RAPID EMERGENCY RESPONSE MAPPING FOR THE 2016 FLOODS IN KELANI RIVER BASIN, SRI LANKA

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ABSTRACT: Beginning on 14 May 2016, a low pressure area over the Bay of Bengal caused torrential rain to fall across Sri Lanka. Some locations saw over 350 mm (13.77 inches) of rain fall in 24 hours. Floods and landslides have caused havoc in as many as 19 districts of the country, including around Colombo, causing floods and landslides which affected half a million people with causality reported over 100 and estimated economic losses closer to $2billion. In recent years, due to an increasing number in the frequency and intensity of extreme meteorological events potentially related to climate change, a growing attention has been paid to the operational use of satellite remote sensing applied to emergency response and relief measures. This is mainly due to the large and timely availability of different types of remotely sensed data as well as geospatial information acquired in the field which may be potentially exploited in the different phases of the disaster management cycle. IWMI jointly with Disaster Management Centre (DMC), Sri Lanka activated disaster charter with Sentinel Asia and escalated International Disaster Charter to access satellite images during the crisis response phase to support government agencies in relief and rescue measures. A total of 13 satellite images both microwave and optical datasets (ALOS-2, Sentinel-1, RISAT-1, RADARSAT-2, TerraSAR-X, FORMOSAT, Landsat-8) were provided by various space agencies to generate flood situation maps on a daily basis. The emergency flood situation maps were regularly shared to national and international organizations within 3-4 hours after the post-event image is acquired by the space agencies to support in relief measures. The derived flood maps were overlaid with local administrative division to give specific information on the priority area to the DMC and Air Force authorities to focus relief measures. These rapid response maps can further be used for post-disaster relief policy and damage assessment.

1. INTRODUCTION

Flood are the third most damaging natural hazard globally. The vulnerability of human and financial capital across the globe to flood impacts are increasing due to changing demographics, rapid change in land use patterns and economic activities prone to serious damage in flood plains In addition, frequent occurrences of extreme precipitation are witnessed around the world due to anthropogenic climate change further increasing the magnitude of flood risk. Recent large flood events in Chennai, India (2015), Bihar-Madhya Pradesh-Uttar Pradesh, India and 16 districts in Bangladesh (2016) demonstrate the capacity gap in South Asian countries to cope with extremes events. While the gross economic loss from flood impacts are large in high-income countries, developing countries suffer larger economic and social impact due to absence of risk management systems (World Bank/United Nations, 2010). This is evidenced from the high mortality rates witnessed in Asia-Pacific region, in particular South Asia region (EMDAT, 2016).

Floods affect one third of total people affected by all natural disasters in Sri Lanka affecting more than 7.8 million people since 2000 (DMC, 2005). Almost 75% of the annual average rainfall occurs during the two monsoon systems: the Southwest (May-Sep) and the Northeast (Nov-Feb), in which 60% of rainfall occurs from few intense storms, causing recurrent floods in Sri Lanka. While mortality from floods in Sri Lanka are way lower than their neighboring South Asian countries, floods affect large extent of geographical area impacting 16 to 23 out of 25 districts. For such a small country, Sri Lanka ranks eleventh in the world on average annual flood exposure due to high population density and concentrated economic activities in flood prone areas. Analysis of three decades of rainfall data from 1980- 2010 in the Eastern Province of Sri Lanka revealed increased intensity of rainfall events (Zihar, 2013). Discernible anthropogenic climate change contributions are attributed to increased frequency of intense rainfall events exceeding 100 mm within 24 hours in recent years as observed in 2010, 2011 and 2012. Obvious human fingerprint influencing bio-physical systems in the form of climate variability, population growth and associated land use changes points to intensified risk to life and property under South Asian monsoon regions including Sri Lanka.

A tropical storm named Roanu struck Sri Lanka on 15th May 2016 and caused widespread flooding and landslides in 22 districts. The magnitude of Roanu storm can be seen in its coverage over Sri Lanka obtained from IMD satellite image (Fig. 1). According to the Department of Meteorology, more than 180 mm of rainfall were recorded in most parts of the country. This extreme flood event in Sri Lanka as a result of cyclone Roanu led to 200 lives lost, affecting 340,150 people and inflicted $2 billion of economic damage which is 2.4 % of GDP (OCHA, 2016 & Aon Benfield, 2016). Within two days from 15 to 16 May 2016, Kelani river basin received 350mm rainfall. Being located on the banks of Kelani river basin, capital city of Colombo was severely affected by one of the worst flood incidents in recent years inundating large part of urban localities, throwing normal life in disarray and imparting heavy economic burden on the people and government.

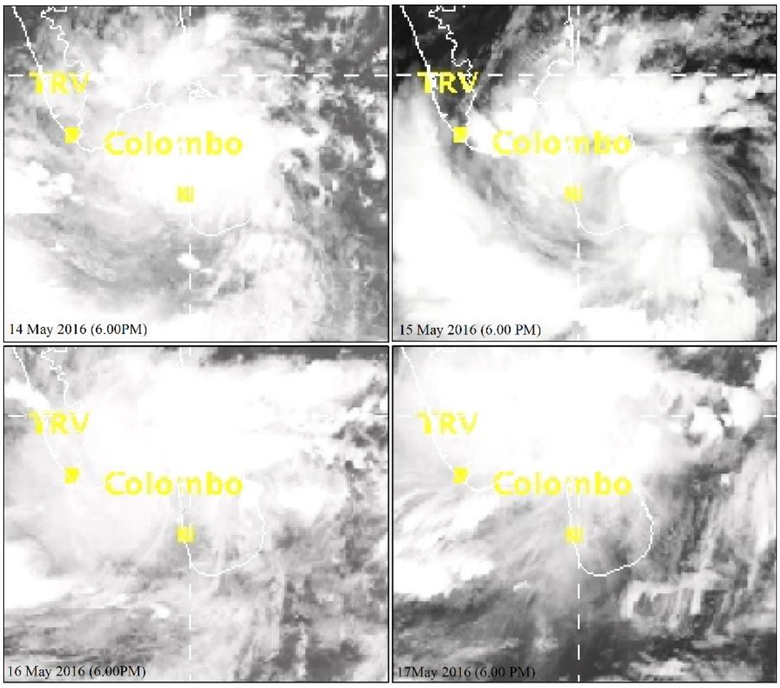

Figure 1. Satellite image from Indian Meteorological Department (IMD) showing extent and movement of Roanu cyclone over Sri Lanka from 14 May 2016 to 17 May 2016.

The serious impact of flood disaster caused by Roanu immediately became on 16 May 2016, the day of extreme rainfall event. Upon realizing the severity of the flood event, IWMI in collaboration with DMC activated a disaster charter on Sentinel Asia system (Fig,2). The Sentinel Asia initiative established in 2005 as a collaboration between regional space and disaster management agencies for the later to access remote sensing datasets for rapid mapping of disaster situation in the Asia-Pacific region (Kaku and held, 2013). The detailed information flow across the charter is given in Fig 2. Being a part of this network, IWMI activated the charted during the May 2016 flood event requesting access to the remote sensing images for rapid response assessment. Remote sensing images based on Synthetic Aperture Radar (SAR) platforms capable of sensing below cloud cover in addition to the available optical images were routinely made available to IWMI and DMC for further processing of datasets. The first image for the May 2016 flood event was made available within 24 hours upon the request. Considering the large-scale flood impact across several provinces in particular the Kelani River basin, the images of both SAR and optical images were processed within 2 to 3 hours upon availability to IWMI and disseminated to the DMC and other stakeholders both development partners and international relief agencies. Though the satellite offers area of inundation extent periodically however the spatial details are still limited for detail flood damage assessment. IWMI carried out quickly aerial survey using Unmanned Aerial Vehicle (UAV) for assessment of flood damages and extent in one of the worst affected localities. Some of the snapshots of this UAV mission is provided in results section.

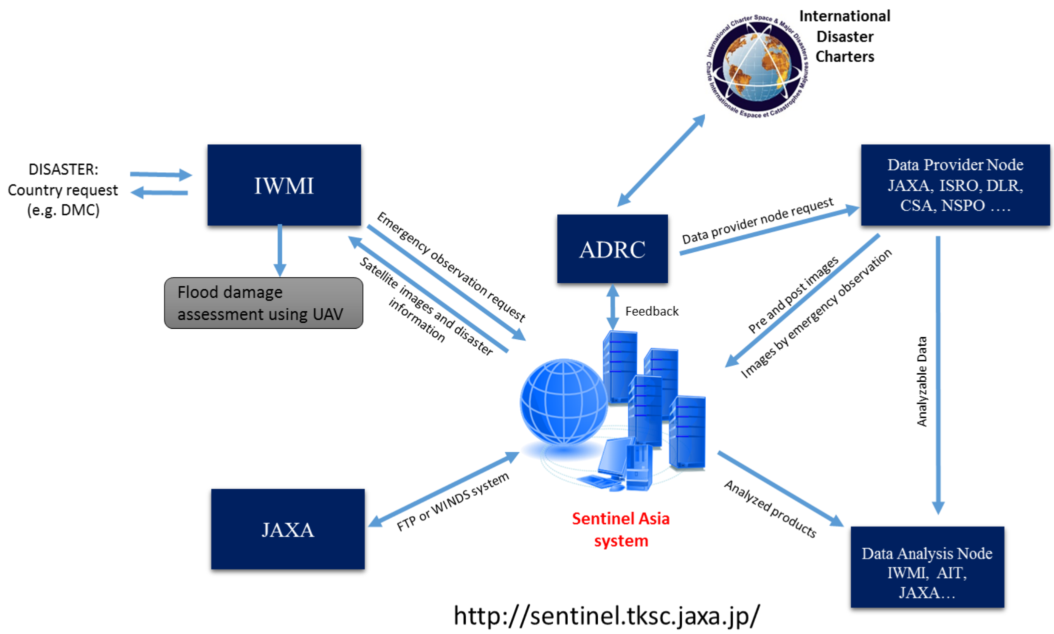

Figure 2. Flow of disaster charter activation and data dissemination

Occurrences of such extreme flood events necessitate quick response to evaluate disaster impacts plan relief and rescue efforts as part of disaster management practices. The rapid response mapping using satellite remote sensing technology is widely used, increasingly preferred alternative option for emergency assessment and operation flood disaster management efforts. Flood maps derived from remote sensing observation platforms play central role in aiding rapid response emergency operations and long term flood hazard assessment (Brivio et al. 2002). Free and frequent availability of optical remote sensing data have been used around the world for mapping the flood inundation using Landsat Multispectral Scanner (MSS), Landsat Thematic Mapper (TM), SPOT, NOAA AVHRR and MODIS datasets (Kuenzer et al., 2013). However, adverse weather conditions and frequent cloud cover during South Asian monsoon necessitate use of SAR images., Application of SAR images for rapid response flood mapping, monitoring and assessment are increasingly used in several South Asian countries India (Bhatt & Rao, 2016; Kumar et al., 2016; Satyabala, 2016; Kumar 2016), Pakistan (Westerhoff et al, 2013; Hidayat et al 2014;) and Bangladesh (Dewan et al 2005; Dewan et al., 2007;) and Sri Lanka (Kaku & Held, 2014).

The main objective of this research is to characterize spatial flood inundation patterns and flood duration for rapid response operations primarily using SAR remote sensing images for the extreme event in Kelani river basin on May 2016. The specific objectives of this research are (1) to generate flood inundation maps during the evolution of May 2016 flood event for rapid response steps, (2) to identify and assess the damage in terms of inundation area and affected people caused by this specific flood event in the study area.

2. STUDY AREA AND METHODOLOGY

Sri Lanka lies between 6º and 10º N latitude and between 80º and 82º E longitude in the Indian Ocean, with a land area of nearly 65,610 km^2 and population of 20 million. The main focus of this study is Kelani river basin located in between 6° 47' to 7° 05' and Eastern longitudes 79° 52' to 80° 13, originates in central hill slopes, flow westwards and emptying into the sea north of Colombo. Located in the wet zone of island, Kelani basin receives contributions mainly from south-west and second inter-monsoon rainfall season. The lowland of the Kelani river basin has the high vulnerability of flooding during south-western monsoon. The Kelani river watershed covers 2500km^2 and the total length of the river is around 145km (Fig 3). Mean annual rainfall in Kelani basin is around 2500 mm while mean annual temperature varies between 26.5 to 28.5 ˚C. The main land-use types are agricultural crop lands, home gardens, residential and forest.

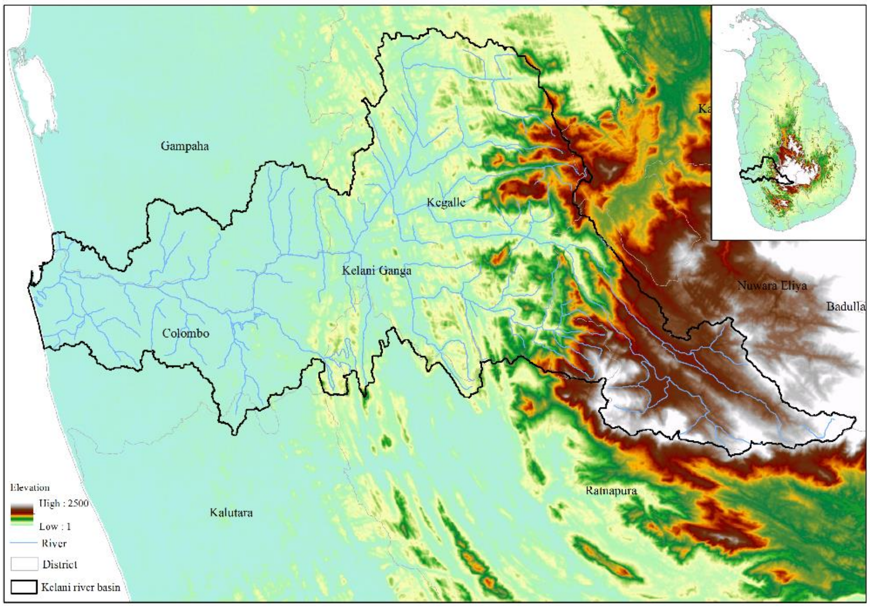

Figure 3. Location of Kelani River basin in Sri Lanka

2.1 Satellite data and Image processing

Remotely sensed data acquired by the six SAR images from satellites consisting of ALOS PALSAR, RISAT, Radarsat-2, Sentinel-1, TERASAR, FORMOSAT, and two optical images from Landsat-8 and FORMOSAT were obtained during the course of May 2016 flood event in Kelani basin (Table 1). Except Landsat-8 image, other remote sensing images (SAR) were provided by respective space agencies as part of Sentinel Asia international disaster charter due to which the coverage area and spatial resolution is not uniform.

Table 1. List of Satellite images used for rapid response mapping

Satellite	Date	Resolution
ALOS-2	16-May-16	6.25m
	24-May-16	6.25m
RADARSAT-2	21-May-16	6.25m
	24-May-16	6.25m
RISAT-1	18-May-16	36m
	20-May-16	18m
TERASAR-X	19-May-16	8.25m
	21-May-16	3m
Sentinel-1	17-May-16	10m
	22-May-16	10m
FORMOSAT-2	24-May-16	8m
Landsat 8	18-May-16	30m

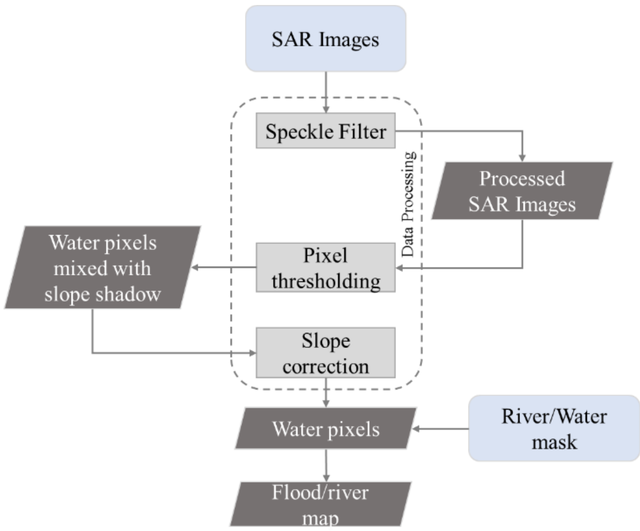

Figure 4. Processing methodology for SAR images to extract flood inundation

In total 20 SAR images and two optical images were used to map the flood inundation extent during the period between 16 May to 24 May 2016 and the spatial resolutions of these images vary from 6.25m to 36m with different spatial coverage in Kelani basin. All the SAR images were radiometrically corrected using gama-map speckle suppression technique with 5*5 kernel. Rule base threshold segmentation method employing contrasting behavior of the water and non-water pixels in the acquired images were used to derive flood inundation maps from SAR images. The threshold value was estimated by analyzing the histogram representing two peaks for water and non-water pixels in each image. By applying respective threshold for individual image, flooded area and permanent water bodies were mapped consisting of two class such as water and non-water. That binary image passes through 3*3 majority filter to further remove noise in pixels which was classified as water pixels in non-water area. The permanent water bodies including lakes, rivers and reservoirs were masked out from the mapped water class to determine only the flood pixels. The images were further processed for topographic effect corrections and removal of processing artifacts by considering the slope greater than 2º in which all the pixels above this value is considered as artifacts of topography while retaining the rest as water pixels (Fig 4). The two optical images were processed using IWMI flood mapping tool (Amarnath et al., 2012). Based on the processed data from SAR and optical images, flood maps were derived and extent of land area under inundation in different Divisional Secretariats Division (DSD) – a lower level administrative demarcation was estimated to demonstrate utility of remote sensing for rapid response mapping.

3. RESULT AND DISCUSSION

The spatio-temporal evolution of flood inundation extent in sections of Kelani River basin right from the onset of extreme rainfall event on 16 May 2016 until eventual normality on 22 May 2016 can be visualized, mapped and assessed from the listed satellite images (Fig. 5). While the Landsat-8 image contain significant cloud covered pixels, the SAR images unaffected by such conditions provided flood status of the area under imaging much clearly. The resultant flood inundation map for the area consisting of Kaduwela, just downstream of locations shown in Fig.4 is used to demonstrate the flood dynamics is shown in Fig. 6. On 16 May 2016 following the intense rainfall event, the flood started following a rapid increase in the water level beyond the carrying capacity of Kelani River (Fig 6a). The drainage points from the localities discharging into Kelani River were chocked completely leading to stagnant flood water in number of locations bordering Colombo and Gampaha districts. The extent of land area under inundation reached its largest extent on 18 May 2016, resultant of high runoff contributions from upstream hill areas covering two third of Kelani catchment. Most of the flat plains covering one third of Kelani catchment area were affected in this flood event inundating large parts of urban and agricultural landscape bordering Colombo and Gampaha districts. From 19 May 2016 onwards the flood waters started receding with the increased drainage capacity in Kelani River and less runoff contribution from upstream area. By 22 May 2016 most of the area under flood inundation recovered to the original conditions. However, due to the flat terrain and inadequate site drainage, some land parcels remained under stagnant water.

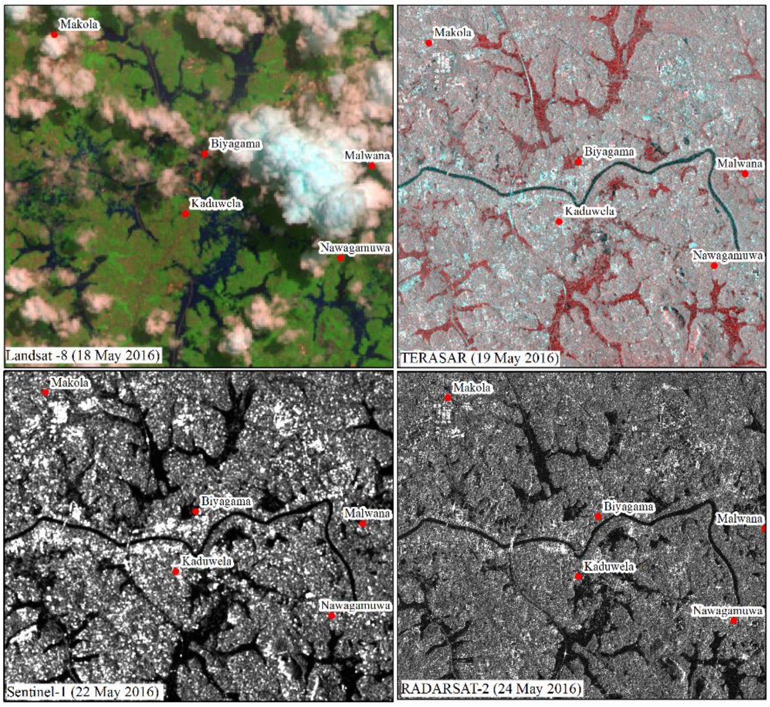

Figure 5. Evolution of flood inundation extent from 18 May 2016 to 24 May 2016 in sections of Colombo and Gampaha district from a) Landsat 8, b) Terrasar-x, c) Sentinel-1 and d) Radarsat-2 images. Dark colors pixels (Black and red) in the images represent flood pixels.

The core objective of this activity is to aid in management during and after flood disaster through mapping inundated area and sharing it with potential end users involved in relief and rescue measures. The satellite images were processed with two to three hours upon availability from the Sentinel Asia network to extract flood inundation. The extracted flood extent from these images were immediately shared with government agencies in Sri Lanka handling disaster management activities consisting of Disaster Management Center (DMC) which handled overall flood management and co-ordination during 2016 flood, Sri Lanka Air Force involved in rescue and air dropping relief supplies, Department of Irrigation and Sri Lanka Land reclamation and Development corporation. In addition, these rapid response maps were made available in online portals such as IWMI Emergency Response Portal[1], Sentinel Asia[2], Relifweb[3] and DMC[4] portal for usability by multi-lateral agencies, NGO and other interested users.

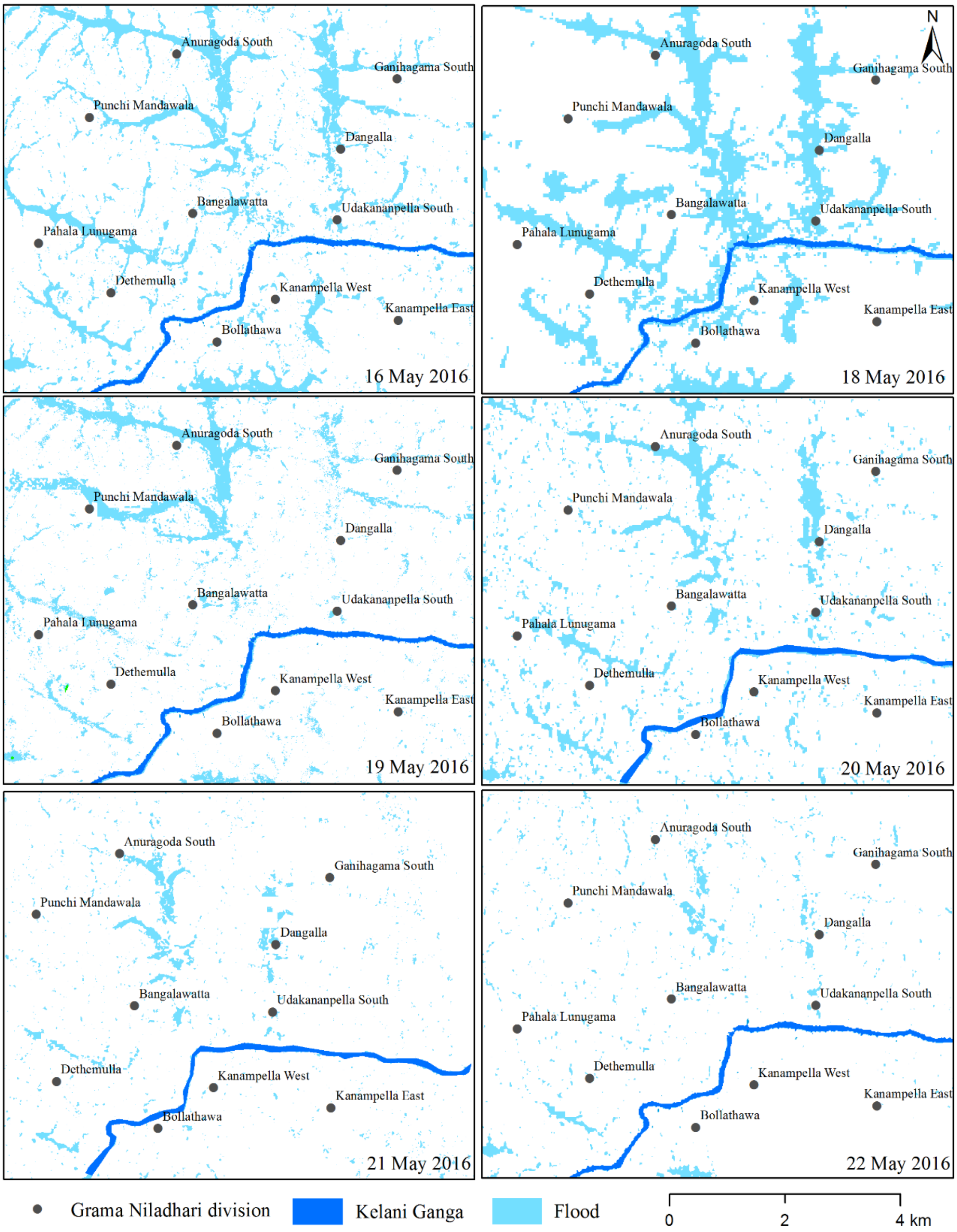

Figure 6. Mapped flood extent from 16 May 2016 to 22 May 2016 showing variations in flood inundated area in portions of Colombo and Gampaha districts.

[1] http://www.iwmi.cgiar.org/resources/emergency-response-products-for-water-disasters/
[2] https://sentinel.tksc.jaxa.jp/sentinel2/thumbnailEmob.jsp?emobRequestDetailAction.requestId=ERLKDM000007&subset_name=Emergency+Observation&submit.countryIdx=26&submit.disasterTypeIdx=#
[3] http://reliefweb.int/map/sri-lanka/mapping-floods-north-western-province-sri-lanka-using-alos-2-palsar-2-satellite-images
[4] http://www.dmc.gov.lk/Maps/RecentSituations/Flood_SL_Sept2016-1.pdf

Upon deriving the rapid response maps, overlay method in ArcGIS environment were used to superimpose flood inundation maps with Divisional Secretariats Division maps to delineate affected area accoriding to sub-administrative units in Sri Lanka for aiding policy makers. Table 2 shows temporal changes in total flood inundation area in different DSDs from 16 of May to 24 May 2016 bordering Kelani River. Sudden spike in extent of flood affected area on 16 May 2016 is clearly noticeable due to intense precipitation during the onset of flooding. However, maximum flood inundation in most of the DSDs occurred from 18 May to 19 May, leading to high level of stagnant water submerging number of dwelling in lowlands. Kaduwela and Avissawella were were the worst affected DSDs with 26 and 16 km^2 of flood affected area. It should be noted that these flood affected area were derived from satellite images of different areal coverage and did not always represent entire Kelani basin. These DSDs are heavily populated some being the suburbs of Colombo and other located in the highly developed Colombo to Kandy route. The result of these intense developments being majority of croplands located in the floodplains of Kelani River basin, which were seriously affected by the May 2016 flood.

Table 2. Flood affected area in six Divisional Secretariats Division along Kelani River (km^2)

DSD division /Date	*16 May*	*18 May*	*19 May*	*20 May*	*21 May*	*22 May*	*23 May*
Avissawella	12.00	16.00	14.00	12.00	9.00	3.00	2.00
Kaduwela	15.00	21.00	26.00	16.00	11.00	7.00	3.00
Biyagama	9.00	11.00	12.00	9.00	8.00	5.00	3.00
Kelaniya	1.20	2.00	3.00	3.40	2.30	4.00	1.20
Kolonnawa	1.30	1.80	2.20	3.00	2.70	2.00	1.10
Homagama	7.30	9.10	8.60	7.00	4.10	3.20	1.80

Extent of flood impacts in Kaduwela DSD was further assessed by deploying an UAV during the course of flooding on 17 and 19 May 2016. The very high resolution images from UAV complemented the rapid response maps by capturing the level of damages at individual plot/house levels. The extent of damages to houses, inundation in roads and damage to crops in gardens are clearly visible in the some of the sample images given below taken from Kaduwela DSD.

Figure 7. UAV image taken on 19^{th} of May 2016 in Kaduvela DSD division

Flood duration map was generated by overlaying all the daily flood inundation maps to calculate the number of days a corresponding pixels was under water with in a given time period. Eight inundation maps were created for nine flood days from 16 to 24 May 2016 based on which the flood duration map was derived (Fig. 8). Three zones where flood inundation lasted for more than 4 days were demarcated. The localities in these zones have to assessed to derive future flood mitigation efforts.

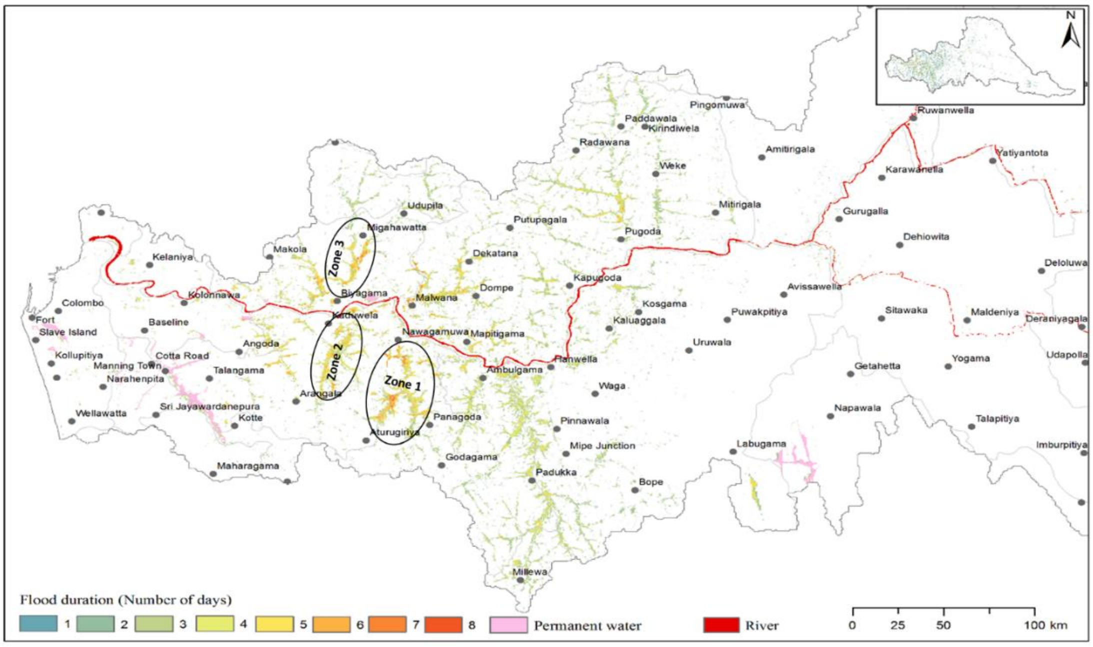

Figure 8. Spatial variations of flood duration in Kelani River basin post May 2016 rainfall event

The created flood maps were regularly used by the DMC to update on the flood situation to the higher authorities, planning of evacuation routes, and supply of relief materials to the affected people. The flood maps were further used as a guide by the DMC and Air Force to co-ordinate relief and rescue missions during the course of the May 2016 flood event.

4. CONCLUSION

In this research, multi-temporal, multi-satellite remotely sensed data with a varying resolution (very high to medium) have been used to detect and create rapid response map of affected areas by May 2016 floods in Kelani River basin in Sri Lanka. These response maps were shared with Sri Lankan government stakeholders involved in overall post-disaster management focusing of relief, rescue and later for loss assessment This activities further reinforce the advantages and success of regional co-operation on space technology application for overall flood disaster management. Based on the overlapping coverage area between different images, this study was able to determine approximate extent of land area affected by floods under different Divisional Secretariats Divisions. Avissawella and Kaduwela were the worst affected divisions located along Kelani River with maximum inundation of 21 and 26 km^2 respectively. This study demonstrates the utility of combining optical (whenever possible) and SAR remotely sensed data to map flood affected area in near real time for rapid response mapping is needed for post-flood disaster management efforts with the aid of regional co-operation.

5. ACKNOWLEDGMENT

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