# Chapter-5

## *SAR DATA BASED ASSESSMENT OF CHANNEL PLANFORM DURING MONSOON*

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## 5.1 Introduction

Flood is a natural phenomenon in which water overflows from its channel over the area which is usually dry. Floods have been a recurrent natural disaster since ages around the world[178]. It causes immense damage to the natural environment and casualties every year around the globe. The impact of saviour floods on channel planform is highly destructive. Such floods generate the high hydronic force required to entrain and transport the river bed material that constitutes the channel and valley bottom.

These flood events produce a large scale modification in channel planform while other floods with low discharge have minimal effect. Floods of similar magnitude and frequency may produce dissimilar morphological changes spatially and temporally, even within the same catchment. The impacts of floods on river planform are strongly associated to the river planform type (meandering, confined, braided), floods frequency, sediment supply, rive boundary conditions, flow patterns, valley orientation, duration of the flood peak and the recurrence interval for the overbank flow[179].

India is highly vulnerably to the flood, and more then 40 million hectares area is flood-prone [180].The flood occurs due to heavy monsoonal rainfall which is considered to be the largest natural disaster in India [181]. These floods play an essential role in the evolution of the fluvial system [164, 165].Study of severe flood disaster events along with other hydrological dataprovide an opportunity for flood disaster risk assessment and management activities.

The monsoon in India contributes more than 80% of the annual rainfall. Therefore, most of the alluvial rivers carry out almost all geomorphic works (erosion, transportation and deposition) during the monsoon season. During the monsoon, the seasonal flow tends to be at least 1-2 orders of magnitude greater than the non-monsoon season over a large part of India. [184].Thus during the heavy rains, there is a sudden increasein discharge takes place in the channel flow, which leads the fluvial activity in the rivers. However, these rives don’t remain in such a high stage during the full monsoon period. It is only limited to the rainy periods and may last after a few days. Such rainfall in the upstream area generates a large amount of runoff in the channel, which leads the flood in the channel. Due to the high magnitude and frequency of floods in the Indian region, it is reasonable to conclude that most monsoon floods can alter floodplain and channel morphology in a significant way [184]. There are many significant changes in floodplain morphology is observed. However, many Indian rivers shows that the various types of flood impact on channel morphology are observed e.g. (i) widening of channel, (ii) scouring of floodplain, (iii) increase incompetence, (iv) Erosion of bars and the formation of chutes, (v) formation of channel-in-channel topography and (vi) deposition of coarse gravel within the channel and floodplain[185].

The heavy rainfall is usually the main cause of massive floods in the rivers. The rainfall over the large part of the Ramganga basin is concentrated from July to October. Obtaining the spatial information from conventional resources is a very challenging task during the rainy period when telecommunication and transportation system gets damaged. In such a catastrophic condition, only remote sensing technology provides real-time and trustworthy spatial information [186].

Obtaining spatial information over a large area using optical remote sensing is not possible due to cloud cover during the monsoon period. Microwave remote sensing can penetrate the cloud cover and collect the data during the monsoon period. So the monitoring of river planform is only possible using microwave remote sensing data during the monsoon season.Microwave Remote sensing-based flood damage assessment is precise input for flood risk reduction and disaster response decisions. A large number of satellites collects the microwave data, which is used for real-time flood inundation mapping and monitoring during the monsoon period. Many researchershave used these datasets for constant flood monitoring and mapping[169–173].

In recent time the quality and quantity of remote sensing data available during the flood period dramatically increase. In such remote sensing data, one satellite is from Sentinal series, which provide free of cost data with high spatial and temporal resolution. Many image processing techniques are available to detect water bodies from the SAR (Synthetic Aperture Radar) images in which the threshold approach is very suitable. Several studies have been done for flood mapping using threshold techniques[174–176]. Sentinel-1 SAR data provide VV and VH polarizations in which VV backscatter provide better delineation water as compared to VH backscatter [170, 177].

Many Geomorphologists have studied the relationship between fluvial geomorphology and hydrology[178–181]. Extreme flood situation can alter the life and fluvial landscape in the floodplain[199]. Bhatt and Rao, (2016) have observed the significant impact of an unprecedented flood using remote sensing images on Ganga river morphology during September 2010 and concluded that Ganga river widened its course from 2 to 12 km at Kannauj district in the present study area[186]. Hooke (2016) has studies impact of the extreme flood on the Nogalte and Torrealvilla river morphology in Spain on the 28 September 2012, which causes several casualties and damage to infrastructure[200]. This flood highly mobilised the sediment and deposited in as a high and flat bar in the river channel. Saleh Yousef (2016) studied the Karoon river in Iranwhich experienced the extreme flood on the 14 April 2016. This flood significantly affected the channel width, and high mobilization of sediment is observed with severe bank erosion in the meandering reaches [201]. The kinetic energy of floodwater is very high so thatextreme floods play an important role in erosion and deposition processes in the floodplain, and it is essential to monitor where the large density of population is settled in the area [187, 188].

These studies have been carried out to investigate the impact of the flood on channel morphology, and no such studies have been done in the Ramganga riverusing SAR data. The real-time flood monitoring and rapid assessment of flood are necessary for disaster management authority to make a plan for relief operation during flood hazards.

The present chapter is an attempt to (i) use the SAR data with hydrological data to providereal-time flood inundation mapping and monitoring of the lower Ramganga and Ganga*doab*and (ii) to quantify the morphological changes of the Ramganga rivers occurred due to the flood.

It is well known that lower Ganga-Ramganga *doab* is one of the most fertile and densely populated regions formed by sediment deposited by Ganga and Ramganga river.In this region, Ganga floodplain is wider than the Ramganga and its width changes along the channel. In the downstream of Farrukhabad district, the floodplain is more extensive due to the shifting of Ganga channel [204]. Ramganga river is severely impacted by the flood in selected reaches (Fig.5.1).

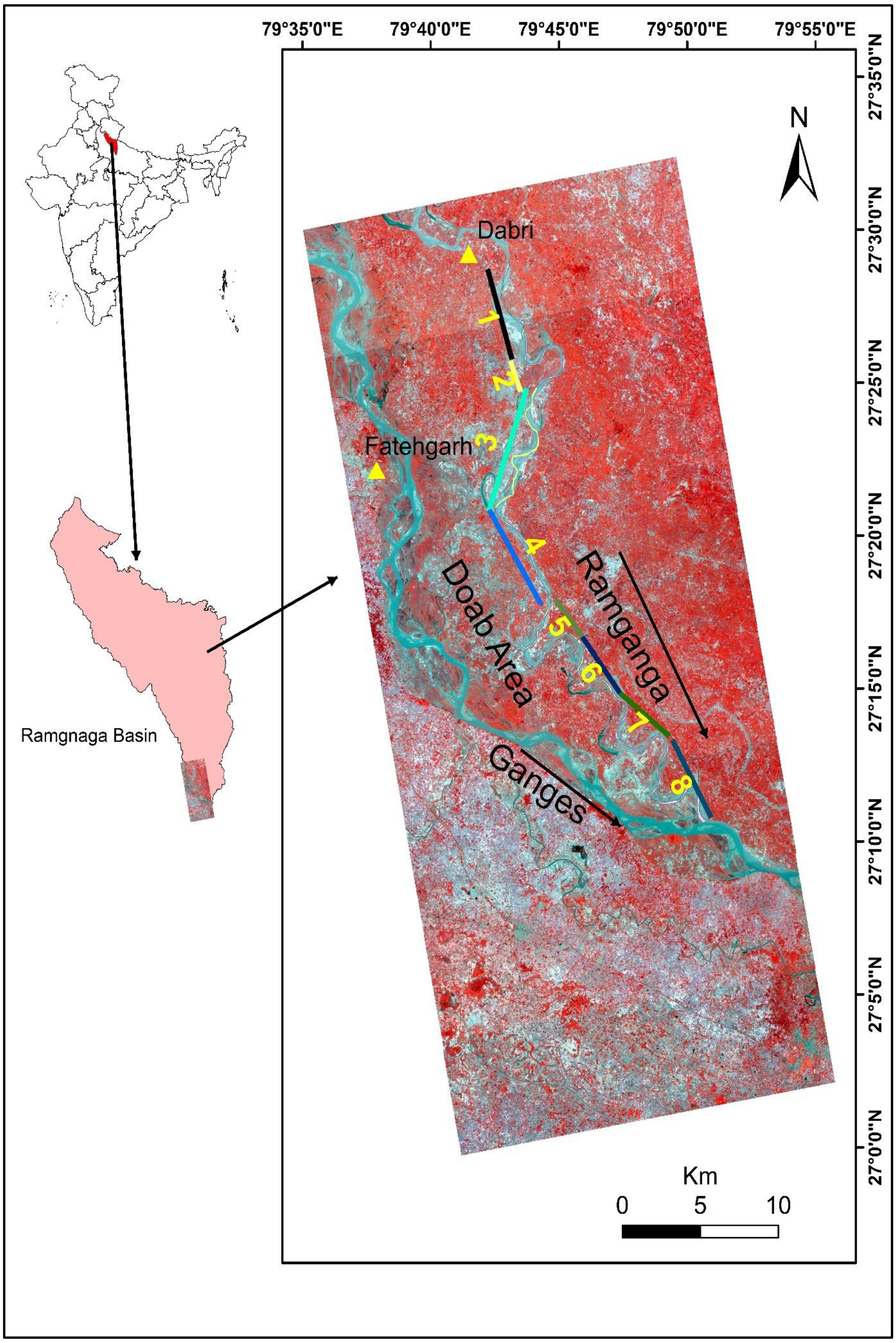


*Figure 5.1 Location of flood effected reaches in Ramganga River*

## 5.2 Data

Sentinel-1 SAR datasets images of dual-polarized (VV and VH) acquired from 09-Aug-2018 to 23-Sep-2018 during the flood seasons (Table 5.1). Sentinel-1 remote sensing data with 5 × 20 m resolution (10-m pixel spacing) Level-1 Ground Range Detected (GRD) in Interferometric Wide Swath (IW) mode are used. Sentinel- 2 data are also used for validation of flood inundation map of the study area.

***Table 5.1 Data source***

| Sr. No | Sentinal-1 Image | Date | Track ID |
|---|---|---|---|
| 1 | S1A_IW_GRDH_1SDV_20180809T003608_20180809T003633_023162_02842B_A8C2 | 09-Aug-2018 | 165 |
| 2 | S1A_IW_GRDH_1SDV_20180818T124618_20180818T124647_023301_0288BA_2216 | 18- Aug -2018 | 129 |
| 3 | S1A_IW_GRDH_1SDV_20180821T003609_20180821T003634_023337_0289D5_4EF2 | 21-Aug-2018 | 165 |
| 4 | S1A_IW_GRDH_1SDV_20180830T124619_20180830T124648_023476_028E47_FE33 | 30- Aug -2018 | 129 |
| 5 | S1A_IW_GRDH_1SDV_20180902T003610_20180902T003635_023512_028F64_63D3 | 02-Sep-2018 | 165 |
| 6 | S1A_IW_GRDH_1SDV_20180911T124619_20180911T124648_023651_0293E3_B406 | 11- Sep-2018 | 129 |
| 7 | S1A_IW_GRDH_1SDV_20180914T003610_20180914T003635_023687_029500_54F5 | 14- Sep-2018 | 165 |
| 8 | S1A_IW_GRDH_1SDV_20180923T124619_20180923T124648_023826_029995_DEBC | 23- Sep-2018 | 129 |
| **Sentinal-2 Image** | | **Date** | **Track ID** |
| 9 | S2A_MSIL1C_20180621T051651_N0206_R062_T44RLR_20180621T081647 | 21-Jun-2018 | 99999 |
| 10 | S2B_MSIL1C_20180914T051639_N0206_R062_T44RLR_20180914T091348 | 14-Sep-2018 | 99999 |

Further, flood hydrograph is generated for the period between 05 August 2018 to 25 September 2018 from daily water level data obtained from the Irrigation& Water Resources Department of Uttar Pradesh (IDUP)[205]. The flood hydrograph is prepared for the two gauge stations (i) Fatehgarh in Farrukhabad district on theGangariver and (ii) Dabri in the Shahjahanpur district on theRamganga river.

## 5.3 Methodology

All images collected from sentinel data hub which has been processed using SNAP (Sentinel's application Platform). In this study, sigma calibration was performed, which create a new image with calibrated backscatter coefficients. The calibrated image was then filtered using Refined Lee filter of 7 × 7 pixel size to remove noise using a speckle filtering process.The SRTM 1-s HGT data has been used for range doppler terrain correction (UN-SPIDER Knowledge Portal). The noise removed, calibrated, and terrain corrected image was binarised using a threshold value [207]. The flow chart of the methodology is shown in Figure 5.2.

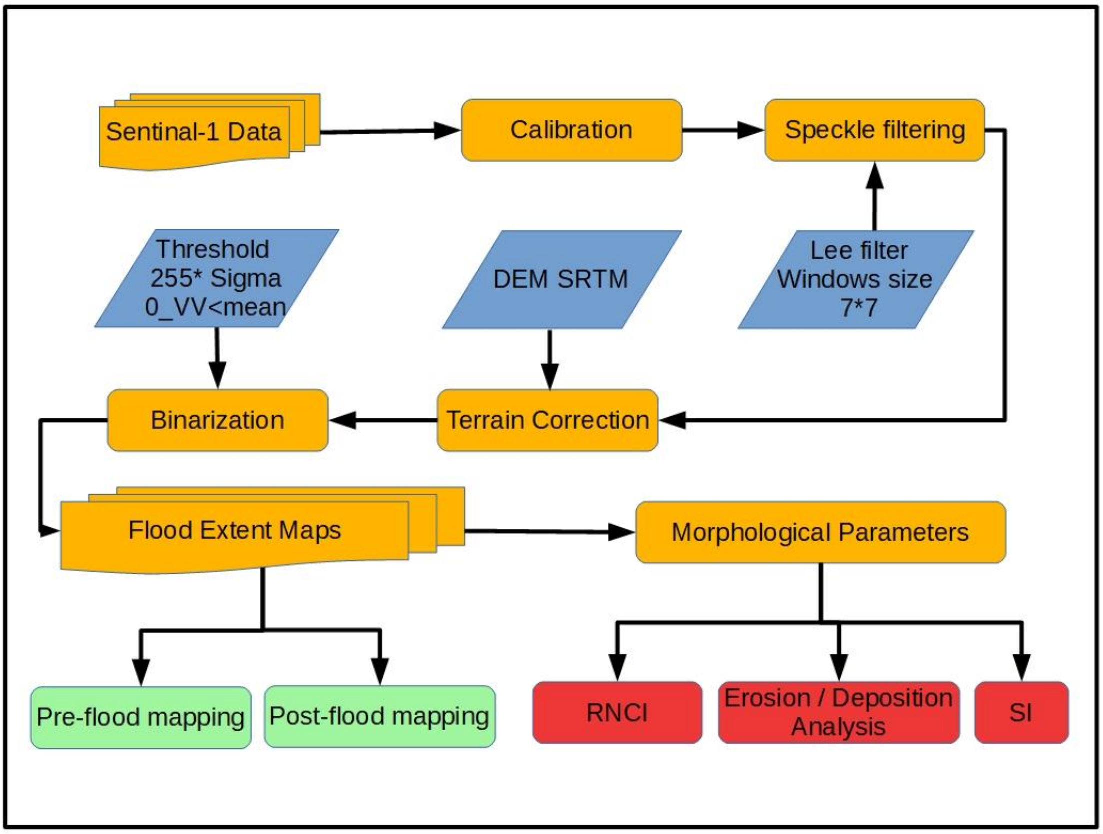


*Figure 5.2 Methodology used in the study*

The active channel is defined as a wetted channel (flow channel). The active channel is the portion of the stream channel in which water is available during the Image acquisition time. The water pixels have very low backscatter coefficient and appear darker due to the specular nature of water against microwave signals. These darker pixels are extract from the SAR data using a threshold value. This threshold value is selected from the histogram of the data, andthese water pixel is extracted using band math operation in SNAP. The classified binary image has two groups of land cover ‘water’ and ‘other classes’. The classified images were imported to ArcGIS (10.1) environment, and the statistics of different classes were assessed.

The river channel was mapped before and after the flood to assess the flood impact on channel morphology. The Active channel width was measured in 10 m intervals using Fluvial Corridor 10.1 and changes were mapped along the lower section of the Ramganga river[208]. The Ramganga river is divided into eight reaches (pre and post-flood) (Fig. 5.1). The morphological indices like sinuosity index (CI) (Eq. 5.1) and river network change index (RNCI) (Eq. 5.2) is calculated. For these indices, the other parameters are also calculated, e.g. flow length (S), erosion area (EA), straight meander length (L), sedimentation area (DA), and the Study period (T) is considered 1 for a single year.

$$CI = S/L \tag{5.1}$$

$$RNCI = \left(\frac{\sum EA - \sum DA}{L}\right)/T \tag{5.2}$$

Sinuosity index is the ratio of the curvilinear length to the straight (shortest) length between the endpoints of the river. The river changes its planform during the time, which can be successfully evaluated using RNCI (River Network Change Index) [50]. The RNCI is a useful morphological index used to identify the current geomorphological process [51]. If the RNCI is positive than the dominant erosion process is taking place, and negative RNCI shows sedimentation in the river [52].

Sentinel 2A images were used for pre and post-flood analysis. Several algorithms available to map the water bodies form the remote sensing data ranging from band density slicing [209], supervised and unsupervised classification [210], spectral water index [211] etc. However, spectral water index algorithmsare considered the best due to low computational cost, user friendly and most reliable [212]. Therefore flood inundation area was mapped using Modified Normalized Differential Water Index (MNDWI). MNDWI required green band (Band 3), and SWIR (Band 11) and these bands havea different spatial resolution (10m and 20m) respectively in Sentinel 2A data. So, that 10m green band required upscaling to 20m [213]. The 20-m MNDWI is calculated as (Eq. 5.3):

$$MNDWI_{20m} = \frac{\rho_3^{20m} - \rho_{11}}{\rho_3^{20m} + \rho_{11}} \tag{5.3}$$

In Equation (5.3),

$\rho_{11}$ = top of the atmosphere (TOA) reflectance of band 11 (SWIR) of Sentinel-2A,

$\rho_3^{20m}$ = TOA reflectance of the 20m upscaled band 3 of the Sentinel-2A dataset,

$\rho_3^{20m}$ = is calculated as the average value of the corresponding 2×2 $\rho_3$ values.

## 5.4 Results and discussion

### 5.4.1 Hydrological observations

During August and September 2018, Ganga and Ramganga *doab* were in flood condition at two gauge stations, one is situated on Ganga river Fatehgarh and another at Ramganga at Dabri.Flood hydrograph prepared from IDUP water level data taken during the period from 5 August 2018 to 28 September 2018 for these two gauge stations (Fig. 5.3). The figure shows that the water level of the Ganga river water level started rising from 5 August 2018 and crossed the DL (danger level) (137.6 m) on 30 August 2018 at Fatehgarh gauge station (Fig. 5.3 Ganga). The Ganga river was flowing above DL for about 12 days (30 August to 10 September 2018). It can be evidently observed that atDabri gauge station, the Ramganga River water levelstarts rising from 5 August 2018 and reached two consecutive peaks between 9 and 18 August 2018 (Fig. 5.3 Dabri). The discharge data for Ramganga river on the 9 august 2018 and in 23 sept 2018 was respectively 424.85 m3/s and 271.469 m3/s and its flood frequency was below then 2- year return preiod.

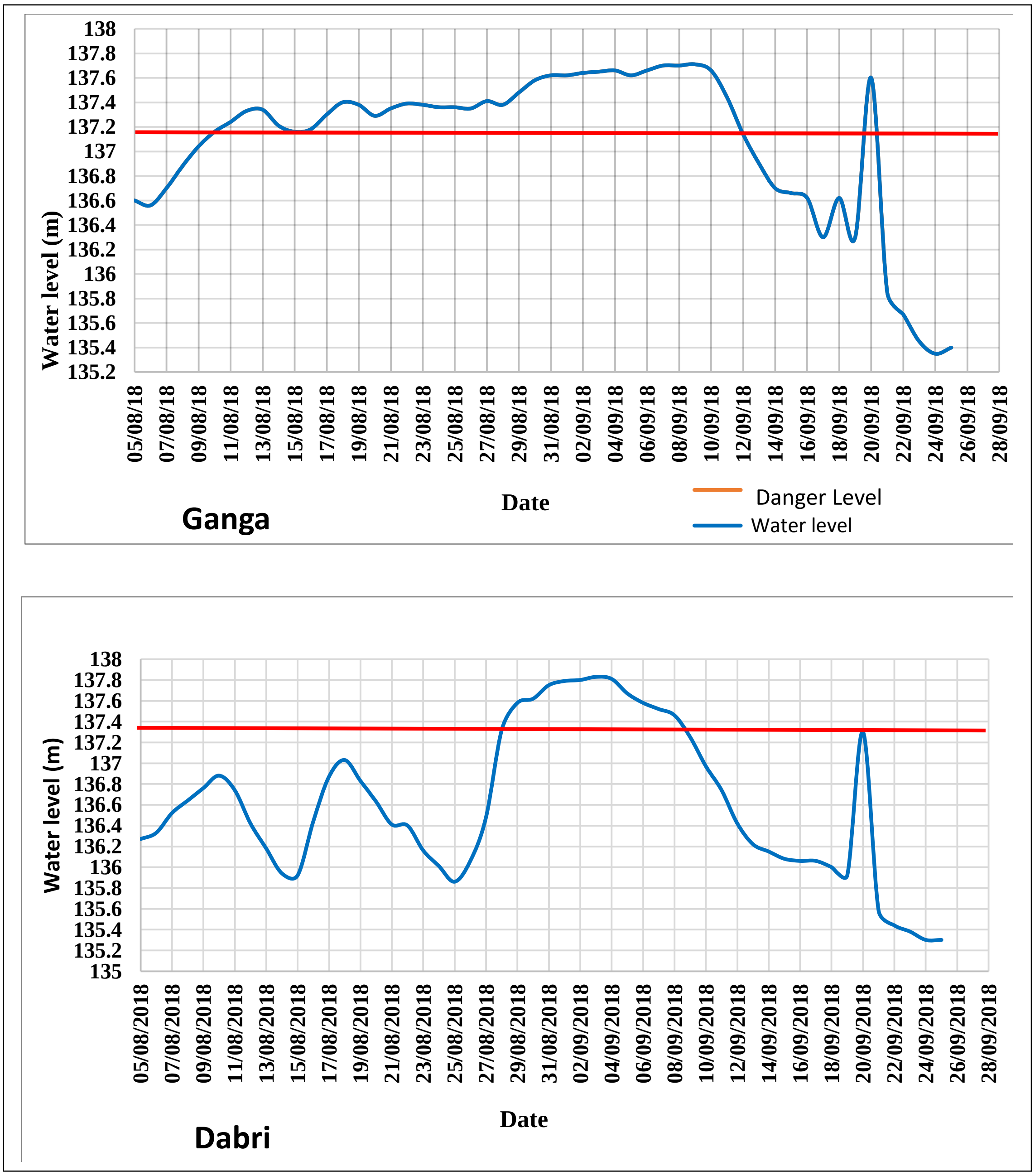


***Figure 5.3 Flood hydrograph for the Ganga river at Fatehgarh and Dabri gauge stations from 5 August 2018 to 28 September 2018***

Then water level again started rising from 25th August and crossed DL (137.3 m) on 28 August 2018. At this location, for thirteen days (28 August to 9 September) the river was above DL. It is clear from flood hydrograph that both rivers was above danger level from 31 August to 10 September 2018, which is also verified by 30 August 2018 remote sensing image (Fig. 5.7), which shows inundation in these regions.

Further, the flooded area within Ganga and Ramganga *doab*are shown in percentage in different dates (Fig. 5.4). The graph shows a sudden increase in inundated areas from 20thAugust to1 September 2018. Whereas on 1 September, 45 percent of the area was under flood after that starts receding. However,on 20 August the area was suffering from a massive flood in bothchannels.

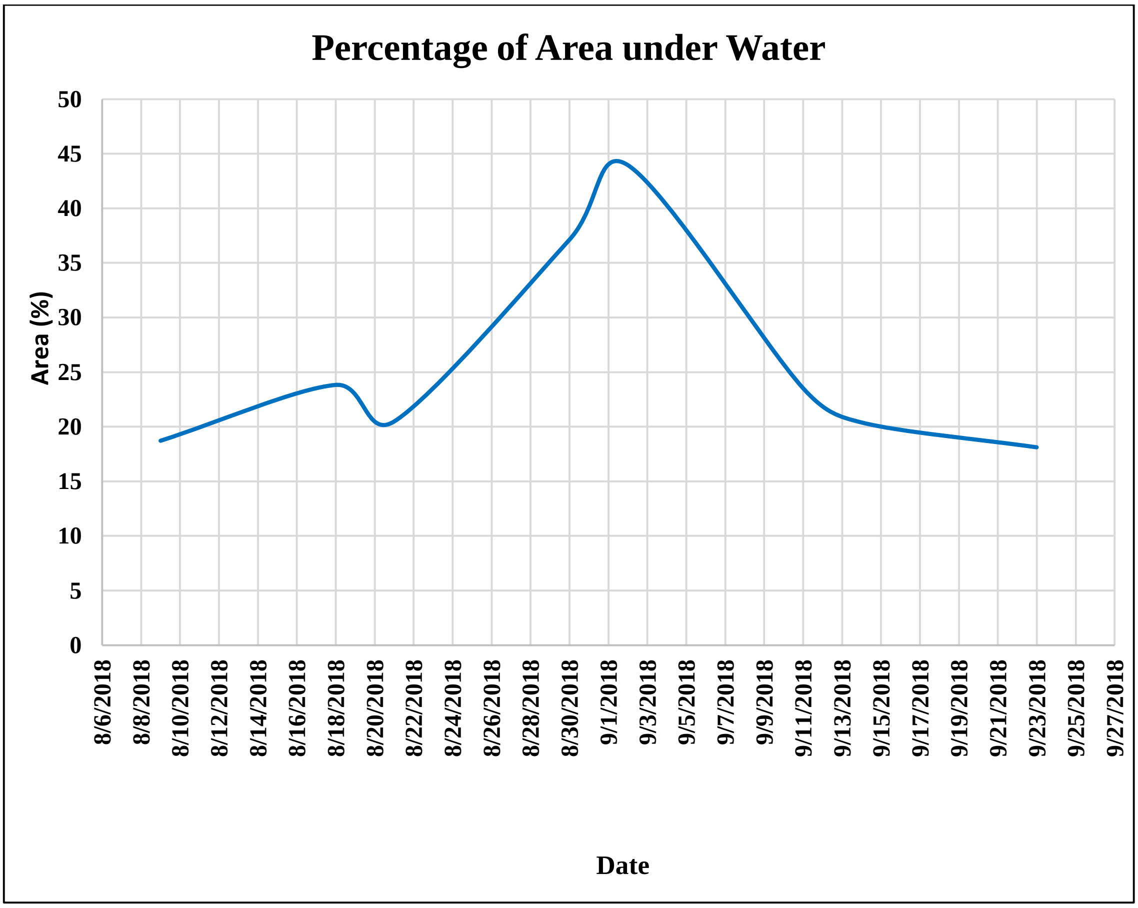


***Figure 5.4 Percentage of the inundated area in Ganga and Ramganga doab***

### 5.4.2 Validation of SAR data classification

For the validation of SAR flood maps, the sentinel-2 data was used in lack of field data during the flood. Dual polarised (VV and VH) Sentinal-1A data of 14 September, 2018 was compared with the data of Sentinel-2. Modified normalised difference water index (MNDWI) was used to extract flooded area from Sentinel-2 data. MNDWI flood extent of 14 September 2018 has been used as a reference data to validate flood extent map from the VV and VH polarisation of SAR data (Sentinel-1) collected on the same day (Fig. 5.5). The classification accuracy for the study area has been calculated for the class 'water' and 'other' as listed in Table. 5.2. The VV-polarized data shows the higher OA (overall accuracy), PA (producer accuracy) and UA (user accuracy) than the VH-polarized data and the same result has been validated by other researchers[197, 198]. So, the flood inundation map is prepared through using VV polarization [216]. This observation is established through the kappa coefficient (κ), which is 0.88 for VV polarization and 0.86 for VH polarisation. In VV polarisation PA and UA of 'water' are less than PA and UA of 'other classes' or non-water pixel. The similar trend is also observed in VH polarisation. The UA is higher than the PA in both land use classes for water and other classes.

***Table 5.2. OA, PA, UA accuracies and kappa coefficient (κ) for validation***

| Polarization | OA (%) | PA of water (%) | UA of water (%) | PA other classes (%) | UA other classes (%) | κ |
|---|---|---|---|---|---|---|
| VV | 94.6 | 91.9 | 93.6 | 96.2 | 95.2 | 0.88 |
| VH | 93.3 | 89.2 | 92.5 | 95.7 | 93.75 | 0.86 |

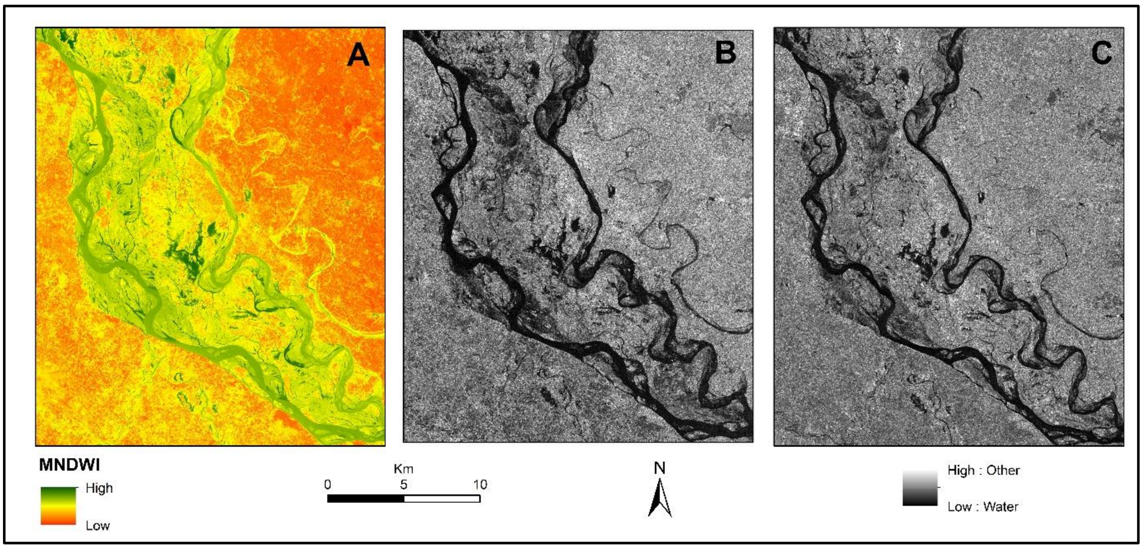


***Figure 5.5 Validation of the results for the region with the Sentinel-2, MNDWI image in which green representing water for 14-SEP-2018, (A) Sentinel-1 SAR image for 14-SEP-2018, VV polarization (B), VH polarised SAR image (C).***

### 5.4.3 Flood monitoring

The multiple images of the study region have enabled the advancement and retreat of floodwater from 09 August 2018 to 23 September 2018 (Fig5.6 & 5.7). SAR data is classified into two land cover classes such as water and non-water.

The flood maps depicted that about 19% area was inundated on the 9 August and slightly increased up to 21% on 14 August 2018 due to the accumulation of floodwater in the low land area in the flood plain (Fig. 5.6). The condition further deteriorated,and the flooded area was increased in the image of 18 August, 2018 due to flooding of the abandoned channel of Ganga and Ramganga river. About 20 % of the area was covered by the flood as shown in the image of 21 August 2018. Here, the 24% water level decreases in the Ramganga river. The worst condition of flood occurs on 25 August because of the enormous amount of water has discharged in these rivers. Theserivers started to flow above the danger level, which increased the flooded area by

25%. It has been reached about 45 % on the 30 August,and 2 September, 2018,which was the highestflood area covered in these periods, which is devastating (Fig. 5.7). After 10 September the water level started to recede in the channel, so the flood area also decreases due to the flow of flooded water in the downstream channel.

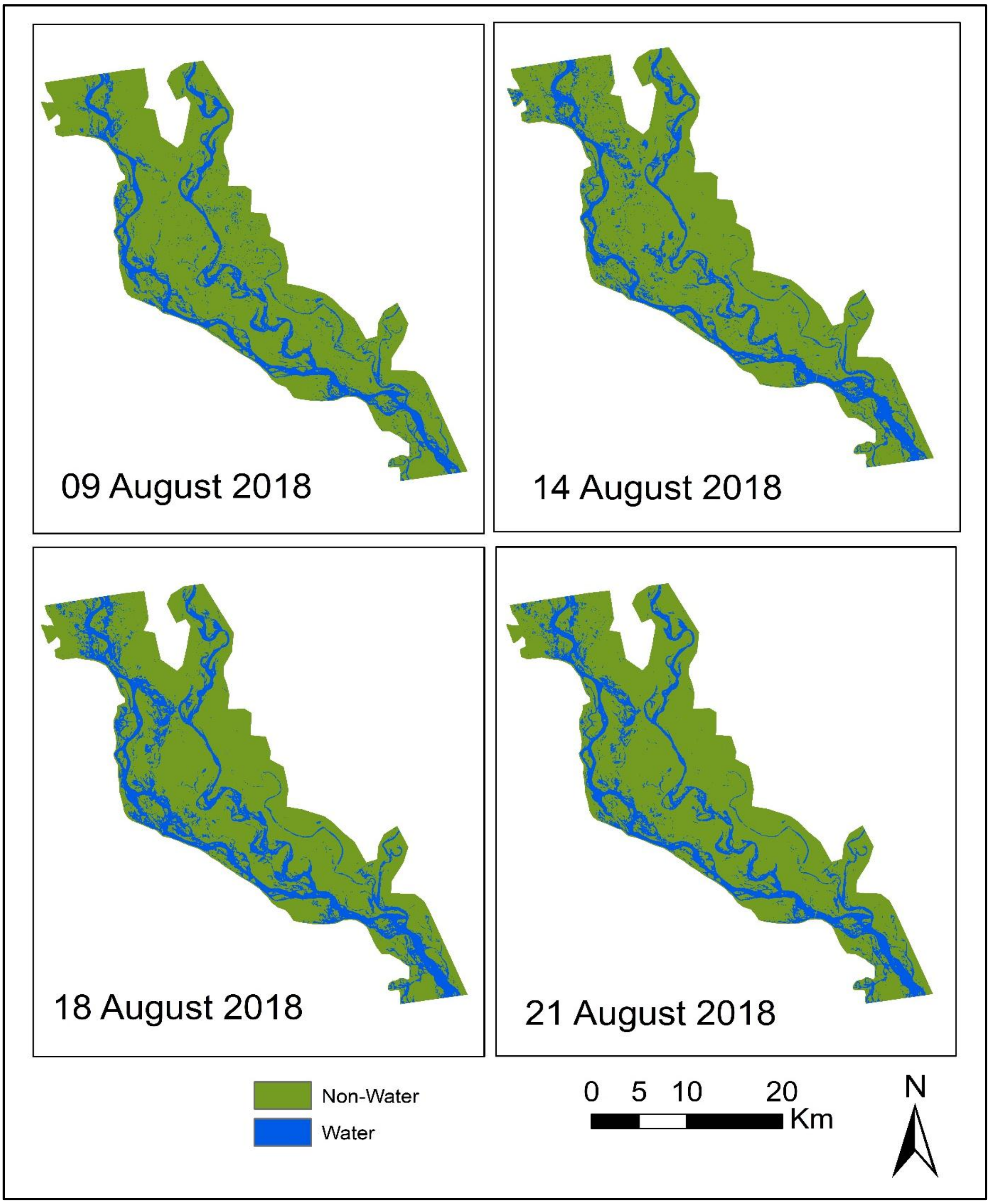


*Figure 5.6 Temporal inundation area maps based on Sentinel- 1 data*

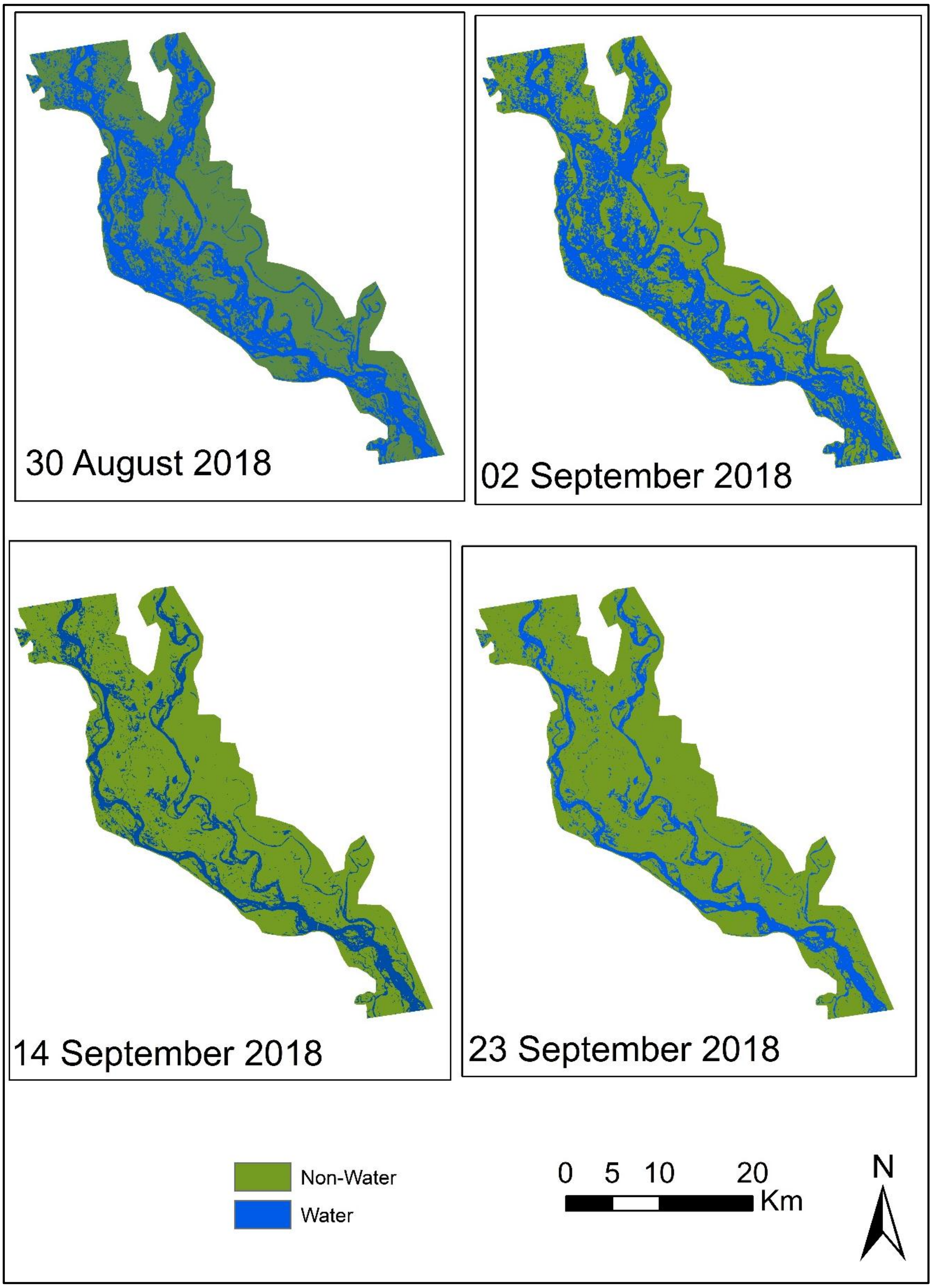


*Figure 5.7 Temporal inundation area maps based on Sentinel- 1*

### 5.4.4 Pre and post-flood observation in Ganga and Ramganga *doab*

Cloud free sentinel-2 data of lean period (21 June 2018) for pre-flood condition was compared with Sentinel- 2 data acquired under peak flood (14 September 2018) for detecting the flood condition in the study area (Fig. 5.8). By visual interpretation of the area, it can be easily detected that during the lean period the flooded area was covered with agricultural land and the rural settlement. This area is completely inundated during the flood. During the lean period (pre-flood) the Ganga river flows towards the south-west margin while during the flood period, the water spread towards the Ramganga flood plain. The left bank of Ganga river has much more flooded area due to the broad flood plain, while the right bank of the Ganga river shows is curved having high cliff line (Fig. 5.8 Post-flood). Post-flood image shows that the channel of the Gangariver is widened it's channel from 300 m to 2 Km upstream of Fatehgarh (Fig. 5.8).

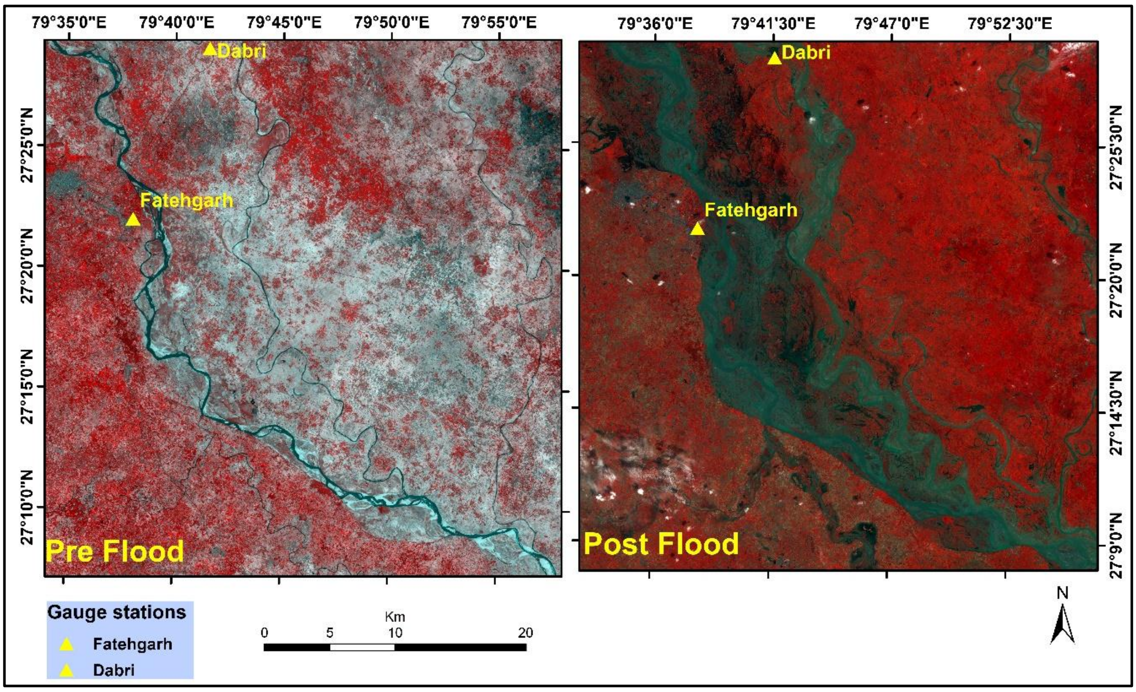


***Figure 5.8 Sentinel-2 image of 2018 and during-flood Sentinel-2 image of 14 September 2018 showing changes in the course of the Ganga and Ramganga river. Triangle in yellow colour represents the location of Gauge Stations.***

Further downstream of Fatehgarh, Ganga river width is only 200 m detected during normal flow which increases up to 3 km during the post-flood period. The river widening of 500 m was observed at downstream of Dabri gauge station which was 80 m wide during the lean periods. This area is densely populated due to the presence of fertile agriculture land and the settlement adjoining the river bank are vulnerable to flood hazards.

### 5.4.5 Effects of an extreme flood on Ramganga river morphology

Riverbankerosion is the complex process which isa result of several factors like channel geometry, geology, river discharge as well as human intervention in the channel. However, bank erosion primarily depends upon the soil type, amount of flow and discharge[217]. So, in the alluvial river, high discharge during the flood with the low gradient flood plain leads to the high river banks erosion. River erosion takes place at the outside of the meander, and the eroded particles are deposited at the inside bend of a meander [218].The alluvial river erodes its channel due to the presence of loose bank materials through lateral erosion, andconsequently, rivers change its planform.

The active channel of Ramganga river has been mapped during pre-flood (09Aug, 2018), and post-flood (23 Sep, 2018) conditions and erosion and deposition in all the eight reaches of the river are mapped (Fig. 5.9). Morphological characteristics were calculated for full reach (Table. 5.3) as well as meander scale (Table 5.4). The pre and post-flood event shows an increase in active channel width from 86.47m to 376.56m. In reach-1 the river takes a southwesterly turn in the middle portion which displays huge erosion of 227.63 ha with less deposition in outer bend side.Reach-2 shows the meandering nature, and a significant amount of erosion of 113.97 ha during floods and a very less amount of deposition takes place at convex banks leads to neck cut off in this section. An almost straight path of river flows was observed in the reach-3 and reach-4. Near about 202.90 ha and 112.89 ha area in these reaches was eroded respectively due to flood erosion. Massive erosion (337.16 ha) is observed in reach-5 near the meander bend due to the low slope towards the southwest direction. No significant amount of deposition is observed in the reach- 6, only widening of the channel takes place. A meandering nature is observed in the reach-7,which shows the enormous amount of erosion on both river banks.A prominent erosion of 194.66 ha area took place in the reach-8 whereas very less amount deposition (0.65 ha) occurred in the confluence area of Ganga and Ramganga.

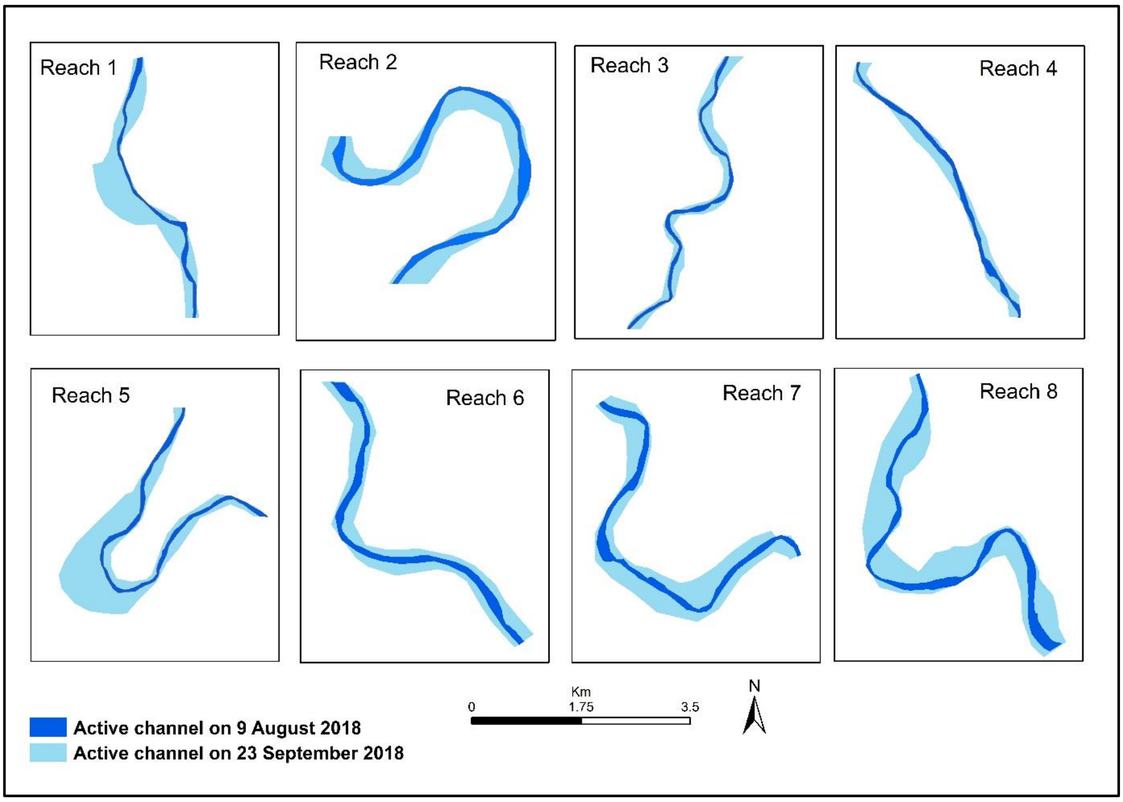


***Figure 5.9 Active channel before and after the flood***

Morphological characteristics for all reaches in pre- and post-flood were calculated for the Ramganga river (Table 5.4). Results show that the width of channel widened from pre-flood (~ 90 m) to post-flood (380 m). Maximum average widening occurs (~ 568.79 m) in reach- 8, whereas minimum widening occurs (~ 250) in reach- 4 after the flood. On the other hand minimum width was ~ 74 m in reach-1 and ~ 105m in reach ~ 8. Average of total reach area is increased by 75% during the flood period in the Ramganga river. In this flood event erosion of the river is dominantly processed the deposition. A total area of ~1650 ha is eroded during the flood and deposition of ~8.5 ha took place. Maximum erosion of ~ 370 ha took place in the reach- 8 and a minimum of ~100 ha in the reach-6. The maximum value (37.93) of RNCI is observed in the reach-5, and minimum value (15.81) observed in the reach-4, andan average RNCI for the full reach is 26 observed (Table 5.4). During the flood,the high amount of flow is forced to pass through the same channel cross-section with higher velocity. Flood increased amount of water in the channel, so the width of the channel increased significantly, andthe river became wider in areas which lead to enormous river bank erosion [202]. Highest sinuosity is found in the reach-5 due to its meander nature of the pattern, and it is increased from 3.08 to 3.21. In the reach- 4, there is a significant change in sinuosity observed due to the presence of the hard geological structure. The average sinuosity index decreased from 1.82 to 1.75 in post-flood periods (Table. 5.3) as the same results arealso found in the case of Karoon river in Iran[201].

## 5.5 Conclusion

In the context of climate change, the precipitation is expected to increase regarding intensity and frequency, leading to more severe floods [219].To respond to the increasing flood risks, flood inundation mapping is required for rapid disaster response and management using SAR data.

*Table 5.3 Morphological Characteristics of Ramganga river before and after Flood*

| Date | Average width (m) | Active channel area (ha) | Flow length (Km) | Sinuosity Index | Total erosion Area(ha) | Total sedimentation area (ha) |
|---|---|---|---|---|---|---|
| 09-Aug-18 | 86.47 | 65.13 | 61.205 | 1.82 | 1656.49 | 4.48 |
| 23-Sep-18 | 376.56 | 271.13 | 58.929 | 1.75 | | |

*Table 5.4 Morphological characteristics of Ramganga in meander scale*

| Reach No. | Pre Flood | | | | | Post Flood | | | | | Flood | | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L (km) | S (km) | Sinuosity Index | Width (m) | Area (ha) | L (km) | S (km) | Sinuosi ty | Width (m) | Area (ha) | Erosion Area (EA) ha | Deposition Area (DA) | RNCI (m/Event) |
| 1 | 5.67 | 6.40 | 1.13 | 74.00 | 46.44 | 5.66 | 6.53 | 1.15 | 450.83 | 272.84 | 227.63 | 1.22 | 35.39 |
| 2 | 2.09 | 6.90 | 3.31 | 82.87 | 55.27 | 2.16 | 6.34 | 2.94 | 296.99 | 166.67 | 113.97 | 2.57 | 16.15 |
| 3 | 7.74 | 9.74 | 1.26 | 82.75 | 84.24 | 7.76 | 9.27 | 1.19 | 307.35 | 286.33 | 202.90 | 0.80 | 20.75 |
| 4 | 6.68 | 7.02 | 1.05 | 94.49 | 64.43 | 6.57 | 6.89 | 1.05 | 252.18 | 175.40 | 112.89 | 1.92 | 15.81 |
| 5 | 2.88 | 8.87 | 3.08 | 82.02 | 69.30 | 2.89 | 9.28 | 3.21 | 461.26 | 405.54 | 337.16 | 0.91 | 37.93 |
| 6 | 4.26 | 5.31 | 1.25 | 87.57 | 43.15 | 4.30 | 5.23 | 1.22 | 284.95 | 141.97 | 98.85 | 0.04 | 18.60 |
| 7 | 4.01 | 7.24 | 1.81 | 84.05 | 61.12 | 3.97 | 6.66 | 1.68 | 390.12 | 255.41 | 194.66 | 0.37 | 26.83 |

In this present chapter, an attempt has been made to near real-time flood inundation mapping and monitoring using SAR images in Ganga and Ramganga doab during, August–September 2018. This area experiences severe floods due to monsoonal rainfall in the upstream regions. Obtaining cloud-free optical datasets during monsoon season is rare; hence, this study demonstrates the application of SAR data for near real-time flood inundation mapping and monitoring. The timely acquisition of the satellite data provides an opportunity to immediately identify the flooded areas for planning rescue and relief operations. It is apparent from hydrological observations that flood conditions at two gauge stations, i.e. Fatehgarh (Ganga) and Dabri (Ramganga) were very severe in the downstream. In this area, two flood waves were observed in the Ramganga River between 9 and 18 August. It is evident from flood hydrograph that both rivers were above danger levels from 31 August to 10 September 2018 as detected in the image.

Understanding of morphological characteristics of a river channel in reaction to the extreme flood and to forecast its impact of the engineering structure (bridges, railways, roads, embankments, etc.) in the floodplain is essential. Statistical modelling of hydraulic, morphological, sedimentological constraints is required to determine the crucial variable that is linked to the morphological changes during the extreme flood. From the analysis of remote sensing and hydrological data, it is clear that from 28 August to 8 September, flood condition was very disastrous in the studied area. This extreme flood occurrence leads to a change in the morphology of the rivers and its floodplain. Results show that the flood significantly altered bank conditions, channel width, and sinuosity. The principal effect is a high mobilisation of channel sediments, and severe bank erosion in the river reaches. Furthermore, a conclusion can be drawn that there were no gauge stations downstream of Ramganga to measure actual water level for the flood-affected area. In such a case, geospatial technology helps to evaluate flood-affected areas and supporting relief decisions during natural disasters.