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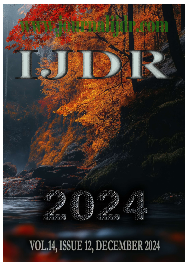

RESEARCH ARTICLE OPEN ACCESS

COMPREHENSIVE ANALYSIS OF RAINFALL PATTERN, SLOPE VULNERABILITIES AND MITIGATION STRATEGIESIN KULLU VALLEY, HIMACHAL PRADESH

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ABSTRACT

This study presents a comprehensive analysis of Kullu district's rainfall patterns and associated vulnerabilities over the past three decades. Results illustrate annual rainfall data, highlighting extreme years like 2010 and 2019 with peak rainfall, and 2004 and 1999 with minimal levels. The trends in both annual and normal rainfall comparisons indicate a notable variability. Despite fluctuations, a marginal 0.0031 percent rise in overall rainfall is observed, suggesting a gradual increase over time. The examination of monsoonal rainfall trends from 1993 to July 2023 reveals a 0.0132 percent upward trend, with distinct variations such as the remarkable 2010 peak and the 2004 low. Descriptive statistics further uncover seasonal patterns, emphasizing maximum rainfall during July and August. The analysis of Z scores presents intriguing deviations from the mean, showcasing years of exceptional performance, like 2010, and periods of deviation, such as 2003 and 2004. The region's topography's influence on flood vulnerabilities is highlighted, with gentle slopes exhibiting better drainage capacity than steeper ones, which are prone to flash floods. The study emphasizes the necessity of effective land management, erosion control, and drainage systems to mitigate risks. Additionally, the study underscores the susceptibility of towns in Kullu District to natural hazards due to their proximity to rivers. The dominance of rangeland and tree cover, along with limited built-up areas, as revealed by the Land Use Land Cover (LULC) analysis, further accentuates the need for disaster preparedness measures, proper land use planning, and robust drainage systems to mitigate potential damages and safeguard vulnerable communities.

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INTRODUCTION

The Indian Himalayan Region (IHR), which spans more than 2,500 km from Jammu and Kashmir in the west to Arunachal Pradesh in the east, forms the northern limit of the nation (Northwest to Northeast). It has been split vertically into the Great Himalaya, Middle Himalaya, and Lesser Himalaya, also known as the Shivalik Ranges (Sati, 2014).According to its geology, the Himalayas may be roughly split into four regions: the Tethyan or Trans-Himalaya, the Foothill or Outer Himalaya, the Lesser Himalaya, the Higher Himalaya, and the Higher Himalaya. Himachal Pradesh, often known as Dev Bhoomi (the country of the gods), is a stunning mountainous state in northern India. With a land size of 21,629 m^2, the state is tucked away in the Western Himalayas and is bordered by Tibet, China to the east, Jammu and Kashmir to the north, and Punjab to the west and south, Haryana and Uttar Pradesh to the south, and Uttarakhand to the south-east. Himachal Pradesh is a tourist's dream thanks to its picturesque landscapes, which include freshwater lakes, rushing rivers, snow-capped mountains, trees filled with flowers and fruits, and a dazzling and colorful diversity of culture, arts, and way of life. The Dhauladhar Range, Pir Panjal Range, and Great Himalayan Range are the three primary mountain ranges that dominate the state.

The state of Himachal Pradesh has a number of risks. It is located in zones III and IV of India's seismic hazard map. In Himachal Pradesh, natural disasters like unheard-of droughts, excessive rains, snowfall, and flash floods caused by cloud bursts have caused loss of life, damage to cattle heads, destruction of public infrastructure like roads and bridges and footpaths, culverts, and drinking water supplies, as well as damage to both public and private property (Kumar *et al*., 2022). A flood is when water overflows onto normally dry terrain. Flooding occurs when a river or other low-lying channel's banks are overflowed by rising water, or when the high banks of a river or other low-lying channel wash over the shore. Floods are caused by natural conditions and phenomenon (topography, rainfall), regional geographical conditions, and human activities that result in changes in land use in an area (Sholihah *et al*., 2020). Floods, on the other hand, are generated not just by severe rainfall but also by other occurrences, particularly in coastal locations. The typical effects of floods are buildings washed away or destroyed by floodwaters; landslides brought on by saturation of water. Drowning mortality among humans and animals, comparatively few major injuries, epidemics, viral diseases, and malaria.Contamination of water (wells, groundwater, piped water supply). Clean water may not be available. Due to the abrupt loss of a whole harvest, the rotting of grains after being soaked in water, and the loss of animal feed, food shortages can happen at any time. Crop storage and go-downs may be overflowing, resulting in a critical food shortage. Floods may alter the characteristics of the soil. Cloudbursts are characterized by intense heating of an air mass, rapid ascent, and the development of thunderclouds (Shrestha *et al*., 2008). It is a quick and intense downpour that falls over a small geographical region in a short period of time. According to meteorologists, rain from a cloudburst is often of the shower variety, with a fall rate equal to or more than 100 mm (4.94 inches) per hour. Cloudbursts are thought to arise as a result of rapid lifting of clouds caused by the region's steep orography. Convective clouds can stretch up to 15 kilometers above the earth after being vertically raised. Cloudbursts often happen between 1000 and 2500 meters above sea level. The intense precipitation is caused by cumulonimbus clouds. The Langmuir precipitation process, in which huge raindrops agglomerate with small, slow-falling raindrops, occurs in cloudbursts when smaller water droplets combine with smaller ones (*Cloudbursts - What Is Cloudburst? [UPSC Notes]*, n.d.).The gravity-caused movement of rock, debris or earth down a slope, ranging from rock falls and topples and a variety of slumps and slides to flows of different materials (Gaurina*et al*., 2015). One of these mass movements is a landslide, which is defined as "the movement of a mass of rock, debris, or earth down a slope" (Cruden *et al*., 1991). A landslide's occurrence modifies the topography of the surface and leaves a recognizable mark (Pike *et al*., 1988).

Study Area: Kullu district is located at an elevation of 1,279 m (4,196 ft.) and is located between 31° 58’ 00” North latitude and 77° 06’ 04" East longitude. Kullu Valley is renowned as the "Valley of Gods" and is located on the banks of the Beas River. According to the Survey of India, the district has a total area of 5,503 km^2 and has remained unaltered from its inception in 1963 (District Disaster Management Authority Kullu, 2017). The economy of this region is primarily based on three industries: horticulture, tourism, and hydropower generating, all of which are highly reliant on the use of land resources (Fig. 1).

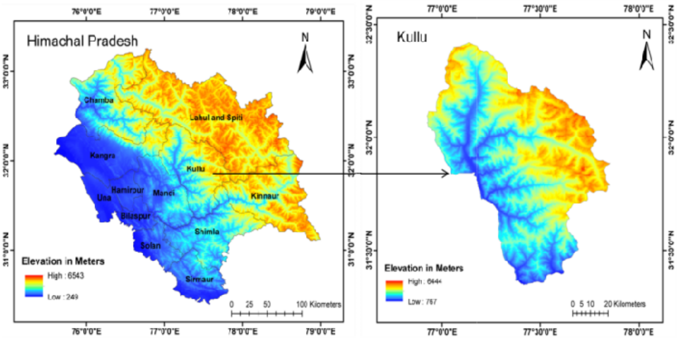


Figure 1. Study Area

METHODLOGY

Trend analysis: Using the non parametric Man Kendall test, Trend analysis was conducted in the current study. For the purpose of analysis of temporal trends of Hydro-climatic series this statistical technique is used.

The Mann Kendall statistics S is provided as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j+1}^{n} \operatorname{sgn}(\bar{x}_j - \bar{x}_i)$$

A time series x_i that is ranked from i=1, 2...n-1 and a time series x_j that is ranked from j=i+1, 2... are both subjected to a trend test.Each data point xi is used as a reference point and compared with the remaining data points x_j.

$$Sgn(x)_j - (x)_i = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ -1, < (x_j - x_i) \end{cases}$$

It has been established that the statistics S is roughly normally distributed with the mean when $n \geq 8$,

E(S)= 0

The variance statistics is given as

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} ti(i)(i-1)(2i-5)}{18}$$

Where t_i, is considered as the number of ties up to the sample i. The test statistics Z_c is compared as

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

Here, Zc exhibits a standard normal distribution.A Z value that is positive or negative denotes an upward or downward trend. For testing an upward or downward monotone trend (a two-tailed test), a significance level is also used. The trend is deemed significant if Zc is higher than Zα/2, where represents the significance level.

GIS Technique: GIS analysis was done by using Arc GIS 10.8. Slope profile of Kullu, Population density of Kullu, Land use land cover 2022 were rectified and Projected in World Geodetic system, UTM zone 1984.

RESULTS AND DICSUSSIOIN

This graph shows the yearly rainfall data of district Kullu for the past 30 years and “Rainfall data was derived using Indian Meteorological Department” site. It includes the comparison between normal rainfall and actual rainfall amount with yearly variations. In this graph we can see years with maximum rainfall and with minimum rainfalls. In 2010 there was maximum annual rainfall in district Kullu and then in 2019 which is second to year 2010 and the amount of annual rainfall in these years was 1337.69 mm in 2010 and 1279.31 mm in year 2019. The increase in rainfall in 2010 was 38.76 percent and in 2019 was 32.71 percent then the normal rainfall amount. And the minimum rainfall in the past 30 years was in 2004 which was 689.01 mm andin 1999 which was 729.73 mm and second to 2004 in amount of rainfall. The decrease in actual rainfall then the normal rainfall amount was 28.52%and 24.30 % in 2004 and 1999 respectively (Fig. 2).

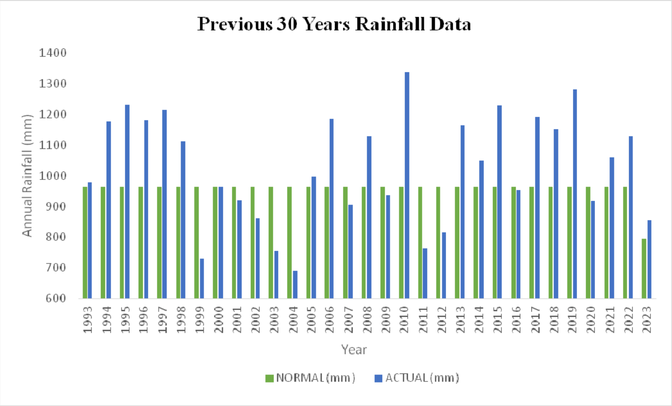


Figure 2. Previous 30 Years Normal Vs Actual Rainfall in Kullu

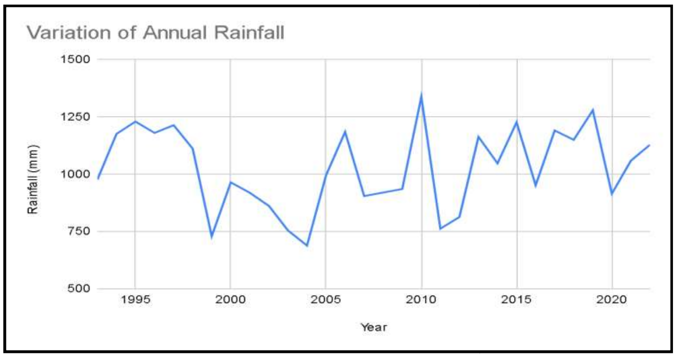


Figure 3. Variation of Annual rainfall for 30 years in Kullu District

This graph represents the variation in annual rainfall of district Kullu. The line showing the dissimilarities in the amount of annual rainfall for 30 years. In this the rainfall is very high in year 2010 having the highest peak and the rainfall is very less in 2004 which is clearly visible in the graph (Fig. 3).

Rainfall Trends in Kullu Valley: With high variation in annual rainfall of the past 30 years and high difference in normal and actual rainfall in Kullu almost every year, with increasing and decreasing amount of actual rainfall then the normal rainfall, the trends of rainfall in district Kullu is very irregular. But bystudying the rainfall amount for the past 30 years we can check the increase or decrease in the overall rainfall in the area.

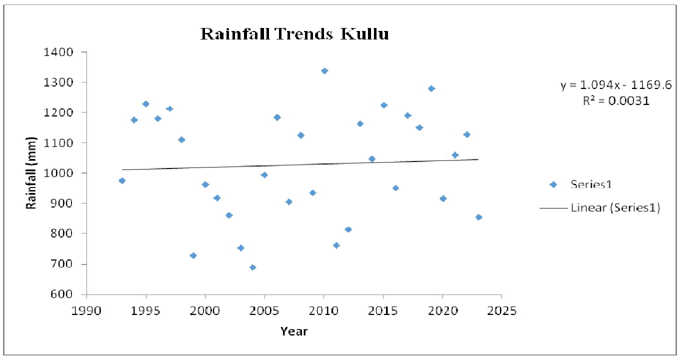


Figure 4. Yearly Rainfall Trends in District Kullu

This graph shows that the overall rainfall in the area has increased over the year. And there is 0.0031 percent increase in the overall rainfall over 30 years. Thus, with time we can say that the overall rainfall of the district is increasing with time (Fig. 4).

Previous 30 years Monsoonal Rainfall in Kullu Valley

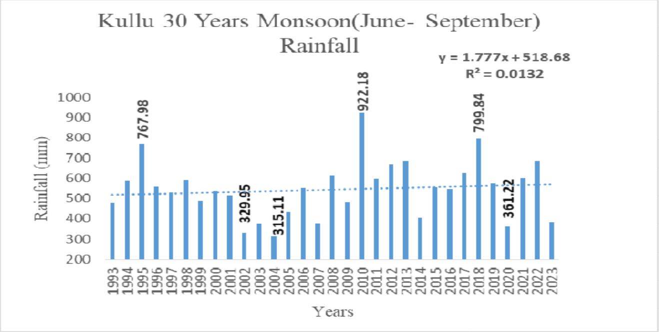
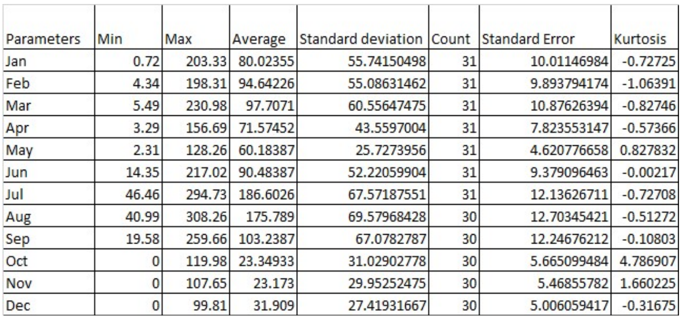


Figure 5. Monsoonal Rainfall Trend in District Kullu

This graph shows the monsoonal rainfall trends of the past 30 years from 1993 to July 2023. There is an increase in monsoon rainfall trend by 0.0132 percent which is represented by the dotted line in the graph. There is variation in the pattern of rainfall. The maximum rainfall in monsoons i.e. June to September was in 2010 which is 992.18 mm and in other two years i.e. 1995 and 2018 the amount of monsoonal rainfall was very high which is 767.98 mm and 799.84 mm respectively. The minimum amount of monsoonal rainfall was in 2004 which is 315.11 mm and in 2002 and 2020 the amount of monsoonal rainfall is very low which is 329.95 mm and 361.22 mm respectively (Fig. 5)

Descriptive statistics of Rainfall from 1993 to July 2023: From 1993 to July 2023 the least amount of rainfall was in the month of December and the rainfall ranges from 0 mm minimum to 99.81 mm maximum rainfall. In July and August, the rainfall was maximum where the maximum number of rainfall is 308.26 mm in August and the closest amount of rainfall to it is 294.73 mm in July in the span of the past 30 years from 1993 to July 2023. The minimum average rainfall in the monsoon season is in June which is 90.48387 mm and maximum is 186.6026 mm in July from 1993 to July 2023. Standard deviation is maximum in the month of August which is 69.57968428 mm and minimum in May and in monsoon season the minimum standard deviation is in June which is 52.22059904 mm. A higher standard deviation shows more variability in the rainfall data, implying that rainfall levels might deviate greatly from the average thus August has more variability in the amount of rainfall in the previous 30 years. A lower standard deviation, on the other hand, shows that the rainfall data points are closer to the mean and that the rainfall has less variation thus in monsoon June is the month with less variation in rainfall amount. In the context of rainfall, standard deviation is a statistical metric that measures the degree of variation or dispersion in the rainfall data. It allows one to see how far apart the numbers are from the average rainfall value. Kurtosis is maximum and positive in October which is 4.786907 and minimum and negative in February which is (-1.06391). In case of monsoon Kurtosis is maximum but negative in June which is (-0.00217) and minimum and negative in July which is (-0.72708). If the kurtosis is positive, this indicates that intense rainfall events are more likely, implying larger tails and consequently increased flood risks. If the kurtosis is negative, severe rainfall occurrences are less frequent, suggesting a more consistent and predictable rainfall pattern (Table1).

Table 1. Descriptive statistics of Rainfall from 1993 to July 2023



Parameters	Min	Max	Average	Standard deviation	Count	Standard Error	Kurtosis
Jan	0.72	203.33	80.02355	55.74150498	31	10.01146984	-0.72725
Feb	4.34	198.31	94.64226	55.08631462	31	9.893794174	-1.06391
Mar	5.49	230.98	97.7071	60.55647475	31	10.87626394	-0.82746
Apr	3.29	156.69	71.57452	43.5597004	31	7.823553147	-0.57366
May	2.31	128.26	60.18387	25.7273956	31	4.620776658	0.827832
Jun	14.35	217.02	90.48387	52.22059904	31	9.379096463	-0.00217
Jul	46.46	294.73	186.6026	67.57187551	31	12.13626711	-0.72708
Aug	40.99	308.26	175.789	69.57968428	30	12.70345421	-0.51272
Sep	19.58	259.66	103.2387	67.0782787	30	12.24676212	-0.10803
Oct	0	119.98	23.34933	31.02902778	30	5.665099484	4.786907
Nov	0	107.65	23.173	29.95252475	30	5.46855782	1.660225
Dec	0	99.81	31.909	27.41931667	30	5.006059417	-0.31675

Mann−Kendall Test: Fig. 6 consists of Z scores for each year from 1993 to 2022. This dataset's Z scores analysis reveals several patterns and trends. The Z scores generally oscillate around or slightly above the mean in the early years, from 1993 to 1999, indicating that the values for these years are close to the average. With a Z score of -1.153846154, 1999 stands out particularly, indicating a significant dip below the mean. The period from 2000 to 2005 continues this pattern of fluctuation around the mean and relatively small deviations from it. However, the Z scores for the years 2003 and 2004 are noticeably negative, indicating a more determined departure from the mean and possibly pointing to below-average performance or results in these years. The Z scores start to rise around 2006, signaling a change in trend where the values for these years are moving above the mean. With a few minor fluctuations, this upward trend continues through 2019, pointing to a period of largely favorable results or higher values during this timeframe. A particularly high Z score of 0.9972527473 in 2010 highlights a year of exceptional performance or an outlier in the dataset, indicating a data point that is significantly above the mean. On the other hand, 2011 shows a Z score of -0.8571428571, which denotes a significant deviance from the mean. Variable amounts of positive Z scores, or values above the mean but with some fluctuations, are visible from 2012 to 2022. The year 2020 stands out because it has a negative Z score, which denotes a year with a value below the mean and might signify a decline in performance or an anomaly in the dataset.

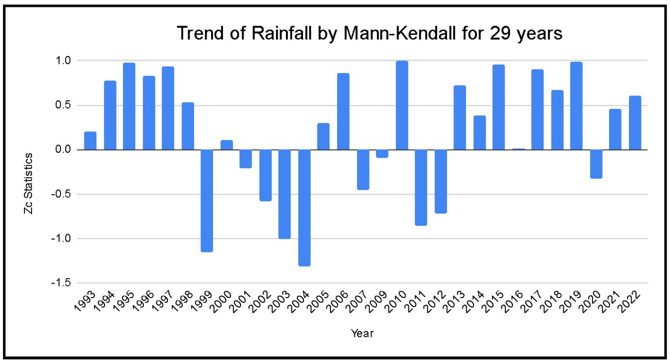


Figure 6. Trend of Rainfall by Mann-Kendall for Past 29 years

Year	Total rainfall	Kendall's Tau	Variance of Tau	Z Score	Rainfall Trend
1993	976.7	0.206043956	2842	0.206043956	Positive trend
1994	1176.22	0.7774725275	2842	0.7774725275	Positive trend
1995	1229.95	0.9752747253	2842	0.9752747253	Positive trend
1996	1180.41	0.8241758242	2842	0.8241758242	Positive trend
1997	1214.14	0.9313186813	2842	0.9313186813	Positive trend
1998	1111.91	0.5357142857	2842	0.5357142857	Positive trend
1999	729.73	-1.153846154	2842	-1.153846154	Negative trend
2000	964.78	0.1098901099	2842	0.1098901099	Positive trend
2001	919.21	-0.2115384615	2842	-0.2115384615	Negative trend
2002	861.95	-0.5824175824	2842	-0.5824175824	Negative trend
2003	755.12	-1.002747253	2842	-1.002747253	Negative trend
2004	689.01	-1.31043956	2842	-1.31043956	Negative trend
2005	995.51	0.2967032967	2842	0.2967032967	Positive trend
2006	1185.04	0.8653846154	2842	0.8653846154	Positive trend
2007	905.07	-0.4532967033	2842	-0.4532967033	Negative trend
2009	935.84	-0.0989010989	2842	-0.0989010989	Negative trend
2010	1337.69	0.9972527473	2842	0.9972527473	Positive trend
2011	762.7	-0.8571428571	2842	-0.8571428571	Negative trend
2012	813.92	-0.717032967	2842	-0.717032967	Negative trend
2013	1163.26	0.7252747253	2842	0.7252747253	Positive trend
2014	1047.65	0.3818681319	2842	0.3818681319	Positive trend
2015	1226.77	0.956043956	2842	0.956043956	Positive trend
2016	952.08	0.008241758242	2842	0.008241758242	Positive trend
2017	1190.91	0.9010989011	2842	0.9010989011	Positive trend
2018	1150.44	0.6675824176	2842	0.6675824176	Positive trend
2019	1279.31	0.989010989	2842	0.989010989	Positive trend
2020	915.37	-0.3296703297	2842	-0.3296703297	Negative trend
2021	1059.3	0.4615384615	2842	0.4615384615	Positive trend
2022	1128.71	0.6043956044	2842	0.6043956044	Positive trend

Slope Profile of Kullu: A land surface's rise or fall is referred to as its slope. Slope is directly related to surface stability. The Slope profile of study area was produced by Arc GIS 10.8's spatial analyst tool.

1. **0.12-11.37% (10.58% of the area):** This range represents relatively gentle slopes. While these areas may still experience some degree of runoff during heavy rainfall, they are less prone to rapid water flow and are likely to have better drainage capabilities. Consequently, the vulnerability to flash floods or cloudbursts is relatively lower in this category.
2. **11.37-18.87% (18.83% of the area):** This range comprises moderately sloping areas. While not as flat as the previous category, the moderate slope suggests that these regions can handle a certain amount of runoff. However, during intense rainfall events, there is a moderate risk of flash floods, especially if other factors, such as soil type or land cover, exacerbate the situation.
3. **18.87-25.30% (25.74% of the area):** This range includes moderately steep slopes. Areas with such slopes are more susceptible to soil erosion and runoff, indicating a higher vulnerability to flash floods, particularly if accompanied by heavy rainfall or cloudbursts. Proper land management practices and drainage infrastructure are crucial in this category.
4. **25.30-31.46% (23.66% of the area):** These regions have steeper slopes, and this elevation increases the vulnerability to flash floods and cloudbursts. Rapid runoff during heavy rainfall events can occur, potentially leading to localized flooding, especially in valleys or areas with poor drainage.
5. **31.46-38.69% (16.30% of the area):** Steeper slopes in this range contribute to faster runoff and greater susceptibility to flash floods, especially during cloudburst events. These areas may be prone to soil erosion and may have a higher risk of landslides, adding to the flash flood potential.
6. **38.69-68.42% (4.90% of the area):** This range represents the steepest terrains in Kullu. These areas are highly vulnerable to rapid runoff during cloudbursts, which can result in flash floods. The steepness of the slopes enhances the risk of landslides, further exacerbating the vulnerability to flash floods and the impacts of cloudbursts.

It's evident that areas with steeper slopes (25.30% and above) constitute a significant portion of Kullu's area. These regions are more vulnerable to flash floods and cloudbursts due to their ability to generate rapid runoff during heavy rainfall.

Proper land management, including measures to control erosion, construction of proper drainage systems, and careful land use planning, is critical in these areas to reduce the risk and potential damage caused by flash floods and cloudbursts (Fig. 7).

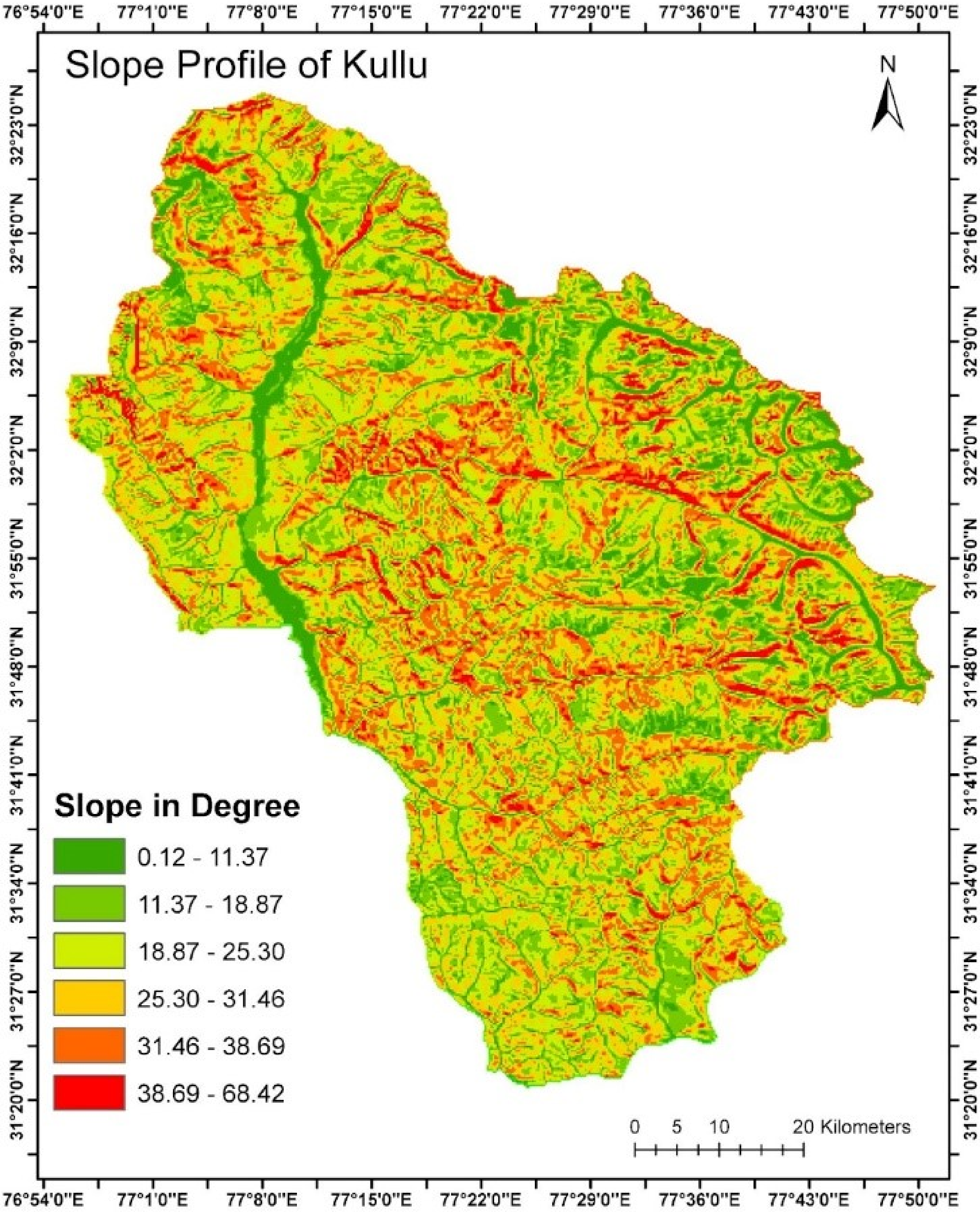


Figure 7. Showing Slope of district Kullu in degrees

Land Use land Cover of Kullu: Understanding land use and land cover is crucial for understanding the biogeochemical cycle, biodiversity, and habitat loss for wildlife (Mishra *et al*., 2020). Sentinel-2, Land use/land cover map produced by ESRI, Microsoft and impact observatory was used to create the LULC map of Kullu. Rangeland is the biggest land cover type in the Kullu region, accounting for around 39.69% of the total area. Tree cover is the second most prominent type after rangeland, accounting for around 30.93% of the area. Snow/ice covers around 18.53% of the territory, indicating that it is a particularly cold or high-altitude location with perhaps colder temperatures and glaciated parts. Built-up places are places with considerable human development, such as residential, commercial, and industrial sectors, and account for around 2.57% of total area. With around 7.64% coverage, bare ground refers to places with exposed soil or limited plant cover. Bare ground may be caused by processes such as erosion, land degradation, or natural characteristics such as deserts or desolate landscapes. Crops, which occupy around 0.41% of the territory, reflect the existence of agricultural activity, where land is used to cultivate various crops. Despite its tiny size, this sector is critical for food production and the local economy. Lakes, rivers, ponds, and other aquatic ecosystems account for just 0.22% of total land area. Understanding how these LULC classes are distributed is critical for regional planning, natural resource management, conservation initiatives, and environmental impact assessments (Fig. 8).

Rainfall Induced Major Disasters in Kullu (1993- July 2023): The graph showing the major disasters in district Kullu from 1993 to July 2023. It includes four types of disasters which are mostly rainfall induced in nature. Cloudburst, flash floods, landsides and drought are the disasters included in this graph. In this graph we can see that from past four to five year there is drastic increase in the number of rainfall induced disasters in district Kullu. 2022 is the year having the greatest number of the disasters having maximum numbers of cloudbursts and the maximum flash flood was in years 2021 and 2022. The drought like condition was only appeared once that is in 2009(Fig. 9).

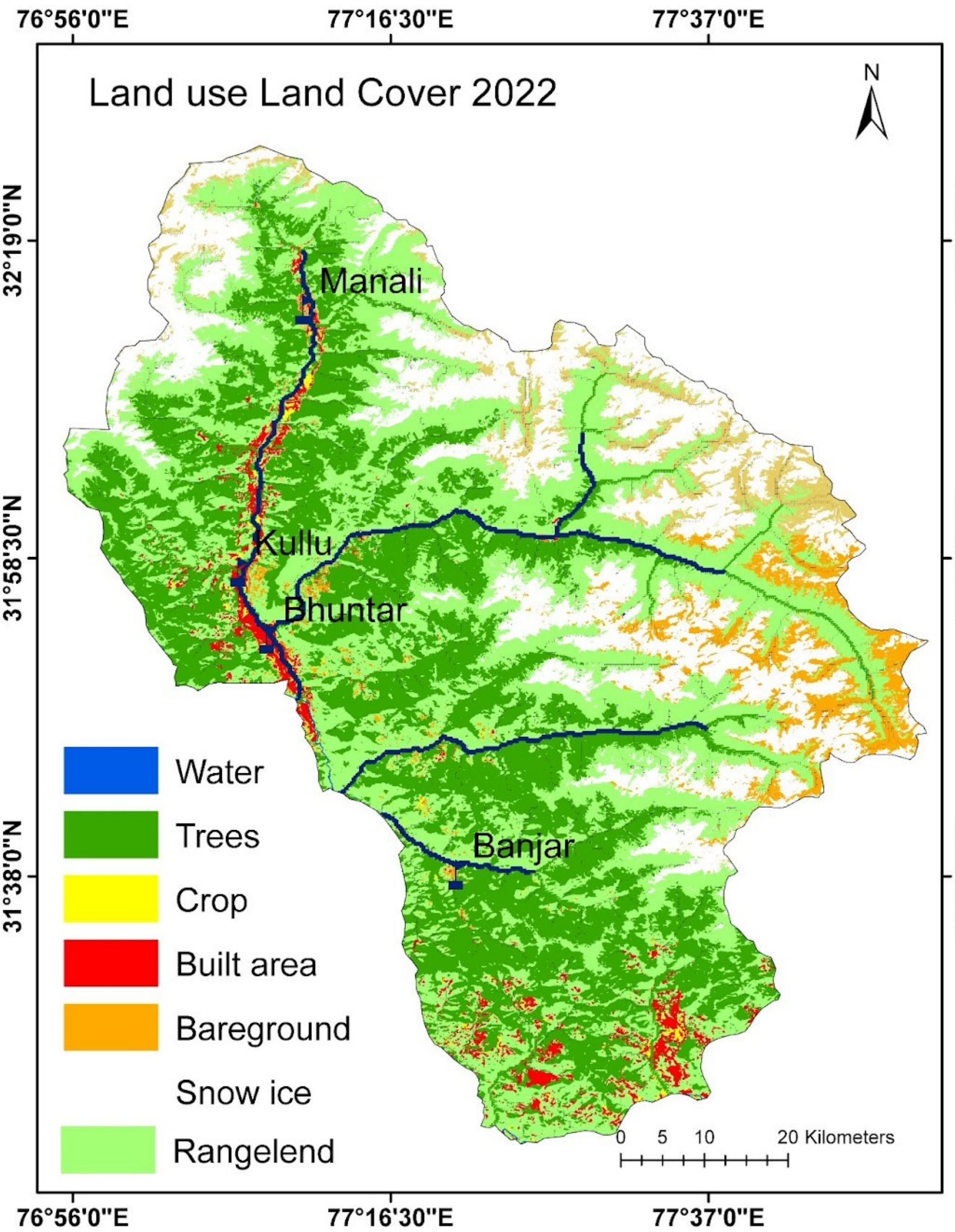


Figure 8. Land Use land Cover of Kullu

Population density and Disaster vulnerability: GPWv411: UN-Adjusted Population Density (Gridded Population of the World Version 4.11) was used to create the Population density map of Kullu. The population density of Kullu district varies across its different regions. The town areas tend to have higher population density due to economic activities and urbanization, while the rural areas are relatively less densely populated. The population density in major towns of Kullu District reveals varying levels of vulnerability to disasters. Manali, with a population density of 67.9-90 persons per square kilometer, is located near the Beas River. Its moderate population density suggests a moderate vulnerability to disasters like floods and landslides due to its proximity to the river. Kullu town, with a population density of 90-109.2 persons per square kilometer, is also situated near the Beas River. Its slightly higher population density indicates a relatively higher vulnerability to similar disasters due to its proximity to the river. Bhunter, with a population density of 90-109.2 persons per square kilometer, is positioned near the confluence of the Beas and Parvati rivers. This location increases its susceptibility to disasters such as floods, particularly where these two rivers meet. Banjar, having a population density of 29.5-57.9 persons per square kilometer, is situated near the Tirthan Valley. While its population density is lower than the other towns, its location near the valley still poses a risk of disasters, primarily related to its topography and local geography. In summary, towns like Manali, Kullu, Bhunter, and Banjar face different levels of vulnerability to disasters due to their proximity to rivers and valleys. Proper disaster preparedness, land use planning, and mitigation measures are crucial for minimizing the impact of potential hazards on these towns and their residents (Fig. 10) (Table 3). Geodatabase of the study area has been prepared. The image (Fig. 11) shows the map of hazard inventory of district Kullu for rainfall induced disasters that are cloudbursts, flashfloods, landslides, and drought. This inventory was made using Google My Maps. It includes the details about nearby area where disaster happened, date on which the disaster happened and the description of damage done by the disaster.

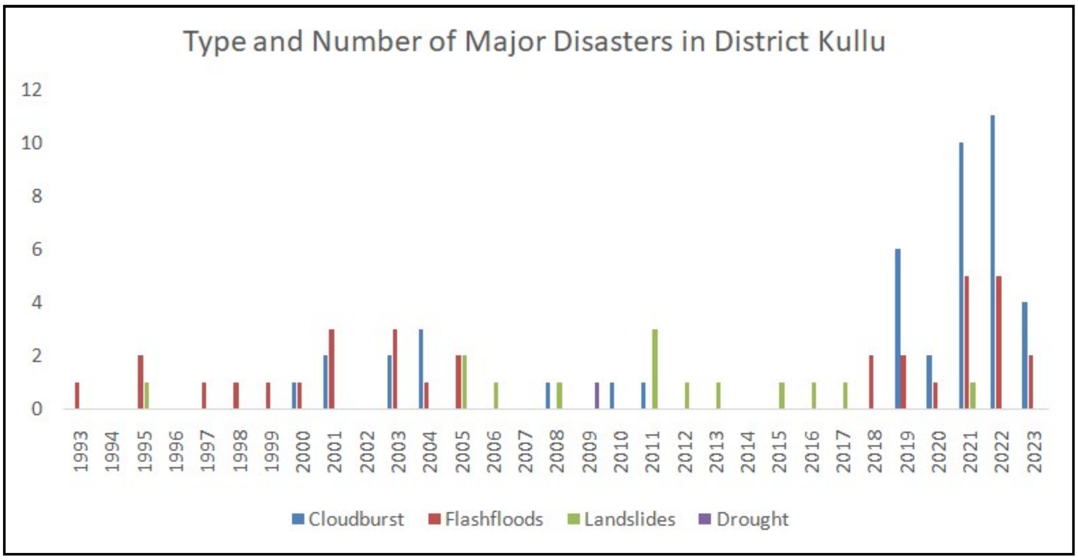


Figure 9. Type and number of rainfall induced major disasters in Kullu (1993- July 2023)

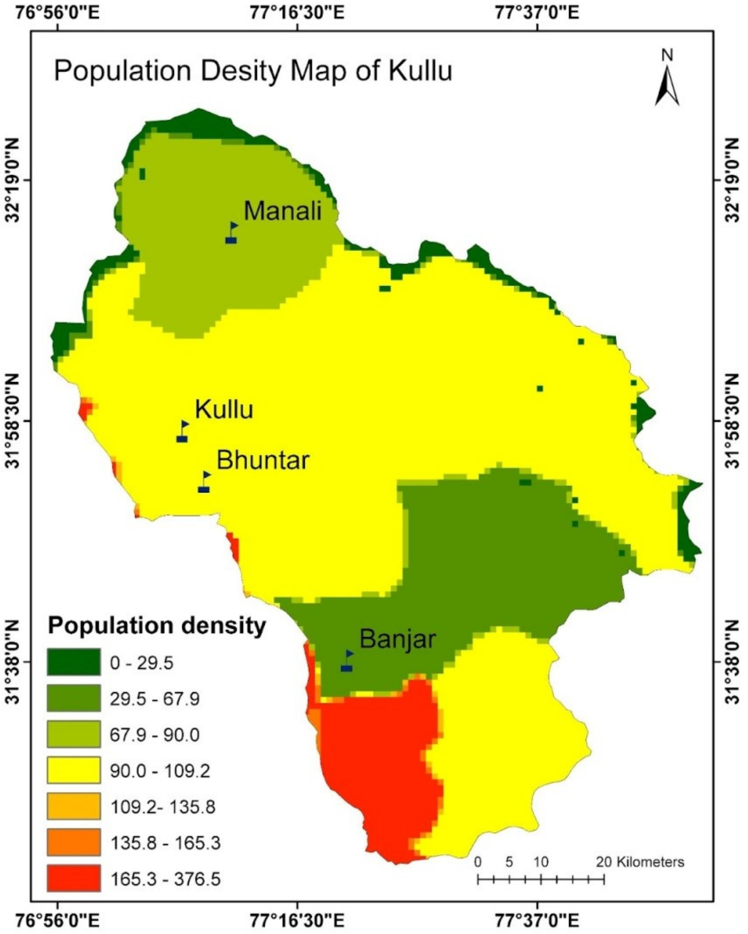


Figure 10. Population density map of Kullu

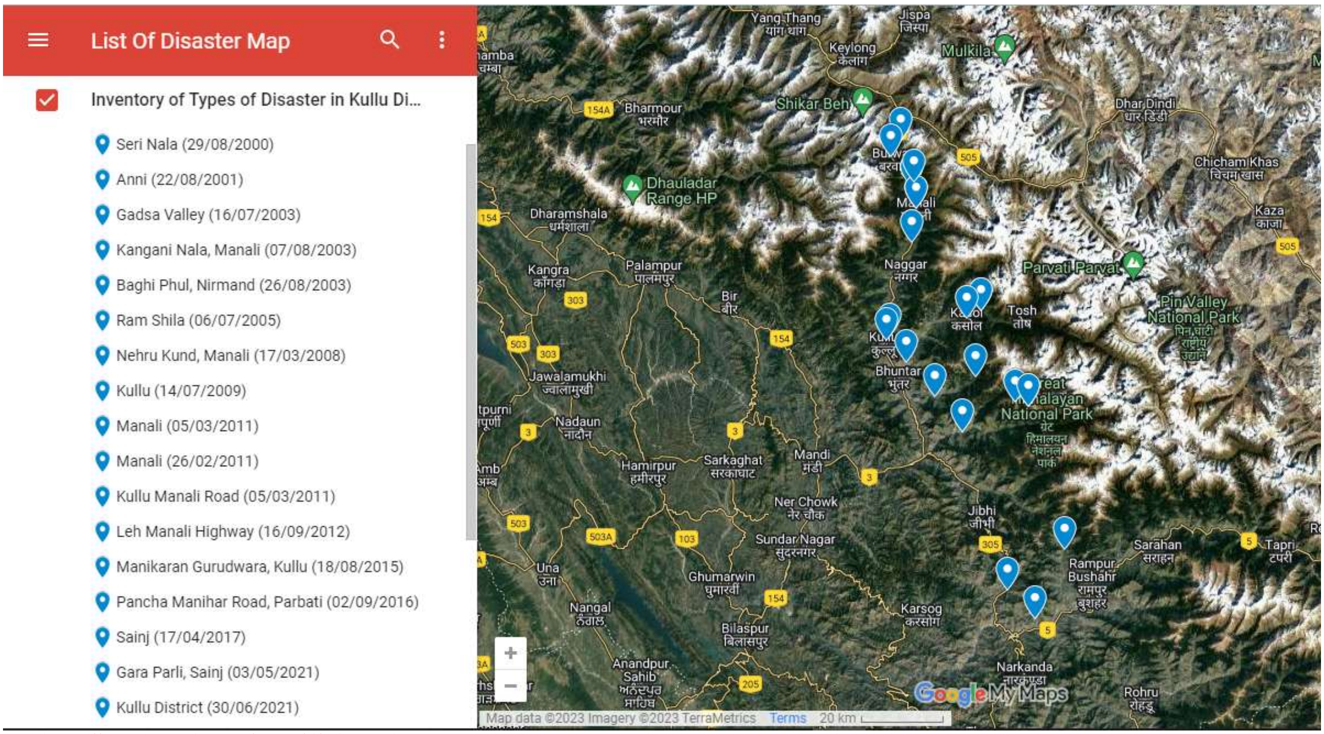
Mitigation Strategies

- ***Mapping of the flood prone areas***: It is a crucial step in lowering the danger in the area. Historical records may be used to determine the locations that experienced flooding, as well as its frequency and breadth. To provide a full picture of the floodplain, the basic map is merged with various maps and data. In the event of a possible hazard, a warning can be given based on the previously established water level heights. The submergence zones in coastal locations are determined by tidal levels and terrain features. Water flow during floods will be accurately shown through flood hazard mapping.
- ***Land use control:*** When the flood plains and coastal areas are inundated by water, it will lessen the risk to people's lives and property. The population in the danger region has an impact on the number of casualties. Reduced densities are preferable in regions where new neighborhoods will be built. In order to lessen vulnerability, action should be done to shift people to better locations in places where settlements have already been established.
- ***Construction of engineered structures:*** Fortifying buildings to withstand flood surges and seepage in flood zones. Elevated locations should be used to create the structure.

Table 3. Population Density of Major Towns of District Kullu

Major Towns	Population density (Persons per km)
Manali	67.9-90
Kullu	90-109.2
Bhunter	90-109.2
Banjar	29.5-57.9

Geodatabase of Hazard Inventory



List Of Disaster Map

☑ Inventory of Types of Disaster in Kullu Di...

- Seri Nala (29/08/2000)
- Anni (22/08/2001)
- Gadsa Valley (16/07/2003)
- Kangani Nala, Manali (07/08/2003)
- Baghi Phul, Nirmand (26/08/2003)
- Ram Shila (06/07/2005)
- Nehru Kund, Manali (17/03/2008)
- Kullu (14/07/2009)
- Manali (05/03/2011)
- Manali (26/02/2011)
- Kullu Manali Road (05/03/2011)
- Leh Manali Highway (16/09/2012)
- Manikaran Gurudwara, Kullu (18/08/2015)
- Pancha Manihar Road, Parbati (02/09/2016)
- Sainj (17/04/2017)
- Gara Parli, Sainj (03/05/2021)
- Kullu District (30/06/2021)

(Source: https://www.google.com/maps/d/edit?mid=1eF1SHoxjJp5n8yLYSRTojlr0HvTWYFQ&usp=sharing)

Figure 11. Geo-database of hazard affected area in district Kullu from 1993 to July 2023

Flood damage reduction is the goal of flood control. This can be accomplished through flood mitigation, which involves reducing runoff through measures like reforestation (in some areas, increasing absorption may be a mitigation strategy), protecting vegetation, clearing debris from streams and other water holding areas, conserving ponds and lakes, etc. Levees, embankments, dams, and channel improvement are all part of flood diversion. Dams have the capacity to hold water and release it gradually. Floods in the lower areas can be caused by dam failure during earthquakes and water release operations. Reduced chance of harm results from flood proofing. Sandbags can be used to block off windows and doors, and dwellings' doors and windows can be sealed. By erecting structures on elevated terrain, homes may be lifted. Construction should be kept away from water features.

- ***Flood management:*** With the introduction of the National Programme of Flood Management in 1954, systematic planning for flood management in India got under way. According to the nature of the issue and regional circumstances, various flood protection strategies, both structural and nonstructural, have been used throughout the past 48 years in various states. Non-structural methods include flood forecasting, flood plain zoning, flood proofing, disaster planning, etc. Structural measures include storage reservoirs, flood embankments, drainage channels, anti-erosion works, channel enhancement works, detention basins, etc. The country's 15.81 million hectares of land have been reasonably protected by the flood management measures implemented thus far (Michael, 2000).
- ***Community based mitigation:*** The building of a dike and a flood wall can be included in the community-based mitigation program, as well as the removal of sediment and reforestation efforts. The neighborhood may help resist floods by setting up work groups to fix embankments, stack sandbags, and gather supplies. Farming methods must be flood-tolerant. Housing must be built to withstand flooding, and the community should build multifunctional shelters. The ability to raise the earth's banks allows for the community's and the livestock's protection during floods.
- Promoting public awareness and education about disaster preparedness and response.
- Focusing on sustainable tourism practices to minimize negative environmental response.
- Creating disaster response plan and conducting regular drill.
- Assessment and Improvement
- Developing Early warning system for Landslides and Flash Floods.
- Planning an evacuation.
- Constant Review and Improvement

CONCLUSION

The comprehensive analysis of 30 years of rainfall data for Kullu district has unveiled a landscape characterized by intricate precipitation dynamics and vulnerabilities. The graph detailing annual rainfall, juxtaposing actual and normal levels, underscores the district's susceptibility to extreme climatic events. The disparities across years, exemplified by the remarkable peaks of 2010 and 2019 and the troughs of 2004 and 1999, illuminate the unpredictable nature of rainfall patterns. Examining these trends over time reveals a landscape of high variability, both in annual and normal rainfall. Despite this variability, a marginal increase of 0.0031 percent in overall rainfall indicates a gradual upward trajectory. The depiction of monsoonal rainfall trends from 1993 to July 2023, with a 0.0132 percent increase, captures the region's susceptibility to seasonal fluctuations. This variability is further reflected in the Descriptive statistics, uncovering months of least and maximum rainfall, and through measures like standard deviation and kurtosis that illuminate the likelihood of intense and predictable rainfall events.The intriguing Z score patterns from 1993 to 2022 suggest years of exceptional performance and deviations from the mean. This insight can aid in understanding the district's resilience to rainfall anomalies. Notably, the study recognizes the pivotal role of topography in shaping flood vulnerabilities. While gentle slopes demonstrate better drainage, the steeper terrains are prone to flash floods and cloudbursts. The imperative of effective land management, erosion control, and drainage systems is underscored in this context, offering practical avenues for mitigating flood risks.The study further highlights the precarious positioning of most towns in Kullu District, perched near rivers that expose them to the full spectrum of natural hazards, including floods and landslides. The Land Use Land Cover (LULC) analysis illustrates the prevalence of rangeland and tree cover, with minimal built-up areas. This accentuates the necessity for judicious land use planning, robust drainage infrastructure, and disaster preparedness strategies to counteract potential damages and protect the vulnerable communities dwelling in these regions.In essence, the comprehensive analysis of Kullu district's rainfall patterns, vulnerabilities, and topography presents a holistic picture of a region in constant interaction with its natural environment. By unraveling the intricate interplay of these factors, this study equips stakeholders, policymakers, and local communities with vital insights to bolster their preparedness, responsiveness, and resilience in the face of climatic uncertainties. As our understanding deepens, the imperative of fostering sustainable land practices, proactive disaster management, and informed decision-making emerges as the cornerstone of safeguarding the district's inhabitants and ensuring their prosperity amidst a changing climate.

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