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Geo-spatial Techniques for rapid Post Disaster Needs Assessment (rPDNA)

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Abstract*: Post Disaster Needs Assessment (PDNA) by conventional techniques is one of the critical challenge to respond and recover in specific timeline. This study aims on providing a rapid damage assessment model (rPDNA) by integrating geospatial techniques to compliment Post Disaster Needs Assessment (PDNA) developed by UNDP, WB and other UN agencies. This model focuses on generating the disaster damage reports within 48 – 72 hours after the disaster, to guide the decision makers on when, how and where to start the PDNA. To improve the speed and accuracy in assessment through rPDNA, various indicators like NDVI, NDWI and texture analysis has been used. Crowdsourcing approach was also adopted to make disaster affected people/victims as volunteers for quick data gathering.

***Keywords*: Damage assessment, Post Disaster Needs Assessment (PDNA), crowdsourcing, cyclone, rapid assessment**

I. INTRODUCTION

Natural Disasters are a result of sudden energy released in either of three basic forms that make up the environment i.e. land, air and water. Disasters can be termed as any events, which affect the earth by decreasing or damaging the usefulness of land, damaging the structures built on the land and causing loss of lives [12]. Countries in the Asian region are more prone to natural disasters due to rapid urbanization, low level of development and climate change [31]. It is estimated that 85% of the people affected by natural disasters live in countries with medium or low level of development due to inappropriate land use patterns and over exploitation of natural resources [19], [33].

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The frequency of various natural disasters like floods, cyclones, earthquakes, tsunamis, heat waves is increasing by each day and there by affecting more no. of people and damaging valuable structures and assets [7]. For instance, the number of events reported from 1900 to 1950 were 508 whereas, the number of events reported from 2000 to 2015 were 6698. In the same period, the number of people affected increased by 47-fold from 73.7 million to 31.5 billion whereas, cost of damages rose 193 times from

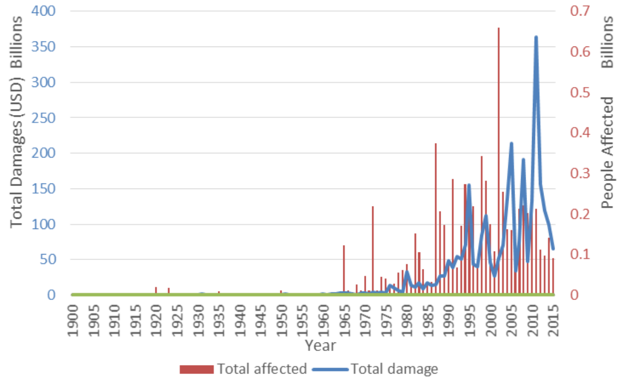

Fig. 1. Number of people affected and cost of damages worldwide during 1900 – 2015 [7]

USD 9.48 billion to USD 1.82 trillion. Fig. 1 is the disaster data from 1900 to 2015 displaying the cost of damages and the number of people affected each year worldwide.

However, the loss of lives and damage to properties are not the only effects of a disaster. The impacts of a disaster also include "negative effects on human, mental and social well-being, together with damage to properties, destruction of assets, loss of services, social and economic disruption, and environmental degradation" [35]. These effects are amplified on a developing nation when compared to the developed ones, destroying their economic growth. The economic impacts of a disaster are associated with "costs and losses of economic activity and stocks, as well as consequential indirect effects on economic flows, such as on GDP" [16]. In order to recover and rebuild from these impacts, assessments are conducted. Although assessments are often conducted after a disaster, different assessments use different methodologies, which only bring lack of clarity than any required information. Due to the need for standardization of post disaster assessments considering multiple sectors, infrastructural needs, shelters and social and community services. Hence, PDNA was developed. PDNA is one such assessment tool developed in 2008 by the EU, the WB and various UN agencies, which analyses situation at the damaged areas and proposes a plan to recover.

Since then, over 30 PDNAs have been conducted for various countries affected by various natural disasters. It is a post crisis response framework to increase nation's resilience to disasters, by responding to the recovery needs of the people and strengthening the national institutions for effective response and recovery [11]. PDNA includes the main elements of the Damage and Loss Assessment (DaLA) method and the Human Recovery Needs Assessment (HRNA) approach and process for a comprehensive assessment of damages, losses and needs, which would lead to the development of a recovery strategy. PDNA involves [34]:

- The collection of pre-disaster data to compare with post-disaster conditions in order to evaluate the magnitude and scale of the disaster
- The assessment of the disaster effects and disaster impacts in each sector to determine the overall recovery needs.
- The prioritization of these recovery needs by way of a recovery strategy.
- A Recovery Strategy that defines clear objectives, appropriate interventions to meet priority recovery needs, the expected outputs and overall intended outcome, and implementation arrangements.

PDNA generally commences after the emergency and evacuation phase i.e. after 2 - 3 weeks from the date of the disaster and takes 11 – 12 weeks to complete the assessment and generate the final report. Although the need for standardization of assessments is met, there are a few weaknesses of PDNA such as:

- PDNA only commences after 2 – 3 weeks from the date of the disaster.
- PDNA guidelines are generalized, i.e. these guidelines are not specific for any nation and type of the disaster, as under developed nations are severely affected than the developed ones, which involves considering different aspects while conducting assessments.
- Organizations involved in the assessment process, require officials and volunteers to team up together and act in a coordinated and systematic way.
- Assessments can sometimes be altered for political benefits.

To address the above mentioned issues, this study proposes a rapid assessment model called as rPDNA (rapid PDNA), which focuses on how geo-spatial techniques can be used in the existing PDNA and assess the post disaster needs of the devastation caused by Hud-Hud cyclone in Vishakhapatnam and standardize the process by reducing ambiguity and enhancing speed in assessment of damage. The study also involves a crowd sourcing methodology using an open source application and a web GIS application for visualizing the damage maps.

II. DATA & METHODS

A. *Data Preparation*

The pre and post disaster satellite images of Landsat-8 (both multi-spectral and panchromatic images) and WorldView-1 (only panchromatic image) were obtained from HDDS (Hazard Data Distribution System) and Digital Globe Foundation respectively. The Landsat-8 images obtained were acquired on 4th October, 2014 and 20th October, 2014 with 30m resolution for multi-spectral image and 15m resolution for panchromatic image. The WorldView-1 images obtained were acquired on 14th May, 2014 and 14th December, 2014 with 2.5m resolution for panchromatic image. Along with the pre-disaster and post-disaster satellite images, spatial data on municipal boundary for the city of Vishakhapatnam was obtained from GVMC (Greater Vishakhapatnam Municipal Corporation) office. The CWC (Cyclone Warning Center) in Vishakhapatnam, has provided the data on cyclone track including details with wind speed and central pressure at 1-day interval. The APSDMS (Andhra Pradesh State Disaster Mitigation Society) provided the damage points on rooftop damages and damaged trees. A total of 872 rooftop damage points and 195 damaged tree points were obtained from the dataset, which were later used for the validation of the results.

In any disaster assessment methodologies, the first and primary step is to collect the baseline data. It involves collecting the general conditions of the economy before the disaster such as social, economic, financial and cultural conditions. This data serves as baseline to compare the post disaster conditions [11].Unlike the conventional PDNA, the development of baseline information for rPDNA was done from generating land use/land cover information. Landsat-8 pre-disaster multi spectral images were used for the development of pre baseline data. Image fusion technique, pan sharpening using PCA method was carried out to the pre disaster Landsat-8 image to increase the resolution of the image to 15m. Using ENVI, a cloud mask was built to assign 'no data' values to cloud covered pixels. Then, the pre disaster image was classified to identify the pre disaster land use of Vishakhapatnam and the area covered by each land use.

B. *Study Area*

The study region selected for this study is Vishakhapatnam city which is situated on the southern part of the India. Vizag (Vishakhapatnam) is the financial capital of Andhra Pradesh. It is located at 17.68°N and 83.30°E. It has the Eastern Ghats to its West and Bay of Bengal in the Eastern side. Orissa and East Godavari Districts are it borders in North and South respectively. The city occupies 540 sq. km of land and also has the largest coastline in the Province. According to 2014 census data, the population in Vizag was 1.73 million. This steady growth in population was due to increasing economic activity which attracted the attentions of various investors and organizations. Although the chances for the development of coastal cities are more, the increase in frequency and intensity of disasters can damage their growth. One such disaster that has affected the growth of Vishakhapatnam is a tropical cyclone Hud-Hud. Hud-Hud which was classified as very severe cyclonic storm by IMD. It made a landfall in Vishakhapatnam at 17.7°N 83.3°E on 12th October, 2014. Hud-Hud caused extensive damages in the city with winds exceeding a speed of 205 kmph (127mph) [2].

The heavy rains with strong winds have inundated a few colonies, destroyed the telecommunication network, uprooted trees, the airport runway was flooded, radar and navigational at the aids were also destroyed. Hundreds of vehicles on streets were also damaged. The estimated damage caused by cyclone Hud-Hud in Vishakhapatnam was around USD 1.5 billion [3].

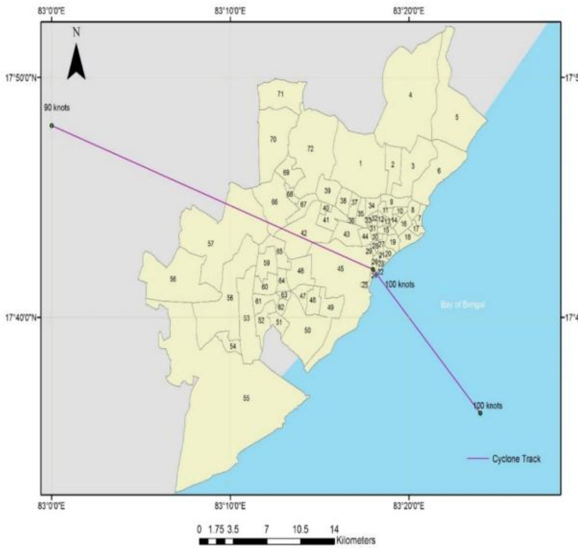

Fig. 2. Track of Cyclone Hud-Hud 2014 in Vishakhapatnam, India

C. *Cyclone Hud-Hud & its' impacts*

On 12th October, 2014 a very severe cyclone Hud-Hud hit the coasts of Andhra Pradesh. It is one of the few cases where a cyclone made a landfall of such intensity and magnitude on an urban city. Hud-Hud originated from low-pressure area over the Tenasserium coast on 6th October, 2014 and moved in west- northwest direction intensifying itself into a cyclonic storm. On 8th October, 2014 it passed the Andaman Islands and continued heading towards west – northwestwards in the Bay of Bengal (Fig. 2).

During its course, the cyclone intensified into severe cyclonic storm and very severe cyclonic storm on 9th and 10th October, 2014 and reached its maximum intensity on the early mornings of 12th October, 2014 with wind speed of 185 kmph over the coast of Andhra Pradesh [15].After the landfall at Pudimadaka, 50 km from the city of Vishakhapatnam, the cyclone headed towards northwest direction and gradually weakened into severe cyclonic storm on that evening and then into cyclonic storm by midnight. On 13th October, 2014 the cyclone turned into deep depression by morning and then degraded as depression moving towards East of Uttar Pradesh and neighbourhood [27].

As all tropical cyclones, Hud-Hud has also caused heavy to very heavy rainfall with strong winds in the coastal part of Andhra Pradesh. Large-scale structural damages were also one of the major consequence of Hud-Hud in the city of Vishakhapatnam and in the neighboring parts of the city. The IMD (2014) reported 24-hour cumulative rainfall of 38 cm until 0830 hours on 13th October, 2014 [15]. Due to the above-mentioned factors, the city witnessed shattered windows and rooftops along with damaged electric and light poles as shown in figure 3. A lot of trees were uprooted due to heavy gales. Paddy crops and orchards were severely damaged due to heavy rainfall across the state [27].

Fig. 3. Damages of Cyclone Hud-Hud 2014 [23]

D. *Methodology*

1) Damage Indicators

a) Damages in Environmental & Productive Sectors

Damages in forest ecosystems is one of the severe disturbances caused by a tropical cyclone which would further ultimately affect the carbon sink (Foster 1988, Foster 1988). Damages can be identified by observing the change in before and after disaster scenarios. Several remote sensing techniques have been used to identify vegetation changes using different methods such as a) damage/change detection based on chlorophyll content changes [18], [20], [24-26], [30] b) by observing changes in water content of leaves [1]. The two mentioned methods use NDVI (Normalized Difference Vegetation Index) and NDII (Normalized Differential Infrared Index) respectively. However, they are both followed by change detection techniques to identify damages in environment. NDVI has been widely used when compared to the latter due to its higher accuracy and wider popularity [36] and is also adopted in this study.

NDVI indicates the photosynthetic activity/greenness of plants/vegetation. It is defined as the ratio of difference between the spectral reflectance in NIR band and Red band to the sum of spectral reflectance in NIR band and Red band [9]. The values range from -1 to +1. Mathematically, it is represented as:

$$NDVI = NIR - R / NIR + R \quad (1)$$

where, NIR = Near Infrared band
R = Red band

The closer the value is to +1 the higher the photosynthetic activity of the plant and similarly, the closer the value is to -1 the lower the photosynthetic activity or indicates no vegetation. To assess the damages in productive and environment sectors, NDVI for both the pre and post disaster satellite images was computed.

b) Damages in Social Sector

The two types of damages are observed in social sector after the cyclone are damages to rooftops and water logging in built up areas (Fig. 3). Different indicators are needed to identify the damages, which are discussed below.

i) Water Logged Areas

Several remote sensing techniques have been used in identifying water logged areas in various scenarios such as density slicing of single band, tasselled cap approach, NDWI and flood inundation using DEM [5], [37]. Various studies were conducted to compare the above mentioned methods. One such work by [17], which identifies the flooded areas of Koa river and compares techniques with one another and the ground truth. The author concludes that NDWI produced better results and followed by results derived using DEM data.

NDWI (Normalized Difference Water Index) is used for delineating open water bodies and enhancing their presence on the satellite images. It is defined as the ratio of difference between spectral reflectance of Green band and NIR band to the sum of spectral reflectance of Green band and NIR band [10]. It also has its range from -1 to +1. Mathematically, NDWI is represented as:

$$NDVI = G - NIR / G + NIR \qquad (2)$$

where, G = Green band

NIR = Near infrared band

Since, heavy rainfall is one of the characteristics of a tropical cyclone, waterlogged areas can be identified using this index.

ii) Rooftop Damages

Due to high wind speeds during a cyclone, parts of the buildings are damaged such as rooftops, windows etc. This study is confined to assessing the damages on the rooftops. There are two basic forms of rooftop assessments done using remote sensing called as quantitative and qualitative assessments [29]. Quantitative assessments such as texture analysis use advanced technology such as digital image processing to identify the damaged buildings. It replaces the conventional pixel based and spectral profile based methods [29].Texture analysis is defined as the descriptor of local brightness variation from pixel to pixel in a neighbourhood of an image [28]. It is used in remote sensing to study the roughness/smoothness of the surface on the image. Statistical approach was chosen to determine the texture in this study called as GLCM. This method is based on the second order statistics of the grayscale image [32]. The texture of the panchromatic image is extracted using co-occurrence filters. The procedure to extract the texture was straightforward. The co-occurrence filter tool was used in the ENVI 5.1 package. Three different texture filters were chosen i.e. entropy filter, mean filter and the variance filter with three different filter sizes i.e. 3x3, 5x5 and 11x11 size filters were applied on one ward and the damaged areas were visually interpreted using the high resolution panchromatic image to decide the best suitable filter for assessing rooftop damages. On comparing the three different texture filters, it was learned that entropy produces better results in this particular case study. An 11x11 texture filter was chosen for less dense built-up areas and 5x5 filter for high dense built-up areas. Entropy filter measures the disorderness of the pixel. If the area is more damaged, the entropy of the pixels would be high. The formula for entropy is as follows:

$$Entropy = -\sum_{i}\sum_{j} p(i,j)\log(p(i,j)) \qquad (3)$$

where, p(i,j) is grey level co-occurrence matrix

2) Extraction of Damage Areas

As discussed earlier, to extract the damaged areas, NDVI and NDWI were used in this study. NDVI change was used to identify pixels of damaged vegetation and NDWI change was used to identify any inundated/water logged areas. Image processing technique i.e. texture analysis was used to identify damages on rooftops. By performing change detection on both pre and post disaster satellite imagery, the changes/damages caused by the disaster can be identified. Fig. 4 shows the methodology adopted for the extraction of damaged areas.

3) Crowdsourcing damage data

Crowdsourcing has been one of the trending topics since more than a decade. It is defined as the act of an organization or institution taking a function which used to be performed by employees and outsourcing it to an undefined group of people in the form of an open call [6], [14], [21]. Mapping with mobiles is probably the most commonly used method of crowdsourcing since ten years as citizens were involved in mapping their environment [13]. The crowdsourcing concept can also be used in verifying damage assessments and provide details on what kind of damages are caused by the disaster and also to understand the needs of the people [13].

EpiCollect, an open source application, which works on both iOS and Android platforms was used for crowdsourcing damage data. It allows users to collect data from the field through mobiles equipped with GPS receiver and a camera. It has a standard architecture which allows the users to modify the application according to one's needs [13]. One of the major advantages of using EpiCollect over other open source crowdsourcing applications such as Open Data Kit and Geopaparazzi is the widespread availability of the application across various mobile platforms, offline data collection and easy visualization of the data [4]. The EpiCollect web application was used to design the data collection form, which involved users entering their name, contact details and Government ID to maintain the authenticity in the data along with damage photos and location of damage.

The users can then load the form in their smartphones and submit their data to the EpiCollect servers. A sample data of 20 points was collected across various damage locations in Vishakhapatnam. One of the major challenges of crowdsourcing would be to train the users/volunteers on how to use the application and submit the damage data.

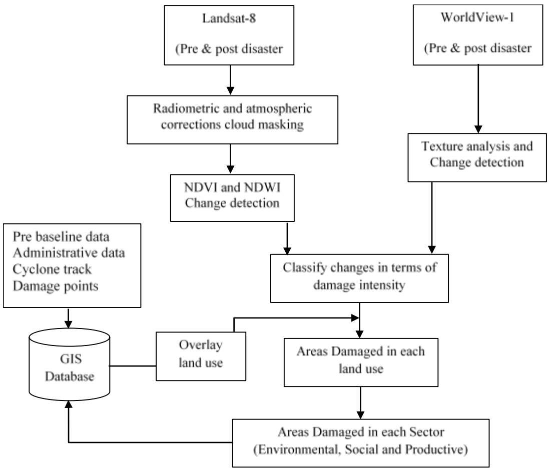

Fig 4. Methodology to extract damaged areas in each sector

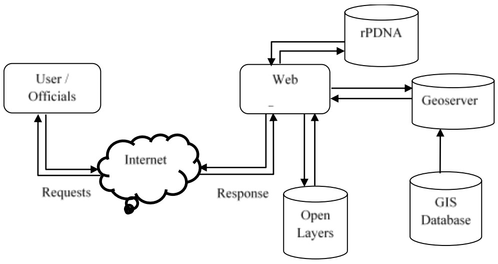

Fig 5. Visualizing damage data using Web GIS Application

The methodology for sharing the sharing the damage results as shown in Fig. 5. It enables Government officials, volunteers, NGOs and other users to visualize the damage data on the application and then coordinate their activities accordingly. Thin client architecture was chosen for the web application over thick and medium client architectures because of their ability to handle several requests at once and also because their ability to run on older/outdated systems with ease and minimum cost of deployment.

III. RESULTS & DISCUSSION

The damaged areas in each sector were identified using the baseline data generated by land use/land cover classification (Table 1). The following table shows the area in each damage class.

Table-I: Damage statistics in each sector

Sector	Area in each damage class (sq.km)			
	Very high	*High*	*Medium*	*Low*
Forest areas	36.58	80.47	8.56	0.033
Open Shrubs/Plantations	13.62	141.09	21.83	0.16
Agricultural areas	0.66	23.79	8.8	0.02
Waterlogged areas	14.71	38.6	29.96	0.32
Rooftops	-	25.4	28.84	10.7

A) Damages in Environmental Sector

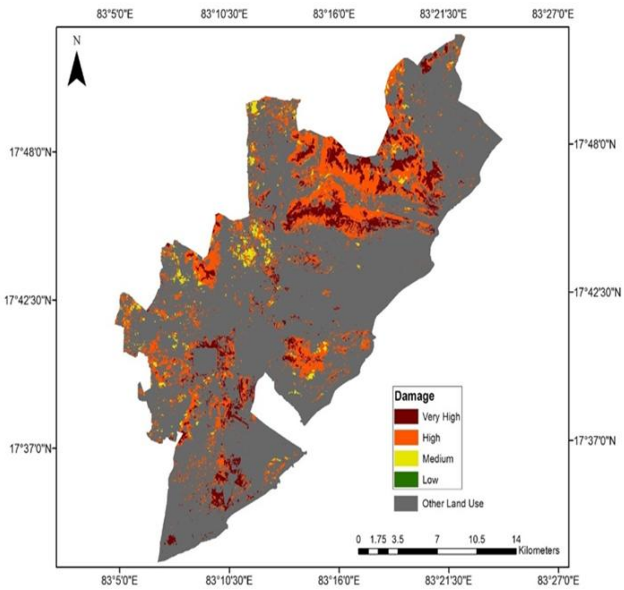

Fig. 6. Damages in forest areas

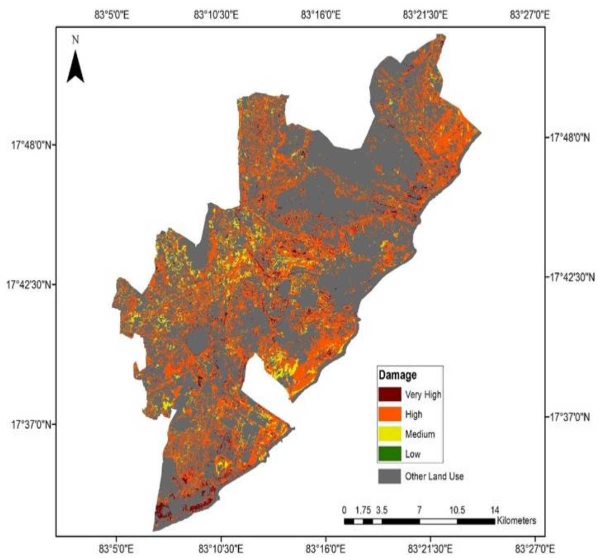

Fig. 7. Damages to open shrubs/Plantations

The forests are mostly occupied in the hilly areas of the city which provides enough proof that due to heavy winds the trees in the hilly regions got severely affected. Around 91% of the total forest areas were highly or very highly damaged which, also means that only 9% of the total forest area has medium or low damage. 76% of open shrub regions have been highly damaged and only 0.086% have limited or no damage (Fig. 6 and Fig. 7).

B) Damages in Social Sector

Rooftop damages were assessed for only 64.94 sq. km out of the 86.3 sq. km of built up of Vishakhapatnam city. Around 44.4 % of the computed area fell under medium damage class and 39% of the area fell under high damage class.

The areas closer to the coast line have more water logging compared to the ones which are far from the coast line. Around 44% of the built up area fell under 'High' class and approximately 35% fell under 'medium' class (Fig. 8 and Fig.9).

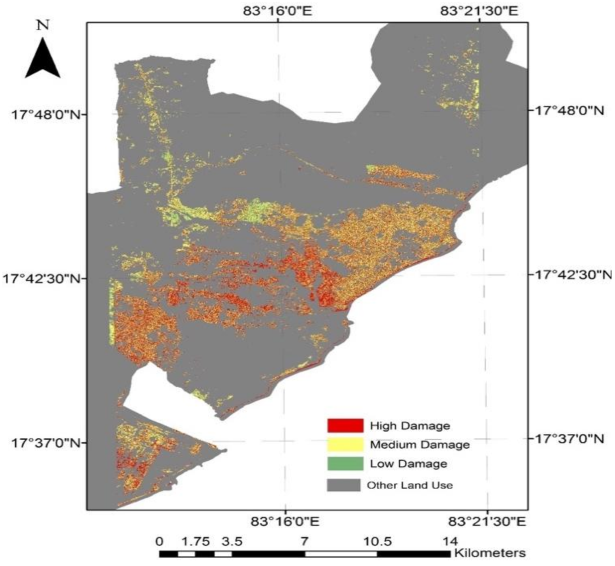

Fig. 8. Rooftop Damages

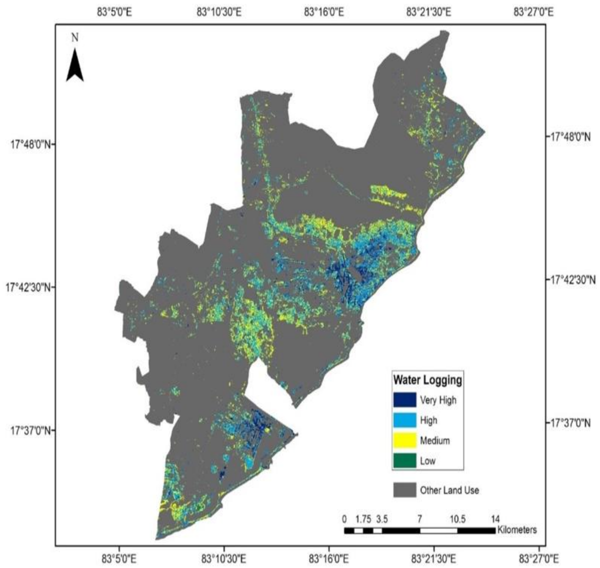

Fig. 9. Water-logged areas

C) Damages in productive sector

The damaged agricultural areas classified into four classes of which, most of the region was highly damaged. Around 64% of the total agricultural land falls in the high damage class and approximately 66% of the agricultural land is at least highly damaged (Fig.10).

D) Visualizing damage data

The web GIS application was designed for displaying the data collected from the EpiCollect application and the damages of the three targeted sectors of rPDNA. Fig.11 and Fig. 12 are the images of the web application to view and share the damage data among other users/officials. A sample of 20 points were collected as a part of crowdsourcing from different users across the city of Vishakhapatnam, which involved various damages such as uprooted trees, damages electric poles, waterlogged areas and damaged houses.

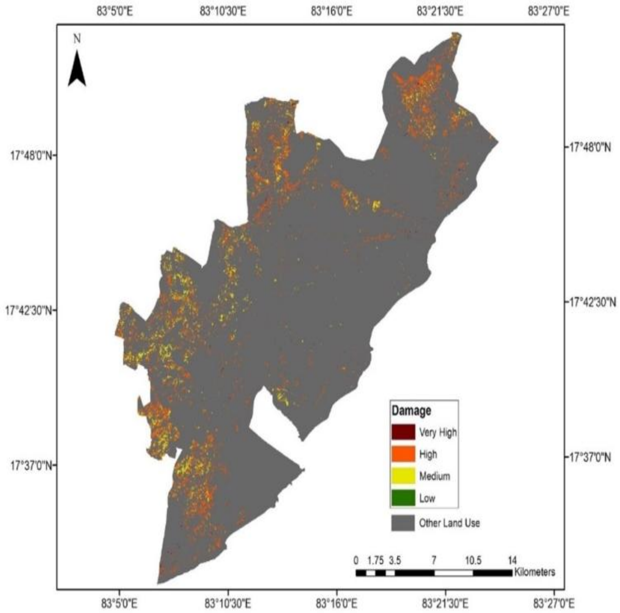

Fig. 10. Damages in productive sector

Fig. 11. Visualizing crowd sourced data

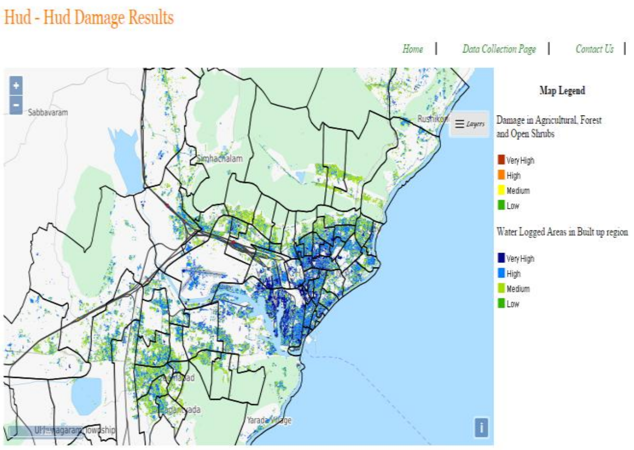

Fig. 12. Visualizing damage data

E) Accuracy Assessment

Table-I: Accuracy of results in environmental & social sectors

Sector	No. of damage points		Percentage (%) of damage points	
	Classified as low or cloud covered areas	*Classified as Medium to very high damage areas*	*Classified as low damage or cloud covered areas*	*Classified as Medium to very high damage areas*
Social	204	668	23.34	76.66
Environmental	43	152	22.06	77.94

To test the accuracy of the proposed methodology, 872 damage points in social sector i.e. rooftop damage points and 195 damage points in environmental sector i.e. damaged tree points were used. Table 2 summarizes the accuracy by calculating the no. of damage points classified as no damage areas. The damage results of environmental sector are slightly more accurate when compared to the damage results in social sector with 77.94% and 76.66% accuracy. In social sector, 204 points out of 872 damage points were classified as low or no damage areas.

As mentioned earlier, the conventional PDNA assesses broader aspects of disaster impacts such as disaster damages across various sectors, disruption of services, the decision making process of the governments and the increased risk and vulnerability of the society. It also assesses the disaster effects such as impacts on macro-economy and impacts on social and human development. The assessments of rPDNA are limited to the first section of disaster impacts i.e. in estimating the damages to infrastructure and physical assets along with damages to environment and agriculture sectors. The results of rPDNA can only serve as an initial synoptic view of the post disaster situation which will further help in conducting PDNA at most affected areas and also understanding the damages of the disaster.

The following are the advantages in conducting rPDNA before the commencement of actual PDNA:

- Provides synoptic overview of pre and post disaster situation.
- Fill in gaps in baseline pre- and post-disaster data/information.
- Substitute non-existing or outdated maps.
- Support the field mission/ data collection planning (where is the most affected area, what type of damage we can expect).
- Extrapolate field observations to produce statistically more reliable estimates of the total scale of the damage.
- Provides early field data using crowdsourcing of damage data.
- Information that is not distorted for political reasons or other forms of misinformation.

IV. CONCLUSION

In this study, the primary objective was to provide a methodology for rapid assessment of damages and to provide an overview or a rough estimation of damages which would then guide the officials and agencies for generating a complete PDNA. This methodology, i.e. rPDNA was designed to generate the damage reports within 48 – 72 hours of the disaster. Cyclone Hud-Hud was taken as a case study to develop this methodology.

Fig. 3 summarizes the timeline of various activities involved in PDNA and also indicates when the rapid assessment should begin. Generally, assessments begin after the evacuation and emergency response phase in a post disaster. However, if the emergency response phase is properly planned without any shortage of resources, rPDNA can start slightly before or along with the rescue and evacuation operations. The rapid assessments of rPDNA can be further followed by the conventional PDNA.

The results were justified using the damage points collected from APSMDMS department. The accuracy was tested for damages in environmental sector (forests and open shrubs/plantations) and social sector (rooftop damages) with 77.94% and 76.66% accuracy. An open-source android app 'EpiCollect' was also made use of to collect the damage points from the users, which would be a source of early field data from the users even before the volunteers reach the damaged areas.

The data collected using the EpiCollect app was transferred from the EpiCollect server to the dedicated server using PHP scripts to share data on the web. One of the important aspects of conducting a damage assessment is to report the data to concerned people. Hence, a web GIS application was developed to share the damage data across different agencies, which would help them in conducting further assessments, relief operations and reconstruction in complete co-ordination.

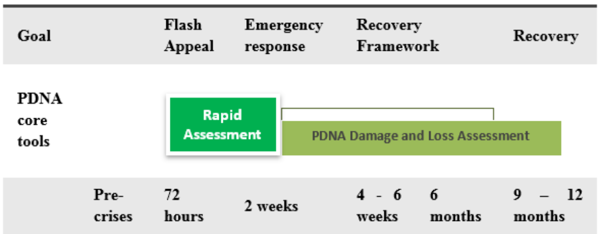

Fig 13. Timeline of rPDNA

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