SUPPLEMENTARY MATERIALS 1

Methodology employed for calculating outbreaks and time series representation of malaria cases in districts with more than 2 outbreaks

Malaria Outbreak: Definition and Calculations

Malaria outbreak refers to a sudden and localized increase in the number of malaria cases within a specific geographic area or population over a relatively short period. Literature suggests several methods are available for calculating a malaria outbreak, for example Hook et al suggested, 95% CI method of a collective distribution [1]; the World Health Organization has suggested three methods for estimating the outbreak threshold: the Cullen method (which uses the monthly mean and two standard deviations of past 5 years of reported cases), the quartile method (which uses the 75th percentile of past 5 years observed cases), and the C-Sum method (which uses the mean of the cumulative cases of previous, current and following months malaria incidence data of the past 5 years) [2]. Besides these methods, a number of other methods have also been proposed for defining the outbreak threshold with varying degrees of success, and there so no clear consensus on the most suitable method [3–6]. Of the three methods to define outbreak threshold suggested by the WHO, the quartile method is the most simplistic and the C-Sum method is the most sensitive to outbreaks. However, past experiences have shown that these methods are more prone to false alarms [7]. In contrast, the mean+2sd method has been shown to be less sensitive to minor peaks, thereby preventing overreaction in areas of stable transmission with minor seasonal fluctuations. As most parts of India experience highly seasonal malaria transmission, in this study we have used different variations of the mean+2sd method for identifying historical outbreaks from time-series malaria data of the past decade. However, it is important to note that one disadvantage of this method is that it may miss malaria epidemics in regions of very low malaria transmission. Furthermore, these methods have been tested with weekly or monthly cases of malaria, and their applicability on annual case incidence data is not known. The rapid declining trend in malaria cases in India over the past decade suggests that a short-term moving average may be more appropriate for estimating the outbreak threshold as compared to the past 5 years data that the WHO recommends. Therefore, we have used a 3-year moving average in this study for estimating the outbreak threshold. The number of standard deviations that are added to this moving average determine the sensitivity of the outbreak detection method. We qualitatively tested the addition of standard deviations ranging from 2 to 5 at 0.5 step intervals on the overall sensitivity of the outbreak detection method and found that the use of 2.5 standard deviations resulted in the least number of false positives and false negatives. Therefore, in this study a 3-year moving average with 2.5 standard deviations was used as the threshold for detecting outbreaks from historical time-series malaria data. The

detailed calculation of malaria outbreak for Balaghat district of Chhattisgarh state in India has been shown as an example in Supplementary Table 1.

Supplementary Table 1: Calculation of malaria outbreak for a district

District	Year	Cases	3 Year Moving Avg.	3 Years Moving SD	**D+2.5*E**	Outbreak If **C>F**
A	**B**	**C**	**D**	**E**	**F**	**G**
Balaghat	2008	2966	-	-	-	-
Balaghat	2009	2707	-	-	-	-
Balaghat	2010	1620	-	-	-	-
Balaghat	2011	1979	2431.0*	714.2**	4216.5	0
Balaghat	2012	2300	2102.0#	553.8##	3486.6	0
Balaghat	2013	2594	1966.3$	340.2$$	2816.8	0
Balaghat	2014	7601	2291.0	307.6	3060.0	1 (Outbreak)
Balaghat	2015	5004	4165.0	2979.3	11613.2	0
Balaghat	2016	3111	5066.3	2504.1	11326.5	0
Balaghat	2017	1407	5238.7	2254.2	10874.1	0
Balaghat	2018	324	3174.0	1799.3	7672.3	0
Balaghat	2019	156	1614.0	1405.0	5126.5	0
Balaghat	2020	2794	629.0	679.0	2326.5	1 (Outbreak)

* Average of first three observations (2966, 2707, 1620)

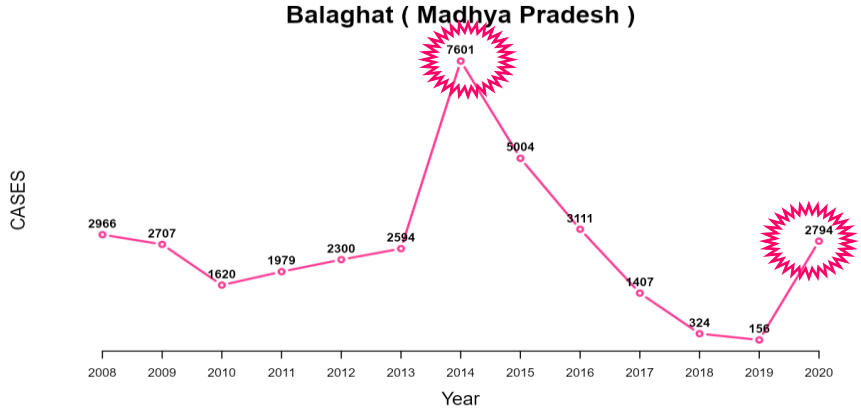
Average of next three observations excluding first one (2707, 1620, 1979)

$ Average of next three observations excluding first one and two (1620,1979,2300)

** Standard deviation of first three observations (2966, 2707, 1620)

Standard deviation of next three observations excluding first one (2707, 1620, 1979)

$$ Standard deviation of next three observations excluding first one and two (1620,1979,2300)



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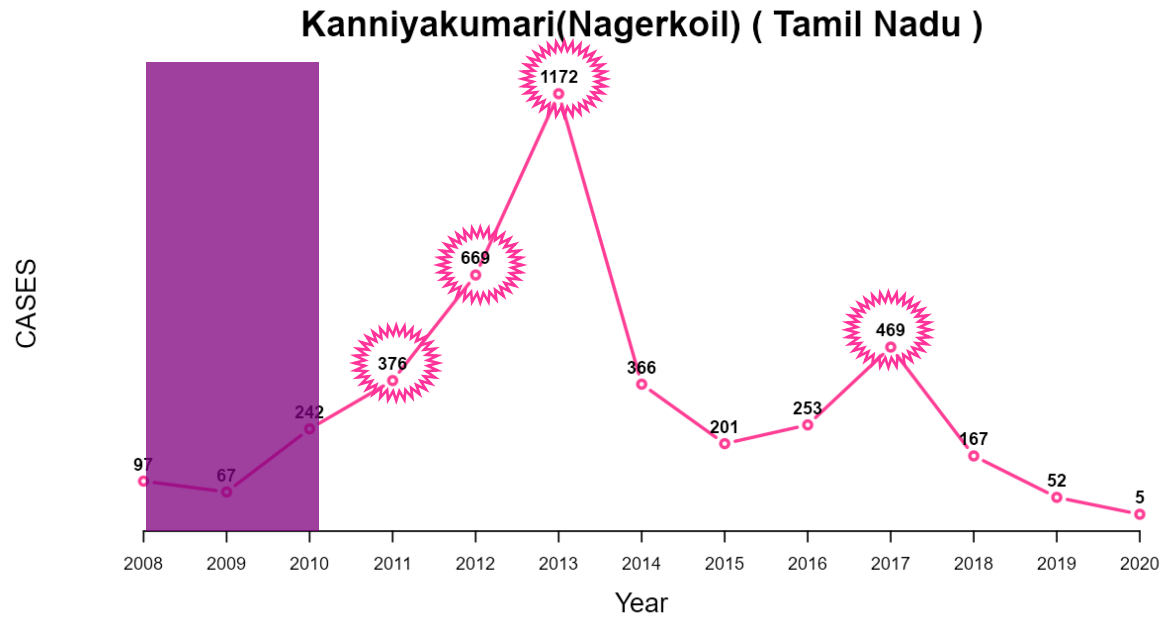
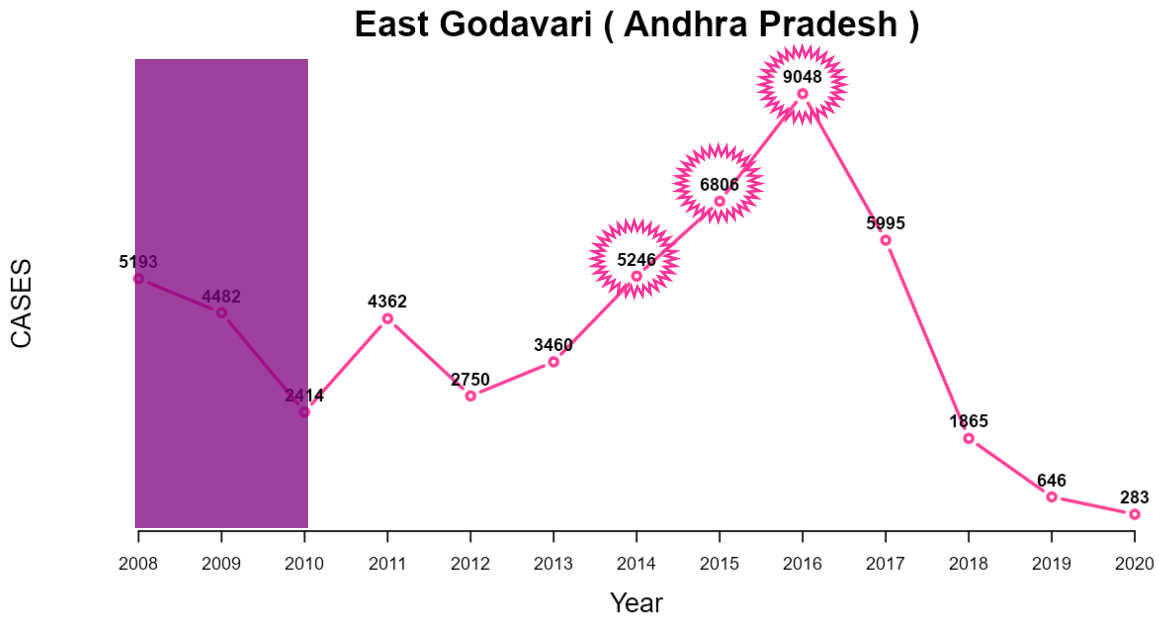
Time series representation of malaria cases over the span of ten years in districts that experienced two or more Outbreaks

Districts (State)

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4482
2414
4362
2750
3460
5246
6806
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1865
646
283
2008
2009
2010
2011
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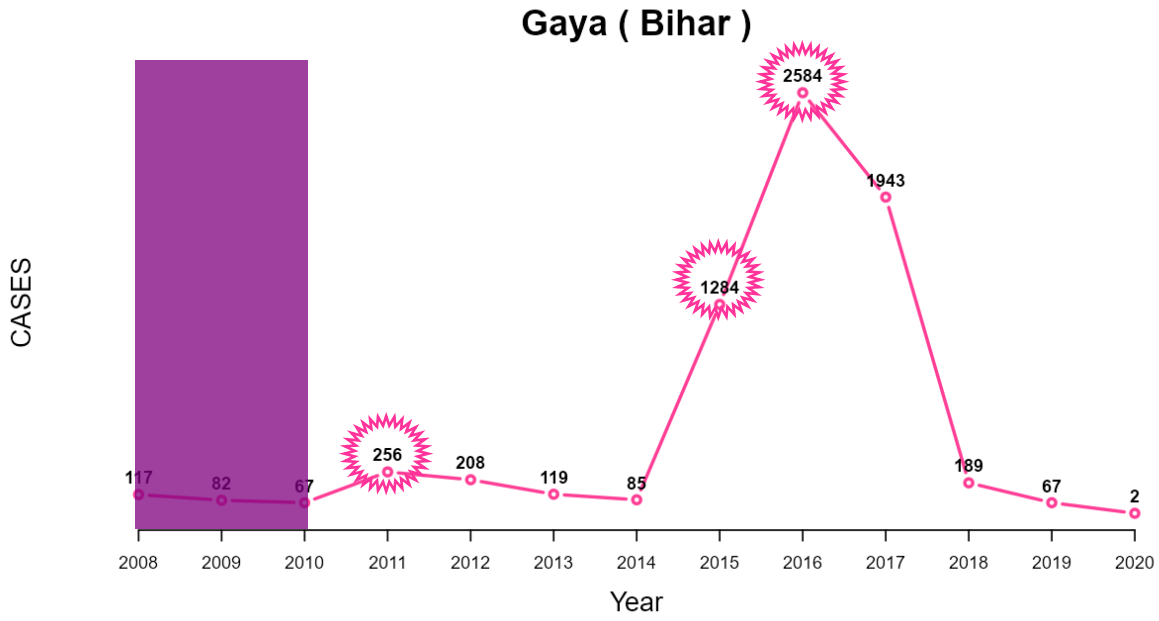
2018
2019
2020


Gaya (Bihar)
CASES
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256
208
119
85
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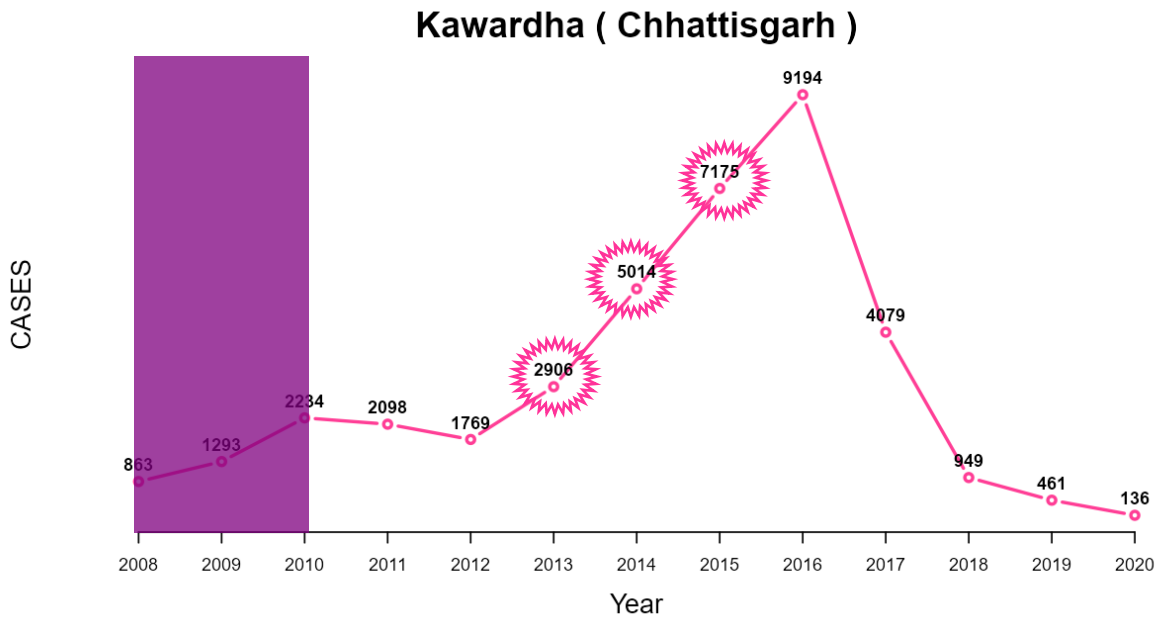
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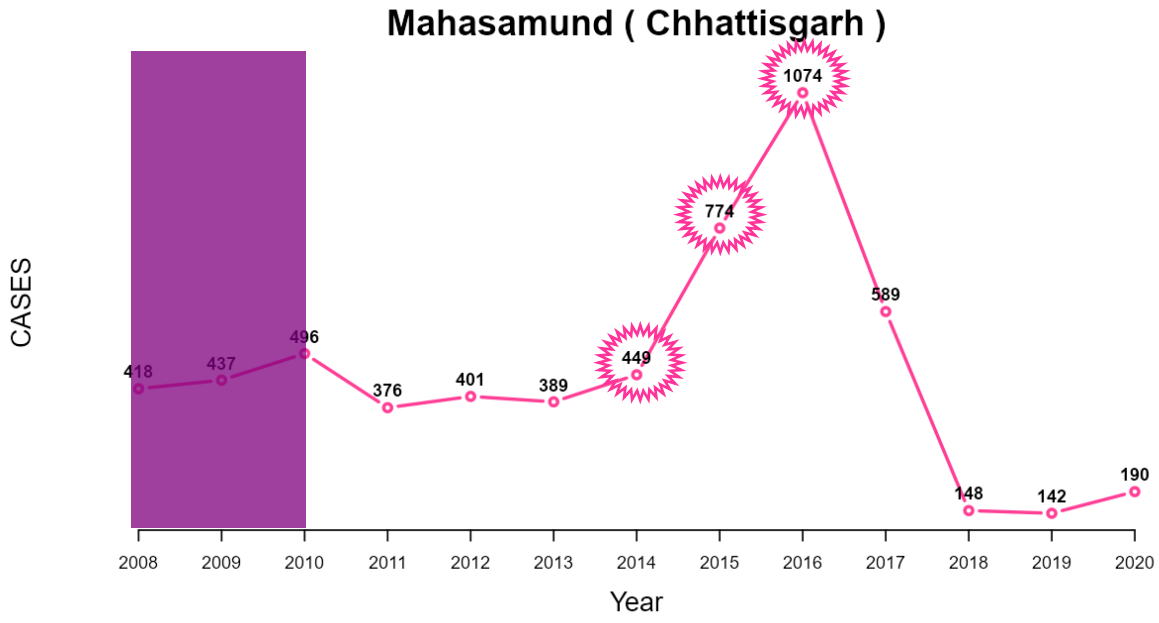
Mahasamund (Chhattisgarh)
CASES
Year
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437
496
376
401
389
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774
1074
589
148
142
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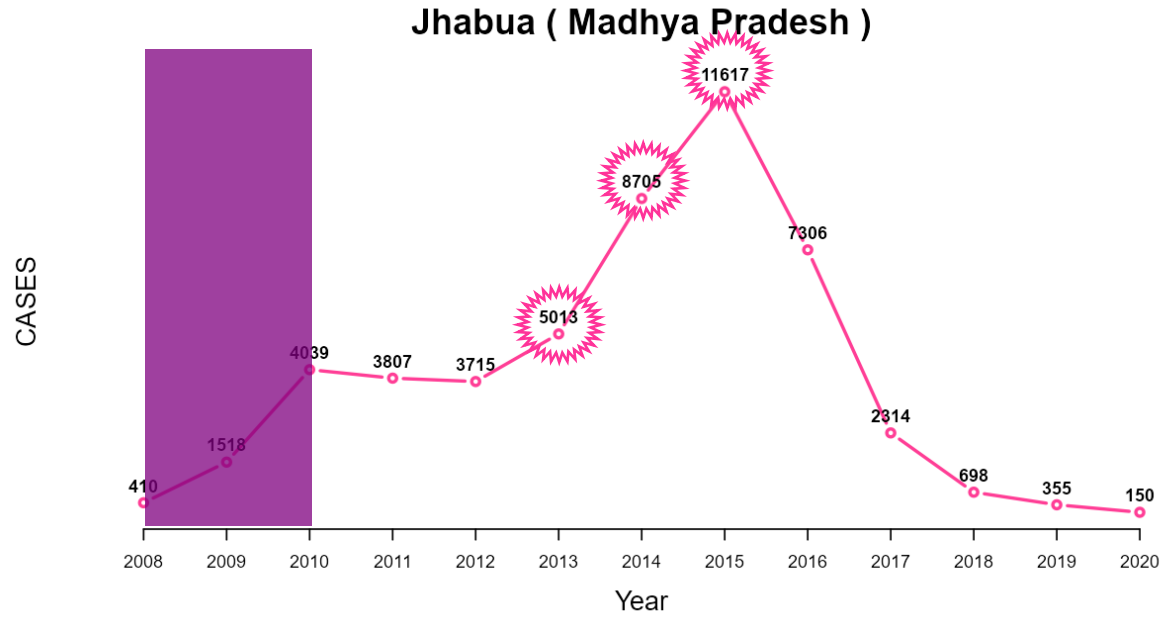
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4039
3807
3715
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355
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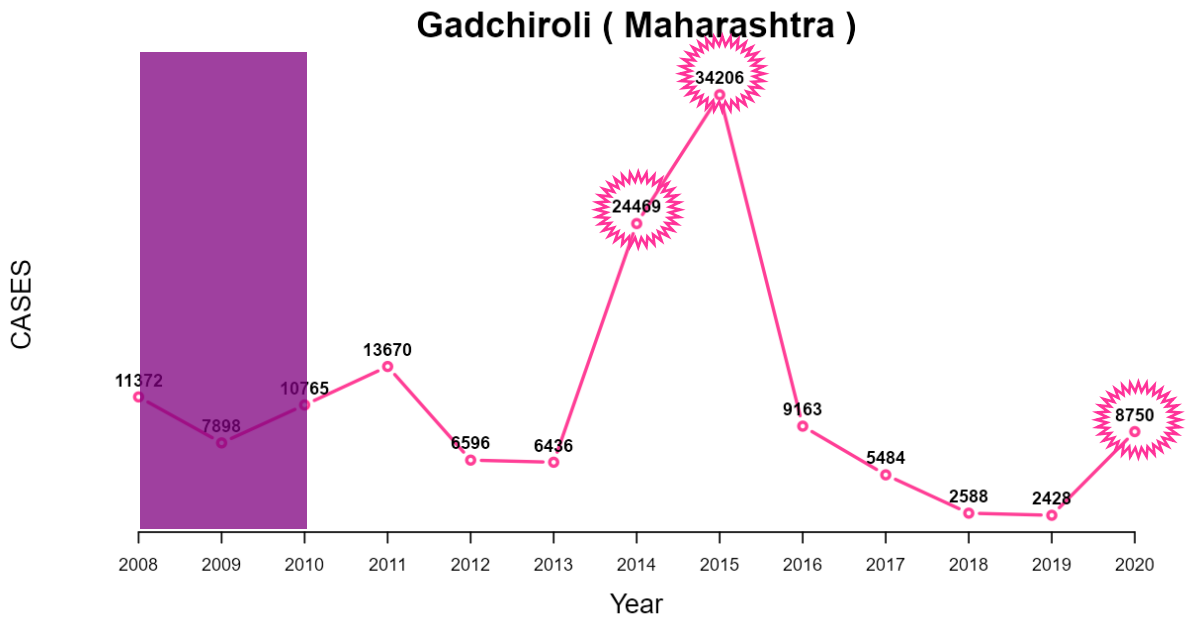
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CASES
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7898
10765
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6596
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2428
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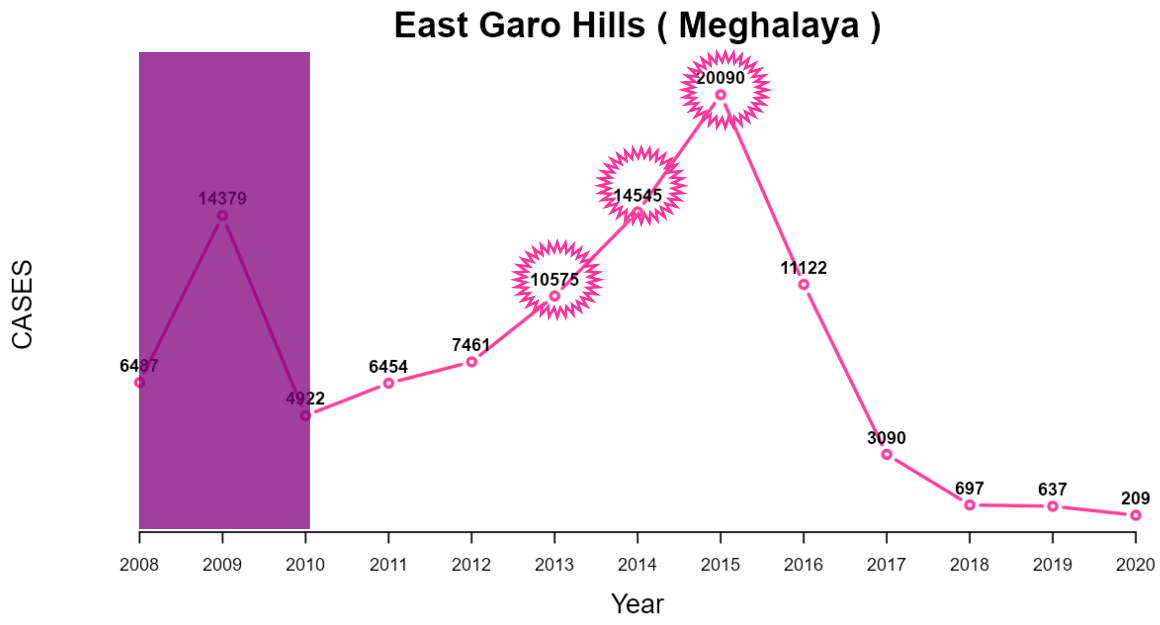
East Garo Hills (Meghalaya)
CASES
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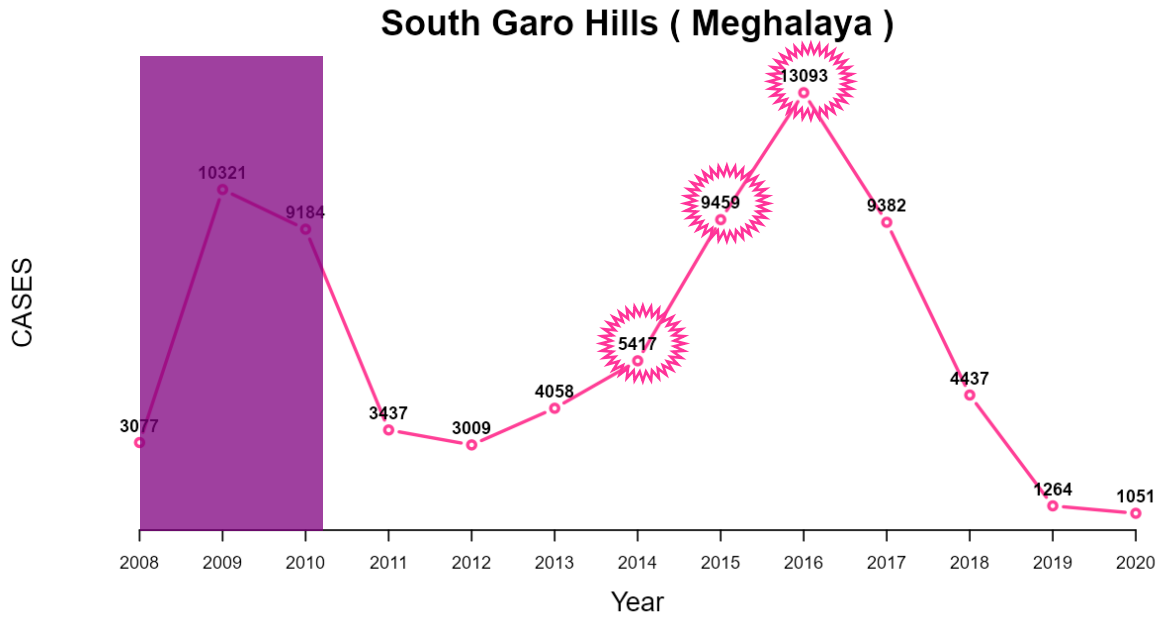
South Garo Hills (Meghalaya)
CASES
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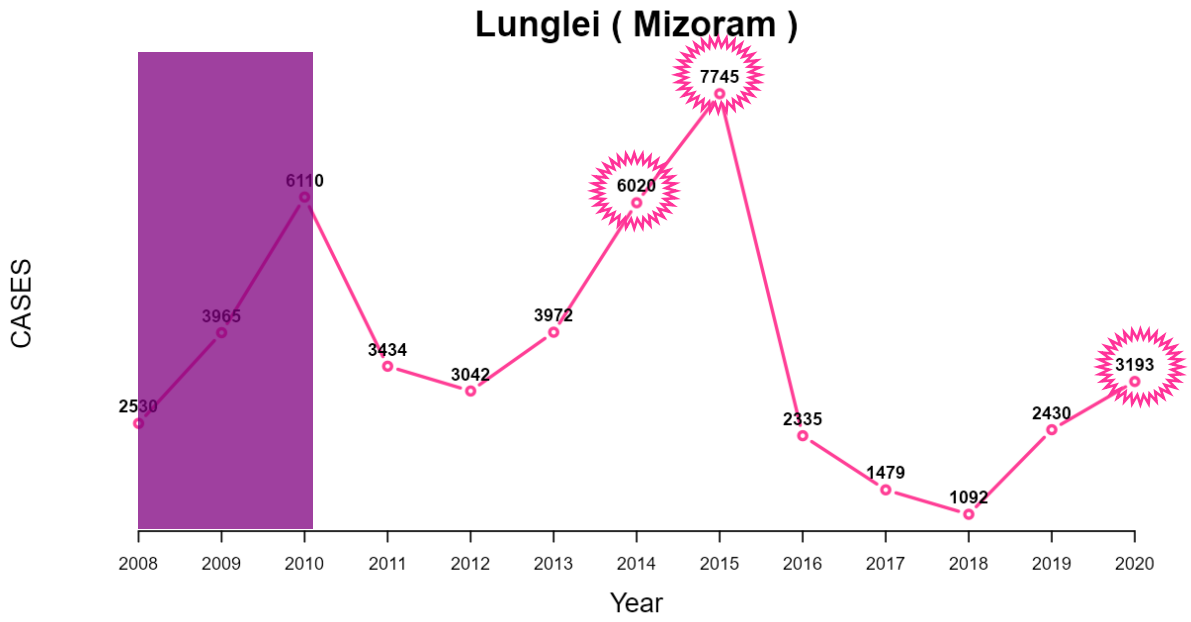
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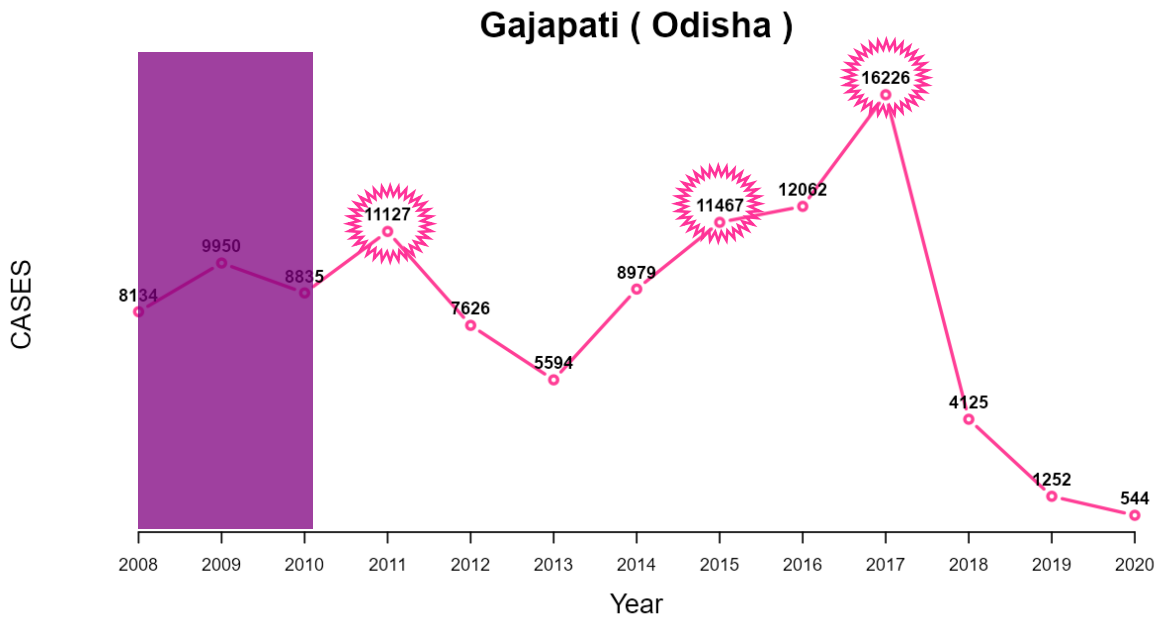
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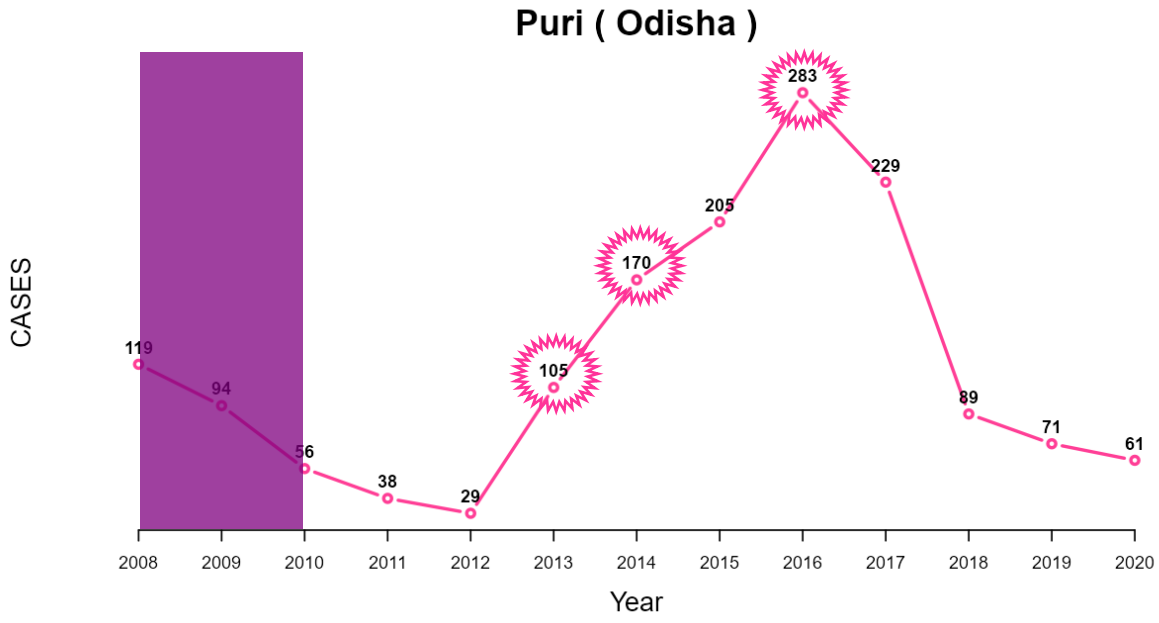
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CASES
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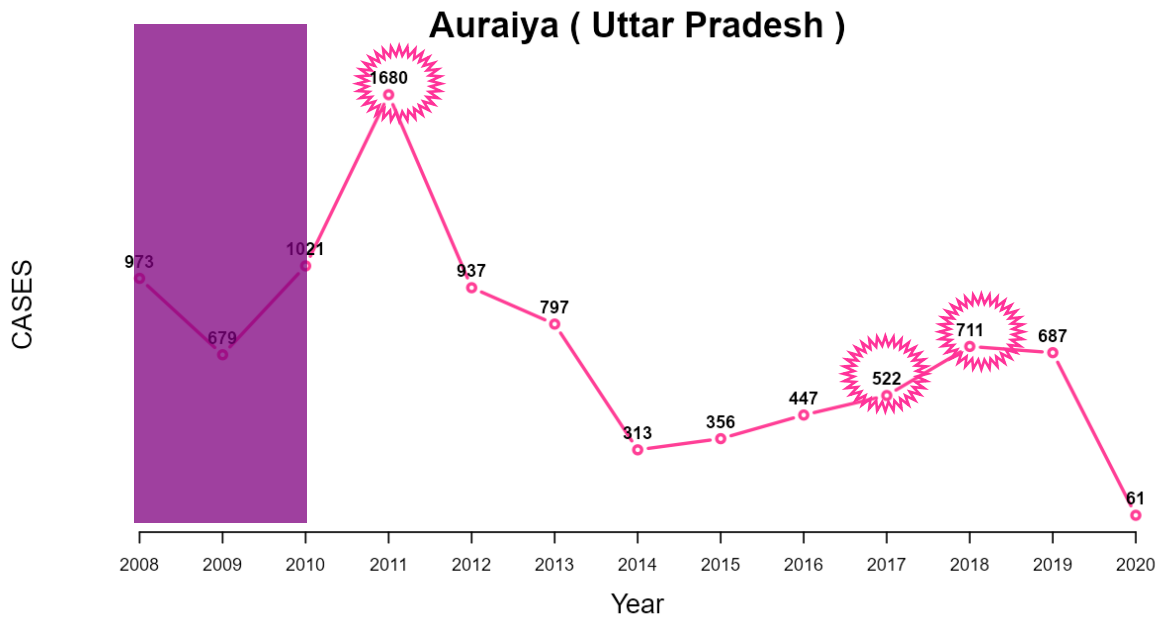
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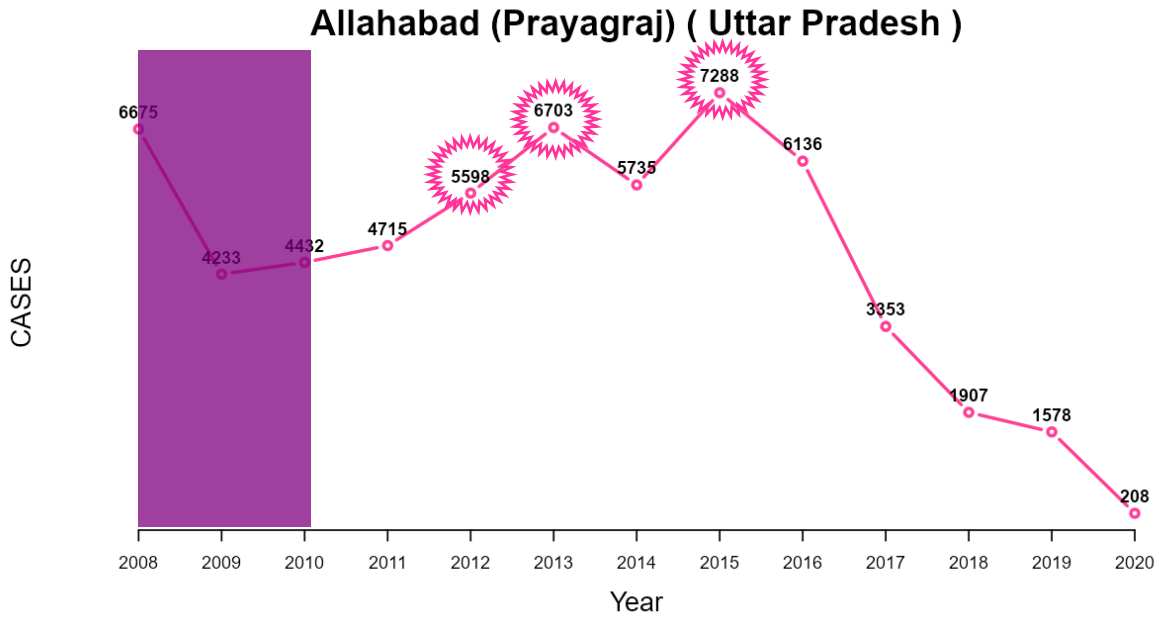
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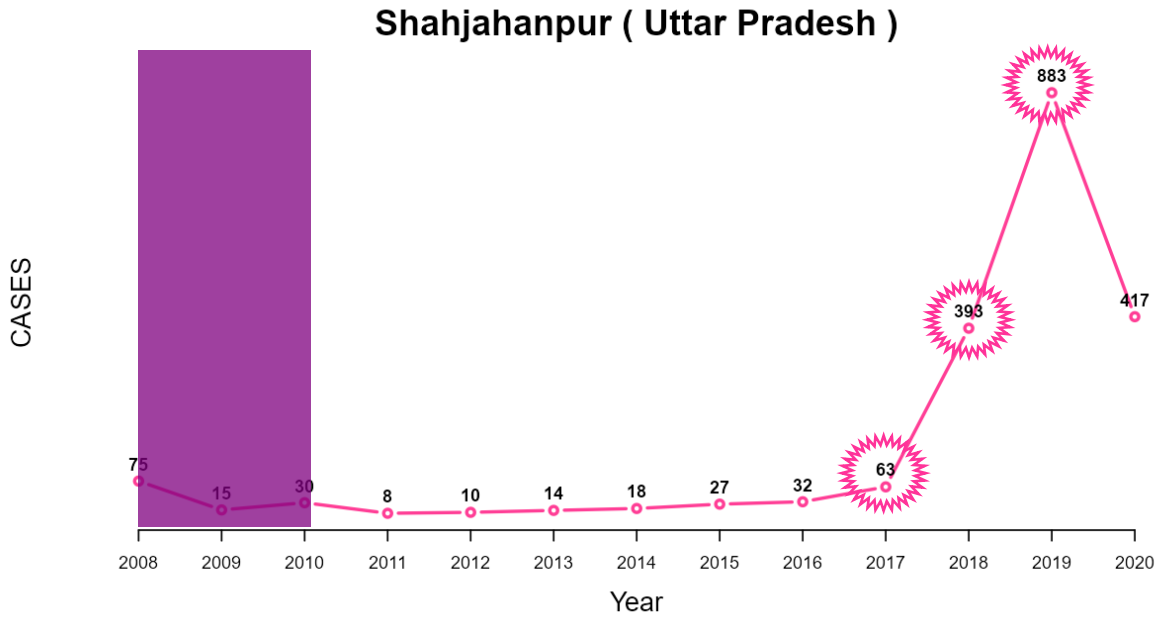
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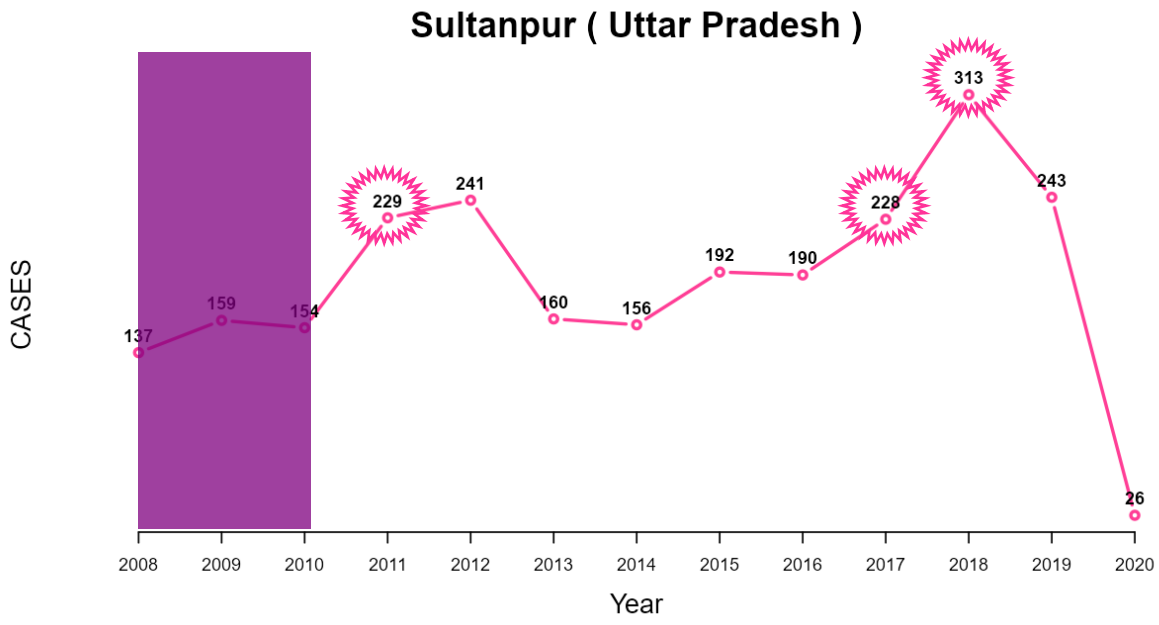
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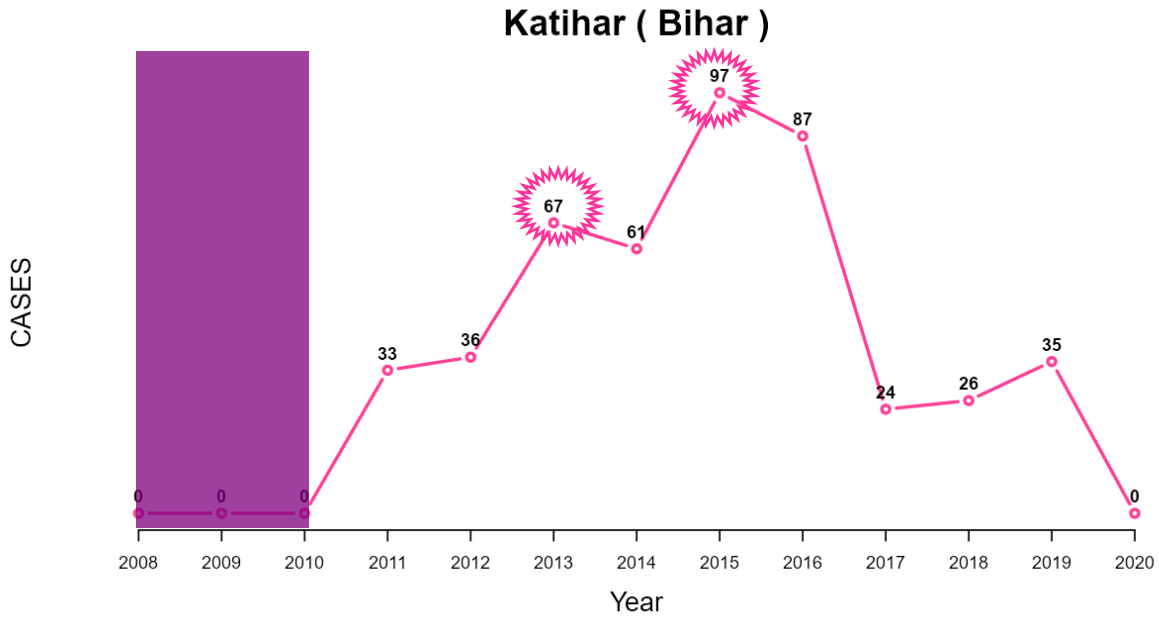
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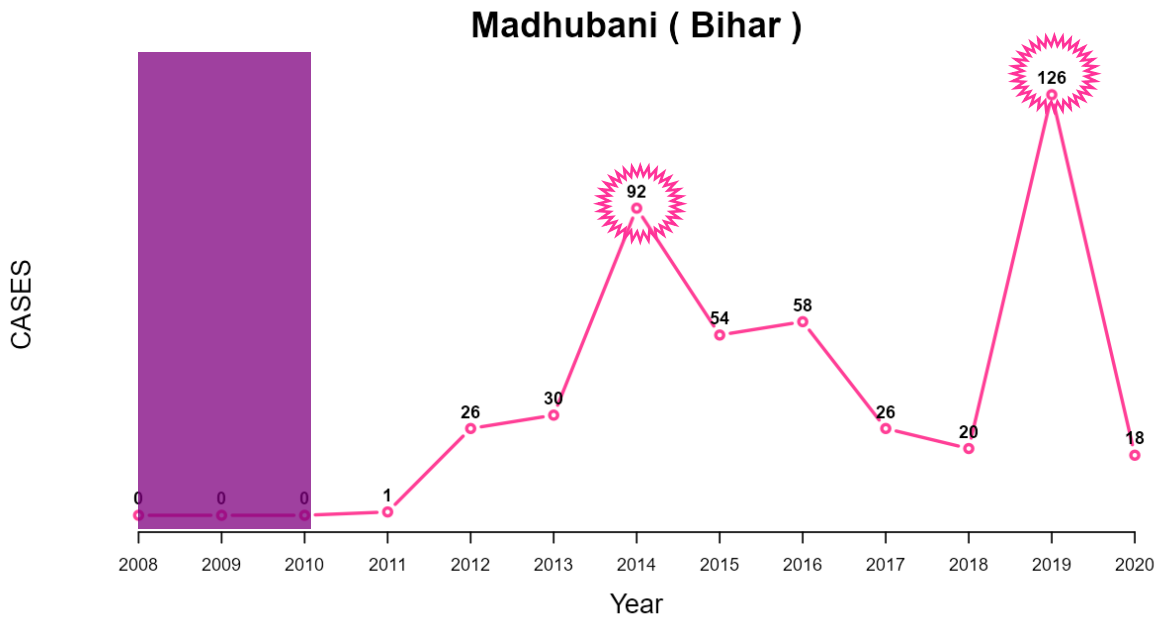
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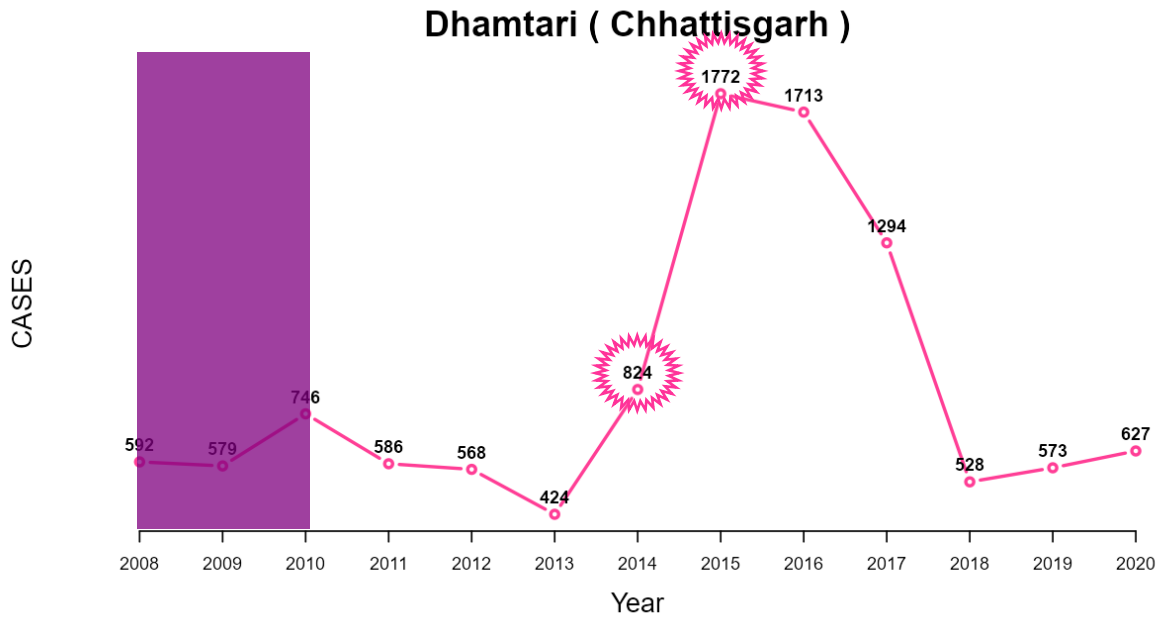
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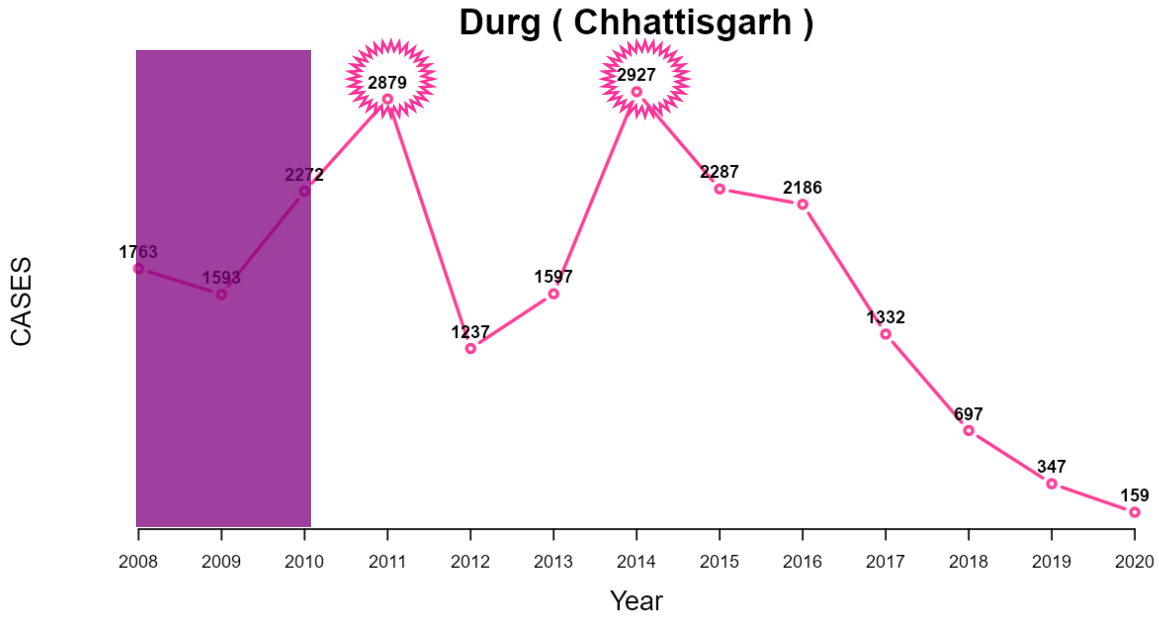
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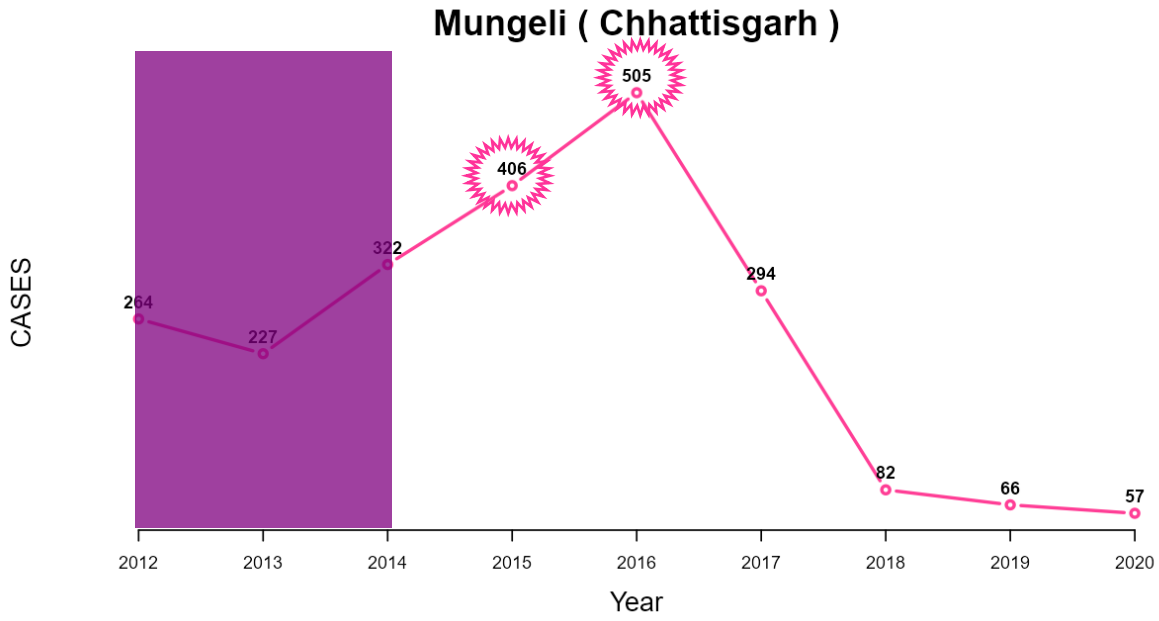
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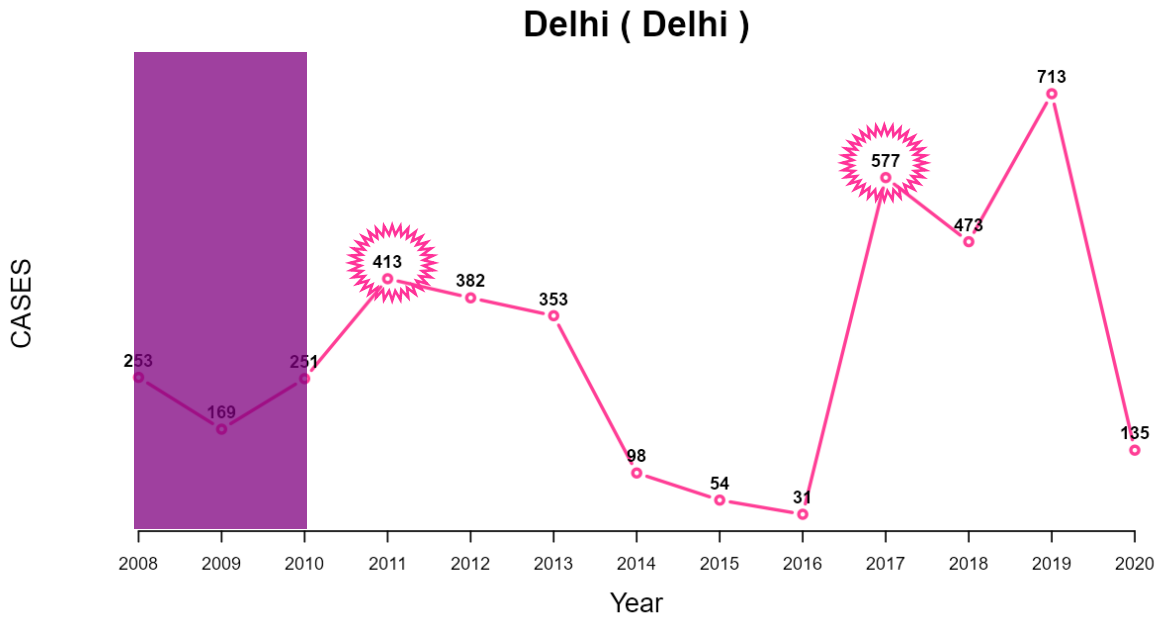
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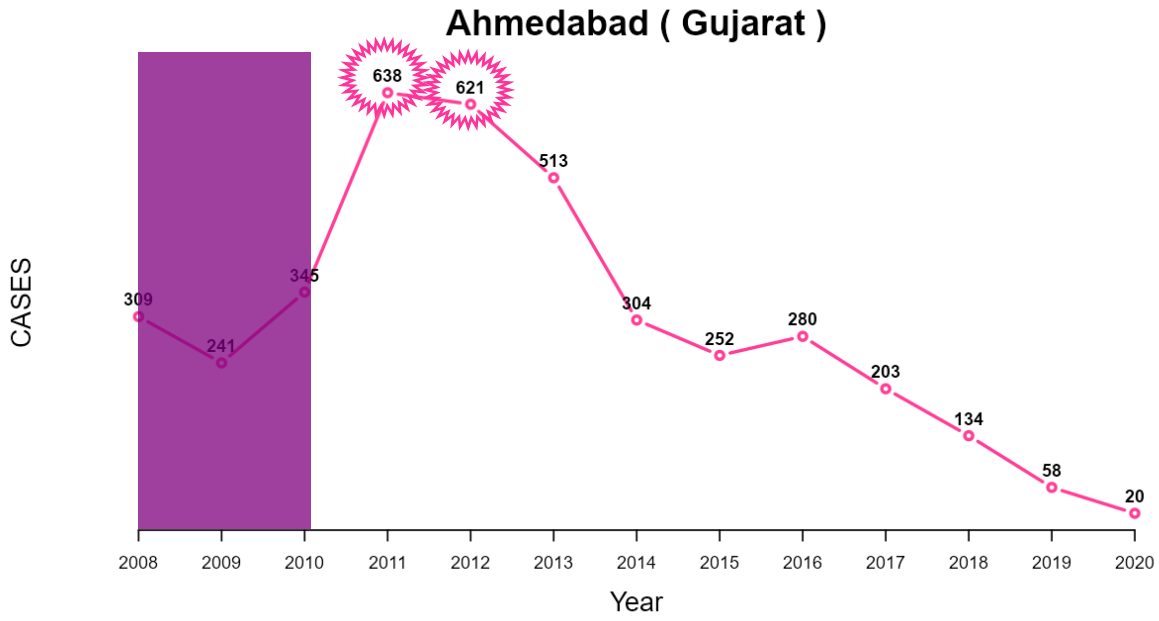
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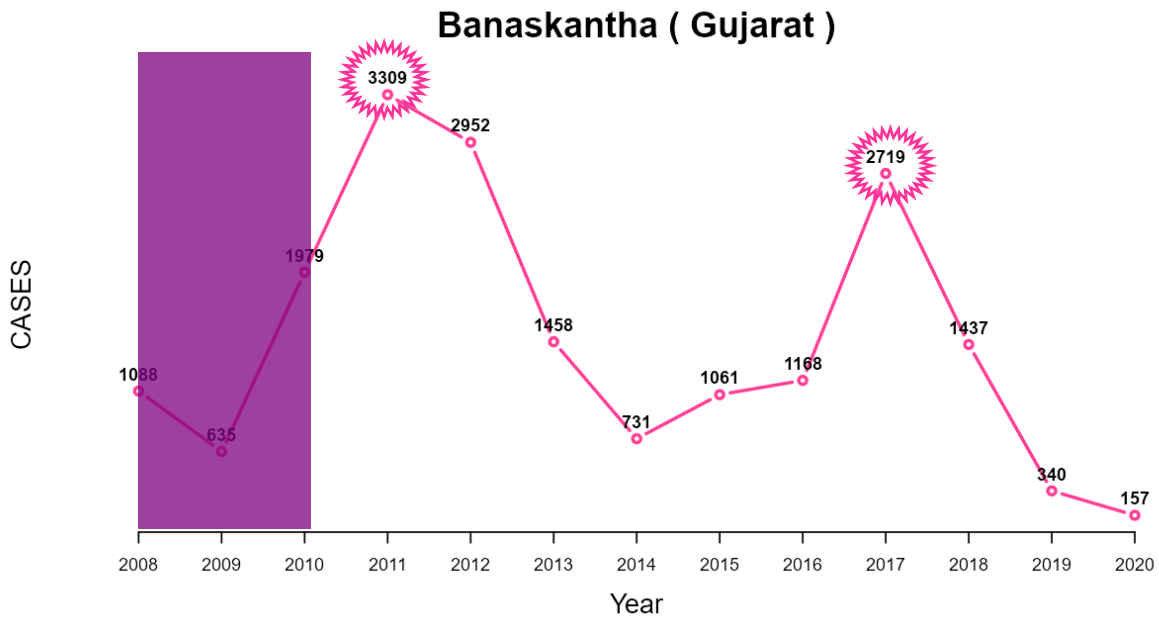
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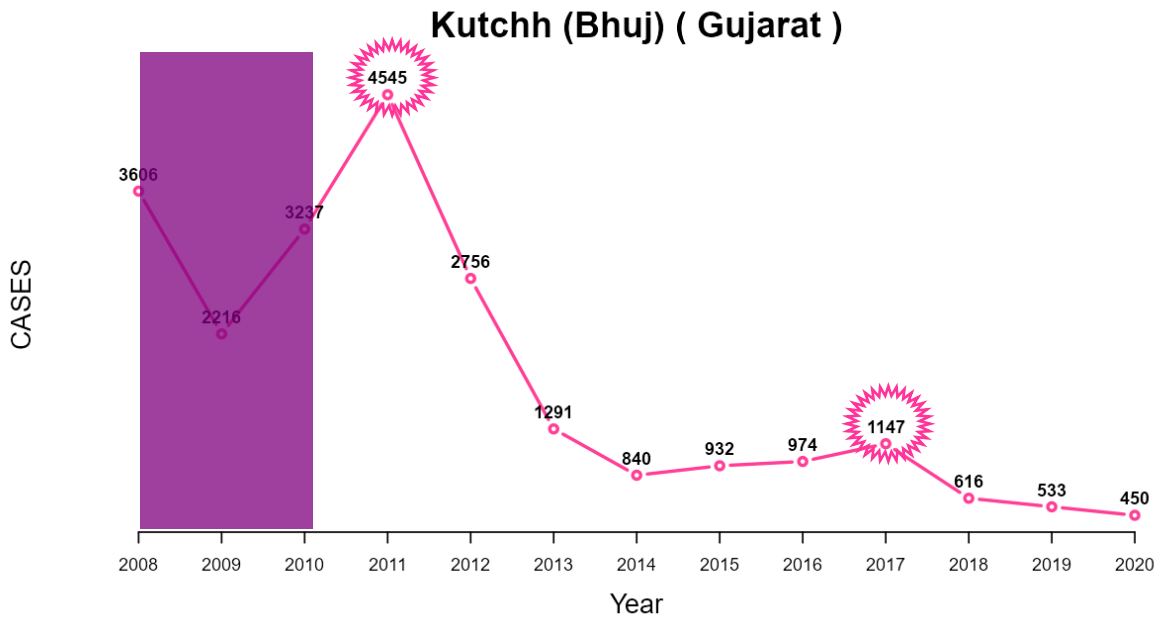
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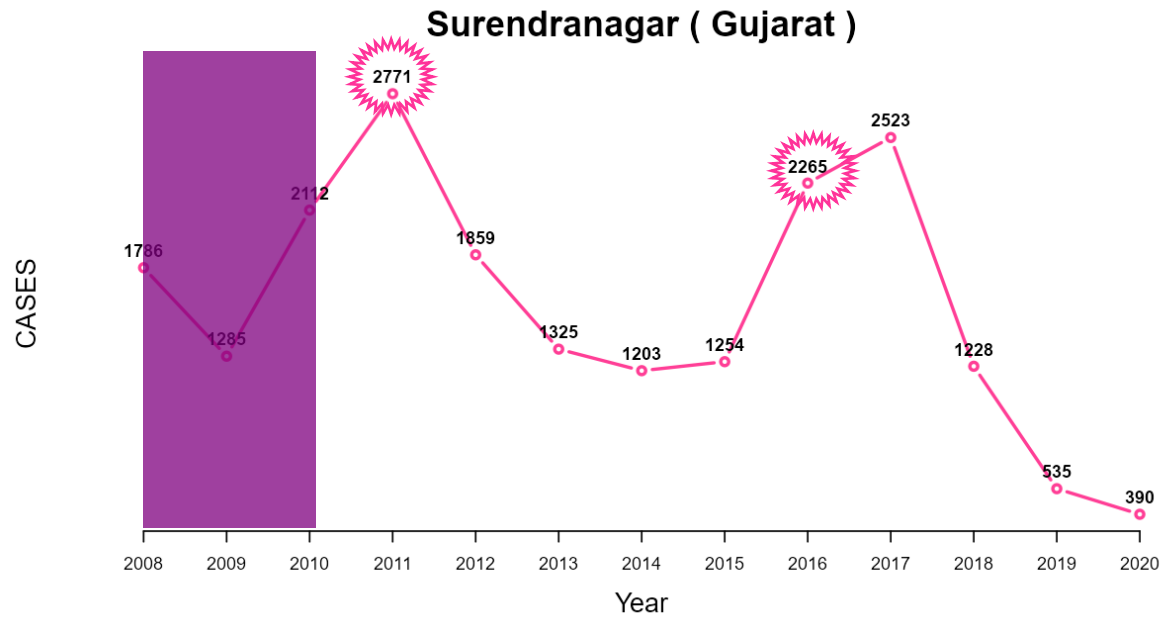
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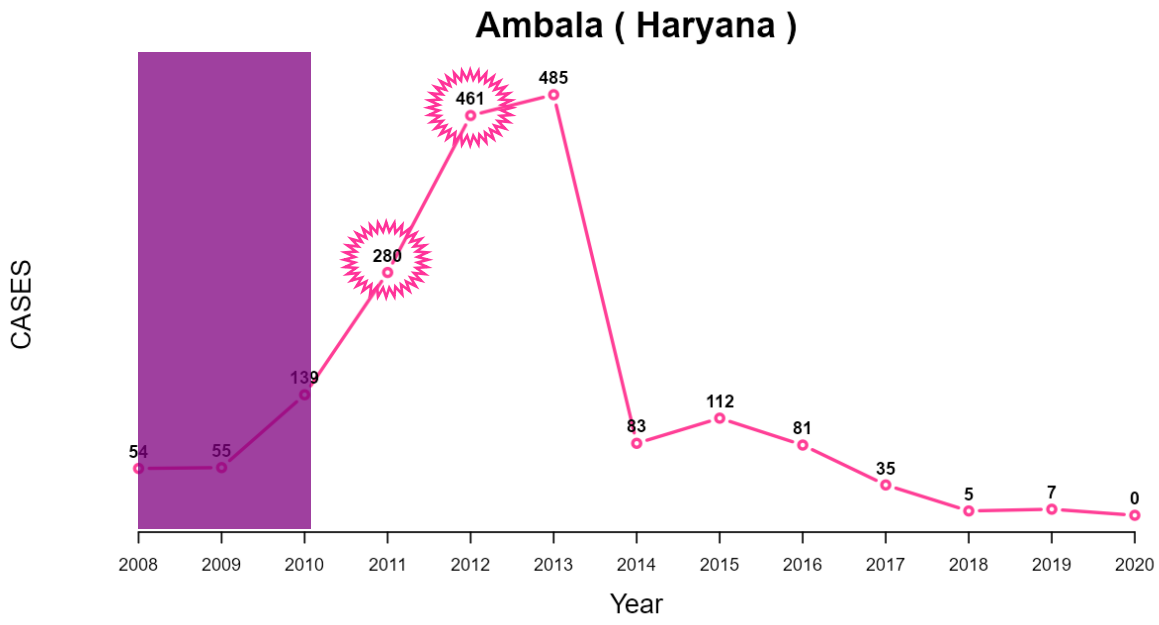
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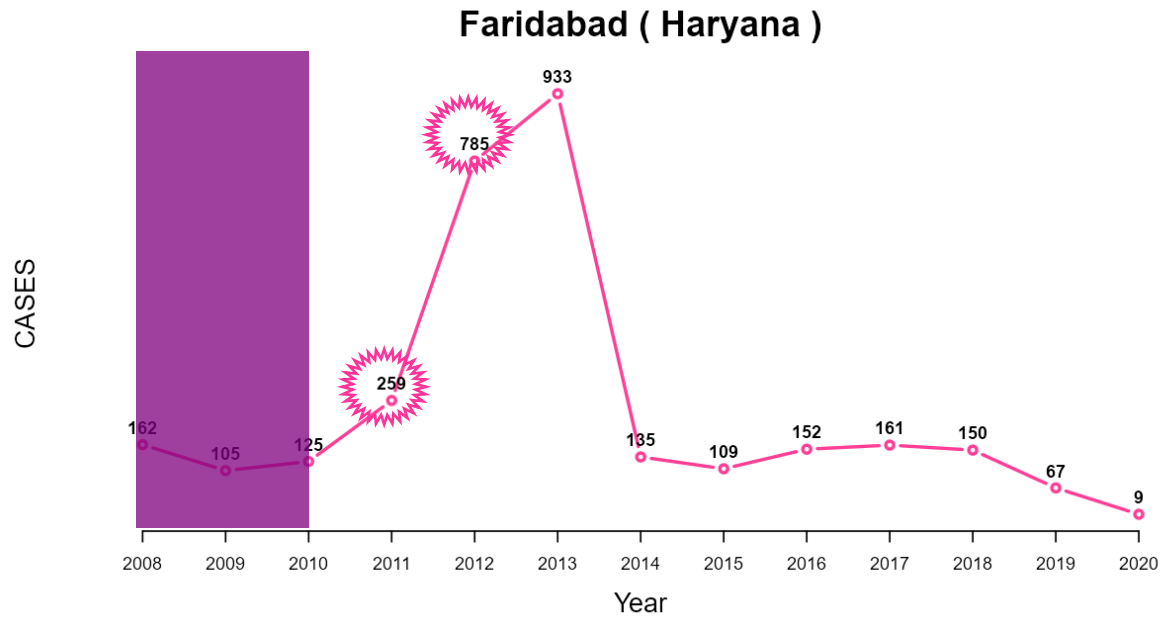
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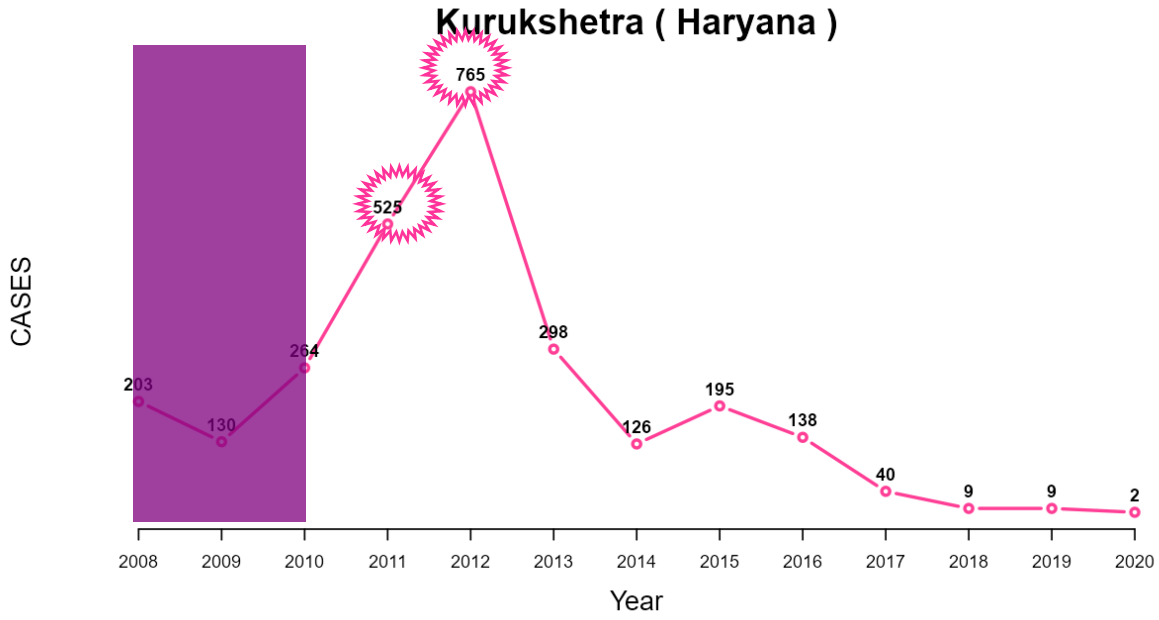
Kurukshetra (Haryana)
CASES
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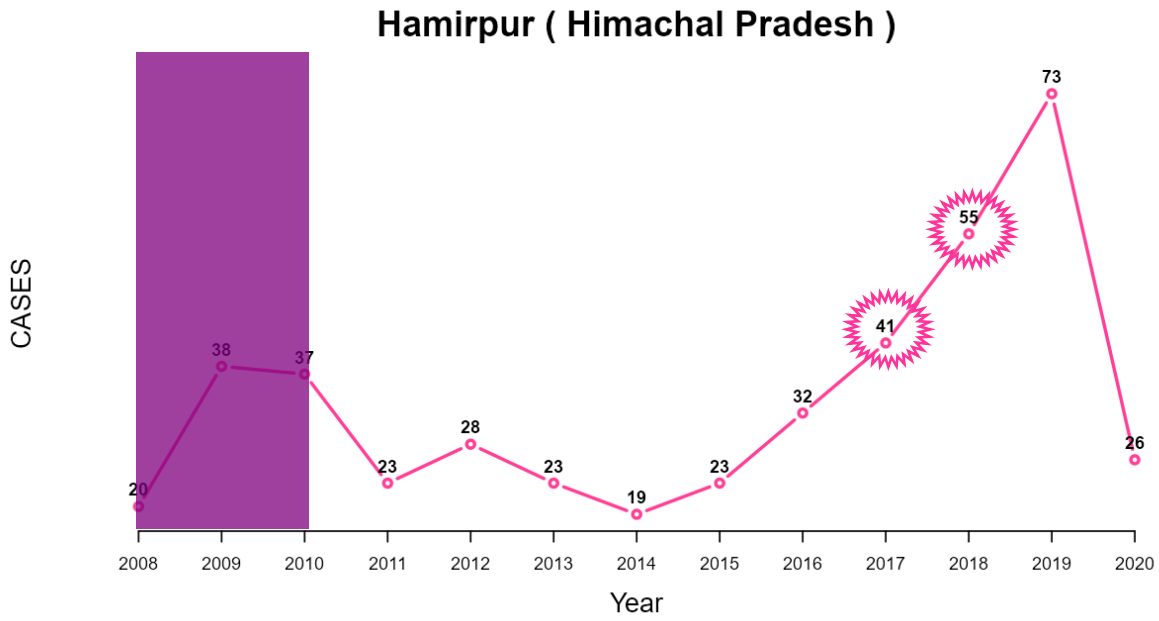
Hamirpur (Himachal Pradesh)
CASES
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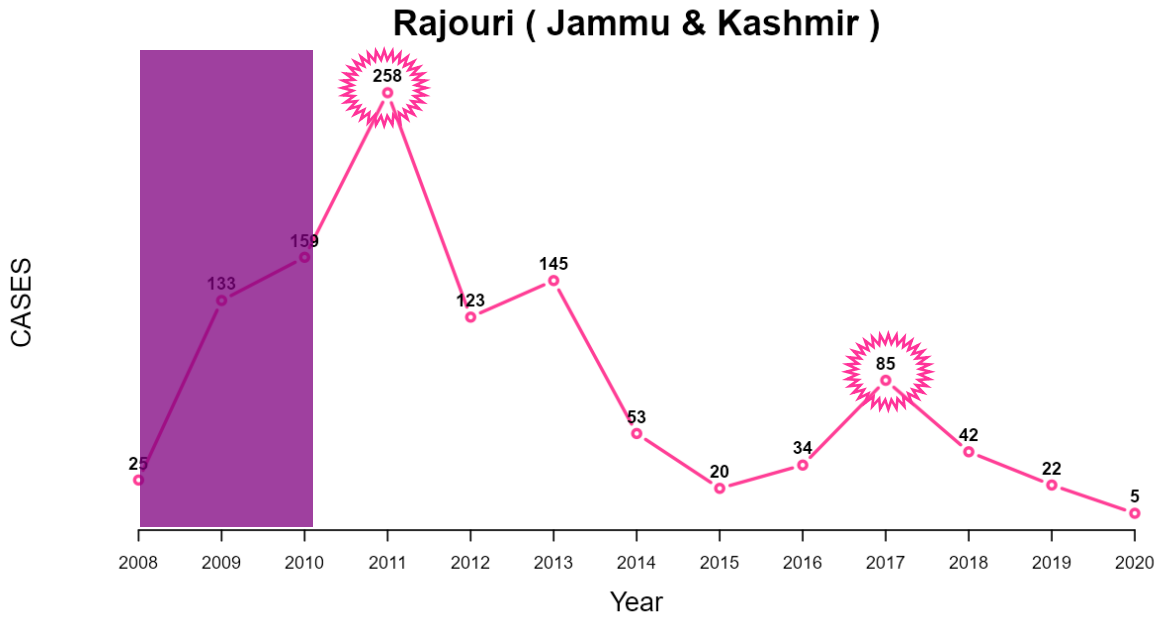
Rajouri (Jammu & Kashmir)
CASES
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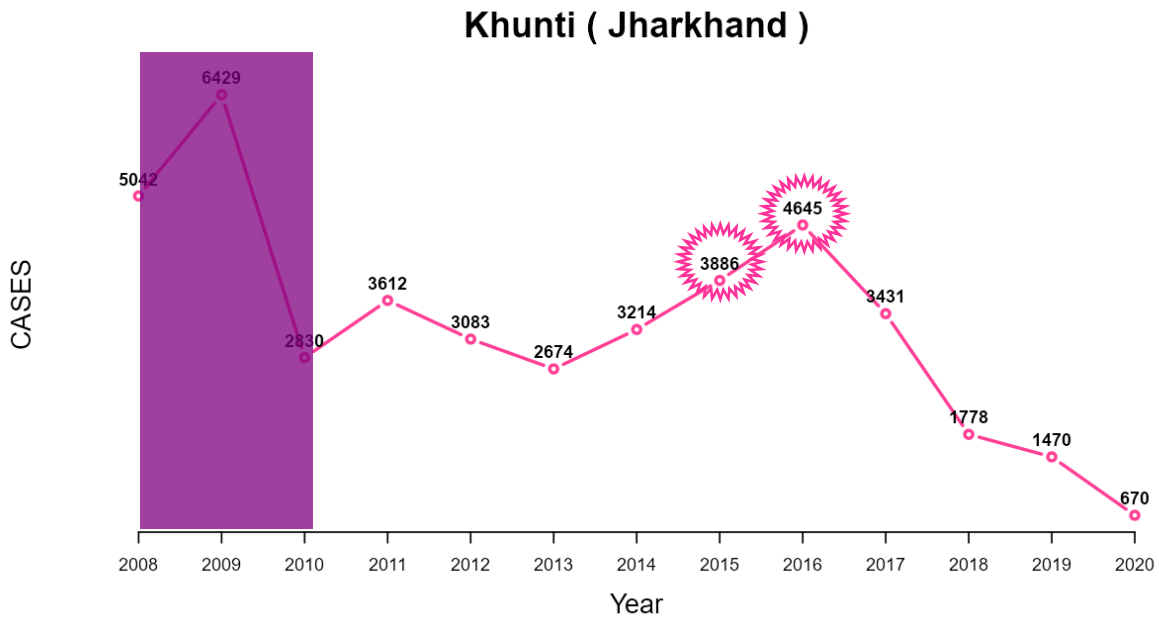
Khunti (Jharkhand)
CASES
Year
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3612
3083
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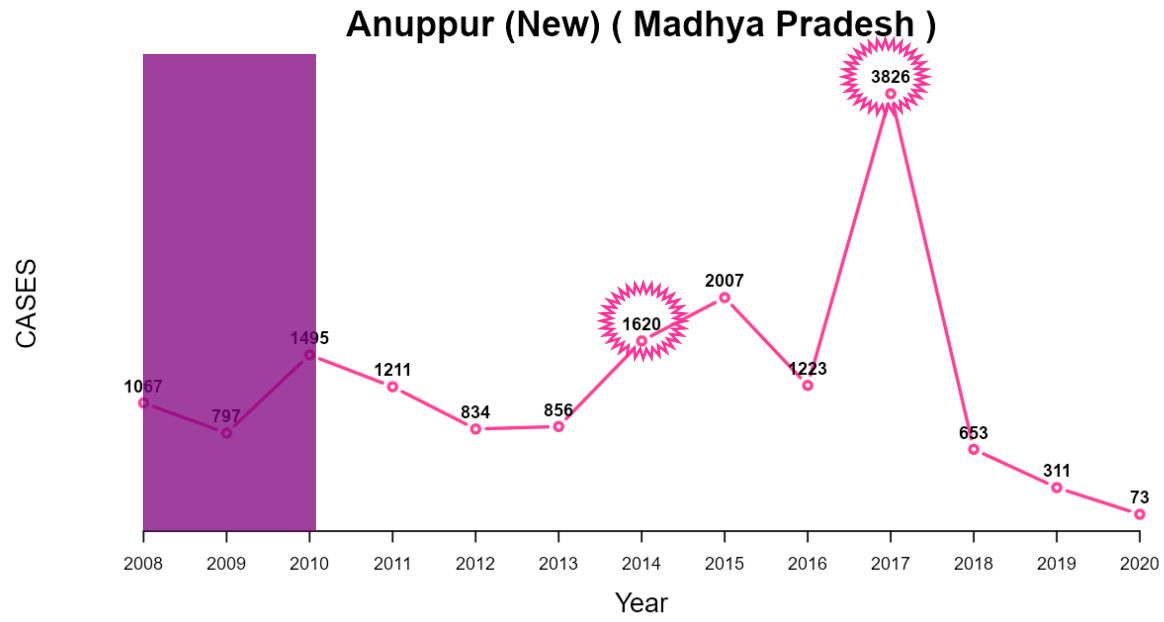
Anuppur (New) (Madhya Pradesh)
CASES
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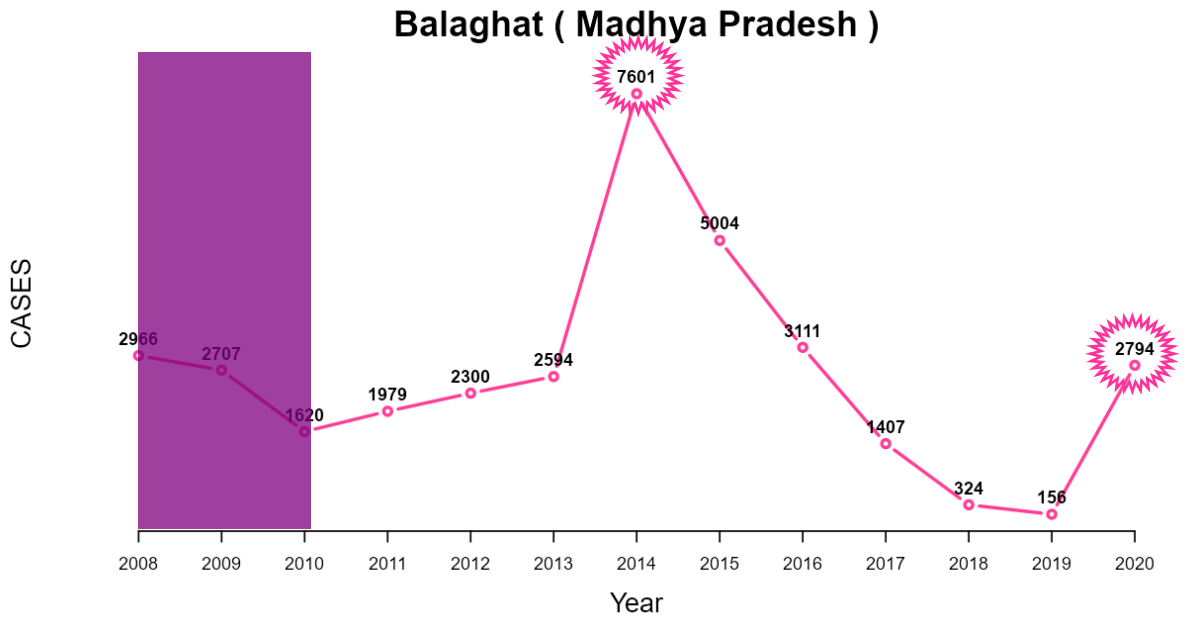
Balaghat (Madhya Pradesh)
CASES
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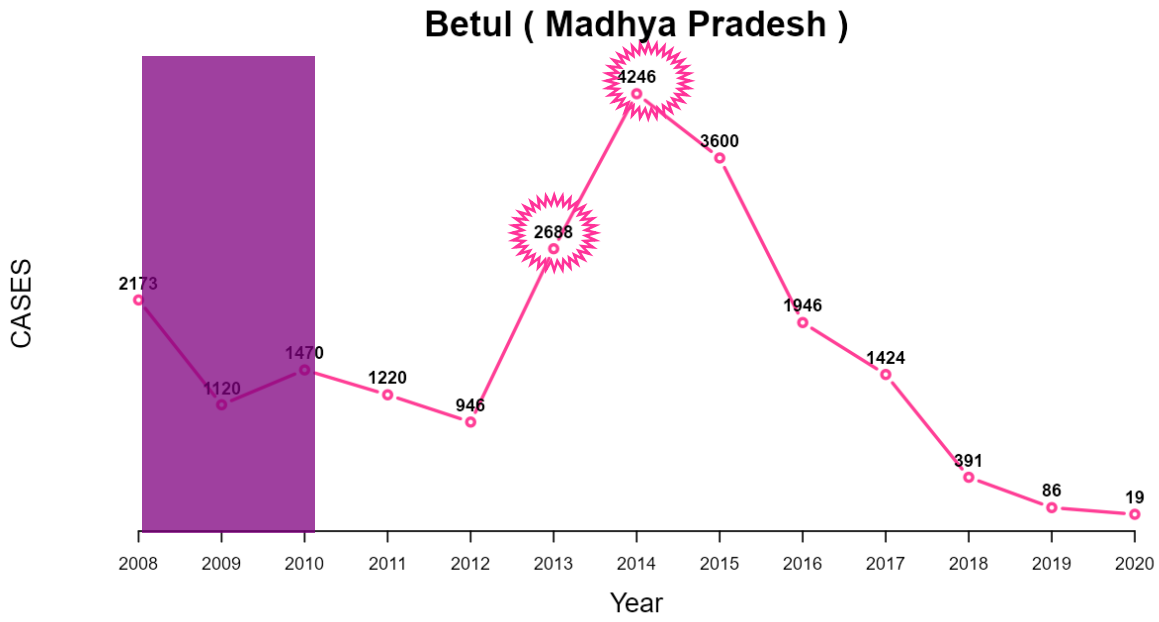
Betul (Madhya Pradesh)
CASES
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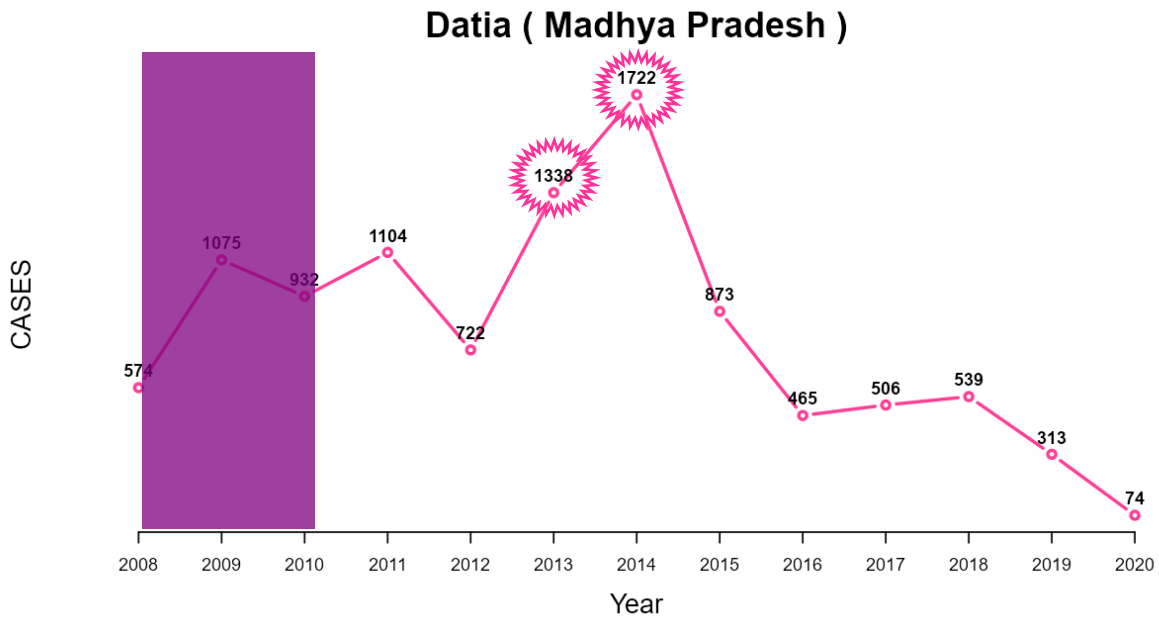
Datia (Madhya Pradesh)
CASES
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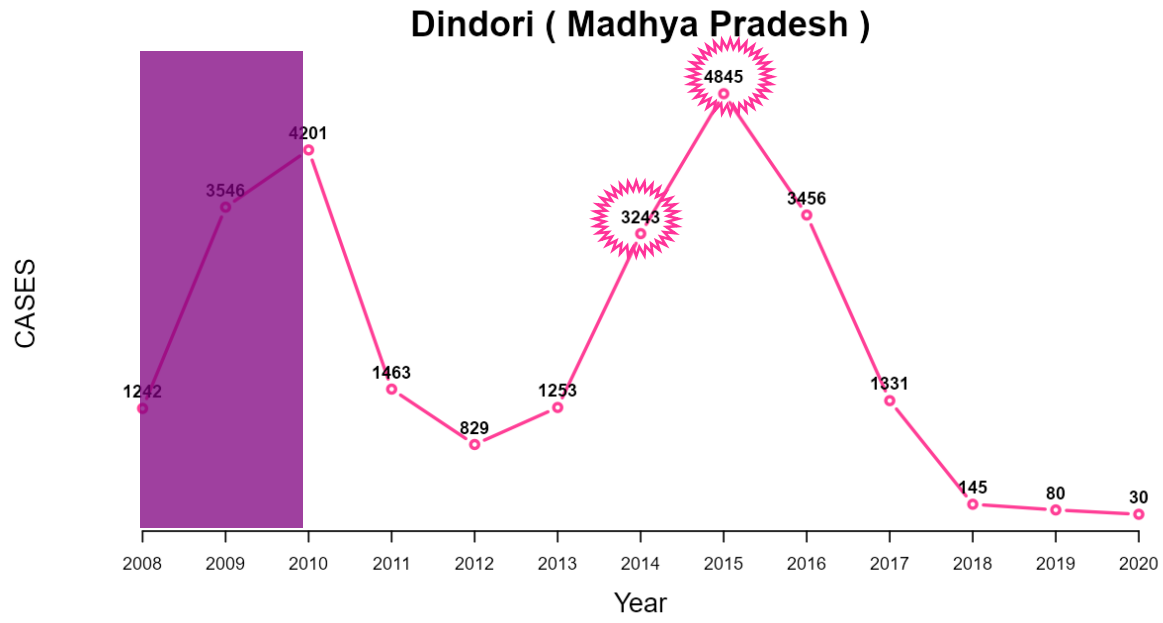
Dindori (Madhya Pradesh)
CASES
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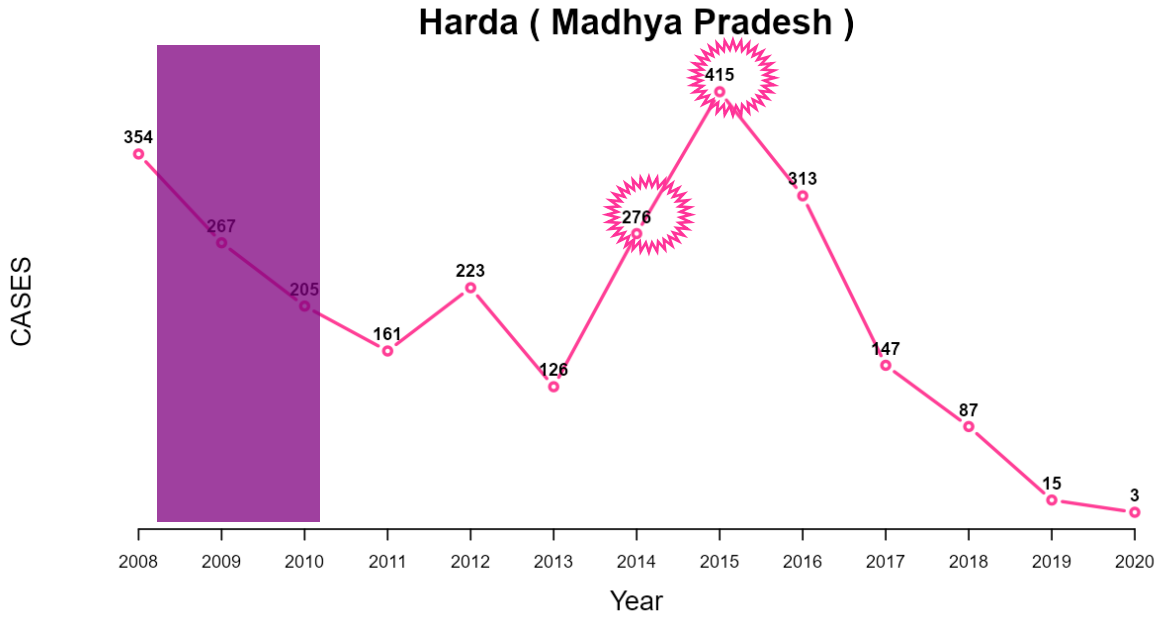
Harda (Madhya Pradesh)
CASES
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354
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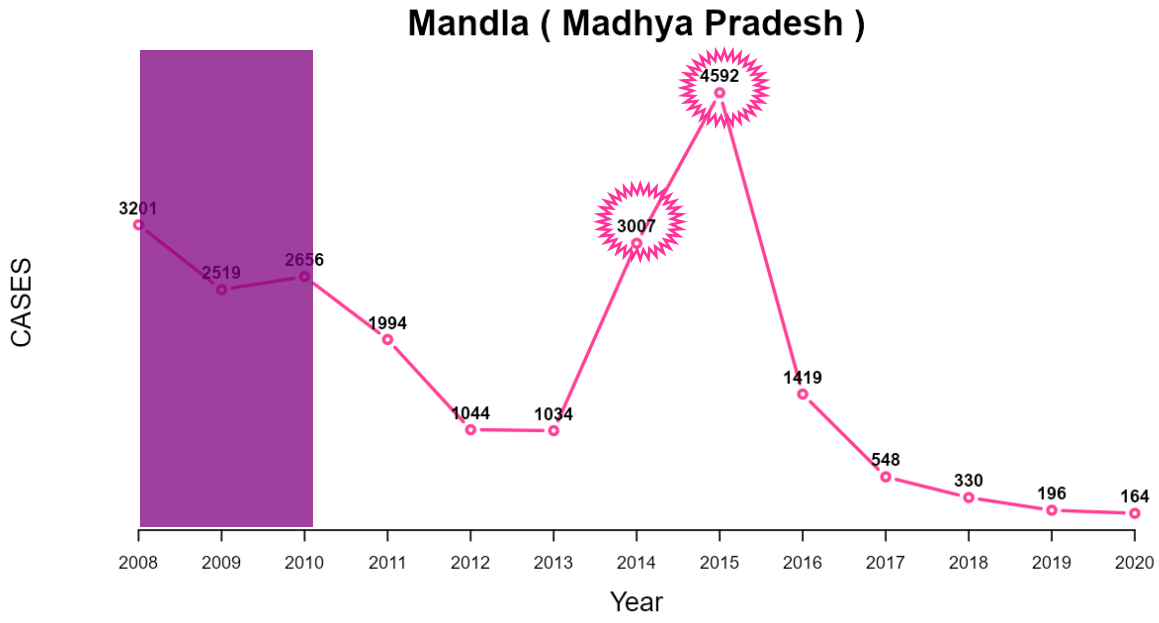
Mandla (Madhya Pradesh)
CASES
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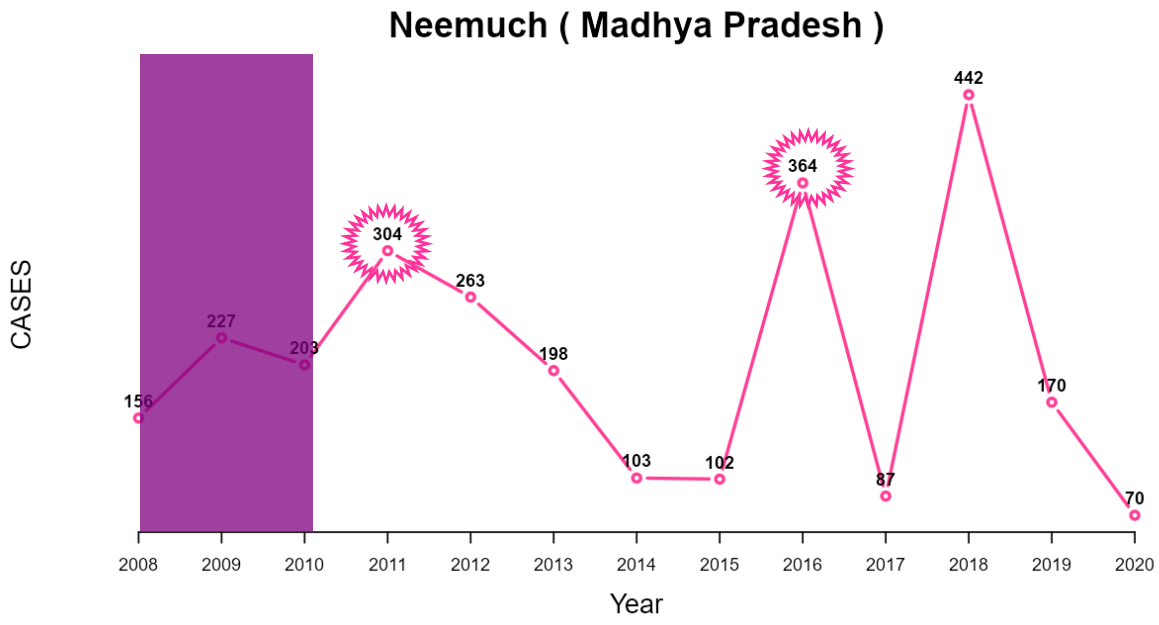
Neemuch (Madhya Pradesh)
CASES
Year
156
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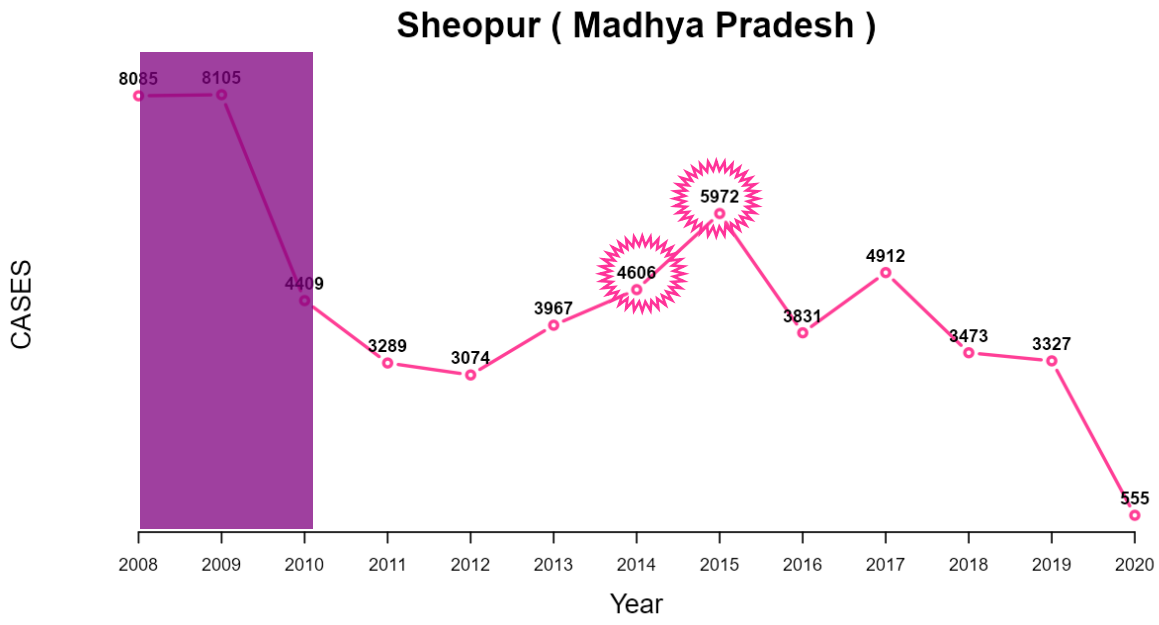
Sheopur (Madhya Pradesh)
CASES
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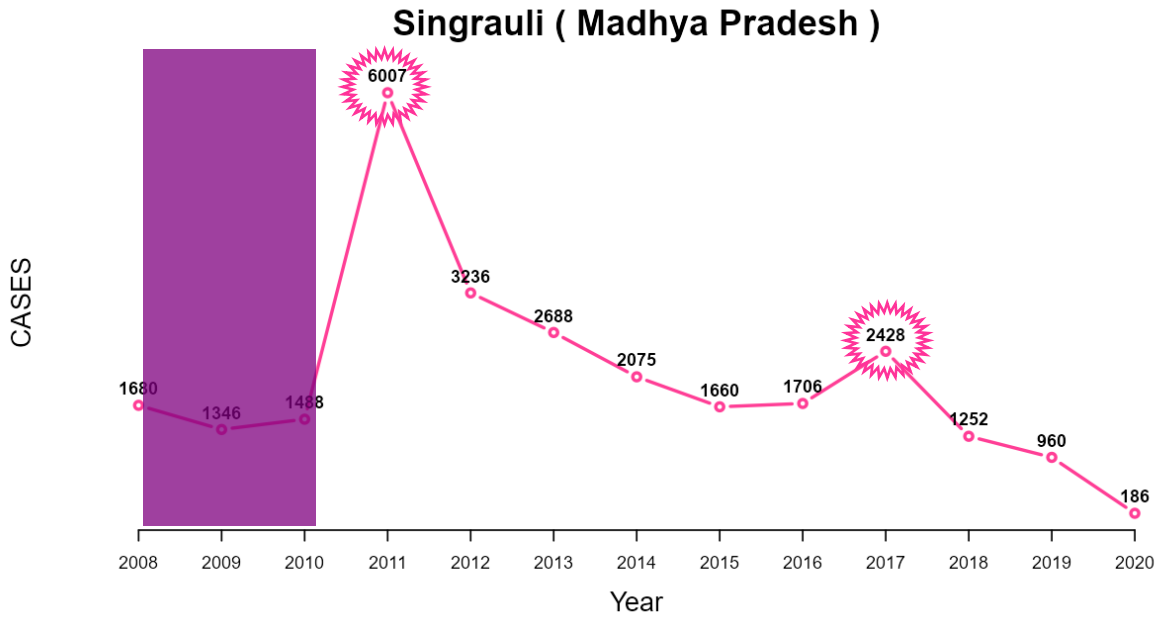
Singrauli (Madhya Pradesh)
CASES
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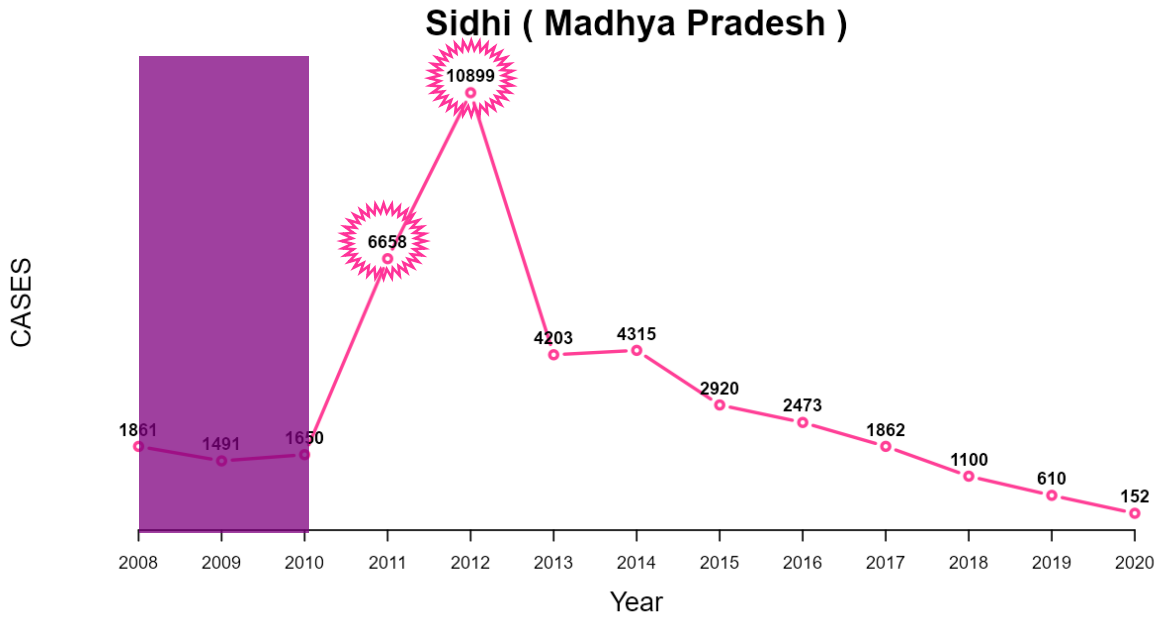
Sidhi (Madhya Pradesh)
CASES
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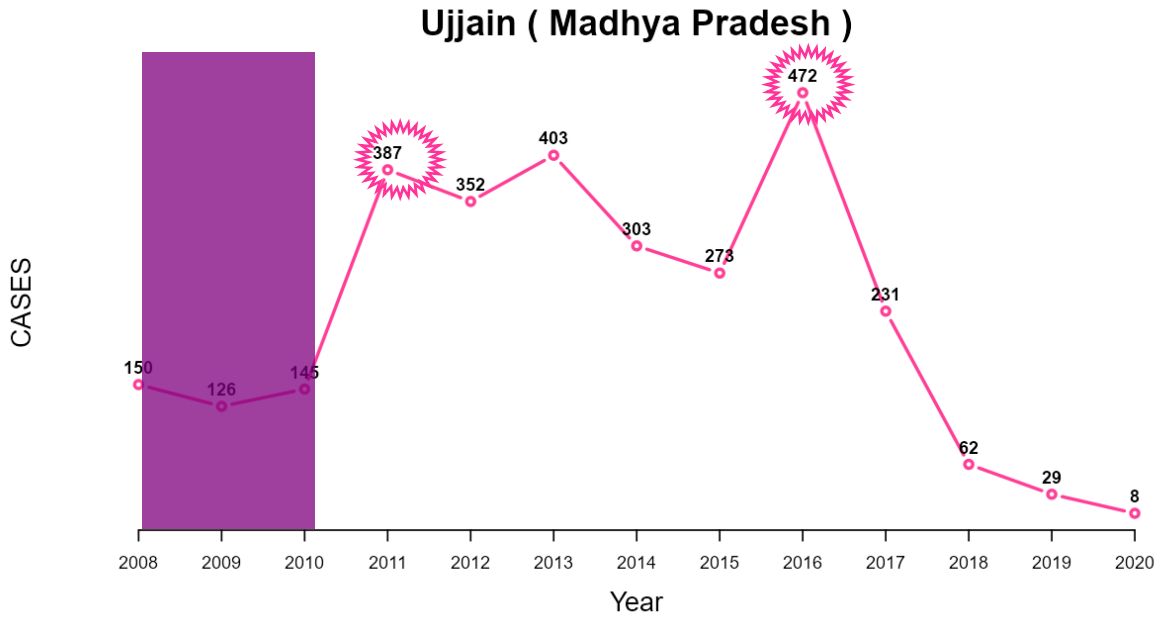
Ujjain (Madhya Pradesh)
CASES
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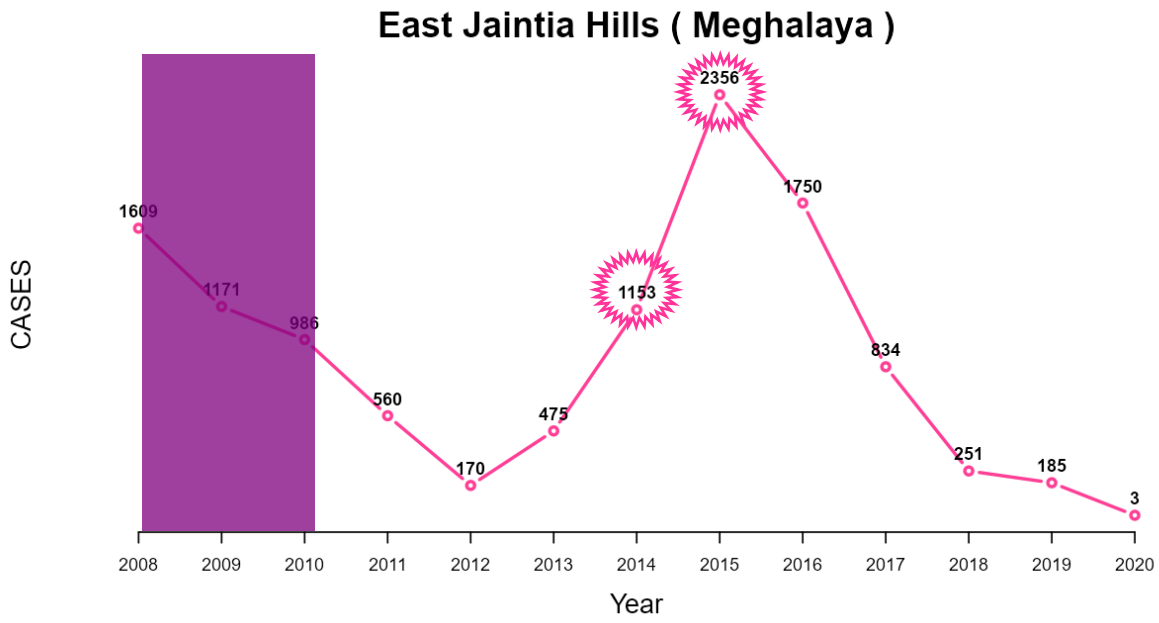
East Jaintia Hills (Meghalaya)
CASES
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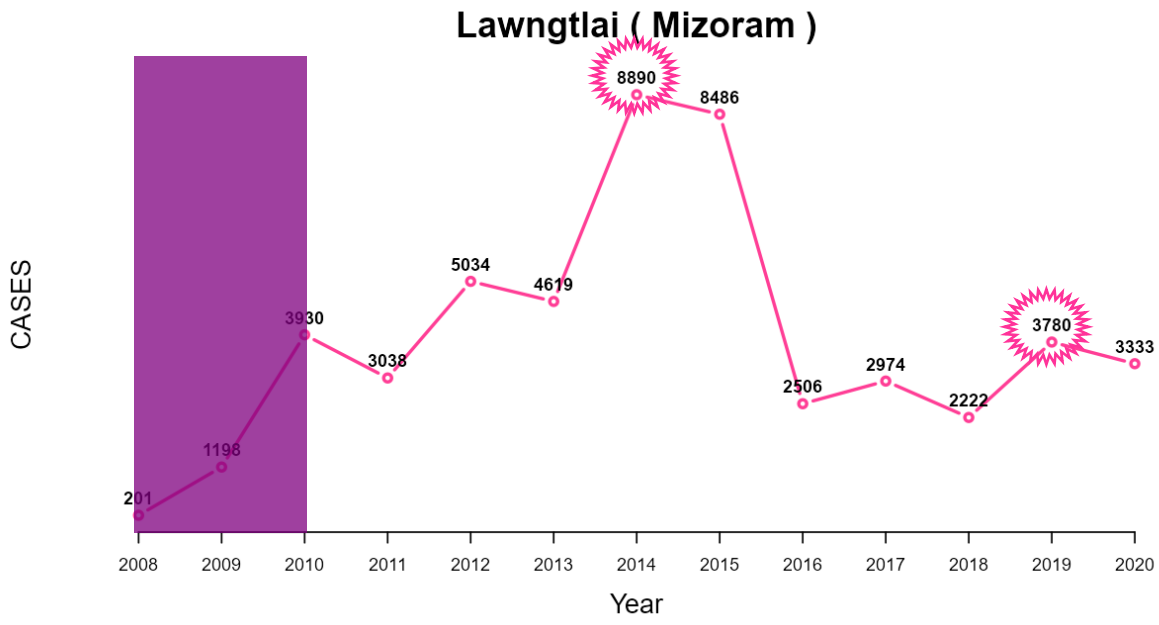
Lawngtlai (Mizoram)
CASES
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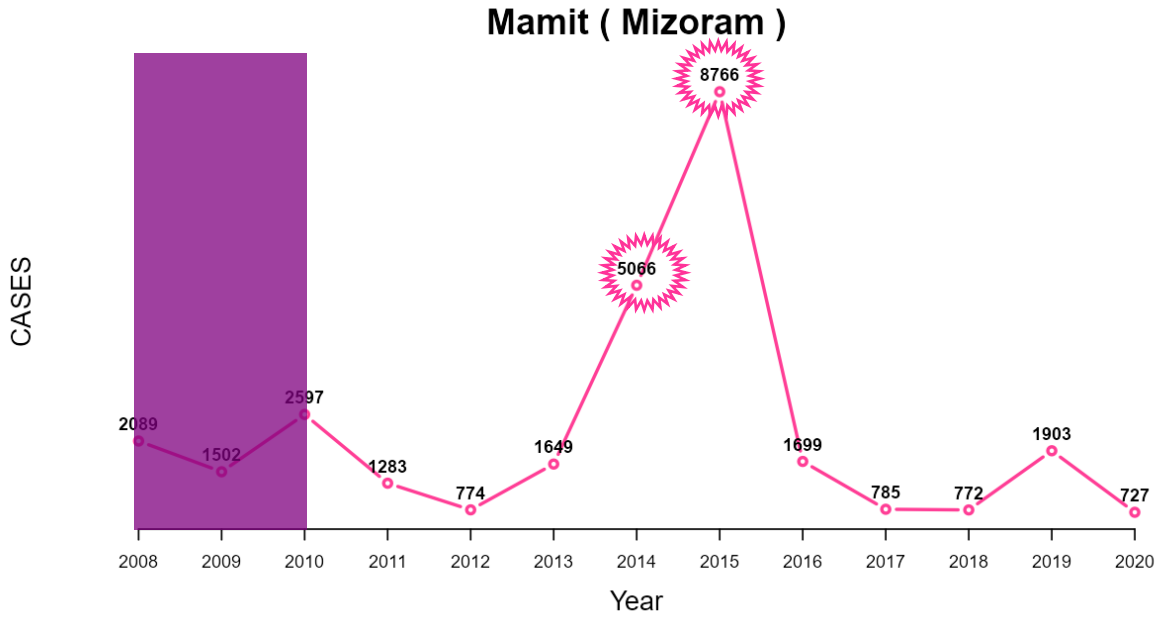
Mamit (Mizoram)
CASES
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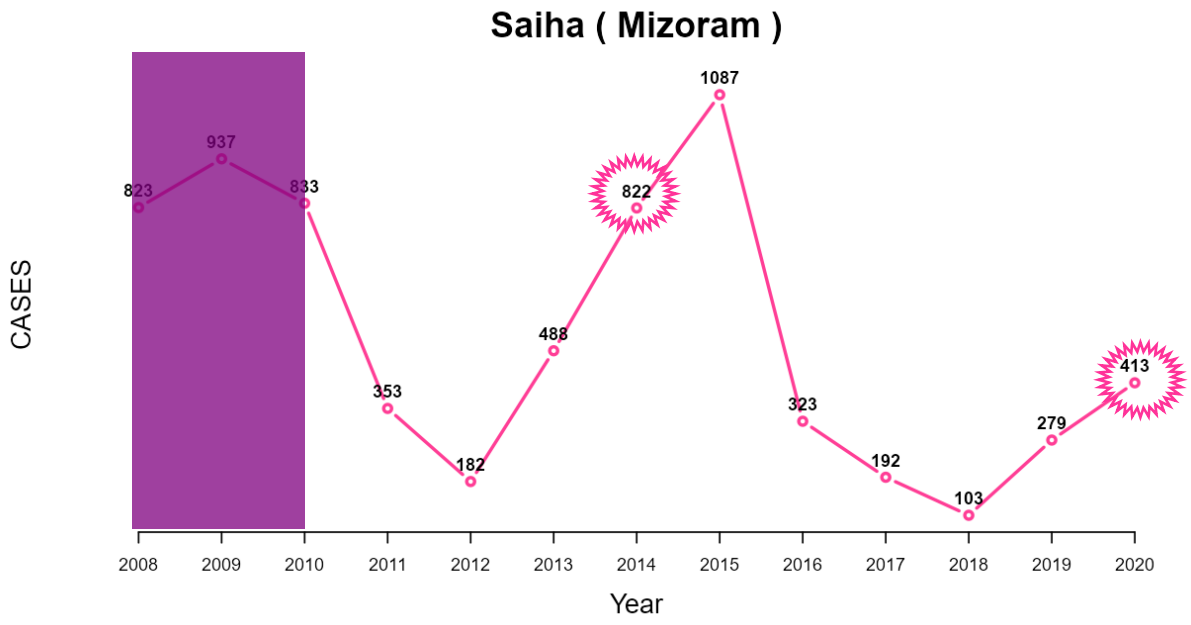
Saiha (Mizoram)
CASES
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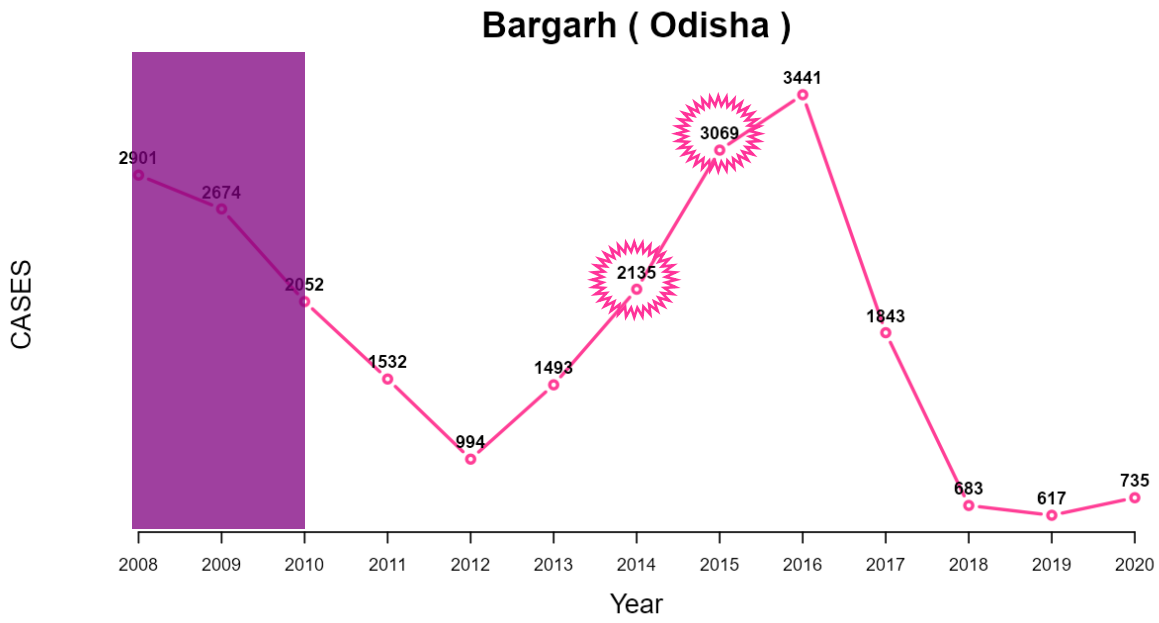
Bargarh (Odisha)
CASES
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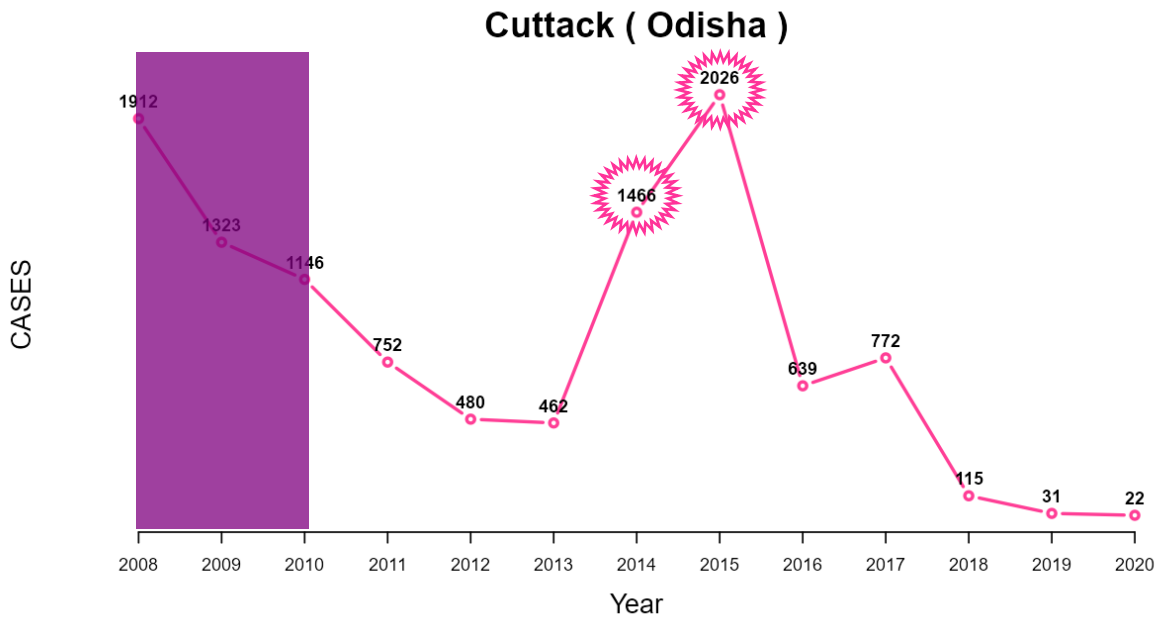
Cuttack (Odisha)
CASES
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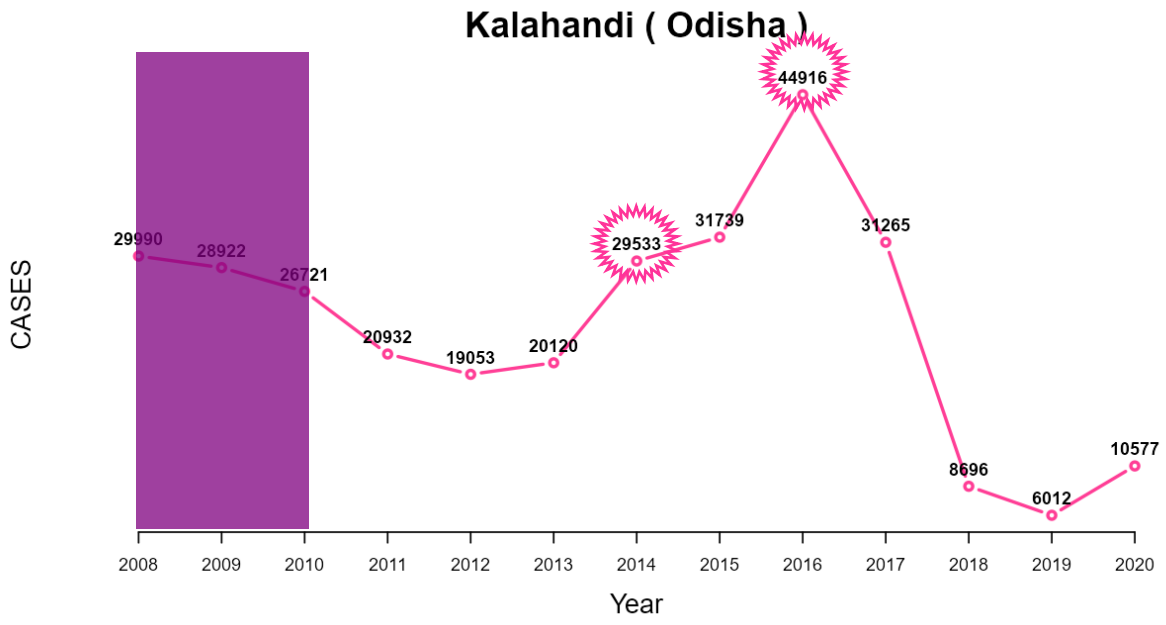
Kalahandi (Odisha)
CASES
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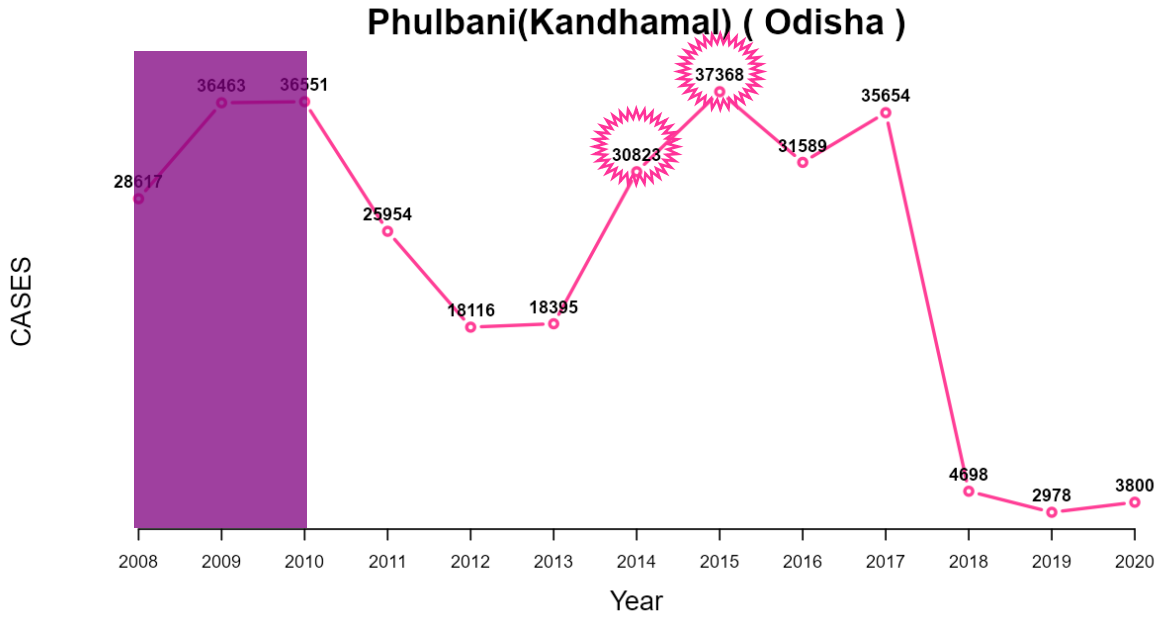
Phulbani(Kandhamal) (Odisha)
CASES
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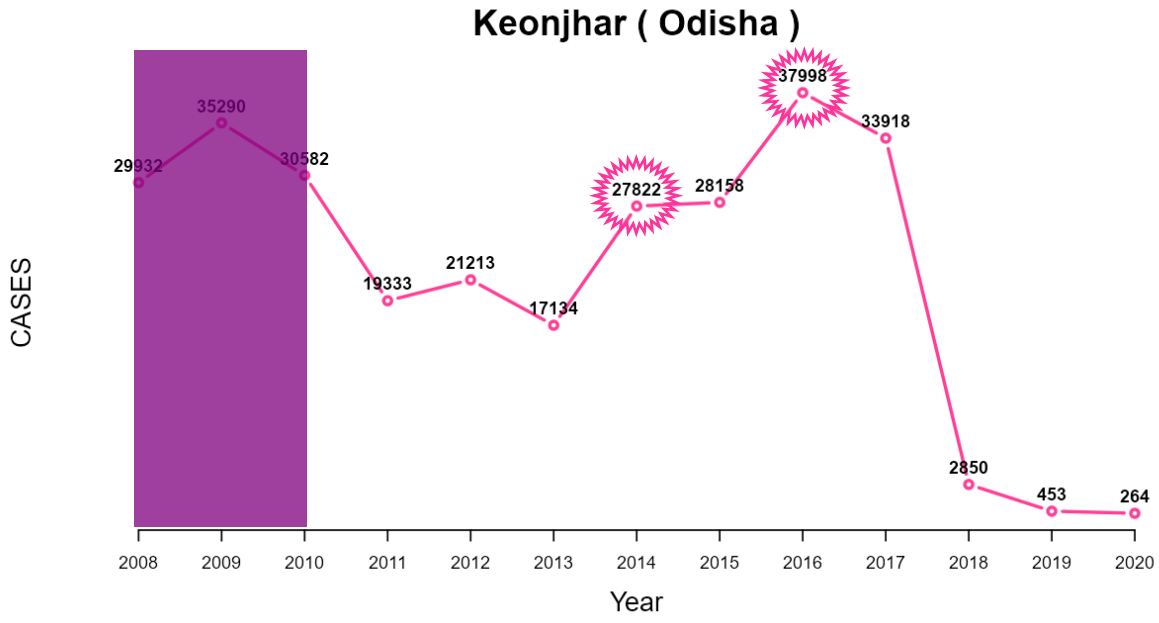
Keonjhar (Odisha)
CASES
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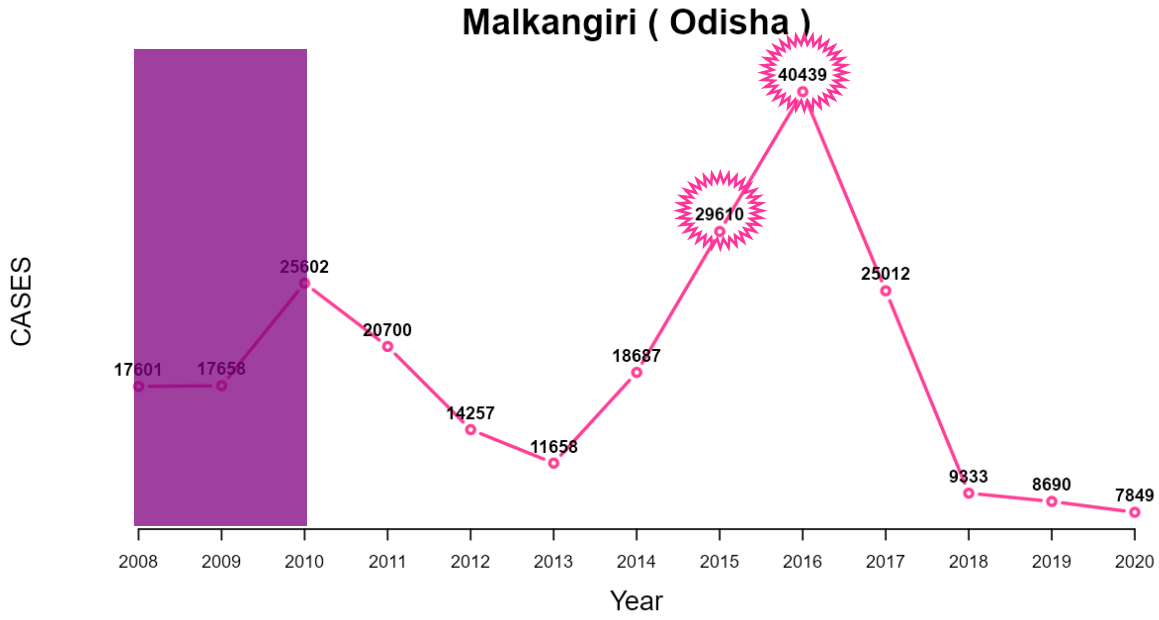
Malkangiri (Odisha)
CASES
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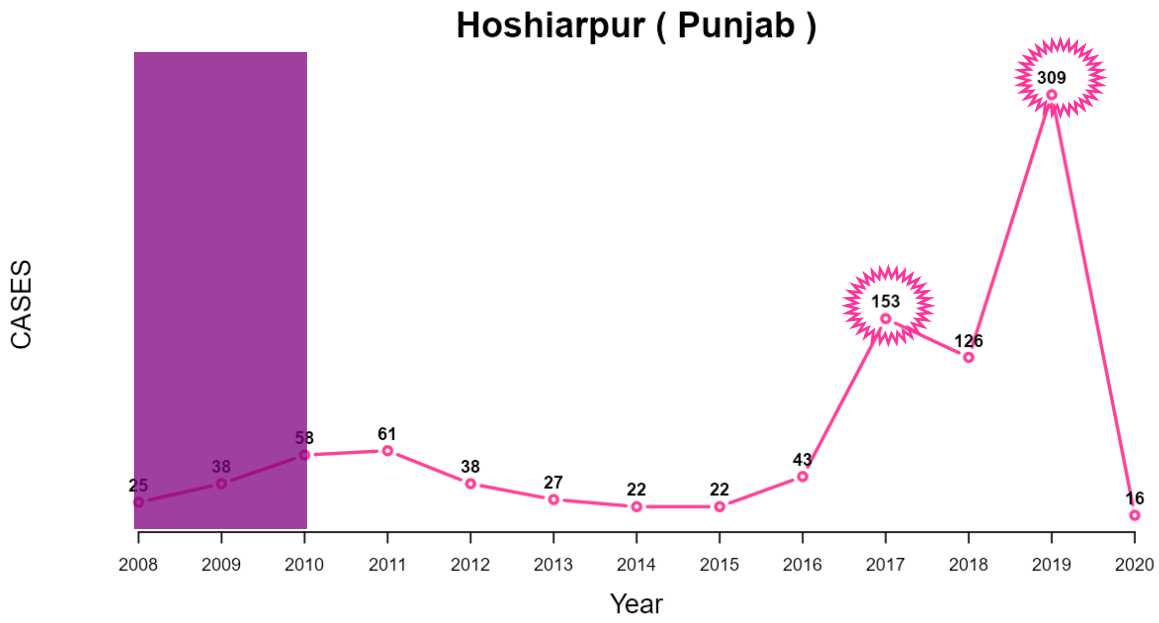
Hoshiarpur (Punjab)
CASES
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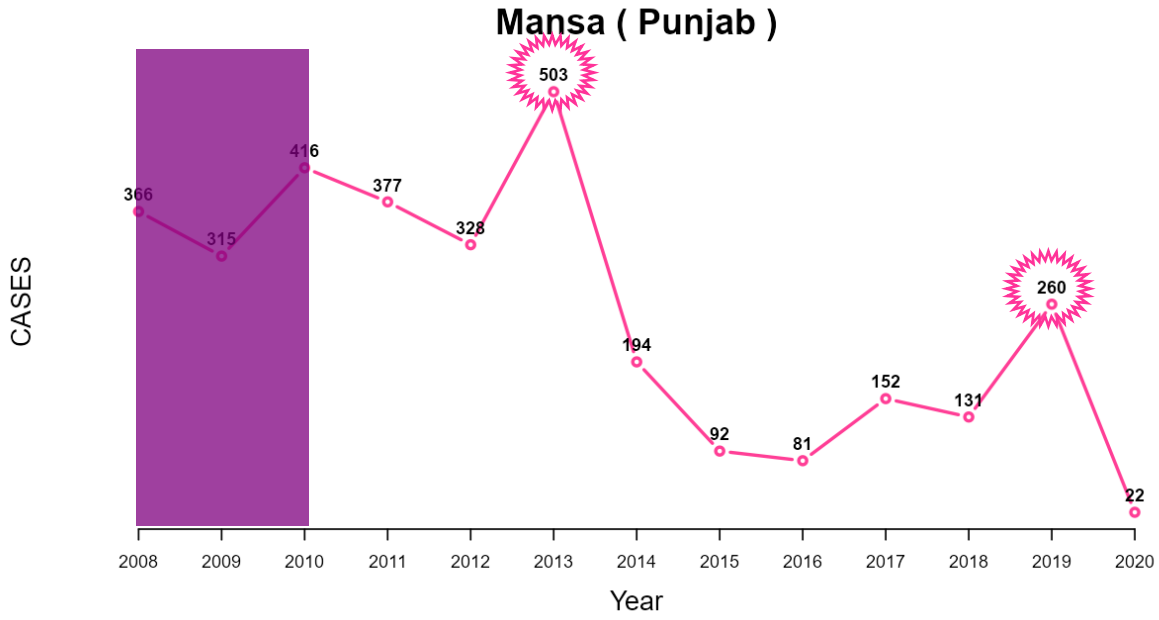
Mansa (Punjab)
CASES
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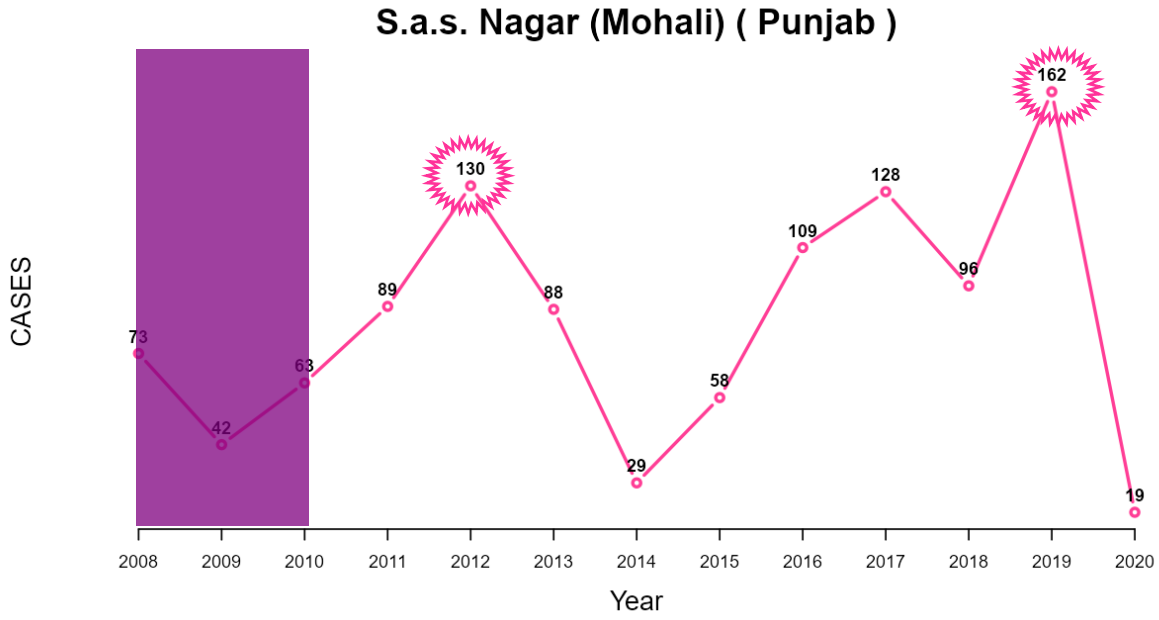
S.a.s. Nagar (Mohali) (Punjab)
CASES
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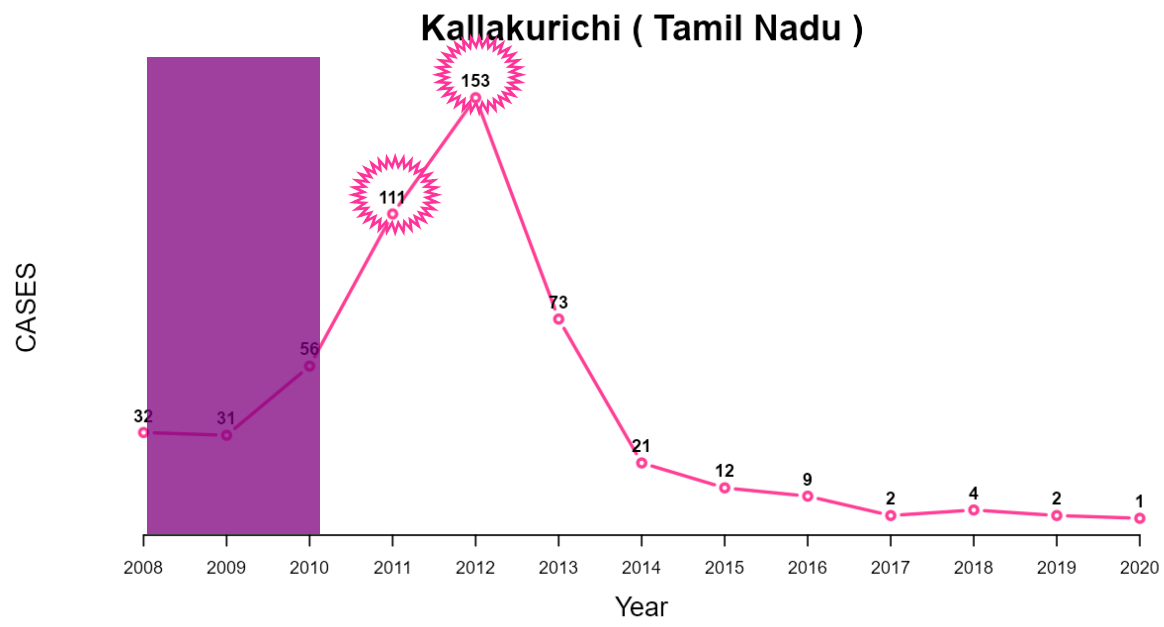
Kallakurichi (Tamil Nadu)
CASES
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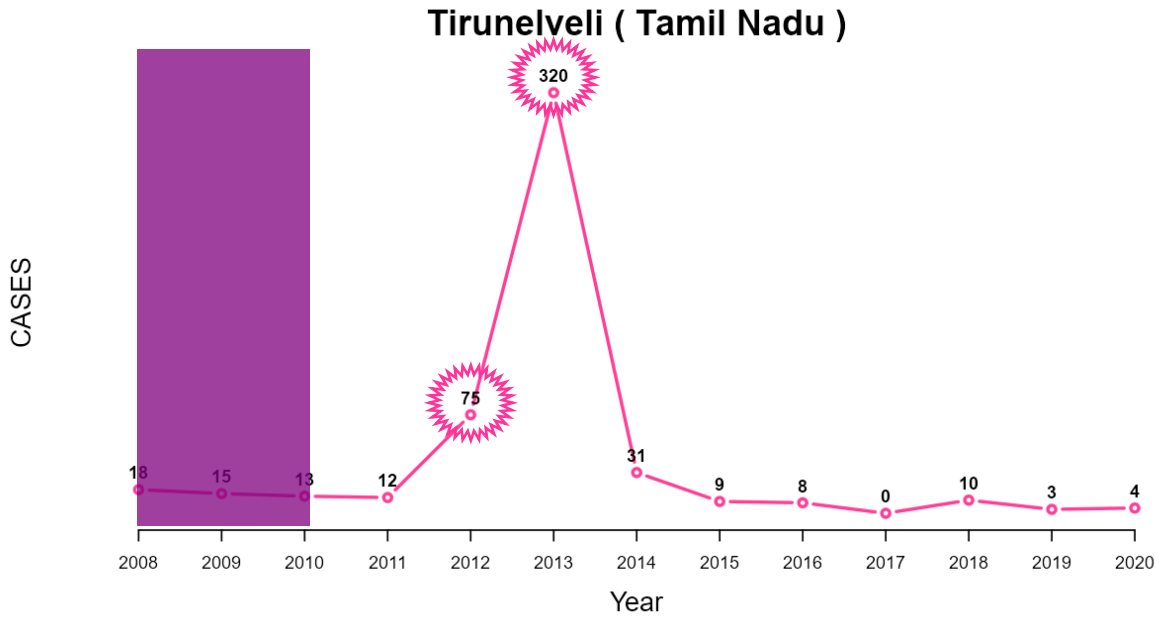
Tirunelveli (Tamil Nadu)
CASES
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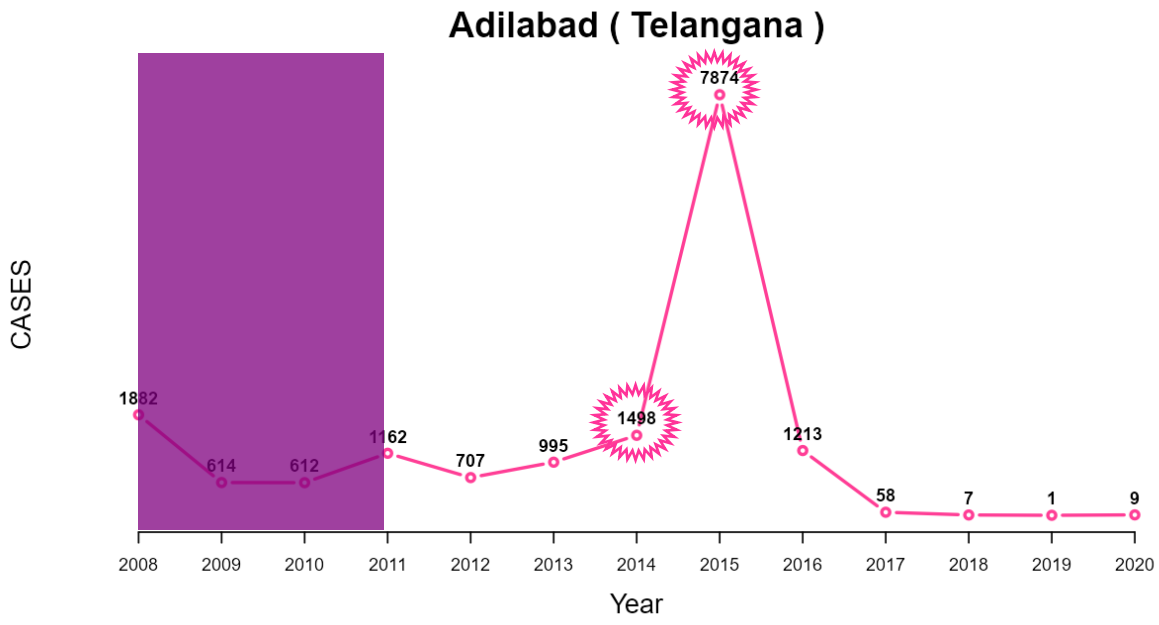
Adilabad (Telangana)
CASES
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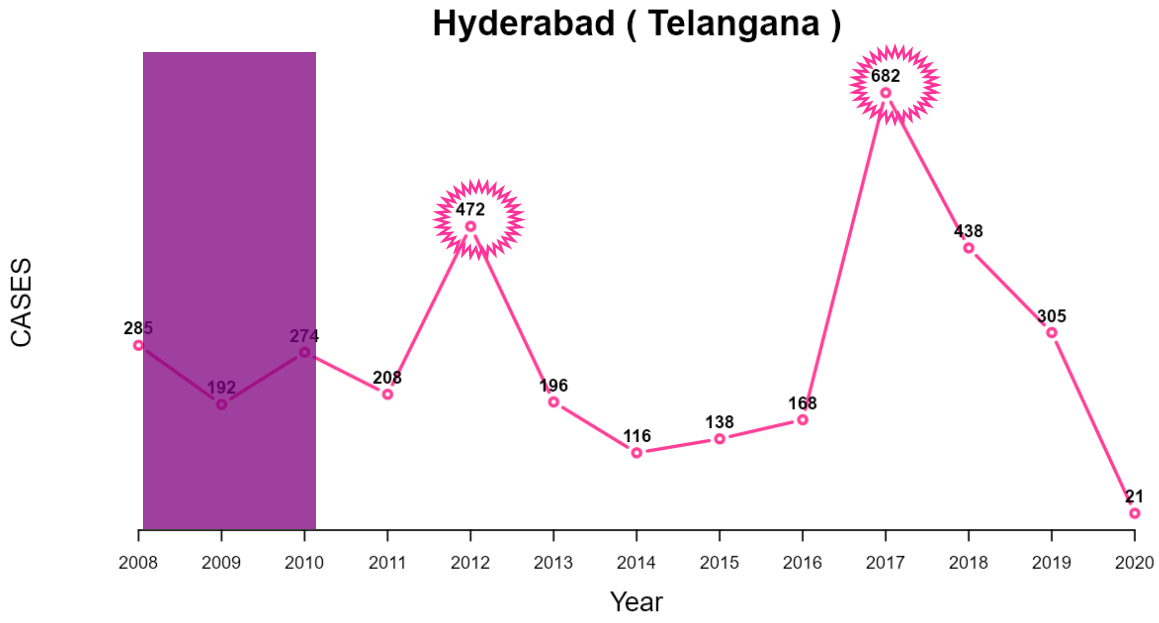
Hyderabad (Telangana)
CASES
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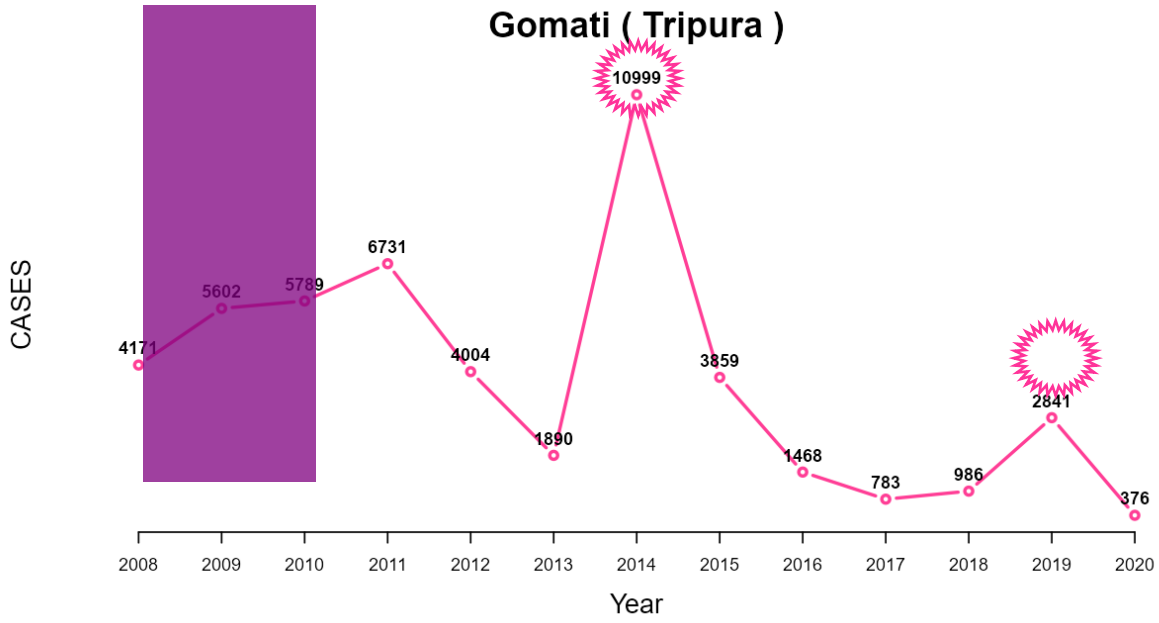
Gomati (Tripura)
CASES
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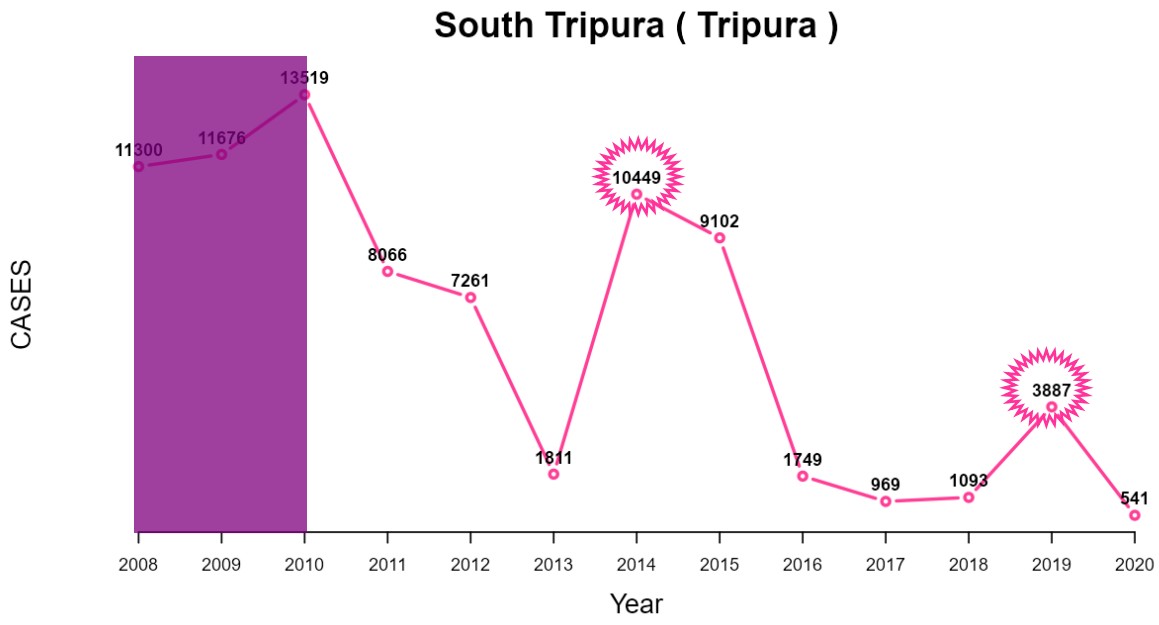
South Tripura (Tripura)
CASES
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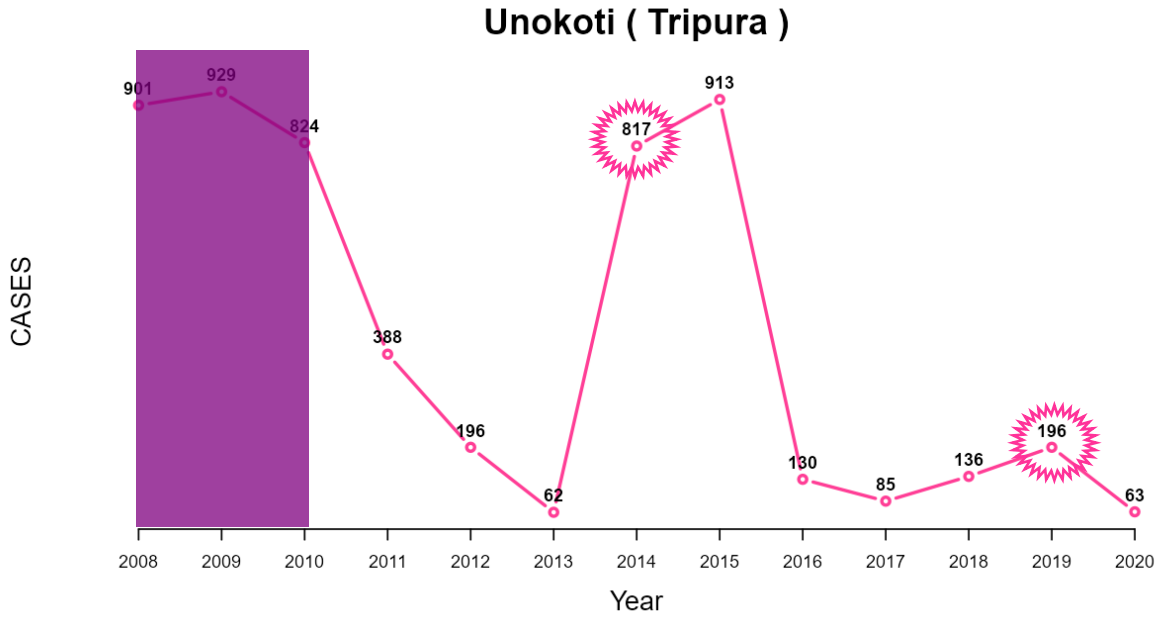
Unokoti (Tripura)
CASES
Year
901
929
824
388
196
62
817
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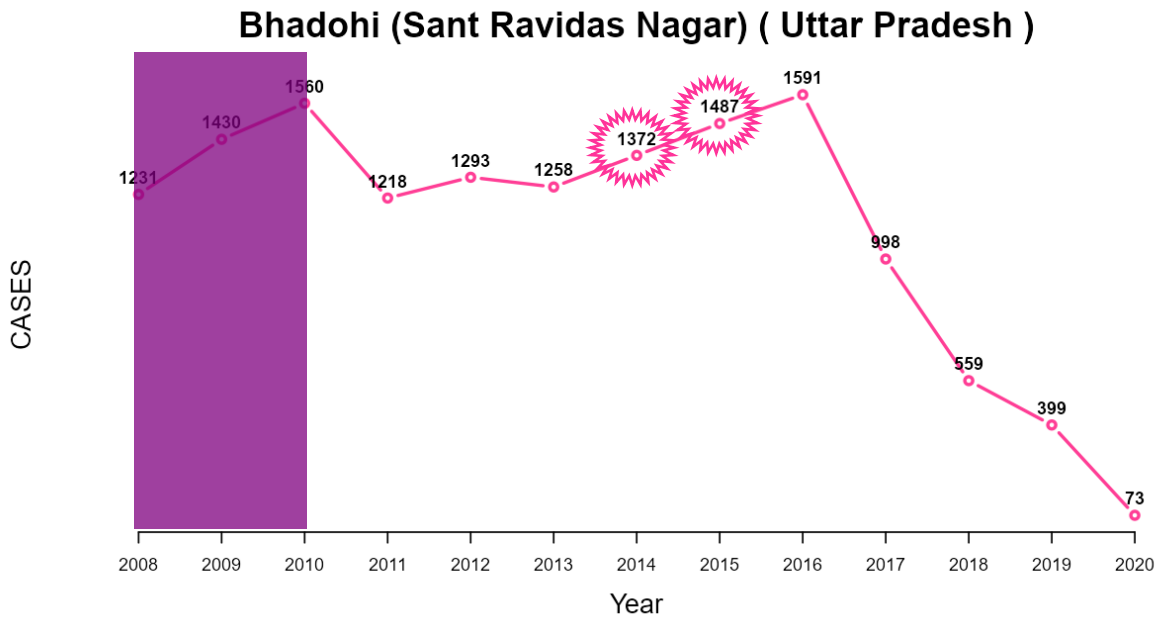
Bhadohi (Sant Ravidas Nagar) (Uttar Pradesh)
CASES
1231
1430
1560
1218
1293
1258
1372
1487
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399
73
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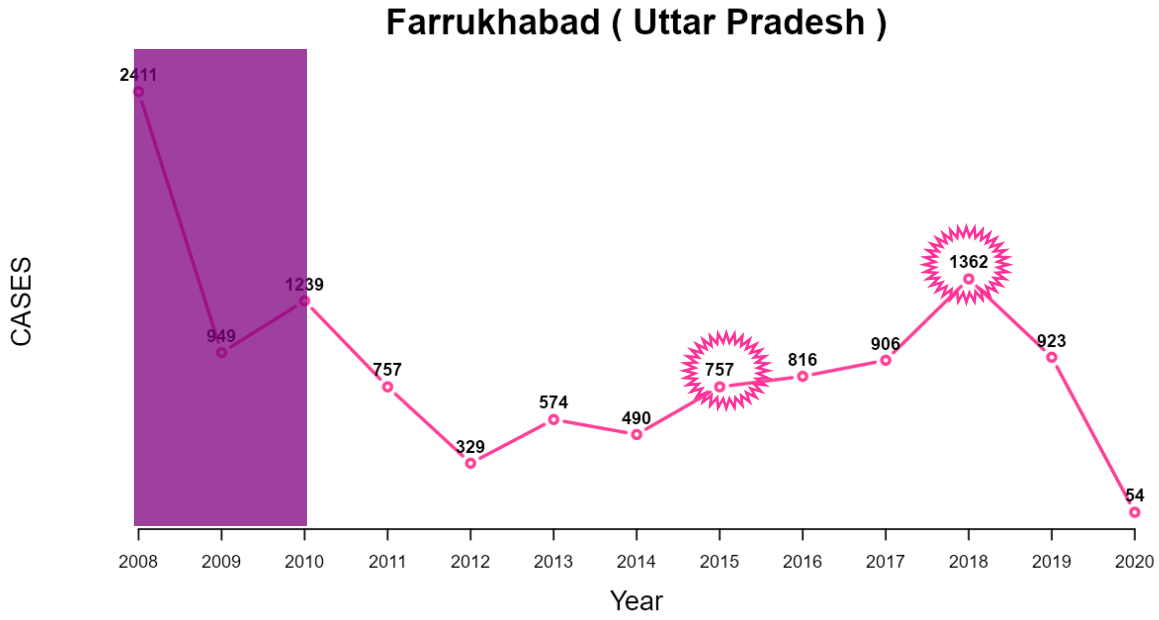
Farrukhabad (Uttar Pradesh)
CASES
Year
2411
949
1239
757
329
574
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923
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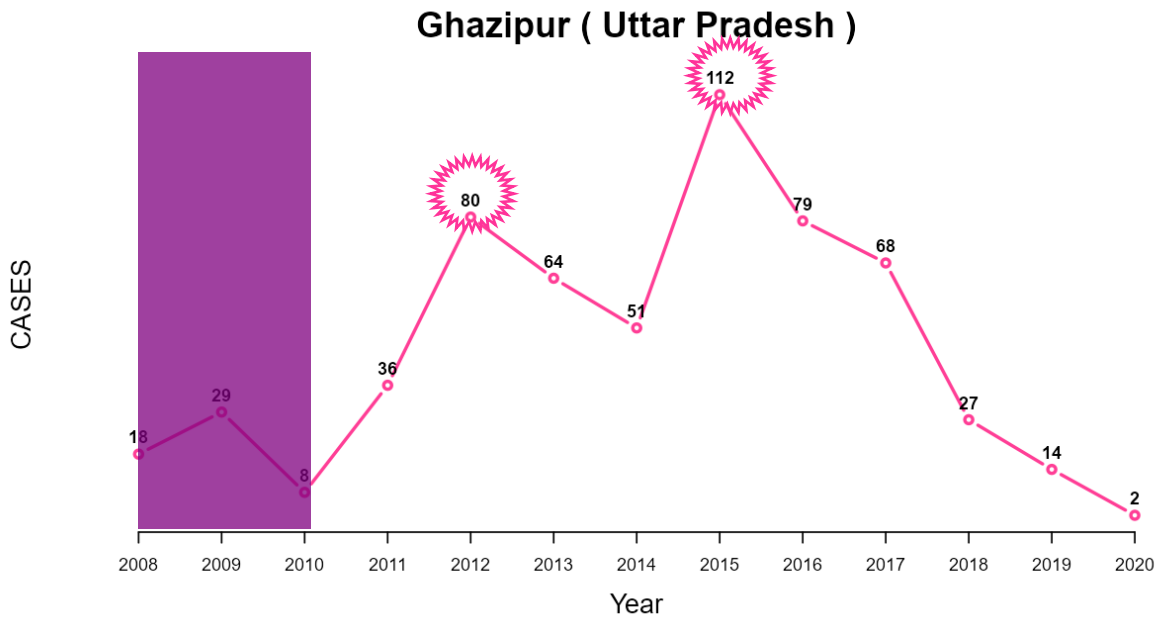
Ghazipur (Uttar Pradesh)
CASES
Year
18
29
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36
80
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112
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14
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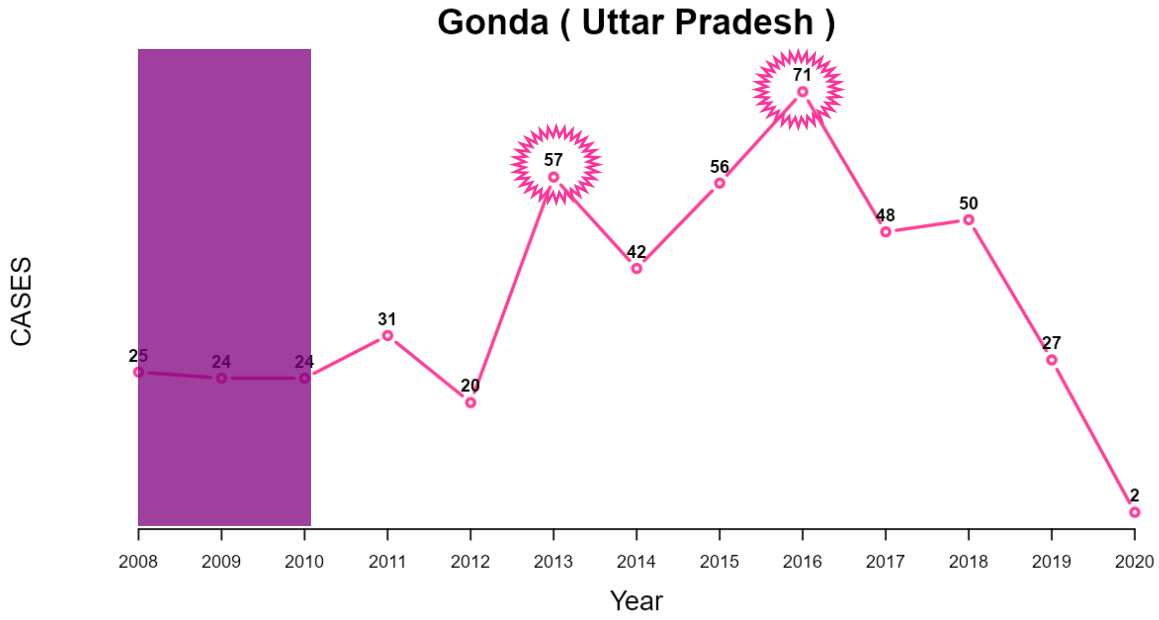
Gonda (Uttar Pradesh)
CASES
Year
25
24
24
31
20
57
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48
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27
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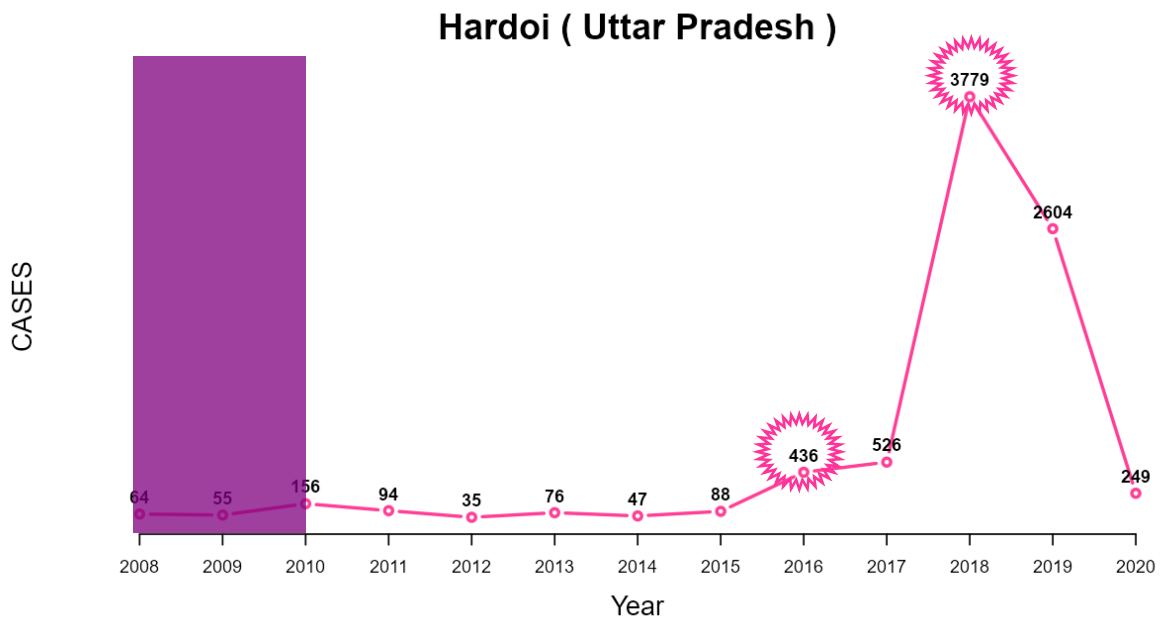
Hardoi (Uttar Pradesh)
CASES
Year
64
55
156
94
35
76
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3779
2604
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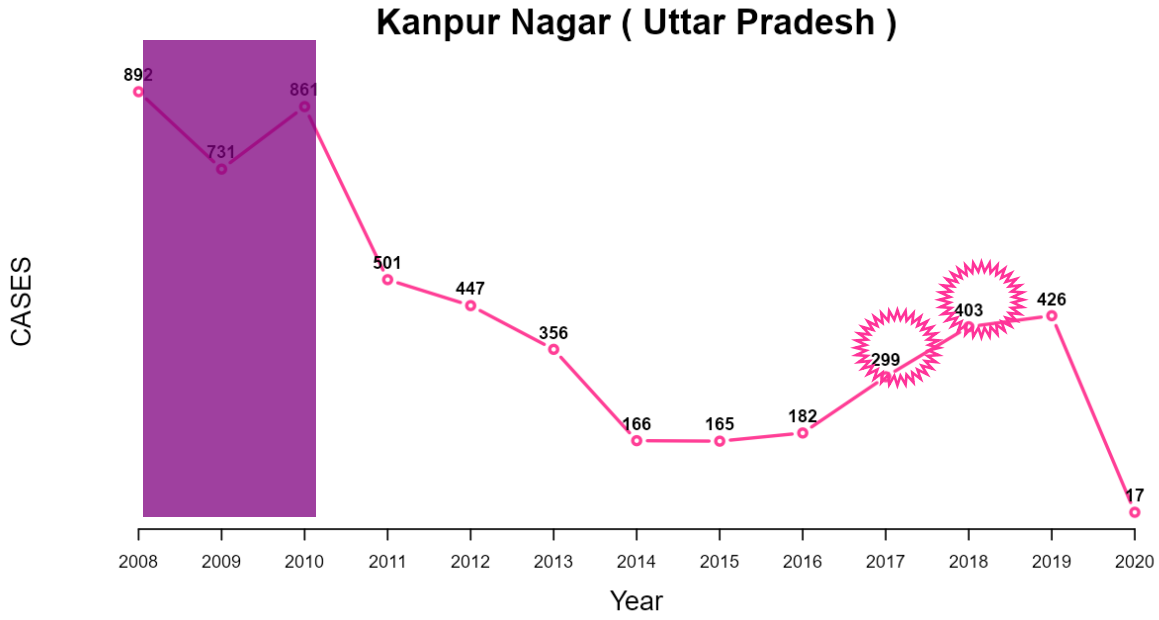
Kanpur Nagar (Uttar Pradesh)
CASES
892
731
861
501
447
356
166
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403
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17
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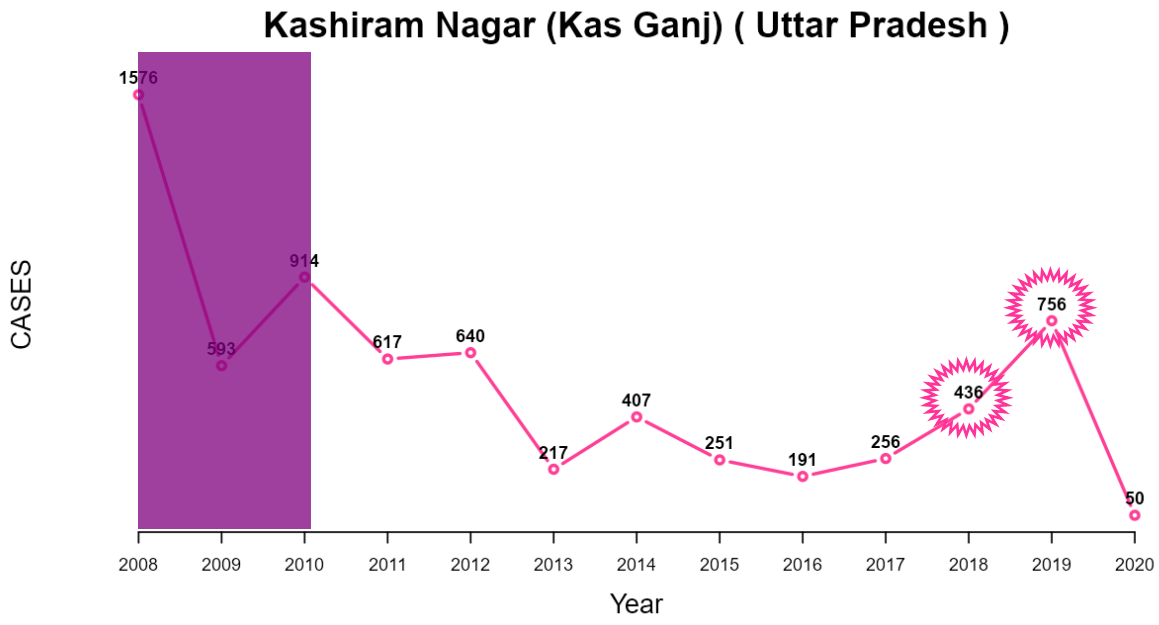
Kashiram Nagar (Kas Ganj) (Uttar Pradesh)
CASES
1576
593
914
617
640
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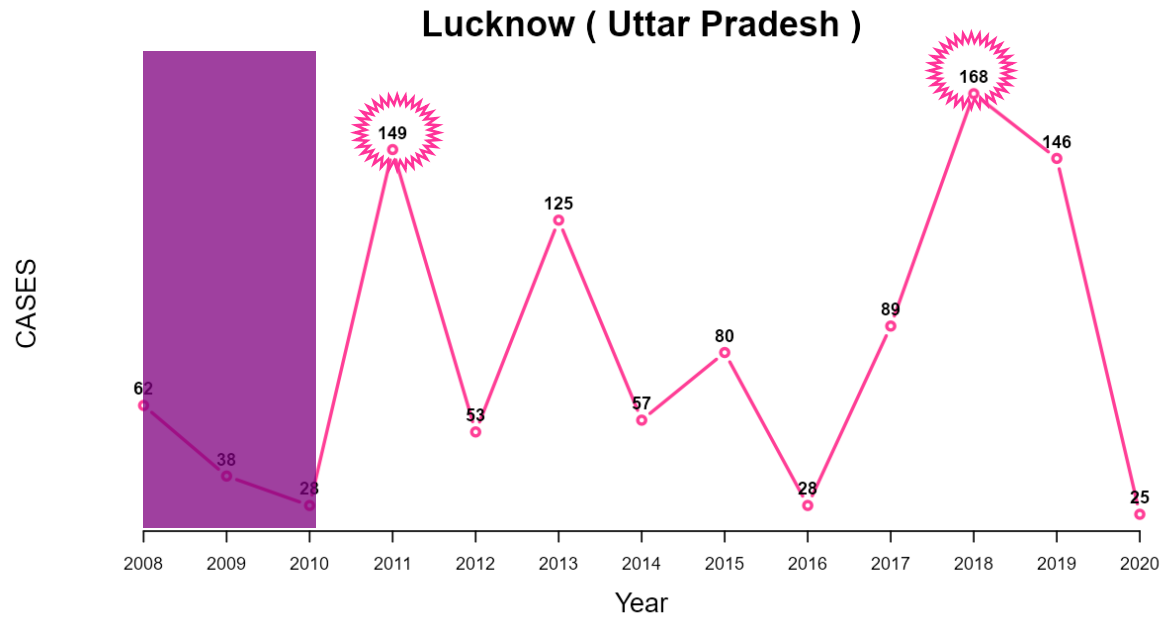
Lucknow (Uttar Pradesh)
CASES
Year
62
38
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149
53
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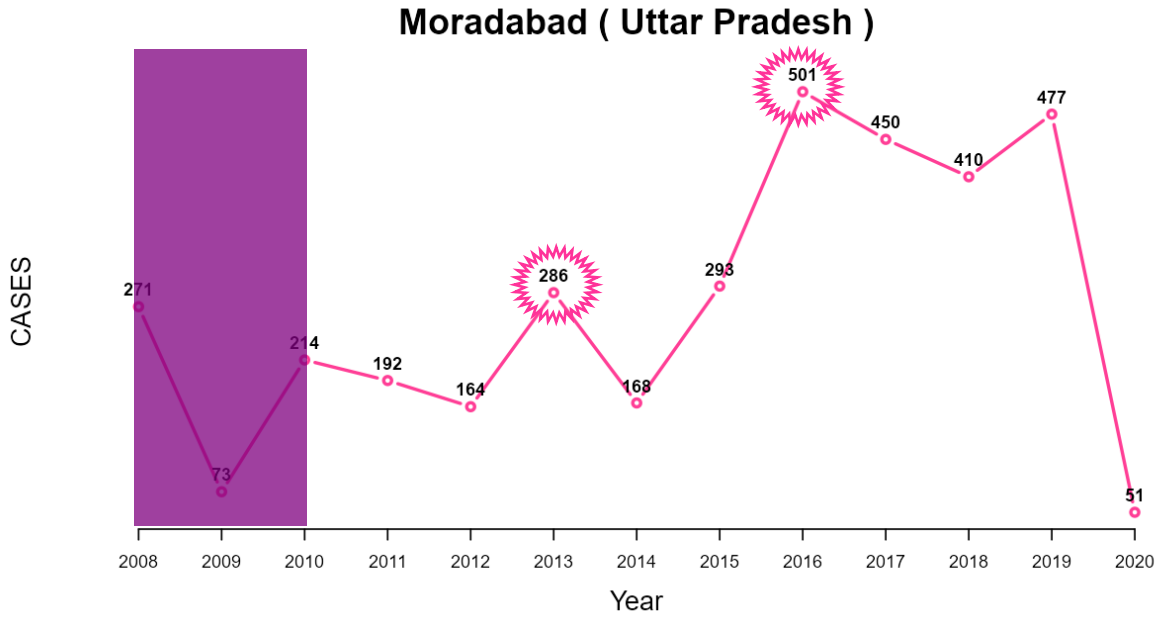
Moradabad (Uttar Pradesh)
CASES
271
73
214
192
164
286
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51
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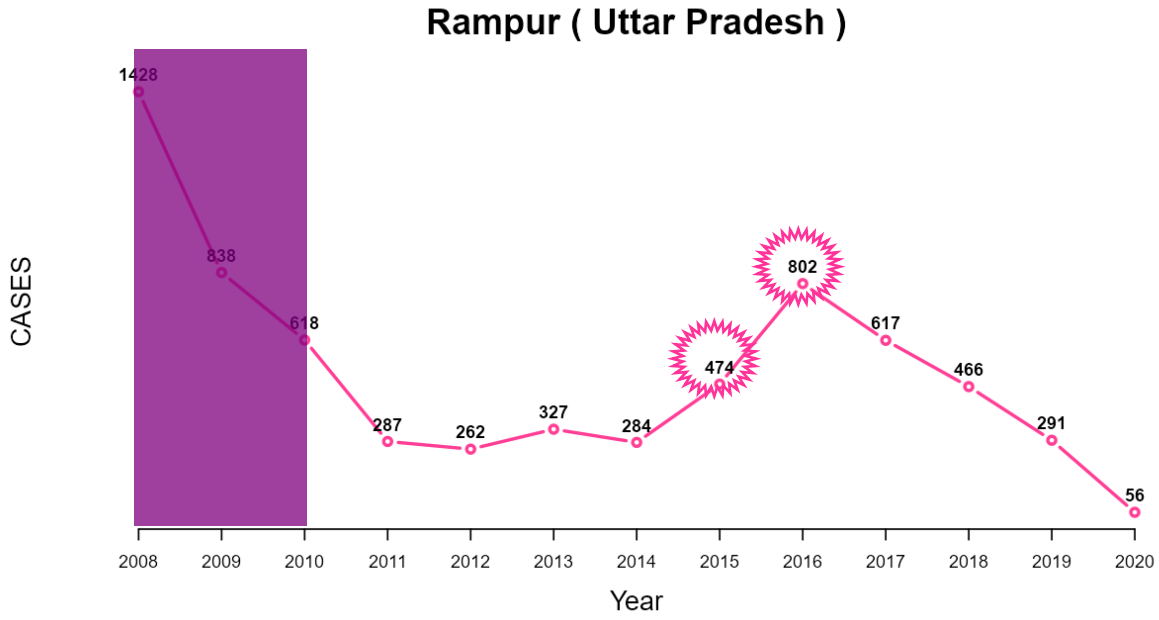
Rampur (Uttar Pradesh)
CASES
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262
327
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56
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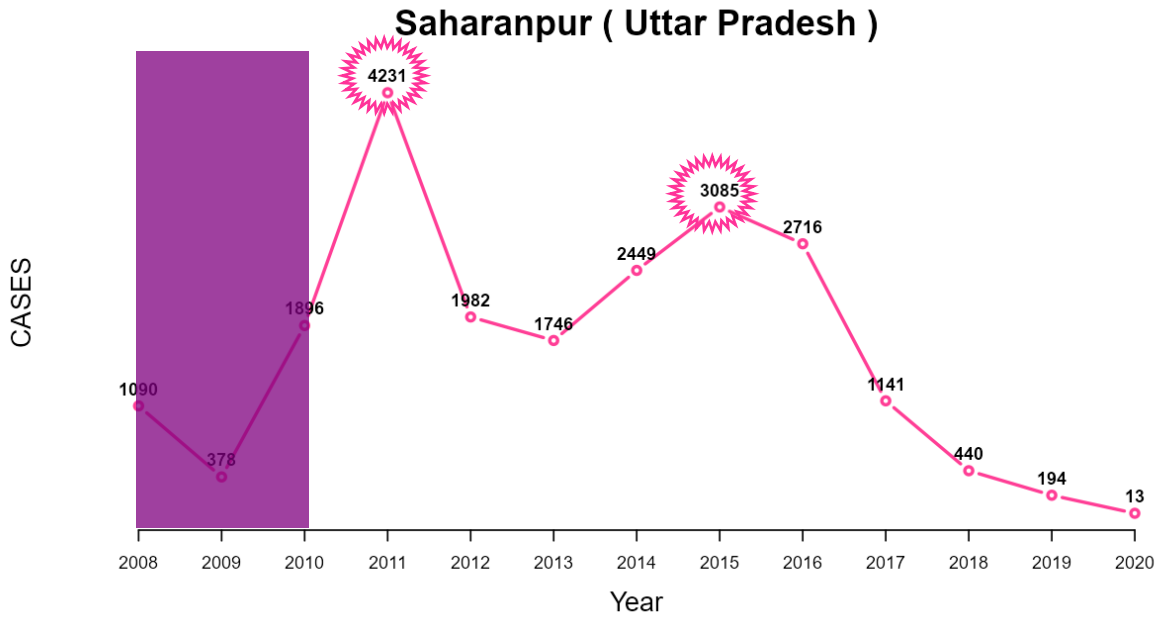
Saharanpur (Uttar Pradesh)
CASES
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1746
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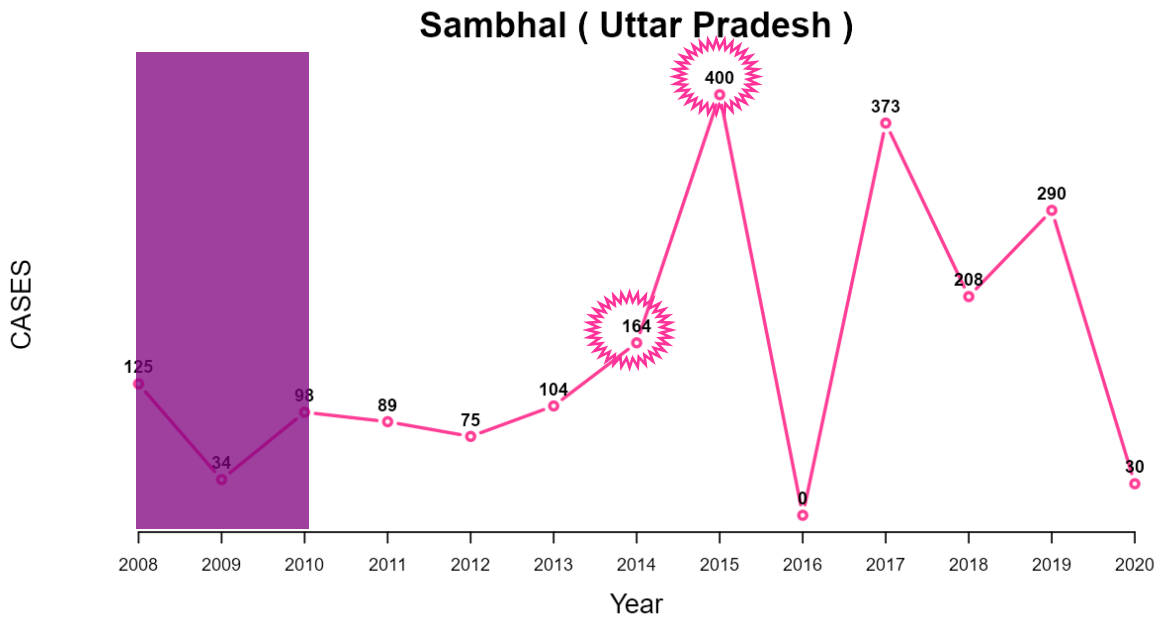
Sambhal (Uttar Pradesh)
CASES
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98
89
75
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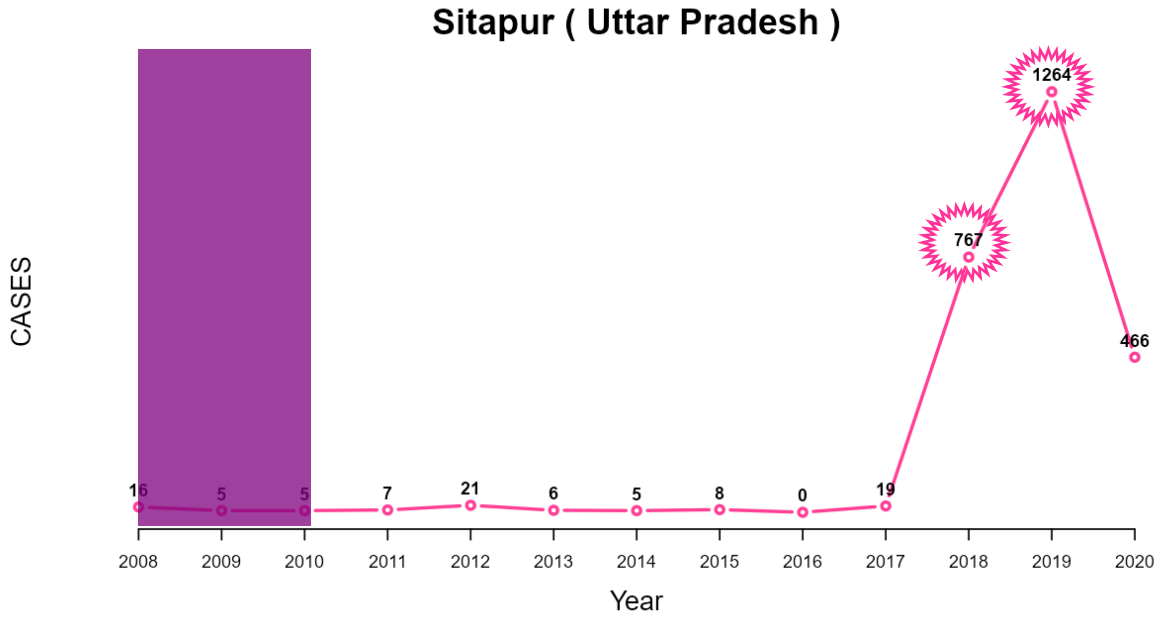
Sitapur (Uttar Pradesh)
CASES
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7
21
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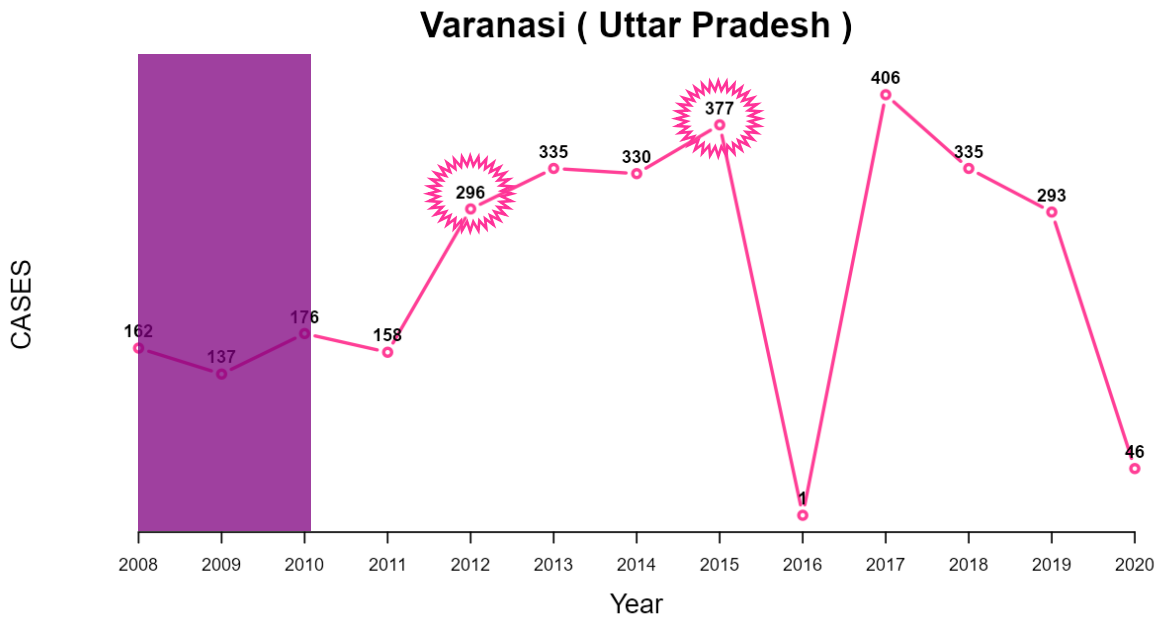
Varanasi (Uttar Pradesh)
CASES
Year
162
137
176
158
296
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293
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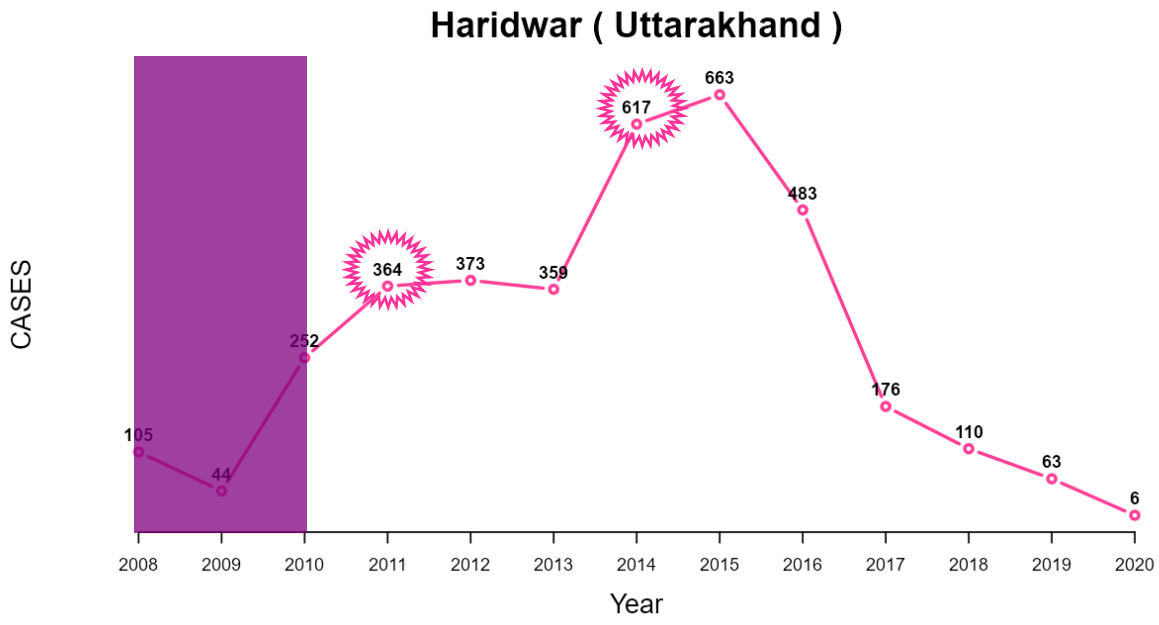
Haridwar (Uttarakhand)
CASES
105
44
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364
373
359
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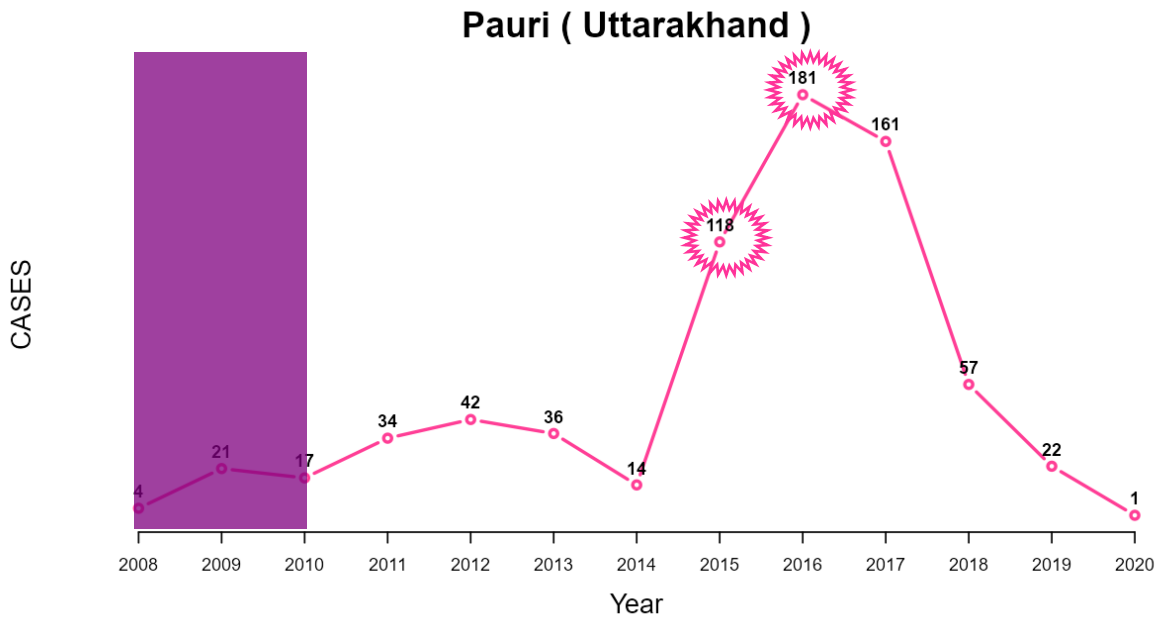
Pauri (Uttarakhand)
CASES
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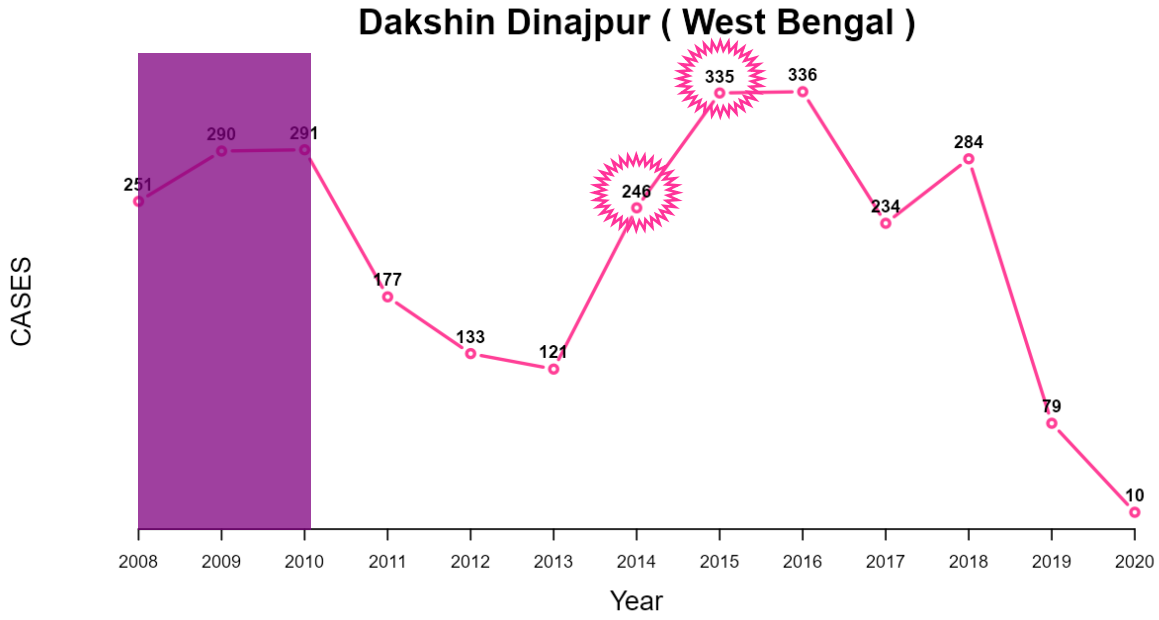
Dakshin Dinajpur (West Bengal)
CASES
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291
177
133
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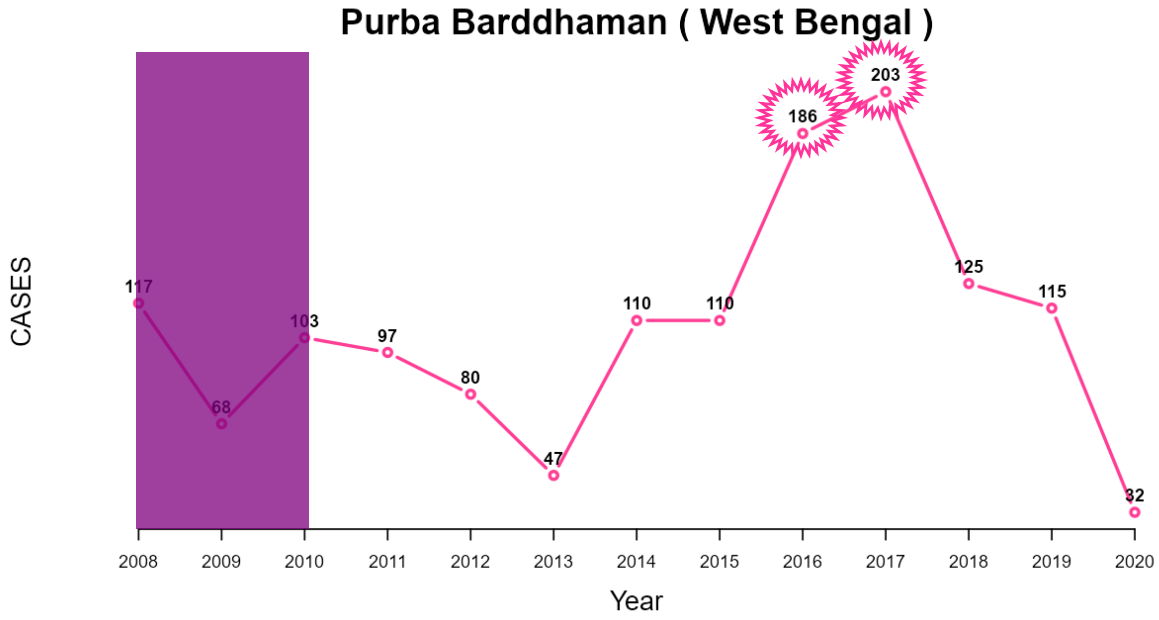
Purba Barddhaman (West Bengal)
CASES
Year
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103
97
80
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115
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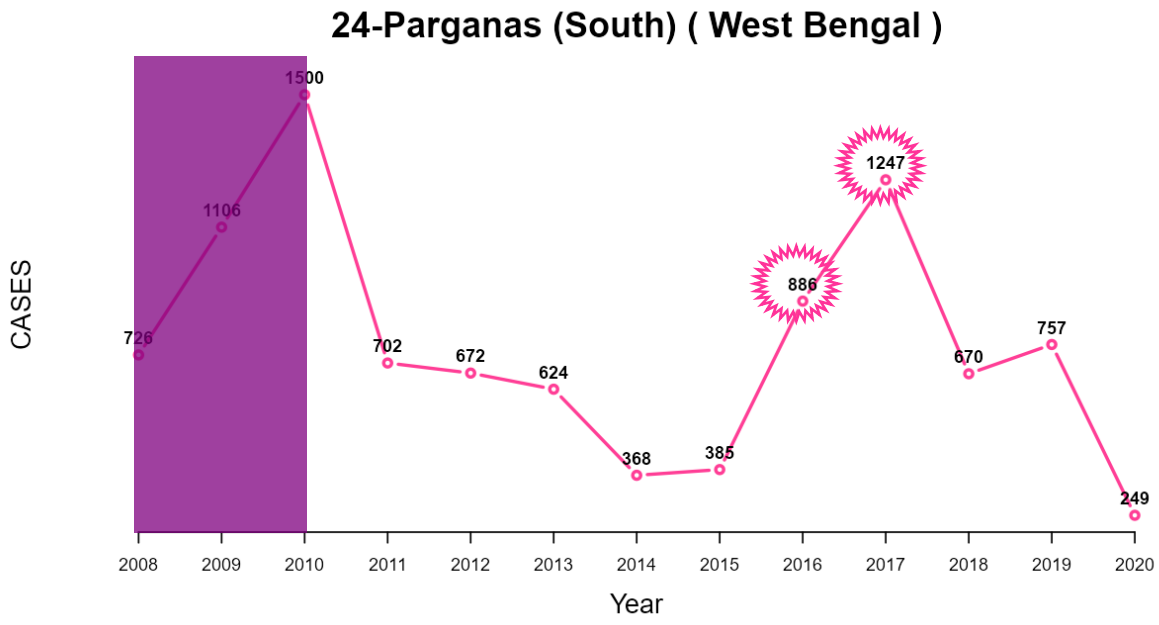
24-Parganas (South) (West Bengal)
CASES
Year
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1106
1500
702
672
624
368
385
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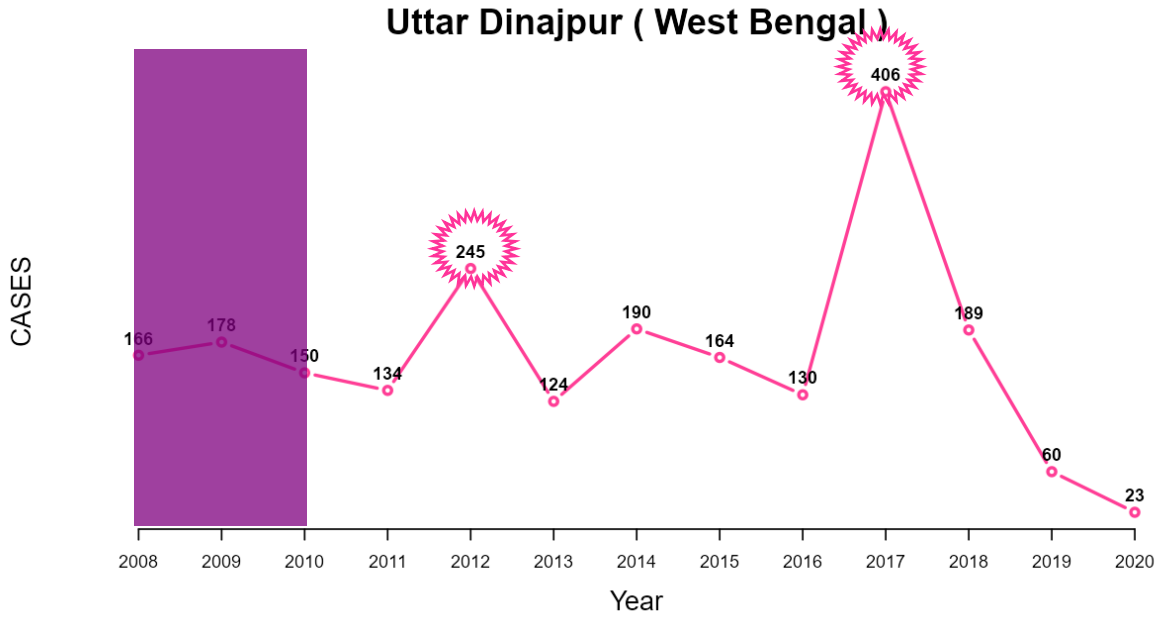
Uttar Dinajpur (West Bengal)
CASES
166
178
150
134
245
124
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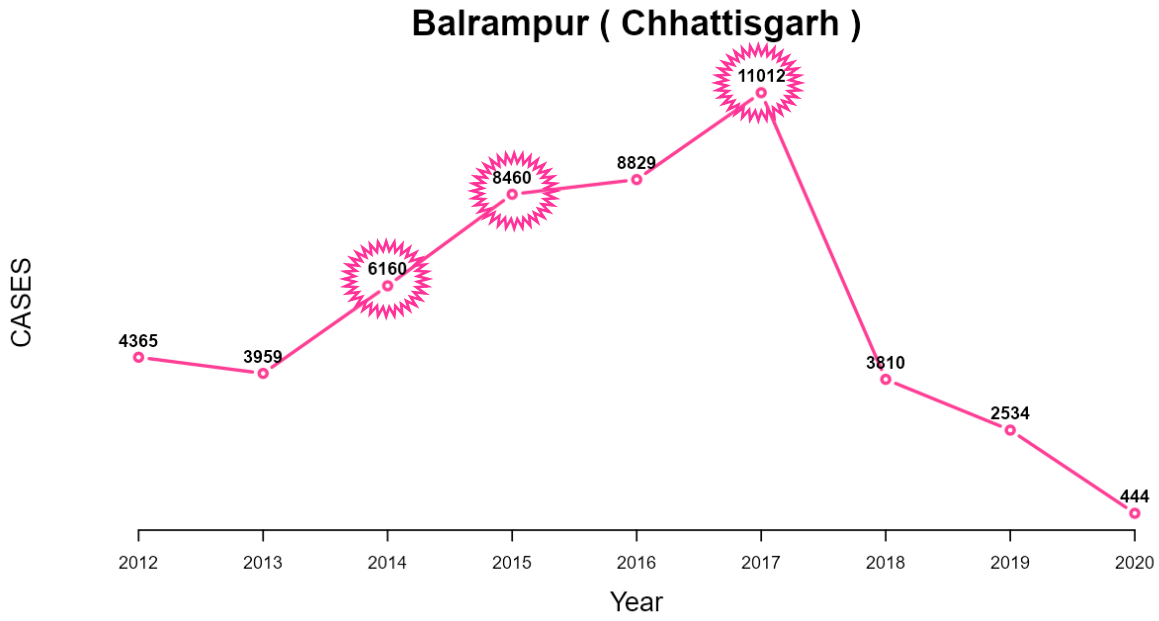
Balrampur (Chhattisgarh)
CASES
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11012
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444
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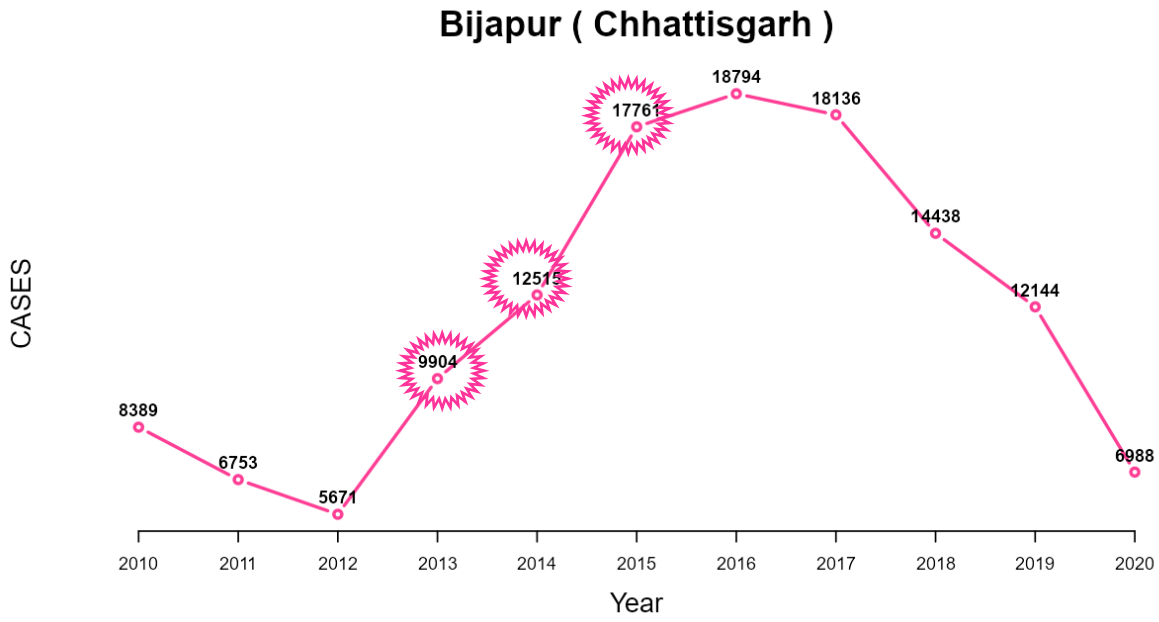
Bijapur (Chhattisgarh)
CASES
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