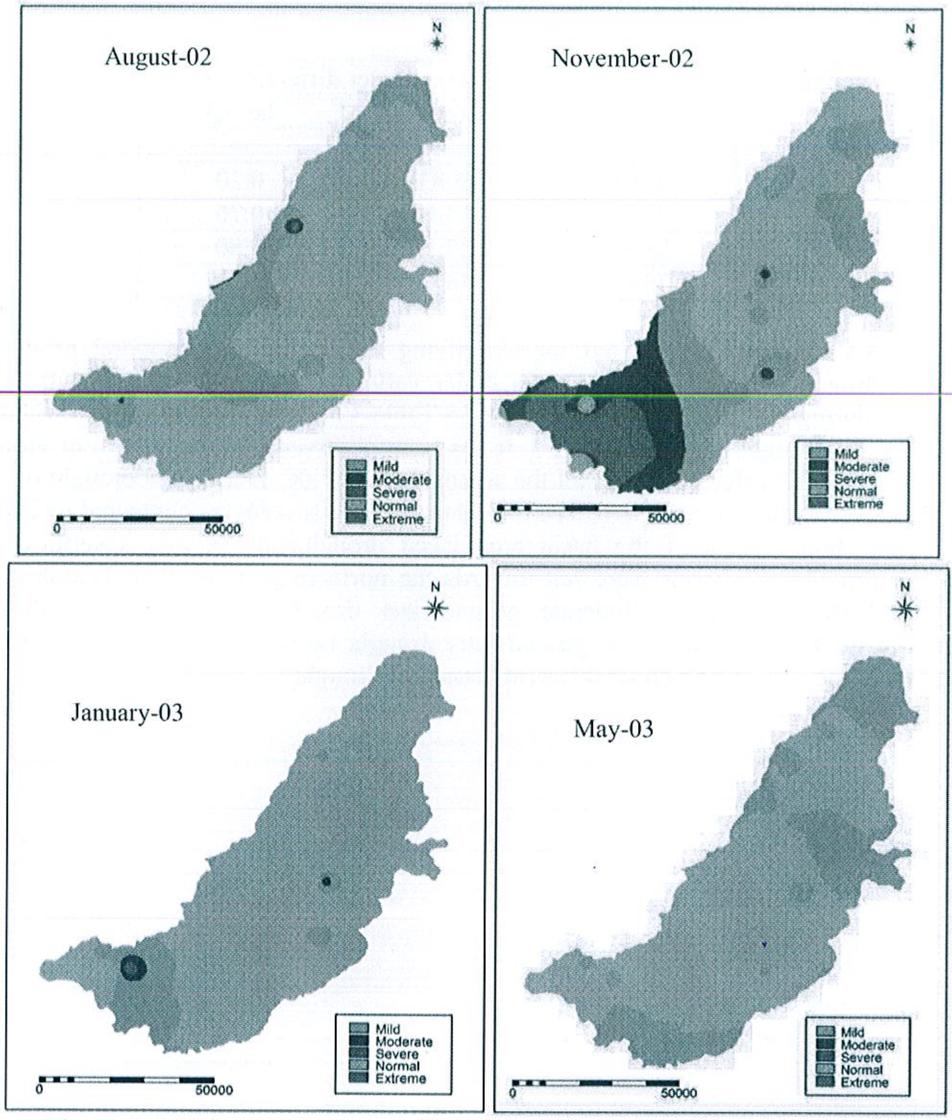

Figure 2. Spatio-temporal variation of groundwater drought during 2002-03

Table 2: Spatial and temporal variation of groundwater drought during 2002-03

Sr. No.	Drought severity	Percentage of area under different severity classes (%)			
		Aug-02	Nov-02	Jan-03	May-03
1.	Extreme	--	4.20	--	--
2.	Severe	0.10	6.83	0.20	--
3.	Moderate	0.44	13.10	0.76	--
4.	Mild	28.57	27.18	9.80	28.78
5.	No drought	70.89	48.68	89.24	71.22

Similar analysis has been carried out for identifying the spatial and temporal progression of groundwater droughts in 2007-08. The area under various groundwater drought classes in the Bearma basin during the various seasons is given in Table 3 and the progression and withdrawal of the ground water drought is given in Fig. 3. It has been observed that the pattern of groundwater drought is completely different during all the seasons of 2007-08. During the drought of 2007-08, the northern areas of the basin experienced drought of higher severity as compared to 2002-03. In August 2007, about 48.4% of the basin area faced droughts of varying severities. Extreme groundwater drought conditions were felt towards the northern parts namely, Gaisabad, Hinota, Barkhera and Barkhera-chain. Moderate groundwater drought existed towards the western boundaries of the basin. However the groundwater drought further progressed in November 2007 with 54.90% of the area falling under different classes of drought.

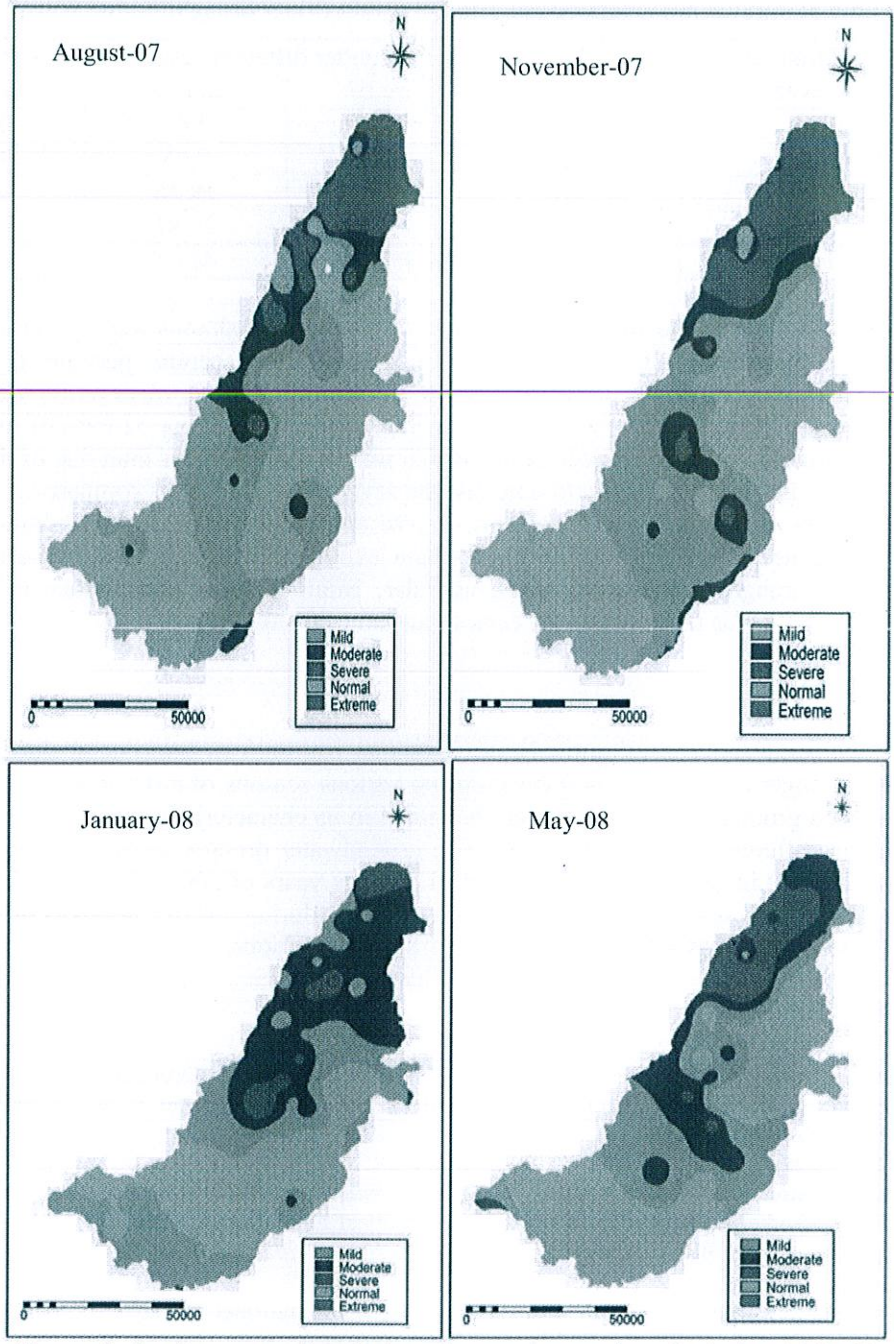

Figure 3. Spatio-temporal variation of groundwater drought during 2007-08

Table 3: Spatial and temporal variation of groundwater drought during 2007-08

Sr. No.	Drought severity	Percentage of area under different severity classes (%)			
		Aug-07	Nov-07	Jan-08	May-08
1.	Extreme	7.95	10.35	2.62	0.61
2.	Severe	5.22	6.52	7.65	4.95
3.	Moderate	10.83	10.86	18.46	28.66
4.	Mild	32.36	36.72	27.81	32.98
5.	No drought	51.60	45.90	46.08	33.42

In this month also the extreme and severe groundwater drought conditions were felt at the northern tip of the basin whereas mild drought conditions existed at the central portions of the basin. Moderate to severe groundwater drought was felt at Patan and Sanga observation wells located towards the central region of the basin. However in January 2009, about 52.99% of the area was under various groundwater drought categories which were marginally less than that of the previous season (54.90%). But it is interesting to note that the severities were less as compared to November 2007 as very less areas experienced extreme, severe and moderate drought conditions. In May 2009, few areas near Barkhera and Barkhera-chain experienced extreme groundwater droughts whereas severe drought conditions existed at Palar, Bilai, Karaiya and Hinota and moderate groundwater drought was felt towards the central portion of the basin.

4. CONCLUSIONS

The spatio-temporal analysis of groundwater droughts has help to understand the variation of groundwater drought and its areal influence during various seasons of a drought years. The study reveals that each groundwater drought event is unique in its characteristics and has varying degree of influence in different zones of the basin. The groundwater drought distribution and pattern is completely different in two of the meteorological drought years of 2002-03 and 2007-08 with the southern portion of the basin facing worse drought scenario during 2002-03 whereas in 2007-08 the northern portions of the basin faced more severe drought conditions.

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