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Exploring extreme flood events of a western state of India during monsoon season of 2019 from space

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सार – महाराष्ट्र ने 2019 के मॉनसून ऋतु में जुलाई और सितंबर महीनों के दौरान विनाशकारी बाढ़ की घटनाओं की एक श्रृंखला का अनुभव किया, जिससे लाखों लोग प्रभावित हुए। महाराष्ट्र के मुंबई, पालघर, ठाणे, रायगढ़, सतारा, सांगली, पुणे और कोल्हापुर सबसे अधिक प्रभावित जिले थे। इन परिघटनाओं पर नज़र रखने के लिए इस अध्ययन में अंतरिक्ष से लगभग वास्तविक समय के उपग्रह अवलोकनों का उपयोग किया गया है। मल्टी-स्पेक्ट्रल उपग्रह सेंसर से अवलोकनों को एकीकृत करने वाले वर्षा एल्गोरिदम से 5 किमी (आधे-आधे घंटे) के बहुत अच्छे रिज़ॉल्यूशन पर सटीक वर्षा की जानकारी की उपलब्धता बाढ़ की परिघटनाओं की प्रभावी ढंग से निगरानी करने का एक उत्कृष्ट अवसर प्रदान करती है। इस मॉडल की उपयोगिता का परीक्षण 2013 में केदारनाथ, 2014 में जम्मू और कश्मीर और 2015 में तमिलनाडु में बाढ़ की परिघटनाओं की जांच करके किया गया। इस मॉडल का उपयोग 2019 में केरल और असम की हालिया बाढ़ की घटनाओं का पता लगाने के लिए भी किया गया।

मुंबई, पालघर, ठाणे, रायगढ़, सतारा, सांगली, पुणे और कोल्हापुर जिलों में जुलाई के पहले, तीसरे और आखिरी सप्ताह में और सितंबर के दूसरे और आखिरी सप्ताह के दौरान कई बार भारी बारिश हुई, जिसके परिणामस्वरूप इन जिलों में भारी बाढ़ आ गई। परिणाम बताते हैं कि इनमें से कुछ जिलों में जुलाई से सितंबर के दौरान भारी बारिश की कई परिघटनाओं से 2000 मिमी से अधिक संचयी वर्षा हुई। जुलाई और सितंबर के दौरान मुंबई, पालघर, ठाणे और रायगढ़ में 1700 मिमी से अधिक संचयी वर्षा हुई। जुलाई 2019 के दौरान सांगली जिले में औसत मासिक वर्षा से लगभग 200% अधिक वर्षा हुई। कई बार हुई संचयी भारी वर्षा के परिणामस्वरूप महाराष्ट्र के विभिन्न जिलों में भीषण बाढ़ आ गई। इस अध्ययन में बताए गए परिणाम बाढ़ आपदाओं के विरूद्ध शमन और अनुकूलन की रणनीतियों के महत्व पर प्रकाश डालते हैं।

ABSTRACT. Maharashtra experienced a series of calamitous flood events during July and September months of monsoon season of 2019 affecting millions of people. Mumbai, Palghar, Thane, Raigad, Satara, Sangli, Pune and Kolhapaur were most affected districts of Maharashtra. Near real time satellite observations from space have been used in this study to monitor these events. Availability of accurate precipitation information at very fine resolution of 5 km (half hourly) from a rainfall algorithm that integrates observations from multi-spectral satellite sensors offers an excellent opportunity to monitor flood events effectively. Utility of this model was tested by investigating flood events of Kedarnath in 2013, Jammu and Kashmir in 2014 and Tamil Nadu in 2015. This model was also used to explore recent flood events of Kerala and Assam in 2019.

Mumbai, Palghar, Thane, Raigad, Satara, Sangli, Pune and Kolhapaur districts received very heavy rainfall from multiple rain episodes during first, third and last week of July, and second and last week of September that resulted in heavy flooding over these districts. Results reveal that few of these districts received cumulative rainfall in excess of 2000 mm from multiple heavy rainy events during July to September. Mumbai, Palghar, Thane and Raigad received a cumulative rainfall in excess of 1700 mm during July and September. Sangali district received an excess of about 200% rainfall than average monthly rain during July 2019. Heavy cumulative rainfall from multiple rain spells resulted in heavy flooding over various districts of Maharashtra. Results reported in this study highlight the importance of mitigation and adaptation strategies against flood disasters.

Key words – Monsoon, Flood, Disaster, Climate change, Satellite remote sensing.

1. Introduction

Recent studies have reported significant changes in precipitation pattern over India resulting in rise in flood events due to increased heavy rain (Goswami *et al*., 2006; Rajeevan *et al*., 2008; Mishra and Liu 2014; Mishra *et al*., 2019). Majority of States in India experienced flood like situation in recent years (Mishra and Srinivasan 2013; Mishra 2015; Mishra 2016; Ray *et al*., 2019; Mishra and Nagaraju 2019; Mishra *et al*., 2019). Flash flooding due to heavy rainfall from multiple rainy spells resulted in heavy losses and affected millions of people. Maharashtra is very prone to floods due to very heavy rainfall during Monsoon season. Maharashtra witnessed a very heavy flooding in 2005 events due to extreme rainy events over some of the districts (Bohra *et al*., 2006). Flood related natural disasters can not be stopped but proper monitoring of these events can be very useful in mitigation and adaptation strategies for minimizing the damage. Flood events over larger areas are difficult to monitor using conventional rain gauges and radars due to their limited coverage. Large scale floods can be monitored by satellite observations. Mishra (2012) devised a rainfall monitoring technique by integrating multiple-frequency observations from satellite to measure heavy rainfall at fine temporal and spatial scale. Usefulness of this technique was validated by exploring flood events of Kedarnath (Mishra and Srinivasan 2013), Jammu and Kashmir (Mishra 2015) and Tamilnadu (Mishra 2016), Kerala (Mishra and Nagaraju 2019), Bihar and Assam (Mishra *et al*., 2019). Present research focuses on exploring heavy flooding over Maharashtra during June-September 2019 using satellite observations from Mishra (2012). High temporal and spatial resolution of the observation helps in exploring the diurnal feature of heavy rain spells.

2. Materials and methods

Mishra (2012) integrated observations from Meteoat First Generation (MFG) satellite with Space borne Precipitation Radar (PR) from Tropical Rainfall Measuring Mission (TRMM) to derive an algorithm for measuring rainfall at 5 km spatial resolution. A rain index was computed using observations from Thermal Infra Red (TIR) and Water Vapor (WV) Absorption channels of Meteosat. WV channel supplements rain signature with moisture and hydrometeor information at mid to upper level troposphere. Using large data sets during monsoon season of multiple years, brightness temperature at TIR and WV channels are compared against rain rate from PR to define non-rainy brightness temperature thresholds and then are divided by non-rainy brightness temperature threshold to get rain coefficients and their product is defined as rain index. Rain indices thus obtained are collocated against rainfall from PR to establish a non-linear relationship between them. This non-linear equation is used to monitor hourly rainfall using brightness temperatures as inputs. Detail of the equation is described by Mishra (2012). Performance of this technique for estimating heavy precipitation was tested by validation against rain gauge observations. A correlation coefficient of 0.70, bias of 1.37 mm/h, root mean square error of 3.98 mm/h, probability of detection of 0.87, false alarm ratio of 0.13 and skill score of 0.22 is reported against hourly rain gauge observations over India during South-West monsoon season (Mishra, 2012). Comparison with available global rainfall products shows that technique adopted by Mishra (2012) outperforms other precipitation products for depicting heavy rainfall over India.

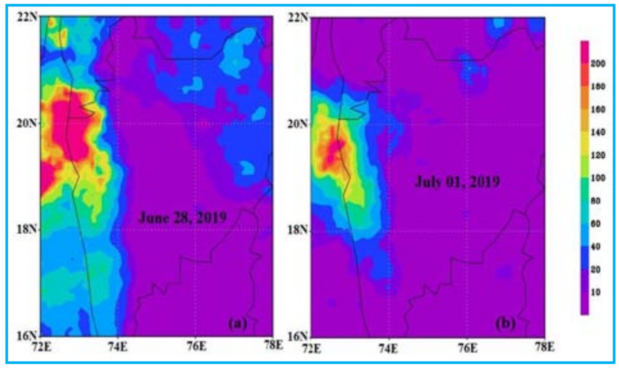
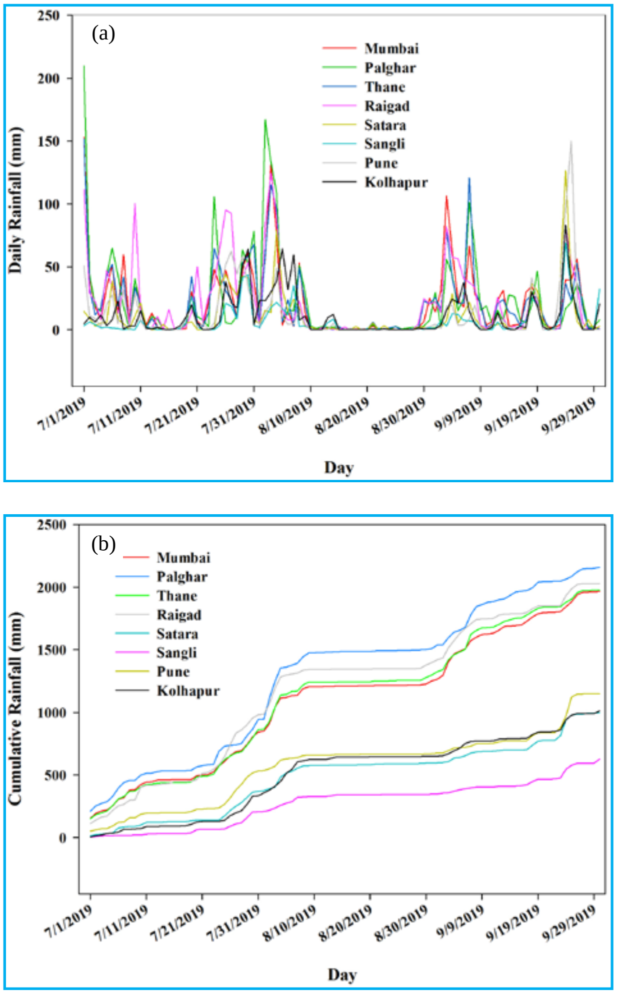


Fig. 1. Spatial distribution of rainfall during June 28 and July 01 2019

3. Results and discussions

Hourly rainfall is estimated following technique described in above section using observation from Meteosat second Generation (MSG) at 5 km resolution. Rainfall accumulation is done from 0300 GMT to 0300 GMT of next day. It was observed that maximum rainfall occurred during June 28 and July 01, 2019 as depicted in Fig. 1. A peak rainfall of about 200 mm/day were recorded over few districts of Maharashtra on these two days.

Fig. 2(a&b) depicts time series of daily rainfall over districts of Maharashtra during July and September 2019. Palghar received heaviest rainfall of about 220 mm on July1, 2019. Other districts received heavy rainfall in multiple episodes during first and last week of July, last week of August, first and last week of September. Multiple rainy episodes resulted in heavy cumulative rainfall over these districts bringing heavy flooding. Mumbai, Palghar, Thane and Raigad received a cumulative rainfall in excess of 1700 mm during July and September. Palghar recorded a maximum cumulative rainfall of about 2200 mm during July and September



Figs. 2(a&b). (a) Time series of daily rainfall and (b) Accumulated rainfall over flood affected districts of Maharashtra during July-September 2019

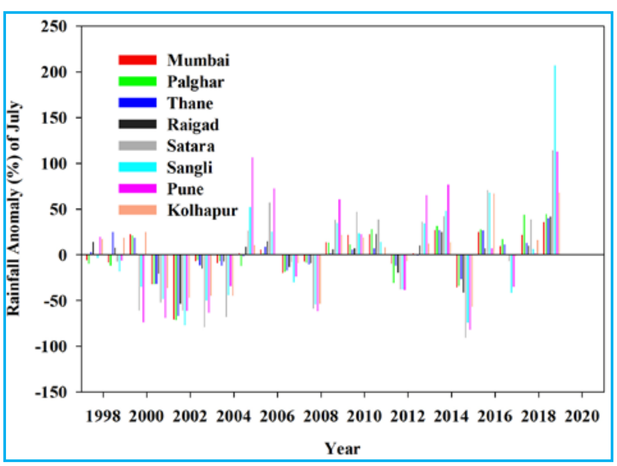


Fig. 3. Rainfall anomaly over Maharashtra in July 2019 over flood affected districts

TABLE 1

Comparison of climatological normal of 5 districts of Maharashtra from Satellite and Rain gauges for July month during 1998-2019

Districts	Climatological normal for July month from IMD Rain gauge (mm) (1998-2019)	Climatological normal for July month from Satellite (mm) (1998-2019)
Mumbai	921.84	887.52
Satara	225.16	214.75
Sangli	88.25	79.65
Pune	190.43	173.67
Kolhapur	286.35	250.34

2019. Satara, Pune and Kolhapur also received cumulative rainfall in excess of 500 mm during these rainy spells.

Fig. 3 illustrates the rainfall anomaly in (%) of flood affected districts in July using long term trends from 1998-2019. It can be seen that Sangali, Pune, Satara, Mumbai, Kolhapur, Raigad, Palghar, Thane received above normal rainfall during July 2019 from multiple rainy spells. Sangali recorded rainfall in excess of 200% of normal. Pune and Satara also received rainfall in excess of 100% of normal rainfall. It was the second heaviest rainfall in Mumbai in the last 45 years. Heavy rains led to the collapse of multiple walls, which caused most of the deaths. A municipal wall in a Mumbai slum killed 21 when it fell. Six died after another wall collapsed in Pune, and three died after one fell in Thane, a suburb of Mumbai. Results reported in this research validate the efficiency of satellite remote sensing for near real time monitoring of flood events. This can be very useful for minimizing the damage caused by flood disasters.

We also have compared the climatological mean of July month from Satellite with rain gauge observations from IMD. For this purpose, 5 districts namely (Mumbai, Satara, Sangli, Pune and Kolhapur) were used because for 3 other districts there was data gap for 4 or more years during 1998-2019. A comparison of these values is presented in Table 1.

It can be seen that the climatological normal from Rain gauge and satellite is in good agreement. Lower values of climatological normal from Satellite as compared to rain gauge is attributed to the fact that satellite underestimates rainfall as compared to rain gauges due to larger foot print. Rain gauges have very limited coverage and sometimes heavy rain fall sweep away these gauges which in turn limits the applicability of

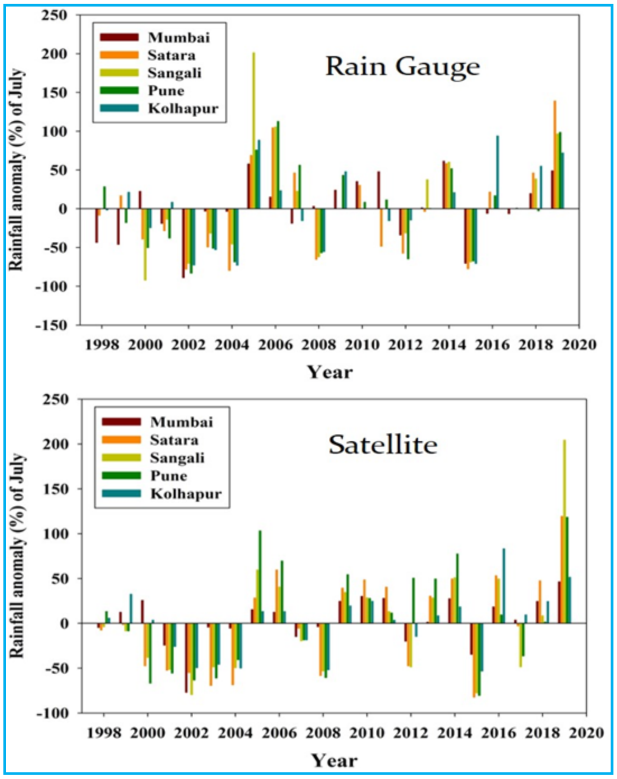


Fig. 4. Shows the comparison of anomaly (%) in July during the period 1998-2019

rain gauges for monitoring heavy rain induced flash flooding.

Fig. 4 shows the comparison of anomaly (%) in July during the period 1998-2019.

It can be seen that both rain gauge and satellite shows above normal rainfall for July 2019 over the districts Mumbai, Satara, Sangali, Pune and Kolhapur.

4. Conclusions

This research focuses on exploring a flood event of Maharashtra in 2019 using remote sensing application. Results report that multi-day heavy precipitation during July to September caused record cumulative rainfall over few districts which triggered catastrophic flash flooding. This paper also highlights the importance of remote sensing technique for near real time monitoring of flood disasters. Radars and rain gauges have very limited coverage and thus are not suitable for monitoring heavy rain induced flash flooding. Past studies report significant increase in flash flooding due to increase in extreme precipitation over Indian region (Rajeevan *et al.*, 2008; Mishra and Liu, 2014). Recent decades witnessed multiple flood events over Maharashtra due to changed precipitation patterns induced by climate change (Mishra and Liu, 2014). Considering the inaction in mitigating anthropogenic warming/climate change, disaster preparedness system is imperative for managing these disasters.

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Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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