MAPPING OF FLOOD INUNDATED AREA AND IMPACT ASSESSMENT USING SAR DATA OVER GHAGGAR RIVER BASIN OF PUNJAB, INDIA

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ABSTRACT: Remote sensing studies are very important tool for mapping and monitoring flood inundated area. Flooding is a natural hazard and largely depends on account of natural factors that pose risks to life and property. The Ghaggar river basin causes substantial flooding in the south-east part of Punjab region owing to higher precipitation in Siwalik region and neighbor states which lead to rise in the water level of Ghaggar flood plain. The present study focuses primarily on the mapping of flood inundated area using SAR data during 2019 floods and the impact assessment in the Ghaggar basin. Further, a comprehensive analysis has been carried out by Global Precipitation Mission (GPM) data to investigate the intensity and frequency of precipitation over the basin. Multi-temporal, dual-polarized (VH & VV) Sentinel-1 (SAR) data have been used for mapping the flood inundated area during July to September, 2019. SAR data is very useful and most preferred for detecting flood inundated area in all weather and day/night time. In this study, binarization technique was applied to separate satellite image pixel values into flooded and non-flooded group. Threshold for backscattering coefficient (σ_0) between -10 to -18dB has been applied to extract the maximum flood pixels. It was also observed that flood extent was in its peak during July 20 to 23, 2019 and on July 27, 2019 and impacted a large part of agricultural and urban patches during this time. The results have been validated with Radasat-1 image and found an accuracy of 82% in both polarizations. The finding reveals that ~9000 hectares of land have been affected in Patiala and Sangrur districts. The results revealed that paddies were mostly inundated by flooding with low elevation and low slope. From the proposed approach, it is found that the SAR data along with GIS can be used efficiently for mapping of flood inundated area. The resultant maps could be utilized by the government officials, resource managers effectively for damage assessment and relief measures.

1. INTRODUCTION

Natural disasters compounded by climate changes cause more than $500 billion in losses every year (Anusha and Bharathi, 2019). Floods are one of the most frequent and vulnerable natural phenomena occurred due to both natural and anthropogenic changes in which water overflows from its channel over the area (Tripathi et al., 2020; Agnihotri et al., 2019). Extreme flood conditions cause immense damage in terms ofhuman lives, environment and economic loses around the world (Klemas, 2014; Ascott et al., 2016; Ibáñez et al., 2012; Barredo, 2007; Reisenbüchler et al., 2019; Bauer et al., 2019). India is highly vulnerable to floods in the world and more than 40 mha area (or one eight of Indian geographical area) is under flood-prone due to its geographical locations, climate, topography and huge populations (NDMA, 2008). River and riverine flooding is a frequent natural phenomenon that mainly occurs when a river catchment receives water through rainfall beyond its capacity (Sanyal and Lu, 2004). The Central Water Commission (CWC) is the principal agency in India, which is responsible for flood forecasting and has fixed danger levels (DL) and warning levels (WL) at different locations (Agnihotri et al., 2019). Such severe flood events are vital to understand with hydrological data, which provide an opportunity for flood disaster risk assessment and management activities (Thirumurugan and Krishnaveni 2019).

Flood happens irregularly over the world and it is a very challenging task to measure flood extent and hydraulic variables such as water levels, warning levels and discharge by conventional methods during the flood period (Balasch et al., 2019). In order to determine the extent of flood, the data can be collected directly on the ground (*in situ*) or through remote sensing (aerial or satellite) (Jensen, 2013). In recent decades, the remote sensing technology provides real-time and trust worthy information to assess the extent of flood affected areas and damage assessment over large geographical areas covering inaccessible areas in frequent interval of time (Bhatt and Rao, 2016; Tsyganskaya et al., 2018a; Deo et al., 2018). Though it is impossible to avoid risks of floods or prevent their occurrence, it is quite possible to reduce their effects and the resultant loses. Remote sensing satellites collect the high spatial and temporal data which is used for flood mapping and monitoring (Tsyganskaya et al., 2018b). Many researchers have used different remote sensing datasets (optical and microwave) for constant flood inundation mapping and monitoring worldwide (Schumann and Moller 2015; Shivaprasad Sharma et al., 2017; Clement et al., 2018; Kumar et al., 2018; Sghaier et al., 2018). In recent time, microwave SAR (Synthetic Aperture Radar) data is particularly useful for flood mapping which can provide frequent observations in almost any weather conditions and during daytime and night time also (Sghaier et al., 2018; Shen et al., 2019). A leading such type of SAR datasets is Sentinel-1 product, which provide free data with high spatial and temporal resolution.Sentinel-1 SAR data provide VV and VH polarizations in which VV backscatter provide better delineation water as compared with VH backscatter (Clement et al. 2018,Sivasankar et al. 2019). Several digital image processing techniques are available to detect flooded area from the SAR images in which thresholding approach is very suitable (Clement et al. 2018; Rahman and Thakur 2017b, Amitrano et al. 2018, Vishnu et al. 2019). Cian et al. (2018) have developed Normalized Difference Flood Index (NDFI) based on SAR data which can be for rapid flood mapping and monitoring.

Ghaggar river was also considered as lifeline for the villages alongside its bank, the river Ghaggar has been termed as the ‘River of Sorrow’ due to the occasional floods it has caused in the past over a decade. The Ghaggar river basin also witnessed unprecedented flooding over the past few decades like September 1988, July 1993, 1995 and 2010 and causes loss of lives, infrastructure damage and destruction of normal cultivating cycle (Saini and Kaushik, 2012). These extreme floods had been occurred due to heavy rainfall for a very long time and huge amount of discharge water from the upstream. Thus, the present study focuses primarily on the mapping of flood inundated area using SAR data during 2019 floods and the impact assessment in the Ghaggar basin. The Ghaggar river basin in Punjab region experienced the extreme flood which significantly affected the crops and infrastructures. Near real-time flood inundation mapping and monitoring during flood disaster using remote sensing data is a vital support to disaster management authority to make a plan for rescue operations and rapid assessment of property loss and damages.

2. STUDY AREA

The study area chosen corresponds to the Ghaggar sub-basin in Punjab. Ghaggar and other sub-basin which covers part of Punjab, Rajasthan and Haryana states of India forms the largest sub-basin of Indus basin with total catchment area of 49978 Sq. Km. The geographical extent of the Ghaggar sub-basin in Punjab lies between 75° 10’ E to 76° 52’ E Longitudes and 29° 35’ N to 30° 54’ N latitudes (Fig.1). The Ghaggar River rises in Shivalik hills in Himachal Pradesh and it flows towards from East to West through Haryana, Punjab and Rajasthan for more than 100 Km. In ancient time, Ghaggar river was considered as perennial river but in recent era it is considered as seasonal due to less and continuous flow. But, during monsoon season (June to September), due high rainfall in Shivalik region leads the water level high in Ghaggar river and all its tributaries.

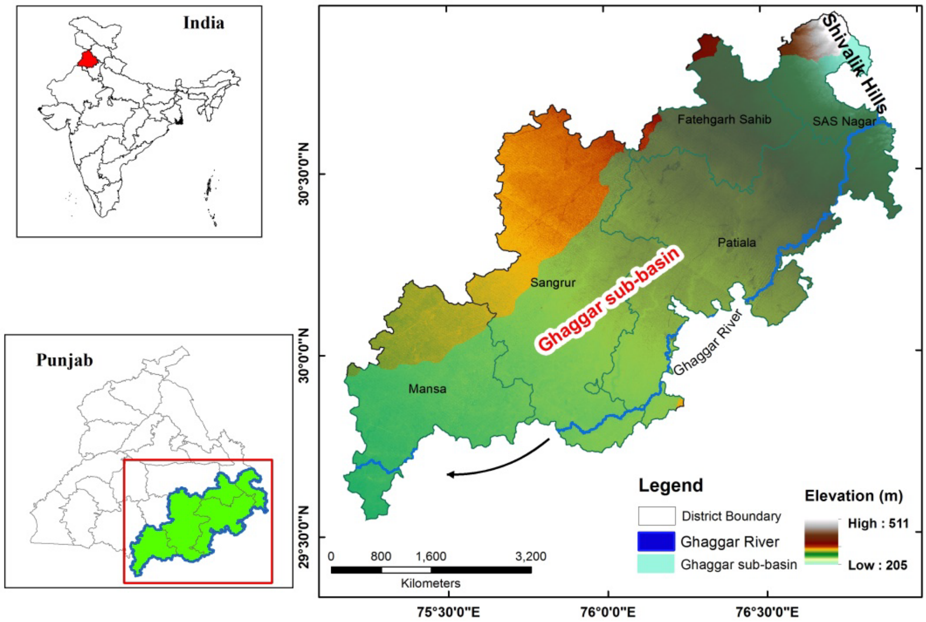

Fig. 1. Study area showing Ghaggar sub-basin in Punjab region overlaid on DEM.

3. MATERIALS AND METHODOLOGY

This research incorporates various space based satellite data including: Sentinel-1 SAR dual polarized (VH & VV) images and GPM (Global Precipitation Measurement) rainfall data. The Sentinel-1 operates within C-band (5.407 GHz) frequencies with 12 days of repeat cycle. Two sets of SAR data (before flood and during or after flood) are required for detecting the extent of flood and mapping of flood. Additionally, ancillary data includes a 30-metre resolution shuttle radar topography mission (SRTM) digital elevation models (DEM) was also used in this study.

3.1 SAR Data Processing

The Sentinel-1 Ground Range Detected (GRD) level-1 processing data are collected over the study area during monsoon season (from June to September, 2019) for analyzing and find the flood inundation area. Sentinel-1 image was initially pre-processed to mitigate the SAR-typical speckle noise signatures from the images for flood classification. Radiometric calibration of the SAR image was carried out to generate the backscatter values. A total of more than 30 sampling point during flooding period were taken to identify threshold value over VH and VV polarization image. The threshold value is used in the binarization process to separate flood pixels from non-flooded pixels. A fixed range of dB values is applied to derive the flood inundated areas. Suitable threshold gives more accurate value which could be used further in other operations.

3.2 Global Precipitation Measurement Rainfall Data

Global Precipitation Measurement product provides real-time rainfall data using dual-frequency precipitation radar (Ku/Ka-band) and a multi-channel GPM Microwave Imager (GMI). Dual-frequency precipitation radar provides three dimensional measurements of precipitation structure and characteristics. The GPM Core Observatory launched on February 27th, 2014 and is a follow-on, expanded mission to TRMM (Tropical Rainfall Measuring Mission) which provides high spatial resolution (10 x 10 km) datasets. This study used daily accumulated rainfall derived from the originally available rainfall product at the interval of 3 hours.

4. RESULTS AND DISCUSSION

The prodigious situation of flood has been observed in Punjab region during period from 18^{th} to 27^{th} July, 2019. Two sets of Sentinel-1 SAR data have been downloaded for mapping the spatial extent of flood over Ghaggar river basin (Fig. 4). Multi-temporal Sentinel-1 SAR image of March 2019 is taken as pre-flood image and those acquired on dated July, 2019 is considered as during flood image. GPM rainfall product is also incorporated in this study to see the spatio-temporal variability of rainfall and the relation of rainfall intensity for the occurrence of flood.

4.1 Spatio-Temporal Variability of Precipitation

GPM daily precipitation data has been used to assess its spatial-temporal variability during monsoon season (June to September) over Punjab region. Heavy discharge from rivers during these periods causes widespread floods. Rainfall maps have been prepared over study region during the flooding period to delineate the location, intensity and frequency of rainfall. Daily rainfall data collected from GPM shows the spatial distribution of rainfall on different district in Punjab region. The results indicated that Punjab has received the maximum rainfall up to 317.95 mm with a mean rainfall of 80.18 mm during the period of 18th to 27th July, 2019 (Fig. 2).

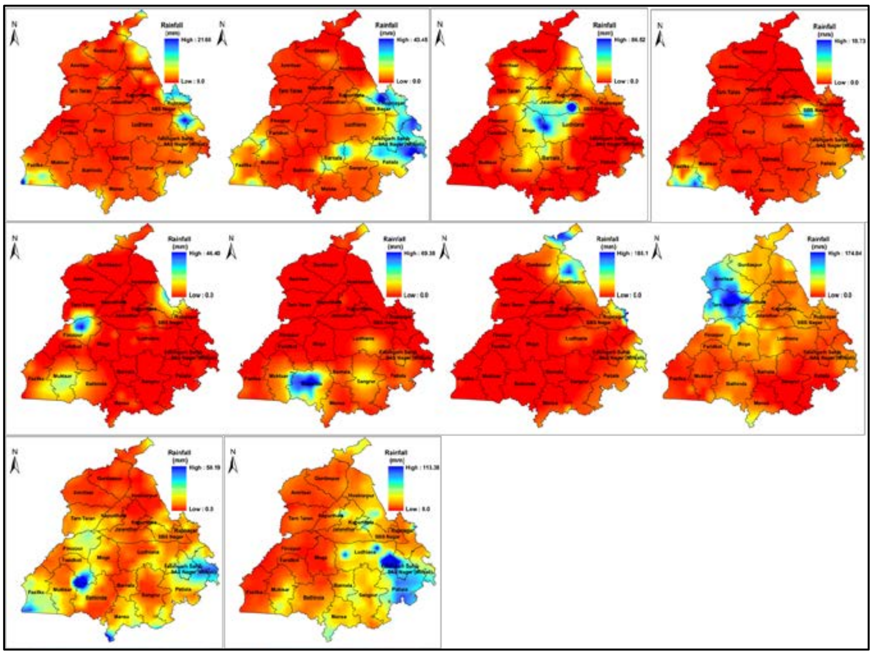

Fig. 2. Spatial variation maps of rainfall over Punjab during the flood period i.e. July 18-27, 2019

However, the districts fall under the Ghaggar sub-basin and Shivalik region received maximum rainfall more than 100mm (cumulative) during July 24-27, 2019 (Fig. 3). Additionally, it was observed that during these days, Ghaggar river basin received a heavy runoff from foot hills of Shivalik region as well as from adjoining states and affected Patiala and Sangrur district with unprecedented floods. The statistics of the diurnal rainfall during flood period from July 18-27, 2019 over different districts in Ghaggar basin is shown in Fig. 3 where the daily rainfall has been analysed for the each districts.

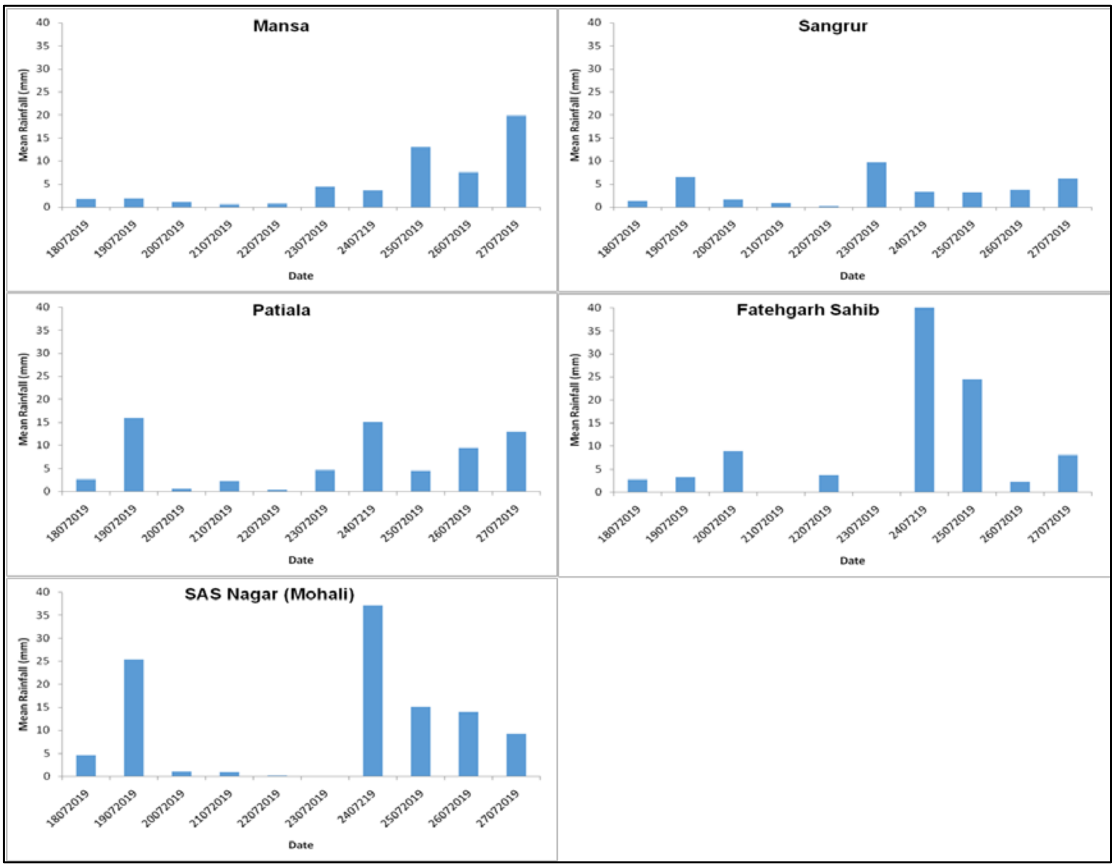

Fig. 3. Temporal variation of diurnal rainfall during flood period from July 18-27, 2019 over different districts in Ghaggar basin

4.2 Flood Extent Mapping using Sentinel-1 SAR Images

Sentinel-1 SAR images are useful for mapping the extent of flood over flooded region. It has the capability of acquiring images with all weather conditions. This study used two sets of SAR data: before flood and during or after flood over affected area for mapping and monitoring the extent of flood. Thresholding technique is applied in SAR images to separate the flooded areas. The threshold value ranges from -10 to -18 dB has been applied for both the polarised band to extract flood water pixels. It was observed that VH polarisation is most useful compared to VV polarisation for classify the flood pixels. The results revealed that paddies were mostly inundated by rain water accumulation, flooding with low elevation and low slope. The area highlighted in red colour indicates the inundated areas during flooded period are shown in Fig. 4.

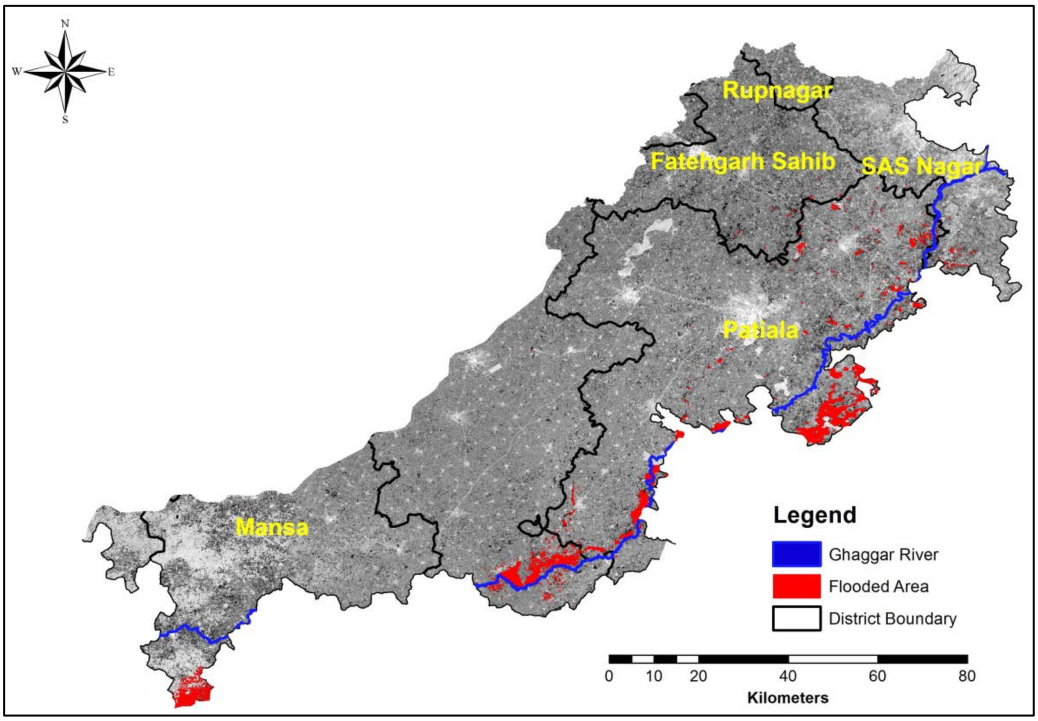

Fig. 4. Flood Inundated map over the Ghaggar sub-basin and the area highlighted in red colour indicates the flooded area.

The district-wise zonal statistics are fetched using ArcGIS to calculate the total affected area. The finding reveals that Patiala and Sangrur districts were severely affected due to the flood and total area of ~9000 hectares of crop lands under flood inundation (Fig. 5). The results was also further validated with Radasat-1 image and found an accuracy of 82%.

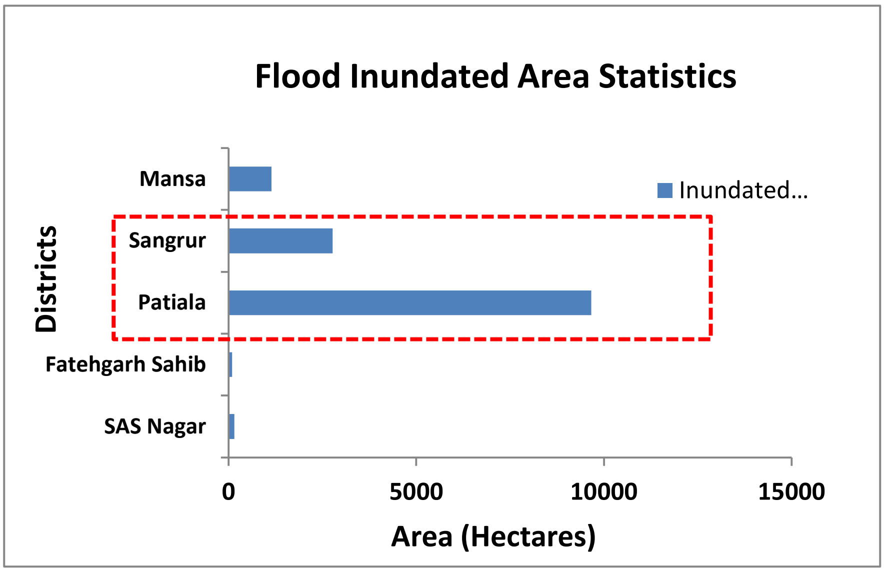

Fig. 5. Area under Flood Inundation (District wise statistics)

A Radarsat-1 image acquired by National Remote Sensing Centre (NRSC) during flood period has been taken for validation and analysing of flood inundated area. It was also observed that flood extent was in its peak during July 20 to 23, 2019 and on July 27, 2019 and impacted a large part of agricultural and urban patches during this time.

From the proposed approach, it is found that the SAR data along with GIS can be used efficiently for mapping of flood inundated area. The resultant maps could be utilized by the government officials, resource managers effectively for damage assessment and relief measures. The inundated area is integrated with district boundary layer for extracting the district-wise inundation statistics. These results are validated against the Radatsat-1 data. The major flood impact has been observed in the middle and lower part of the Ghaggar river basin which lies at the foot of the steep slopes of the Shivalik hills of Himalaya. These extreme floods had been occurred due to heavy rainfall for a very long time along the steep slopes of the Shivalik hills and huge amount of discharge water from the upstream. Ghaggar river basin is also characterized with number of palaeochannels which are the low-lying part of the alluvial plains within the basin and played a role in bringing flash floods.

5. CONCLUSION

The present study planned to analyse the impact of flood over the Ghaggar sub-basin that occurred during last week of July, 2019. This study shows that SAR image has capability of acquiring image all time and different weather conditions and is very helpful to delineate the extent of flood over flooded region. This study also discussed about binarization technique for extracting the flooded area and calculates the total affected areas. The flood inundated area is computed by two different set of images. Based on the results of the present study, it can be concluded that satellite data with geospatial technology can provide effective solutions for better management of disasters like floods. Near real-time flood inundation mapping and monitoring during flood disaster using remote sensing data is a vital support to disaster management authority to make a plan for rescue operations and rapid assessment of property loss and damages. Integrations of various hydrological and climatological data with different machine learning models can be useful for better forecast and also be future prospects of work in this research area.

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