

Winter frequency of western disturbances and precipitation indices over Himachal Pradesh, India: 1977-2007

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RESUMEN

Los Himalayas desempeñan un papel importante en el clima y el tiempo meteorológico de la India, y controlan tanto las perturbaciones del oeste (PO) durante el invierno como el monzón del suroeste durante el verano. En los meses de invierno (diciembre a marzo), los vientos del oeste asociados con PO causan precipitaciones, en ocasiones asociadas a fuertes nevadas y extensas avalanchas sobre Himachal Pradesh. Por tal motivo, el presente estudio analiza la variabilidad temporal de la frecuencia de PO y de diversos índices de precipitación (como número de días húmedos y lluviosos, días con precipitación fuerte y muy fuerte, e intensidad de la precipitación de 1977 a 2007) en Himachal Pradesh durante el invierno. También se analizan las características sinópticas asociadas con PO intensas que provocaron fuertes precipitaciones sobre la región durante el periodo señalado. El análisis de datos revela una tendencia decreciente estadísticamente significativa (con un nivel de confianza $> 95\%$) de las PO en la región de estudio. Debido a que la precipitación invernal en Himachal Pradesh ocurre sobre todo como resultado de las PO, tanto la precipitación total como los días con precipitación fuerte y muy fuerte han disminuido en la región. El análisis también muestra una disminución de alrededor de 25% en los días de precipitación fuerte y de 13% en la precipitación invernal total sobre Himachal Pradesh respecto de su media respectiva (de 1977 a 2007).

ABSTRACT

The Himalayas have an important role in Indian weather and climate, since they control the western disturbances (WDs) during winter and the southwest monsoon during summer. During the winter months (December to March), westerly winds associated with WDs cause precipitation, sometimes along with heavy snowfall, extensive avalanches, etc., over Himachal Pradesh. Therefore, this study examined the temporal variability in the winter months frequency of WDs and various precipitation indices like wet days, rainy days, rather heavy and heavy precipitation days, and precipitation intensity during 1977 to 2007 over Himachal Pradesh. The study also examined synoptic features associated with intense WDs that caused heavy precipitation over the region during the same period. Analysis of data reveals a statistically significant (confidence level $> 95\%$) decreasing trend in the frequency of WDs over this region. Since winter precipitation in Himachal Pradesh mainly occurs due to WDs, total winter precipitation and frequency of rather heavy and heavy precipitation days have decreased over the region. The analysis also shows a decrease of about 25% in heavy precipitation days and of 13% in total winter precipitation from their respective mean (from 1977 to 2007) over Himachal Pradesh.

Keywords: Himachal Pradesh, precipitation, western disturbances.

1. Introduction

Winter precipitation plays an important role over the Western Himalayan Region (WHR), particularly in Himachal Pradesh, for various sectors like agriculture, water resources, horticulture, hydroelectric power generation and regional economy. Winter precipitation in the WHR occurs under the influence of extratropical systems known as western disturbances (WDs) (Dimri and Dash, 2012; Yadav *et al.*, 2012). These are the extratropical upper air troughs or cyclonic circulations (CCs) in midlatitude westerlies that move west to east across the Himalayan region (Das *et al.*, 2002; Das 2002; Lang and Barros, 2004; Puranik and Karekar, 2009). Under its influence, CCs sometimes develop south of the system at lower levels, in which case they are known as induced CCs. Some WDs produce well-distributed and large amounts of precipitation along with heavy snowfall/rainfall, landslides, cloudbursts etc. over the Himalayan region, while others pass across this area without causing precipitation (Malurkar, 1947). Hence, studies related to WDs and their associated weather are essential to the WHR.

There are many studies related to WDs and their associated weather over the WHR in literature. Pisharoty and Desai (1956) and Rao and Srinivasan (1969) studied the synoptic aspects of WDs and their associated weather over the WHR. They found that about 6-7 WDs per month move across the region. Singh and Kumar (1977) found that WDs intensified over the WHR in association with a pre-existing surface low over central Iran overtaken by a strong upper frontal layer. Rangachary and Bandyopadhyay (1987) and Hatwar *et al.* (2005) studied the synoptic features associated with extreme weather over the WHR. They found that widespread precipitation along with extensive avalanches over this region occur under the influence of WDs along with a high amount of moisture coming from the Arabian Sea, the Bay of Bengal or both. Das *et al.* (2002) studied the frequency of WDs in the premonsoon season, as well as its relation with monsoon rainfall and its advancement over northwest India. Their study found a significant decreasing trend in the frequency of WDs during May. Dimri (2005) studied the contrasting features associated with surplus and deficient precipitation years during the winter season to assess the wintertime synoptic weather system affecting the western Himalayas. He found higher heat flux convergence in excess years

and higher flux of convergence of kinetic energy with higher dissipation of kinetic energy during surplus years. Dimri (2007) studied the meridional transport of heat, momentum, potential energy and moisture associated with WDs over the Himalayan region due to mean and eddy motion. He observed that significant meridional transport due to mean motion takes place in the upper troposphere at 300 hPa and 200 hPa. Raju *et al.* (2011) studied kinetic energy associated with intense WDs that caused widespread precipitation over northwest India, finding that this phenomenon occurred due to strong flux convergence and adiabatic production of kinetic energy.

There are also studies related to temporal and spatial variability in precipitation over the Himalayan region. Shrestha *et al.* (2000) studied precipitation across Nepal and found significant variability at annual and decadal time scales. Bhutiyani *et al.* (2008) have done trend analyses of discharge data from rivers in the northwest Himalayas, finding out that the number of high-magnitude flood events in this region have increased in the last three decades. Bhutiyani *et al.* (2010) also studied precipitation trends in the northwest Himalayas and did not find any trends in precipitation during the winter season or significant decreasing trends in precipitation during the monsoon season. Kumar and Jain (2010) studied the trends in seasonal annual rainfall and rainy days in the Kashmir Valley using data of five stations within this area. They found decreasing trends in monsoon and winter rainy days over all the stations and a decreasing trend in annual rainfall over three stations. However, there is hardly any study in literature related to frequency of WDs and variability of precipitation indices over the WHR with particular focus on Himachal Pradesh. Therefore, we have studied the frequency of winter WDs and several precipitation indices like total winter precipitation, wet days, rainy days, and rather heavy and heavy precipitation days by using daily precipitation data for the period 1977 to 2007 over Himachal Pradesh. We also examined the synoptic features associated with intense WDs that caused heavy precipitation (≥ 64.5 mm) events over Himachal Pradesh during the same period.

2. Data and methodology

In the present study we used daily precipitation data of 15 rain gauge stations at Himachal Pradesh

for the period 1977 to 2007 during winter months (December to March). The sources of data are the Bhakra Beas Management Board and the India Meteorological Department. Locations of the rain gauge stations are given in Table I and shown in Figure 1.

Table I. Latitude and longitude of the rain gauge stations.

| Station No. | Name | Latitude (°N) | Longitude (°E) |
|-------------|---------------|---------------|----------------|
| 1 | Kalpa | 31° 32' | 78° 15' |
| 2 | Shimla | 31° 06' | 77° 10' |
| 3 | Manali | 32° 16' | 77° 10' |
| 4 | Kasol | 32° 00' | 77° 19' |
| 5 | Rampur | 31° 26' | 77° 38' |
| 6 | Dharamshala | 32° 16' | 76° 23' |
| 7 | Naina Devi Ji | 31° 18' | 76° 32' |
| 8 | Bhunder | 31° 50' | 77° 10' |
| 9 | Ali | 31° 14' | 76° 54' |
| 10 | Kotla | 31° 30' | 77° 15' |
| 11 | Sawarghat | 31° 14' | 76° 43' |
| 12 | Kahu | 31° 13' | 76° 47' |
| 13 | Daslehra | 31° 25' | 76° 33' |
| 14 | Suni | 31° 14' | 77° 6' |
| 15 | Berthin | 31° 25' | 76° 38' |

If daily data of a particular month is lower than 80% in a station, the data of that month is discarded. To study the precipitation indices (Kumar *et al.*, 2012; Brunetti *et al.*, 2000), we divided daily precipitation into the categories shown in Table II.

Table II. Precipitation categories*.

| No. | Event | Precipitation |
|-----|--------------------------------|------------------------------------|
| 1 | Wet day | Daily precipitation ≥ 0.1 mm |
| 2 | Rainy day | Daily precipitation ≥ 2.5 mm |
| 3 | Rather heavy precipitation day | Daily precipitation ≥ 35.6 mm |
| 4 | Heavy precipitation day | Daily precipitation ≥ 64.5 mm |

* Precipitation intensity: Average precipitation amount per wet day.

For calculating the frequency of WDs, we considered only those systems that caused precipitation (at least over two stations) over Himachal Pradesh, and we analyzed trough/circulation in midlatitude westerlies associated with WDs from geopotential height (GPH) at mid-tropospheric levels (Zafar and Rasul, 2009) by using NCEP/NCAR reanalysis data (Kalnay *et al.*, 1996).

Finally, trend analysis of WDs and other precipitation indices were carried out by using a linear regression method (Pant and Rupa Kumar, 1997; Krishnakumar *et al.*, 2009) and the Mann Kendall non-parametric test (Kendall, 1976; Kumar and Jain, 2010; Subash *et al.*, 2011). In this study, the trend is said to be statistically significant if the confidence

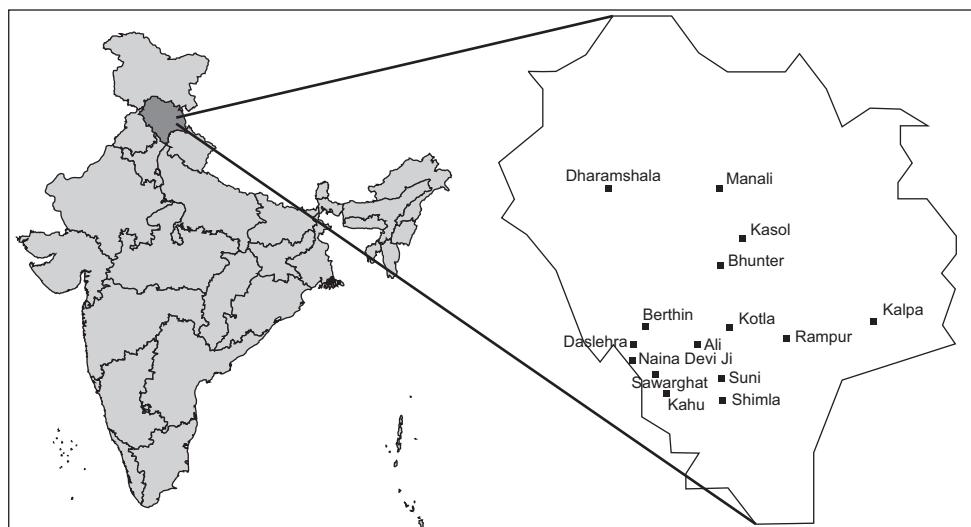


Fig. 1. Location of rain gauge stations in Himachal Pradesh, India.

level is $\geq 95\%$. The anomaly percentage of any parameter is calculated as:

$$(\text{series value}/\text{series mean}) \times 100$$

3. Results and discussions

3.1 Characteristics of intense WDs

To study the synoptic characteristics of intense WDs, we analyzed about 40 intense WDs that caused heavy precipitation over Himachal Pradesh by using NCEP/NCAR reanalysis data for the period 1977 to 2007. In general, the following synoptic features are observed in intense WDs:

- A trough roughly located along 68° E longitude and south of 24° N latitude or a CC around 68° E longitude and 31° N latitude at 500 hPa GPH.
- An induced CC located over Central Pakistan and the adjoining Rajasthan area or a trough that extends from north Pakistan and the adjoining Jammu and Kashmir to the Arabian Sea at 850 hPa GPH.
- A large amount of moisture incursion from the Arabian Sea over the region.

A typical example of a trough and induced CC associated with intense WDs that have caused widespread (at more than 75% stations) precipitation with heavy rainfall in a few places (more than 25% of stations) is shown in Figure 2. The trough in 500 hPa GPH is roughly along 67° E longitude- 16° N latitude

along with an induced CC over west Rajasthan and the adjoining Pakistan area at 850 hPa GPH.

3.2 Winter precipitation indices characteristics

The average precipitation during winter months for the period 1977 to 2007 over the entire region is of 268 mm. However, this average is 344 mm over a high altitude region (> 2.0 km) (by averaging the precipitation of all stations with altitude greater than 2.0 km), 260 mm over a middle altitude region (between 1.0 and 2.0 km) and 225 mm over a low altitude region (< 1.0 km).

The average frequencies of wet and rainy days over the entire region within the study period are 23 and 17, respectively. The frequencies of rather heavy and heavy precipitation days are 1.5 and 0.3, respectively, but in a high altitude region the average frequencies of wet days, rainy days, rather heavy precipitation days and heavy precipitation days are 27, 21, 2.1 and 0.3, respectively. This indicates higher indices of precipitation amount and frequency at higher altitudes, as compared to lower altitudes.

3.3 Winter disturbances

The total number of WDs during the study period for winter months is 369 and their annual frequency during the winter season is 12. Its frequencies during December, January, February and March are of 2, 3, 4, and 4, respectively, whereas earlier studies found that the average frequency of WDs is 6-7 per month across the WHR (Pisharoty and Desai, 1956;

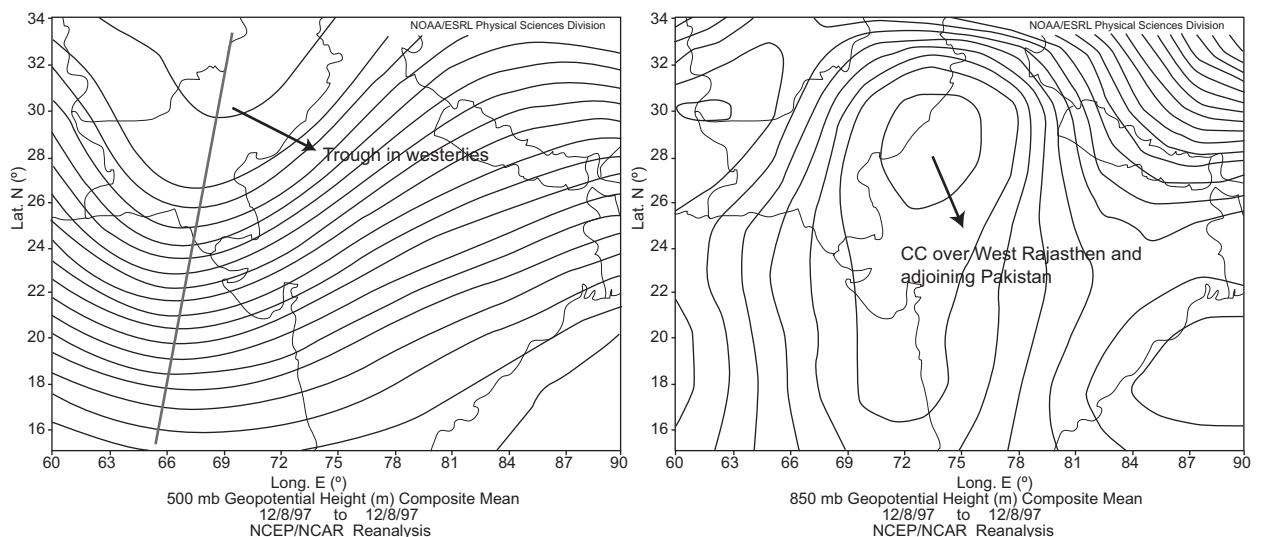


Fig. 2. Locations of troughs and CCs in 500 and 850 hPa GPH, respectively.

Rao and Srinivasan, 1969). However, our study is based only on central parts of the Himalayas. Further, analysis of data by the linear regression method and the Mann-Kendall non-parametric test indicates a significant decreasing trend in frequency of WDs (Fig. 3) over the region for the period 1977 to 2007. Our study shows a decrease in the frequency of WDs of about 11% from their mean frequency from 1977 to 2007. Earlier, Das *et al.* (2002) observed a decreasing frequency of WDs in the pre-monsoon season (March to May) with a significant decrease during May over northwest India. Shekhar *et al.* (2010) observed no trend in the annual frequency of WDs over higher altitudes in the Western Himalayas.

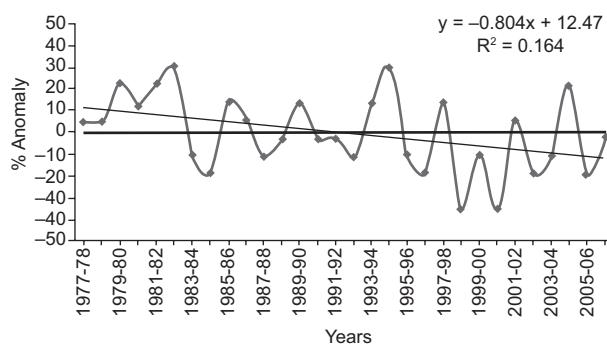


Fig. 3. Winter frequency of western disturbances over Himachal Pradesh.

3.4 Total winter precipitation

Total winter precipitation over Himachal Pradesh shows a decreasing trend (Fig. 4) of about 13% in precipitation from its mean from 1977 to 2007. Earlier studies (Pant *et al.*, 1999; Kumar and Jain, 2010; Shekhar *et al.*, 2010; Dimri and Dash, 2012) also showed decreasing trends in winter precipitation over various parts of the WHR, which may be due to

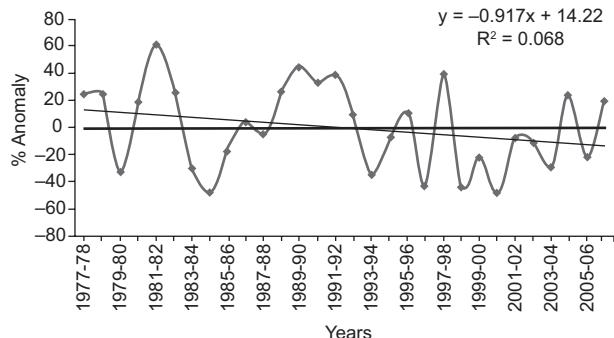


Fig. 4. Winter precipitation trends over Himachal Pradesh.

the significant decreasing frequencies of WDs over the region.

3.5 Wet and rainy days

Time series of wet and rainy days are shown in Figures 5 and 6, respectively. Our study shows a decreasing trend both in wet and rainy days. A decrease of about 14% and 13% was found for wet and rainy days, respectively, from their respective means during the 1977-2007 period. Kumar and Jain (2010) also observed a decreasing trend in winter rainy days over the Kashmir Valley in the Himalayas.

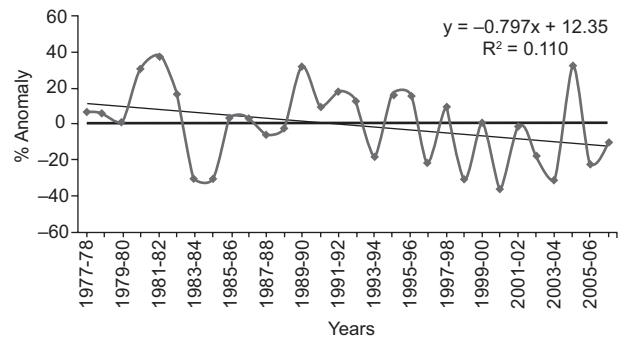


Fig. 5. Wet days trends over Himachal Pradesh.

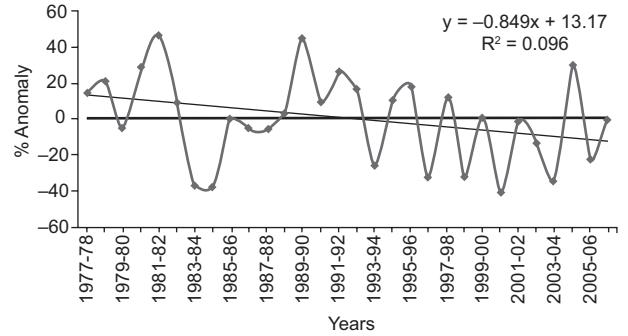


Fig. 6. Rainy days trends over Himachal Pradesh.

3.5 Precipitation intensity

The analysis of daily precipitation reveals no change in precipitation intensity over Himachal Pradesh during the study period (Fig. 7).

3.6 Rather heavy and heavy precipitation

Time series of rather heavy and heavy precipitation days are shown in Figures 8 and 9, respectively. Both series show decreasing trends over Himachal Pradesh during the study period. The analysis

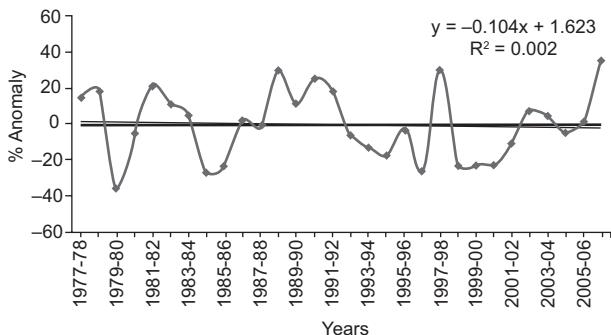


Fig. 7. Trends of precipitation intensity over Himachal Pradesh.

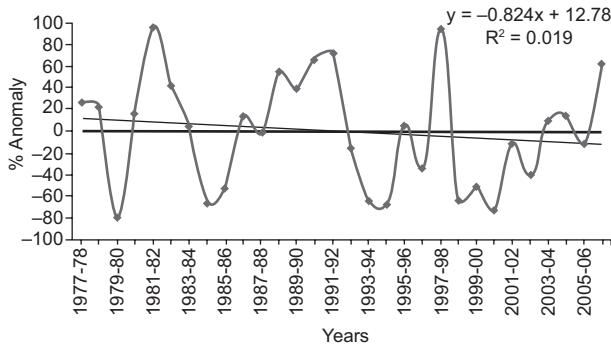


Fig. 8. Rather heavy precipitation trends over Himachal Pradesh.

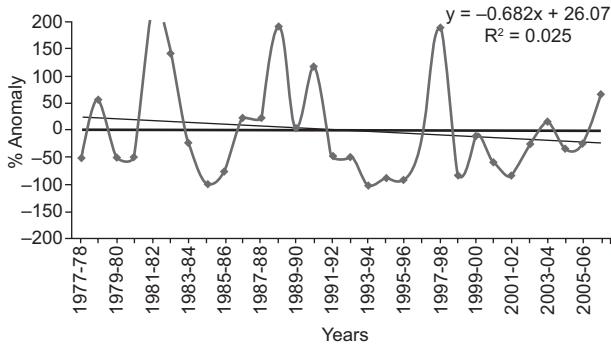


Fig. 9. Heavy precipitation trends over Himachal Pradesh.

indicates a decrease of about 12% and 25% in rather heavy and heavy precipitation days from their respective means during the 1977-2007 period. However, long-term changes in heavy precipitation events are not uniform over different parts of the India. Goswami *et al.* (2006) found significant increasing trends in extreme heavy precipitation over central parts of the country. Kishtawal *et al.* (2009) observed a significantly increasing trend in the frequency of

heavy rainfall over urban regions of India during the monsoon season. Guhathakurta *et al.* (2011) observed decreasing frequency of heavy rainfall events over major parts of central and north India and increasing frequency in peninsular, east and northeast India. Kumar *et al.* (2012) observed decreasing trends in heavy precipitation over the Andaman and Nicobar islands.

4. Conclusions

Based upon the analysis of daily precipitation data and NCEP/NCAR reanalysis data for the period 1977-2007, the following conclusions are drawn:

Heavy precipitation over Himachal Pradesh generally occurs in association with a trough roughly situated along 68° E longitude and south of 24° N latitude or a CC located around 31° N latitude and 68° E longitude in mid-tropospheric (500 hPa) westerlies; a CC located over Central Pakistan and the adjoining Rajasthan area, or a trough extended from north Pakistan and the adjoining Jammu and Kashmir to the Arabian Sea in a lower level (850 hPa). In addition, there should be a good amount of moisture incursion from the Arabian Sea over the region.

Total winter precipitation and precipitation indices are greater at higher altitudes as compared to lower altitudes. Tyagi *et al.* (2013) also observed an increase in winter precipitation with the increase in altitude over the WHR.

The mean frequency of winter WDs that caused precipitation over Himachal Pradesh is 12, with a highest monthly frequency (four) during February and March. This study shows a significant decreasing trend in the frequency of WDs over Himachal Pradesh.

All precipitation indices (i.e., total winter precipitation, wet days, rainy days, rather heavy and heavy precipitation days) show decreasing trends over the region during the study period. However, no trend is observed in precipitation intensity over the region. It can be broadly inferred from the study that the decreasing trend in precipitation indices is mainly due to significant decreases in the frequency of WDs affecting Himachal Pradesh.

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