Eco. Env. & Cons. 28 (November Suppl. Issue) : 2022; pp. (S481-S488)

ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i07s.079

Flood Mapping in Valley Districts of Manipur Using Satellite-based Synthetic Aperture Radar (SAR) Images

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(Received 23 June, 2022; Accepted 22 August, 2022)

ABSTRACT

Impacts from flood pose high risk to lives and properties of river plain inhabitants across the globe. Plains of Northeast India, including central valley in Manipur, often experience floods of variable intensities in different seasons of the year. Current flood mitigation measures of the region scarcely consider the dissimilarity in inundation patterns produced by floods of different seasons. Considering this, the current study examined the inundation pattern of pre-monsoon and monsoon floods in five valley districts of Manipur using Synthetic Aperture Radar (SAR) data of Sentinel-1 satellite. SAR images of April (pre-monsoon) and July (monsoon), and a pre-flood image (March) of the year 2017 were employed for the analysis. The results indicate that the extent of inundation during monsoon flood (20222 ha) was about four times larger than the pre-monsoon flood (4297 ha). Imphal West and Thoubal districts witnessed largest area under inundation during pre-monsoon and monsoon flood respectively. And moving from pre-monsoon to monsoon, Kaching, Thoubal Imphal East, and Bisnupur experienced the largest percentage climb in inundation area while it only changed slightly in Imphal West. This suggest that spatial pattern of flooding exhibited significant variations among the districts between the floods. Therefore, to be more effective in future, flood management strategies need inputs from flood mapping studies performed using space-based SAR data.

Key words : *Flood Mapping, SAR data, Pre-monsoon, Monsoon, Flood risk management*

Introduction

Globally flood causes maximum damage to live and properties out of all-natural hazards. Threat from flood continues to increase as population expands into flood prone areas and climate change makes extreme rainfall events more intense and frequent (Jongman, 2021). River plain areas in Indian subcontinent regularly experience inundation of varying severity. The impact of flood is more persistent on society, economy and environment when it occurs after heavy rainfall or huge volume of water drains from upstream to the plains. People inhabiting plains of northeast India have a long history of encounter with flood. The people of Brahmaputra plains, for example, witness devasting floods almost annually (Rao, 2020; Rahman, 2020). Central Valley of Manipur is another place in the region where floods occur on a regular basis. Here, past floods have impacted the lives of the people on numerous occasions and the risk from flood has increased in recent decades due to changes in population and socio-economic activities in areas prone to inundation (Mastec Report).

Information on spatial pattern of inundation is critical for future flood risk management but if generated in near real time (NRT), can also aid disaster rescue agencies. Flood mapping is traditionally performed through in-situ data collection, a process that is not only inaccurate and costly but impractical for rescue agencies. Remote sensing has been widely used as a more practical tool for mapping flood. Though flood map prepared by using satellite data may not prevent flood from happening but enables reduction of effects and the resulting losses. Synoptic perspective with good spatial resolution, ability to delineate flood extent and record permanently are some of the advantages of this technology over in-situ and other data sources. Since images obtained at shorter wavelengths from passive sensors have penetration problems through cloud cover during floods, satellites with active sensor that operate at microwave bands have been preferred for flood mapping. Accessibility and technology barriers to such data have also got drastically reduced in recent times as they are freely available shortly after acquisition and due to the proliferation of open source processing software.

In Manipur, previous studies on flood in the central valley have not made use of the microwave images acquired by Synthetic Aperture Radar (SAR) sensors for inundation pattern analysis even though this technology has been utilized extensively elsewhere in flood hazard mapping. The resulting information deficiency has limited decision-making regarding flood risk management in the state. In view of the above considerations, the goal the of present study is togenerate detailed inundation maps of pre-monsoon (April) and Monsoon (July) floods of 2017 in five valley districts of Manipur with the following objectives:

1. To analyse the inter-district spatial pattern of inundations between the two floods with the aim to understand causal factors of flood.
2. To explore the utility and suitability of SAR based technology particularly Sentinel-1 image in developing accurate flood maps in Manipur.

Materials and Methods

Study Area

The study area encompasses five valley districts of Manipur viz. Imphal (West & East), Thoubal, Bishnupur and Kakching and correspond to Imphal river basin where its tributaries also drains in north to south direction. A few smaller streams (Nambol and Nambul) are inland rivers that drains into the Loktak Lake. The Location map of the study area is shown in Fig. 1(a). The valley districts occupy only 10 % of the total geographical area of the state but due to high population density 57% of its population inhabits the valley. Due to overall gentle terrain and network of rivers and streams, floods of varying intensity occur in pre-monsoon and monsoon seasons from time to time. During monsoon season from June to September, in years with anomalously high monsoon rains, many rivers overflow their banks flooding surrounding lands. This often endanger agriculture and properties of the people in the valley. Being the rice bowl of the state, frequent flooding in these districts potentially affects the food security of the local people and the state.

Data and SAR Pre-processing Techniques and Flood Extent Extraction

For flood area mapping, three Sentinel-1 images were downloaded for the study area directly from the *Alaska Satellite Facility, NASA*. These images were acquired in C-band (3.75-7.5cm) within the microwave portion of the electro-magnetic spectrum in interferometric (IW) mode with a minimum swath of 250km. Although images with multiple polarisation mode was available, vertically emitted and vertically received (VV) SAR images were used in the study. In terms of degree of processing, the images were level-1 ground range detected (GRD) products (Table 1). Three SAR images obtained in different time periods were used in mapping flooded areas as two sets of remotely sensed images, before the flood and during the flood, are required to distinguish between flooded area and permanent water bodies. In disaster mapping, the former is termed as an archive image used generally for reference and the latter is known as crisis image.

Images were processed with Sentinel Application Platform (SNAP), an open-source software available at Copernicus Hub (ESA). Step-by-step methodology applied on the archive image and crisis images to map flood inundated areas is given in Fig. 1(b). Standard procedure for pre-processing Sentinel-1 SAR data described by Filipponi (2019) was used for this study. First step involves extraction of study area from the Senitinel-1 images whose single scene typically covers much larger area. Multi-looking process was then performed on the subset images to reduce speckles present on SAR data. This enhances interpretability of the image and also speeds up pro-

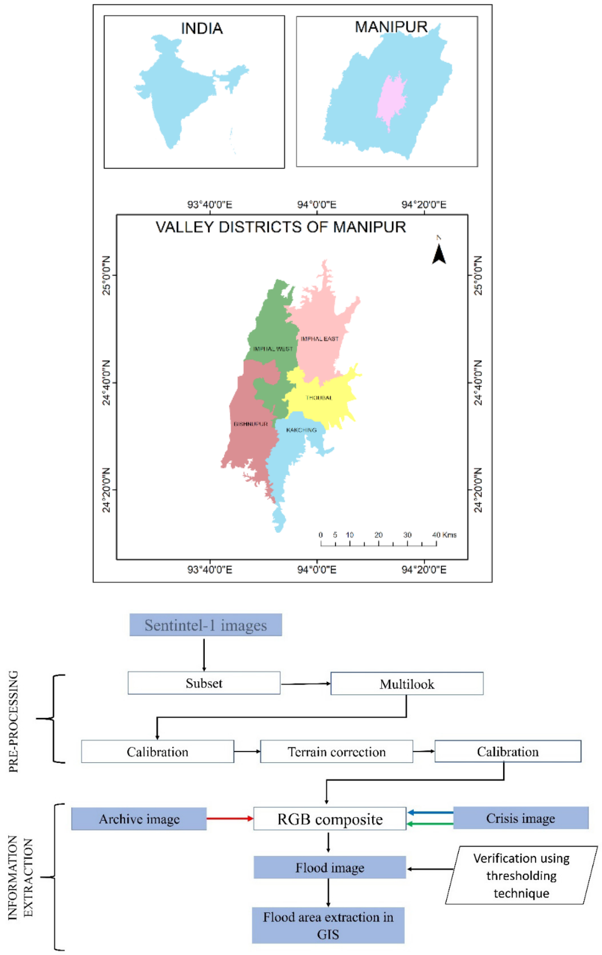


Fig 1(a). Location map of the study area and (b) methodology flowchart

cessing time because of the reduced dimensionality of the data. Radiometric calibration transforms the Digital Numbers (DNs) of the multi-look applied image to a physical quantity (dB) by comparing strength of observed backscatter to that expected from a unit area. Next it is essential to remove spatial distortions introduced in the SAR data due to topographic complexities, and to project the image into a coordinate system. To achieve this, the images are terrain corrected using Range-Doppler Terrain Correction process and projected. Terrain corrected images are further calibrated for the same reasons mentioned above. All the techniques described were applied to the archive and crisis images (Uddin, 2019).

A simple flood mask procedure called RGB composite technique is used to distinguish permanent water bodies from flooded areas. In this technique pre-processed archive image is loaded in the red channel of monitor while blue and red channels are fed with the crisis image. The output is a false colour composite (FCC) image, where flooded areas appear red, non-flooded areas appear in grey tones whereas permanent water bodies manifest in a uniform dark colour. The flooded area appears red because the archive image (no flood) in red channel has higher backscatter than the crisis image which has low backscatter for flooded areas. In radar remote sensing, standing water acts like specular reflector with maximum backscatter occurring in directions away from the sensor, giving water its characteristic dark signature in radar images. The inundation areas were extracted in GIS environment for further analysis. These steps were repeated for the two flood events. Lastly, thresholding technique of water mask generation was applied on the flood images to verify the accuracy of the RGB technique (Liang and Liu, 2020).

Results

This section provides the results of the analyses of Sentinel-1 SAR data acquired in April and July of 2017 which marked the peak flood extents during the two flood events. April flood and July flood are use to describe pre-monsoon and monsoon floods respectively, at times interchangeably, in the subsequent arguments for the purpose of this study. Table 2 presents the summary of the district wise extent of inundation during, and changes between, pre-monsoon and monsoon floods.

Table 1. Details of SAR data

Satellite/ sensor	Images captured	Mode/Beam	Processing level	Polarization (Single/Dual)	Swath width	Resolution
Sentinel-1A	I. Archive image (March) II. Pre-monsoon flood (April) III. Monsoon flood (July)	Interferometric wide swath (IW)	1-GRD	VV	250km	10m

Pre-monsoon (April) Floods

Fig. 2 (a) which represents the flood data of the five districts in pre-monsoon (April) is prepared based on the analysis of SAR data for the study area. It reveals that during the pre-monsoon floods 4297 hectares of land was inundated by flood waters. It is further found that variable portions of these districts are inundated giving a distinct spatial pattern, with four districts witnessing large areas of flooding while one district remaining completely dry. Spatial pattern of inundation in the districts for April flood is shown in Fig. 3. Among the districts that experienced flood, Imphal West and Imphal East have 3044 and 665 hectares of land under water and account for about 85% of the total inundation. Incidentally, these are also the most urbanised districts of the state alluding that pre-monsoons floods have

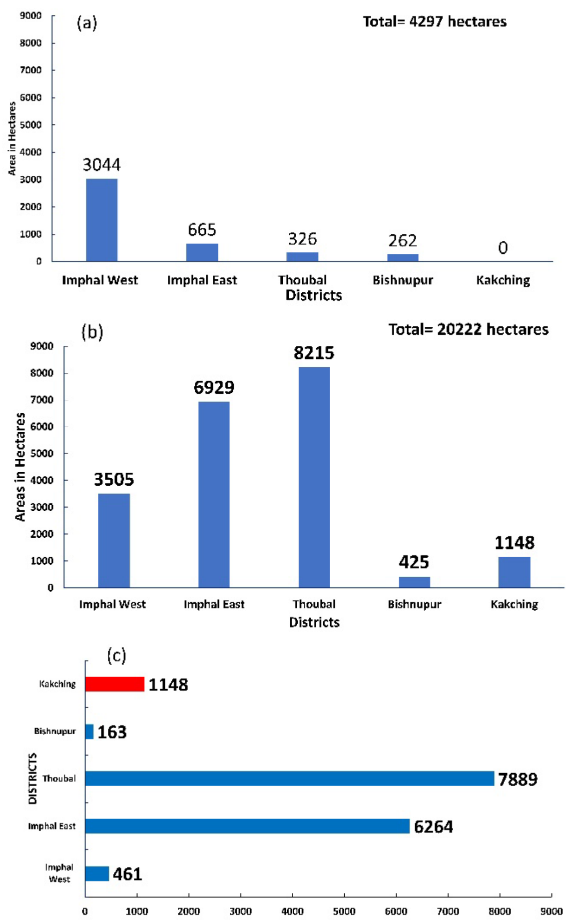


Fig. 2. Bar diagrams showing district wise flood inundated area in hectares (a) pre-monsoon flood (b) Monsoon flood, and (c) flood area increase from pre-monsoon flood to monsoon flood.

Table 2. District wise flood areas and increase from April to July (hectares)

Districts	Flood Inundated Areas in Hectares		Flood area increases in hectares (April to July)
	April Flood	July Flood	
Imphal West	3044	3505	461
Imphal East	665	6929	6264
Thoubal	326	8215	7889
Bishnupur	262	425	163
Kakching	no flood	1148	1148
Total	4297	20222	15925

Source: Author's analysis

strong imprint of urbanisation influence. On the other hand, areal extent of flooding in Thoubal and Bishnupur are 326 hectares and 262 hectares respectively with Kakching district having no area under flood waters during this season. The share of flood area to district area is also not uniform across districts. The values vary between 6% (Imphal West) to the lowest 0.5% (Bishnupur). Overall low inundation percentage is on expected line as precipitation during pre-monsoon is from short spells of intense thunderstorms. The volume of precipitation is, therefore, not large to produce flood discharge in otherwise low flowing rivers emerging just out of dry winter season. Dense population and installation of critical infrastructures in Imphal Districts (West & East) though make the relationship between percentage area under flood inundation andimpacts complicated.

Monsoon (July) floods

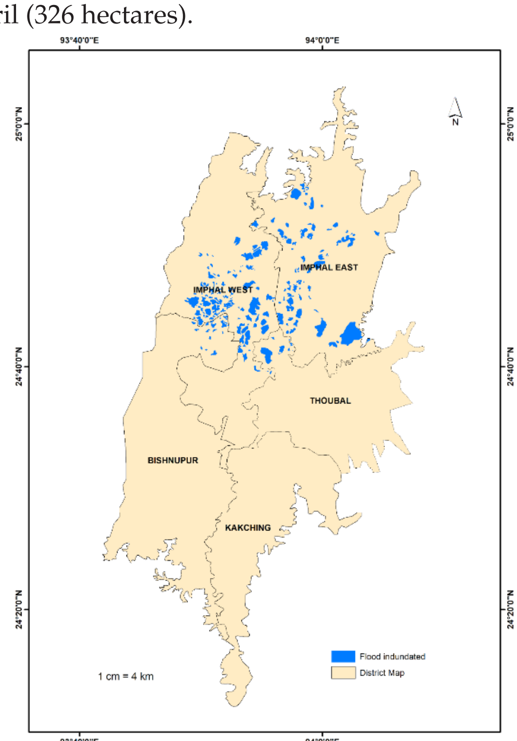
During July flood, a maximum of 20222 hectares is inundated with all valley districts having at least some areas under water. As evident from Fig. 2(b) and Fig. 3(b), Thoubal with an inundated area of 8215 hectares was the most affected district. This is followed by Imphal East with flood area of 6929 hectares. An area of 3505 hectares was inundated in Imphal West while the corresponding figures for Kakching and Bishnupur are 1148 and 425 respectively. Interestingly, Kakching which remained unaffected during April has been inundated during the monsoon flood.

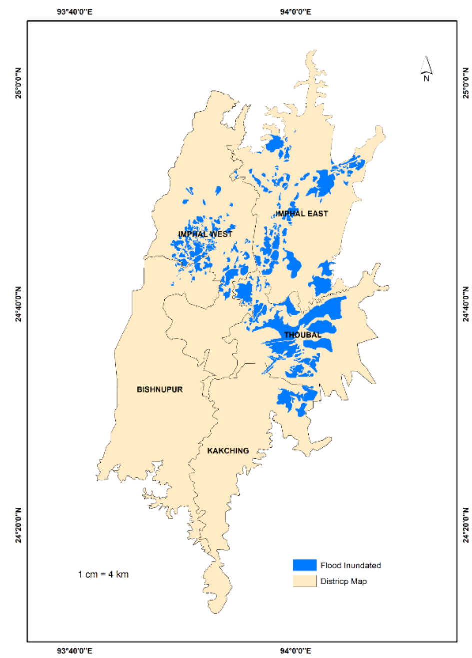
The figure shows there are dramatic variations in the inter-district spatial pattern of flooding during this season. This is apparent if we look at the percentage of district land submerged under flood waters. The percentage range between lowest (0.85%)

in Bishnupur to the highest of 15.98% for Thoubal. In Imphal East 6.75% of its area got flooded while for Imphal West and Kakching the figures are 6.75% and 5.97%. Thus, in all the five districts a larger area of land has been inundated during the July flood but with different percentage increase.

Flood pattern changes from April to July

As mentioned above, most floods in the valley districts of Manipur occur during monsoon months. Flood in this season affects not only a larger area but also tend to be more destructive. In fact, almost all the past devastating floods, 1966, 1989 and 2000 to name a few were monsoon floods originating from river water breaching embankments at multiple points following days of incessant heavy monsoon rains. It is of no surprise, therefore, that a much larger swath of land has been inundated in July across all districts as compared to April. Information on flood area increase from April to July is presented in Fig. 2 (c). It shows that an additional 15925 hectares have been flooded during July. This means that from July to April, there was almost a fourfold increase in inundation area with unequal rate among the districts. Interestingly, among the districts, Thoubal registered by far the biggest increase in inundation area + 7889 hectares, which is twenty-four times the area flooded in the district during April (326 hectares).





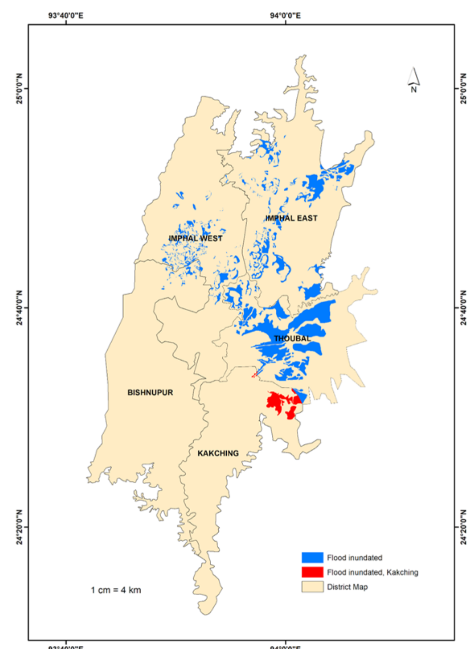


Fig. 3. District wise inundation map(a) pre-monsoon,(b) monsoon and (c) inundation area increase from pre-monsoon to monsoon flood. (*Source:* Prepared by the author)

With regard to Imphal East, an additional 6264 hectares came under water, a nine and half fold jump from the pre-monsoon flood. Since Kakching was not affected in April so all of its inundated area is from July flood. Study of district wise flood area increase from April to July, reveal substantial overlap of inundated areas between the two floods in Imphal West and Bishnupur. As a result, less than 1% of additional land was flooded in July relative to April, understandably in the adjoining areas of previously flooded areas. There was thus striking district wise interchanges in the areal extent of flood in both absolute and percentage terms between the floods except in Imphal West.

Discussion

Causes of inter-district inundation patterns during the two floods

Flood is the most destructive hazard of Manipur, and occur with regular periodicity in the valley districts of the state. However, there is a dramatic difference in the intensity and spatial pattern of flood occurrence among districts. Since, the knowledge of which areas are inundated and which are not is critical for mitigation purpose and in understanding causal factors of floods, a discussion on the same is presented in the context of April and July floods of the year 2017. In general, many interacting factors cause and influence flood in riverplains: heavy and prolong rainfall, levee breach by river water, dam failure, land cover cartelistic in the catchment areas among others. Irrespective of the season of occurrence, floods that occur in plain districts of Manipur originate from atmospheric conditions favouring heavy and prolong rainfall events.

Accordingly, the observed increase in flood area from April to July is due largely to higher volume and prolong rainfall received during monsoon month. It was reported that rainfall received in the valley after the month of March, for the year 2017, was highest after 1956 (Eastern Mirror, 2017). Since monsoon generally sets in the first week of June, the antecedent conditions of the catchment areas were wet before the peak flood of July. Consequently, there was an overall increased intensity of flood in July relative to April, although the ultimate cause of both floods stemmed from atmosphere. Previous studies on the influence of antecedent moisture state of catchment on floods have shed lights on how wet or dry catchment could change the intensity of floods.

Tarasova *et al*. (2019), for instance, explained that if the antecedent condition of catchment is wet, as is the case in July in Manipur valley, soil moisture and groundwater levels are high, hence most of the rainwater flows as surface runs off and directly contributes to the flood. On the other hand, during dry conditions of April rainwater infiltrates into the soil, usually with less effect on the flood. Thus, differences in the persistence and volume of rainfall, and resulting changes in catchment moisture conditions, prior to the peak flood, broadly account for the expansion of inundation area from April flood to July. However, explanation for changes in flooding pattern is more complex, as illustrated in floods of Imphal West district. It was the most flooded district during April, but the inundation area expanded only slightly relative to Thoubal and Imphal East districts in July. This marginal change in areal extent and location of inundation area in Imphal West reflects strong influence of rapid and unplanned expansion of urban land use in the city peripheries.

Land use changes, such as urbanisation in the flood plain affect the nature of flood in many ways. Overlay analysis of flood maps of the district on Google Earth images suggest low lying areas adjacent to urban development and settlements have been inundated with flood waters during April and July events. The impervious urban surface reduces infiltration contributing to increased surface run off fraction of the precipitation thereby promoting accumulation of water in low lying unattractive lands of the urban periphery. Pradipkumar and Priyalina (2020) study on the effects of land use changes on flood in Imphal areas also observed significant in flood peaks.

A perusal of Thoubal flood map reveals that most newly inundated areas of July are situated in and around Lilong locality of the district. This area has peculiar hydrogeomorphic characteristics that favour flood. Here, Imphal and Iril, two of the largest rivers of Manipur, meander and the latter join the former as a left bank tributary. Further downstream from this point, Thoubal River, another stream significant for its discharge volume, makes confluence on the left bank of Imphal River. Slow meandering and confluence of rivers are factors which create conditions for levee breach during flood events. These rivers drain following the general north to south slope of the central valley of Manipur contributing to the accumulation of flood waters in channels. In fact, the largest number of levee breach was observed along the banks of these rivers in Thoubal district with the consequent widespread inundation.

Imphal East experienced a surge in the inundation area during July due to combined effect of natural and human factors. Having a dense drainage density network, presence of many low-lying wetlands, and a high rate of urbanisation contributed why the district was flooded extensively in July. Here, Kongba, Imphal, and Iril rivers flows in close proximity on a rapidly urbanising landscape where wetlands often spill water during rainy season. Kakching is vulnerable to flooding in monsoons only as it remained unaffected during pre-monsoon. Southerly location of district raises the chance of it being affected by river flood that occur primarily during anomalously wet monsoon season. The impact of the July flood was felt differently among the districts. Overall, there was a severe reduction in the paddy production of the state as about 25% of agricultural area got affected by flood (Assam Tribune, 2017). Worryingly hundreds of households were also submerged under flood water. The state government reported that as many as 14000 households in the five districts were inundated during the July flood (IAG, Manipur 2017).

With more than 9000 households under flood water, Imphal East district bore the brunt of the effect, while corresponding figures for Thoubal and Bishnupur were 4000 and 859 respectively. As an immediate response to the flood, 39 official relief camps were established and the state officially declared the disaster as a 'State Calamity'. In sum, the spatial pattern of flood was found to be different between pre-monsoon and monsoon seasons primarily due to antecedent moisture conditions of the catchment that preceded the flooding. District wise inundation pattern between the two floods was largely on account of peculiar hydrogeomorphic and urbanisation induced land use changes in each district. Future flood reduction and management strategies should consider the factors noted above along with the district wise distribution of the impacts, through the use of space-based microwave.

SAR Sentinel-1 data for flood mapping

Space based earth observation data are now increasingly employed to aid in disaster risk management (Cozannet, 2020). Despite being an essential tool, preparing near real time accurate map of flood is a challenge using both traditional in-situ data methods and remotely sensed optical data. Fields visits are often impeded during flood events and cloud cover during flood events shields ground from passive sensors. SAR systems, which operate in microwave wavelength, function independent of atmospheric conditions and can penetrate through cloud cover. As a result, SAR data is preferred over optical systems for flood detection and mapping. Currently, many satellites exist that operate and provide SAR data for all parts of the globe on a consistent basis. But Sentinel-1 SAR images are mostly employed for the purpose as they are freely available with high temporal resolution of days. Sentinel Analysis Platform (SNAP), a dedicated software for Sentinel data processing and analysis, is also accessible to public with no cost. Many studies have demonstrated the utility of SAR Sentinel-1 for flood mapping through many case studies (Anusha and Bharathi, 2020; Rahman and Thakur, 2018; Clement *et al.*, 2017). The approach adopted for flood detection and mapping in this study benefits from earlier studies but deviates at the same time as it uses RGB technique as a primary means of flood detection and mapping. However, cross verification of inundation areas was performed using commonly employed thresholding method (Liang and Liu, 2020). The advantage of RGB technique lies in rapid flood mapping and amenability of the output to be exported in multiple file formats including Google Earth compatible KMZ/KML file, where the same can be overlaid for further detailed analysis. This feature of the output facilitates ground-based verification and accuracy assessment through precise identification of inundation spots on high resolution Google Earth images. Considering the high temporal resolution of the Sentinel-1 system, simple but accurate RGB technique is invaluable for preparing rapid flood maps to aid disaster responders and long-term flood mitigation planning.

Conclusion

This study used an approach based on satellite SAR data to map floods of pre-monsoon and monsoon seasons in five valley districts of Manipur. The total inundation area determined through Sentnel-1 images was 4297 ha in April and then increased to 20222 ha in July, with a gain of 370%. All districts witnessed higher inundation area during monsoon flood. Thoubal registered the maximum inundation area during monsoon flood among all districts. Imphal East, Kakching and Bishnupur show substantial increase in areal extent of flood from April to July. On the other hand, the pattern of flood for

Imphal West exhibited only slight variation between the floods. The changes in the overall flood pattern indicate factors responsible for inundation vary among the districts. Knowing these causes could help policy makers device district specific risk management strategies for flood impact mitigation in the long term. Accurate flood maps thus have the potential to improve disaster response and provide additional insights useful in long term disaster preparedness. The first step is to make extensive use of SAR data for the comparative advantages it offers over optical and in situ-based data in flood mapping.

Acknowledgment

Author is grateful to the Alaska Satellite Facility (NASA) and European Space Agency (ESA) for enabling SAR images and SNAP software used in the study freely downloadable.

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