Disaster Governance in India

SERIES - 5

CENTRE FOR DISASTER MANAGEMENT
Lal Bahadur Shastri National Academy of Administration, Mussoorie-248179

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LBSNAA

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DIRECTOR'S MESSAGE

Sanjeev Chopra
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Due to its unique geographical and geological conditions, India is vulnerable to various natural disasters. In India, the incidents of flood, drought and other natural disasters are on the rise and pose a major challenge to the society in general and administration in particular. Each disaster heightens the sense of urgency to equip ourselves better in coping and managing them. In this context, the training of civil servant in Disaster Management assumes critical significance.

The recurring incidence of such disasters necessitates learning from our own experience as well as the best practices adopted all over the world in the field of disaster management. Well documented best practices that can be circulated widely for creation of awareness at all levels of administration play an important role in such a context.

It gives me immense pleasure to note that Centre for Disaster Management, LBSNAA is bringing out an edited case studies series "Disaster Governance in India" Series 5, for the year 2018-19 under the project "Capacity Building on Disaster Management for IAS/Central Civil Services Officers" sponsored by National Disaster Management Authority (NDMA). This is a compilation of case studies, learnings and experiences of the officer trainees, as part of their district training.

I hope this will be useful for both the officer trainees and the administrators in handling disasters and emergency situations across the country.

Sanjeev Chopra

PREFACE

Disasters have never ceased to adversely affect human civilization. Natural disasters and man made disasters have increased both in frequency and fury over the years. India has suffered enormously, in terms of loss in lives and livelihoods and damage to both public and private property due to recurrence of disasters. In response, various strategies have been formulated and implemented with regard to mitigation, prevention, response, rehabilitation and reconstruction. These activities span pre-disaster and post disaster time periods. All these efforts have the same underlying goal – to reduce the impact of disasters on our society!

No administrator can afford the luxury of waiting for a disaster to happen in his or her jurisdiction to learn from it. It is therefore imperative to be able to convey the experiences of practitioners to each other, in an effort to educate about the variety and intensity of challenges faced in this dynamic field. The responses might not have been the best in all cases – but they would certainly be elucidating some aspect of disaster resilience to the discerning eye.

In continuation to the successful publication of the fourth series of the publication "Disaster Governance in India" by the Centre for Disaster Management, it is our privilege to publish the fifth series - for the year 2018-2019. The book will be useful to administrators, at various levels, who are handling Disaster Management. It can also serve as a good reference material for ATIs and CTIs for their in-house courses.

Raghuraj Rajendran, IAS
Deputy Director (Sr.) & Director
CDM, LBSNAA

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Saurabh Gaharwar, IAS

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Uttarakhand ($28^{0}43'$-$31^{0}27'$North and $77^{0}34'$-$81^{0}02'$East) is a north Indian Himalayan state well known as Dev-Bhumi. The state is famous worldwide for its ecological richness, bio-diversity, culture and above all tourism. The state is divided in two divisions (Garhwal and Kumaon) and consists of 13 districts.

Almost entire geo-morphology of landmass is formed of mighty Himalayas with various geomorphic features such as valleys, rocky mountains, lakes, gorges etc. Several rivers take origin from this region and during their course cause much erosion and denudation. The rainfall pattern is highly varied with average rainfall 1229mm^{2}.

Himalayas are tectonically active, and consists of uplifted loose sedimentary and metamorphic rocks. The presence of various faults such as main central trust, frontal fault, trans Himalayan thrust etc make this place tectonically active. The increasing pressure exerted by Indo-Australian plate is postulated as one of the activating factors. Therefore, the state is highly prone for all sorts of Natural disasters. In addition, the devastating potential of such hazards have been accentuated by various human activities like degradation of ecological balance, scrupulous exploitation of land, unscientific constructions etc. Being a tourist state, there has been fast paced construction of infrastructure in last decade along with population growth, tourism pressure, agricultural practices, forest degradation, dam-reservoir construction etc. which has further amplified the intensity of risks. These hazards are now one of the prime hindrances in state's economic development.

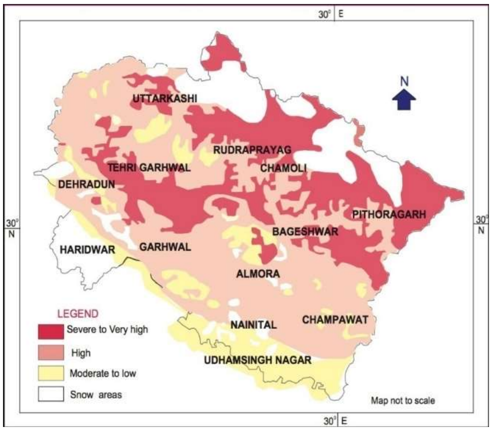
Common disasters of the region are earthquakes, landslides, avalanches, flood and flash floods, cloudbursts etc. Because of unprecedented rain, earthquakes and cloud bursts; slope failures and subsidence of land is frequent in Uttarakhand. These are known to cause much loss to property and human lives. In Uttarakhand, landslides are particularly frequent along "Main Boundary thrust" and "Main central thurst".

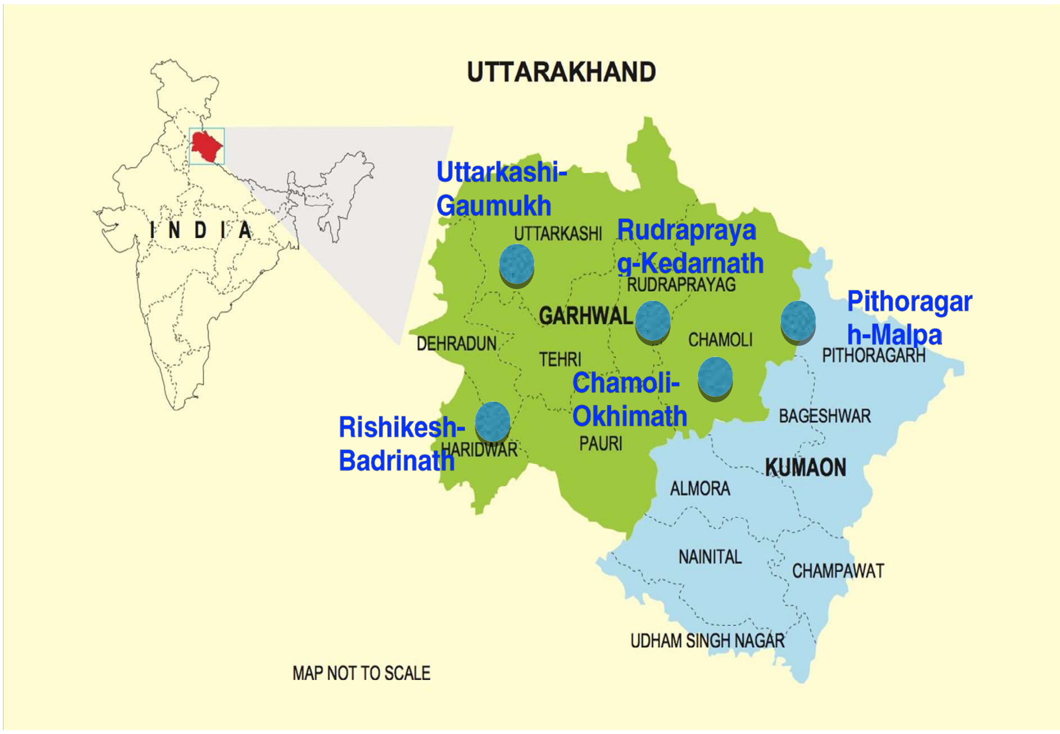
There is increased likelihood of landslides especially in monsoon (Sarkar et al, 2005). Recent events were: (DMMC report, 2012)

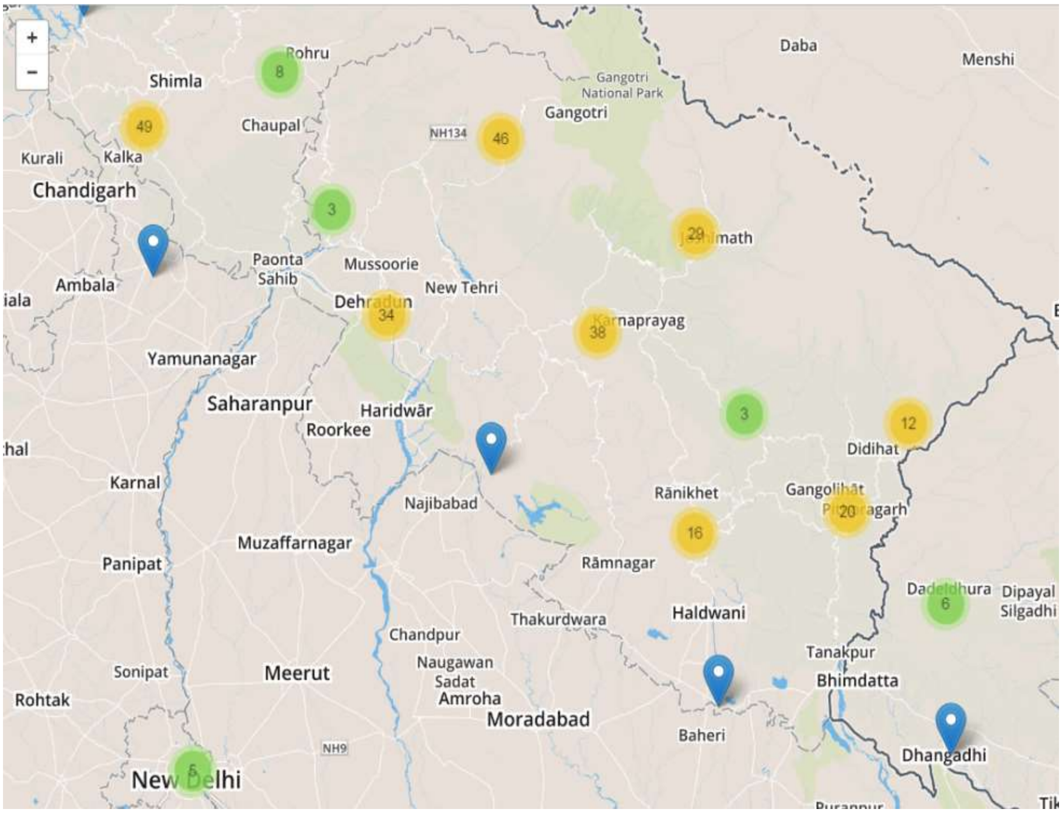
Event	Geology	Devastation
Malpa, Kali Valley, 1998	Dolomite and argillaceous limestone (sheared and fractured)	Especially affected temporary shelters en route to Kailash-Mansarovar, ~ 200 casualties
Mandakini valley, Rudraprayag, 2001		~ 20 casualties
Varunavat Hills, Uttarkashi, 2003	Quartzite + phyllites (are highly weathered and fractured)	No casualty but huge loss to property
Badrinath, Chamoli, 2004		Cloudburst, 16 killed and many trapped
Govindghat, Chamoli, 2005	Cloudburst followed by landslide	11 casualties with loss of property
Dharchula, Pithoragarh, 2007	Excessive rainfall	15 casualties
Berinag-Muniyari road, Pitoragarh, 2009	Cloud Burst	3 casualties
Ganga-Alaknanda valley, 2010		~220 died, with major damage to roads.
Okhimath, Rudraparayag, 2012		68 deaths, with damage to agricultural lands and roads.

1. Introduction

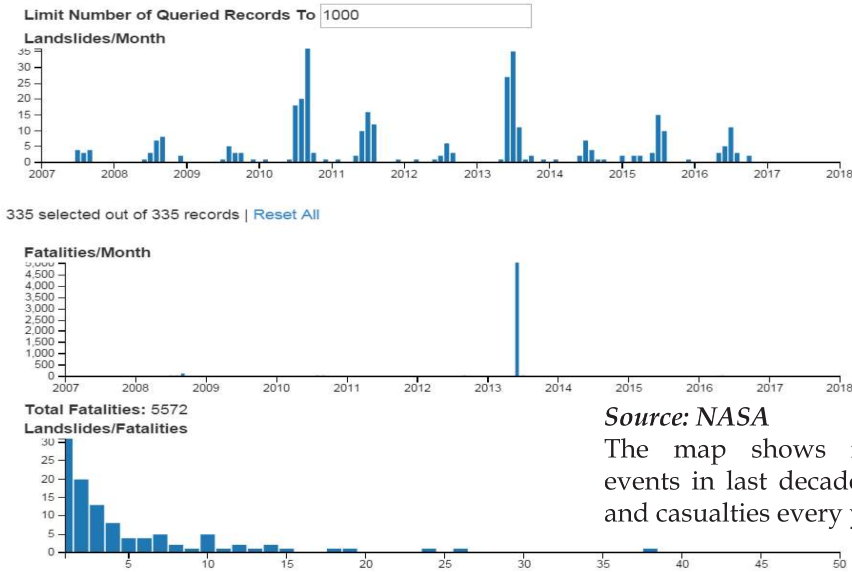
There is a great relationship between disasters and human life on earth. Both try to maintain the balance on either side, and in case of any deviation one upholds another. Among, various types of natural disasters, landslides are commoner, more devastating and impacting human lives. Three are various precipitating factors, but mode of action and impact are more or less same, be it Nepal Avalanche or 2013, Uttarakhand disaster. These are being further aggravated in intensity and frequency by anthropogenic actions.







Comparative analysis of Landslide Mitigation Strategies



Source: NASA

The map shows recent landslide events in last decade with frequency and casualties every year.

Various studies have revealed that developing countries are facing largest brunt of such condition, in light of recent climatic changes. The risk to human life is more in developing countries, however to property is more in developed countries. Therefore, the demand of time is international collaboration to reduce such losses by encompassing effective and long-lasting mitigation strategies. These measures require both engineering and non-engineering solutions along with multi-disciplinary approach. Much investment is needed not only in monetary terms, but also in participatory terms so as to reach the 2030 goal of Sustainable Development.

2. Literature Review:

2. 1 Landslide:

The phenomenon of landslide has afflicted any nations worldwide, notably Japan where projected loss entails amounting to $4 billion annually (Schuster, 1996). In India, hilly areas alone account for economical cost approximating to $1-2 billion (Sassa et al, 2005).

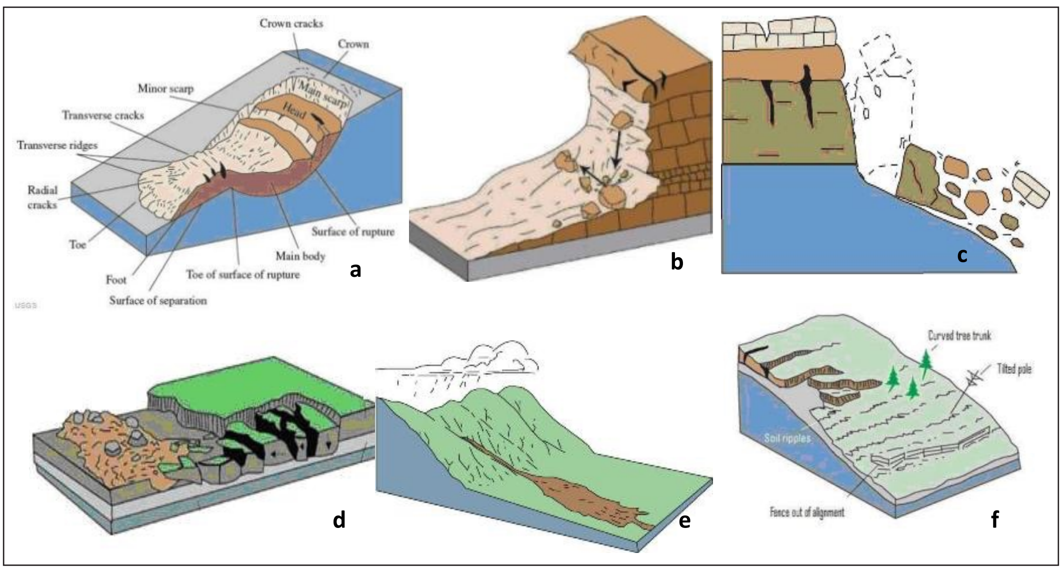
A landslide is a movement of rock or soil, either rotational or translational, along gravity with little internal deformation. Various contributing factors build up the inertia for its movement.

2.2 Classification of landslides (Varnes, 1978):

Type of movement	Motion	Type of material		
Falls	Occurs due to loss of support on free face	Rock fall	Debris fall	Earth fall
Topples	Occur on steep slope due to rotation on a pivot	Rock topples	Debris topples	Earth topples

Type of movement	Motion	Type of material		
Slides	Occurring on surface of rupture, (rotational and translational)	Rock slump	Debris slump	Earth slump
Lateral Spread	Occurs during extension of upper layer of rock on soft soil on gentle slopes	Rock spread	Debris spread	Earth spread
Flows	Continuous movement of mass of unconsolidated materials	Rock flow	Debris flow	Earth flow
Combination		Combination of two or more principal types		

Landslides are predominantly rock or soil, however if main components are sand sized finer particles its known as earth, and if coarser fragments its known as debris.



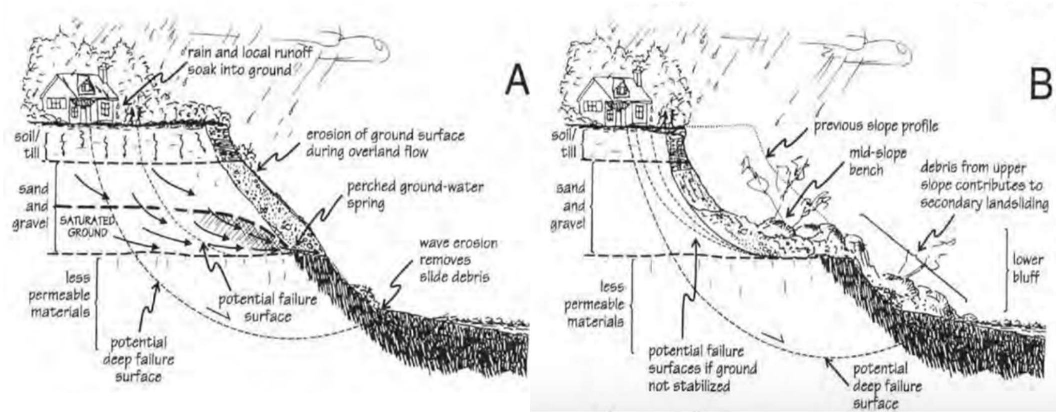
Schematic diagram showing a) Components of landslide; b) rockfall; c) Topple; d) Debris flow; e) creep; f) Lateral spread. [Source: USGS]

2.3 Contributing factors:

i) Climatic/ hydrologic factors: Rainfall is most common precipitating factor with most landslide events related to prolonged and intense rain. (Baum, 2000). Higher altitudes of Uttarakhand are also prone to "rain on snow" events, where there was rapid melting of snow due to wind and rain.

ii) Geomorphology of Slope: This includes height and steepness, which do affect the stability. Accentuating factors are over steepened conditions, along with loss of vegetation, porousness of upper mantle and precipitation intensity. The geomorphology of the slope determines the type of landslide, which can occur:

a) Debris avalanches: near surface loosened soil weakened by precipitation leads to transport as slate or slab.
b) Debris flow: within the drainage channels, surface water may lead to run-off of rapid movement of fluidized debris.



iii) Geologic and Geotechnical factors

iv) Human factors: These factors are substantial contributor, and primary include cutting of slopes, constructions on slope, disposal of waste, removing vegetation etc. this all leads to decrease in porosity of soil and hence surface run-off.

2.4 Remedial measures:

Remedial measures to correct an ongoing landslide or its prevention are a function of reducing causative-driving forces or increasing countering forces. Common measures employed are (AGS, 2000):

1) Slope geometry modification based on advanced numerical methods.
2) Drainage designing and mitigating debris flow.
3) Holding and retaining assembly.
4) Stabilizing man made or natural slopes.

However, they are used in combination depending on social, economic and environmental feasibility for both immediate and long term control. Need is to encompass flexibility so as to adapt and accommodate measures required at various intervals.

2.5 Mitigation options:

While appraisal of any project in such landslide susceptible region, risk management should look into following options.

i) Accepting risk: only if it is in possible range.
ii) Avoidance: i.e. deserting project and looking for alternatives.

iii) Diminishing probability: Buttressing structures to check commencing circumstances such reprofiling, drainage, anchorage etc.

iv) Minimizing repercussions: i.e. standardizing measures, advancing behavior of disaster or relocation of development initiatives.

v) Monitoring and early warning systems: to look into emergency solutions.

vi) Transferring unpredictability: insurance etc.

vii) Postponement of development: in case of cent certainty.

These various methods are combined in most cost effective way and weighted for maximal risk reduction. (Zoghi, 2005).

A) Engineering Methods:

1. Modification of slope geometry
   - Removing or utilizing material derived from the area driving the landslide.
   - Reduction of general slope angle.
2. Drainage
   - Surface drains
   - Trench drains strengthened with geomaterials and geosynthetics.
   - Hydrological effect of coarse materials
   - Vertical/ Horizontal boreholes and wells
   - Vegetation planting causing reinforcement of soil layer.
3. Retaining Structures
   - Gravity walls with reinforced concrete walls
   - Polymer and metallic reinforced earth structures.
4. Slope reinforcers
   - Rock bolts with soil nailing and anchors.
   - Grouting
   - Stone or columns of cement.
   - Plantation providing root strength.

Slope Geometry Modification:

The initial and most advantageous method for repair is drainage followed by slope geometry modification (Hutchinson, 1977). However, in cases of deep-seated slope disasters modification of geometry is preferred because of cost effectiveness. This involves precise localization of size, shape and position where altercation is done. Therefore, so as to simplify the method, Hutchinson (1977) provided a neutral line method for site localization.

Drainage Methods:

As, pore water is main factor reducing shear strength; its drainage is most common reinforcing method and successful too as long term solution, with caveat of long-term maintenance (Bromhead, 1992). Ditches and pipes are employed to divert shallow groundwater, and counterfeit or deep vertical drains for drainage of failures by crisscrossing shear surface. The common examples of such structures are drainage wells, tunnels and borehole drains. (Japan Landslide Society, 2008).

Retaining structures:

Structural methods are retaining walls of concrete or reinforced earth cast structures. These are particularly valuable in high devastating and unviable areas. The common drawback is expense and maintenance. (DOE, 1994)

Newer non-structural approaches are being favored which include stabilization using cement, soil nailing and grouting. This is due to lower cost and less risk of failure as there is no need of opening the slope as required in structural measures.

The modification of non-structural methods is strengthening slopes by biotechnical stabilization, which utilizes vegetation along with structural engineering solutions. Vegetation intercepts rain, ensures reinforcement of soil by buttressing soil mantle. However, in certain cases, weight of vegetation accentuated by wind forces, along with dilatation effects of roots on rock joints can be destabilizing factor, though are minor events (Geotechnical Engineering Office of Hong Kong, 2000). This method is in addition cost effective and environmentally sustainable.

Debris flow mitigation measures:

Check Dams are most popular methods for debris flow mitigation. They are of various types notably, Concrete check dams which holds runoff sediment and also reduce the amount of discharge, aptly known as "sediment control function". For reducing costs, local sediments are used covered with steel wells. The additional benefit is saving time by deriving such sediments from construction site.

Sometimes, logs as remains of forest are used for blending with forests so as to maintain the serenity of landscape.

B) Numerical measures for apt plan and design structures:

These are employed for appraising cost effectiveness, and include 3-D seepage analysis and deformation analysis for designing and planning purpose. Use of computer ensures safer and effective designing and marking for stabilization piles.

Effectiveness and acceptability in remedial measures depend on a) engineering feasibility (geo-hydrologic conditions), b) Economic feasibility (maintenance, tangible benefits etc.), c) legal regulatory conformity (local structural codes), d) social acceptability and e) environmental sustainability. Landslides are handled depending on precipitation cause, kinds of material, available resources etc.

Certain examples:

i) "Stabilization of Slopes: An Experience from Norway" (V Thakur et al). Use of cost competitive deep soil stabilization methods.

ii) "Modeling the Behavior of Rockfall Protection Fences (Cantarelli G.C. et al). Use of metallic nets as a barrier from rockfall.

iii) "An evaluation method of landslide prevention works in Yuzurihara Landslide" (Nobuaki KATO et al). This explains the role of monitoring along with effective prevention methods.

C) Remote Sensing methods:

A massive landslide occluded flow of Sunkoshi River in Sindhu Pal Chowk District of Nepal, leading to creation of 3 km upstream lake with risk to life, property and hydropower projects. Therefore, in view of potential hazard, satellite data was employed. NSRC (ISRO) was frontrunners in such emergency situation, and highlighted that it was an old landslide zone, with added inputs for dam height and reservoir volume. This information was particularly helpful in tackling the menace. It was well demonstrated that telemetry data along with remote sensing inputs can be quite helpful in initial disaster response mechanism. this can be added with spatial and temporal information for response planning in advance. (P. K. Champati Ray, 2015)

An advancement of the GIS technologies is Incident Command System/ Incident Response system (ICS/IRS). ICS based on authorization ensures responsibility-based access to information, mobilization of all resources, and a decision based on multitudes of possibility. This will avoid common human mistakes due to cognitive crunch in higher emotive stress, and will improve effectiveness and efficiency. (Amarjeet Kaur et al, 2015).

D) Community involvement:

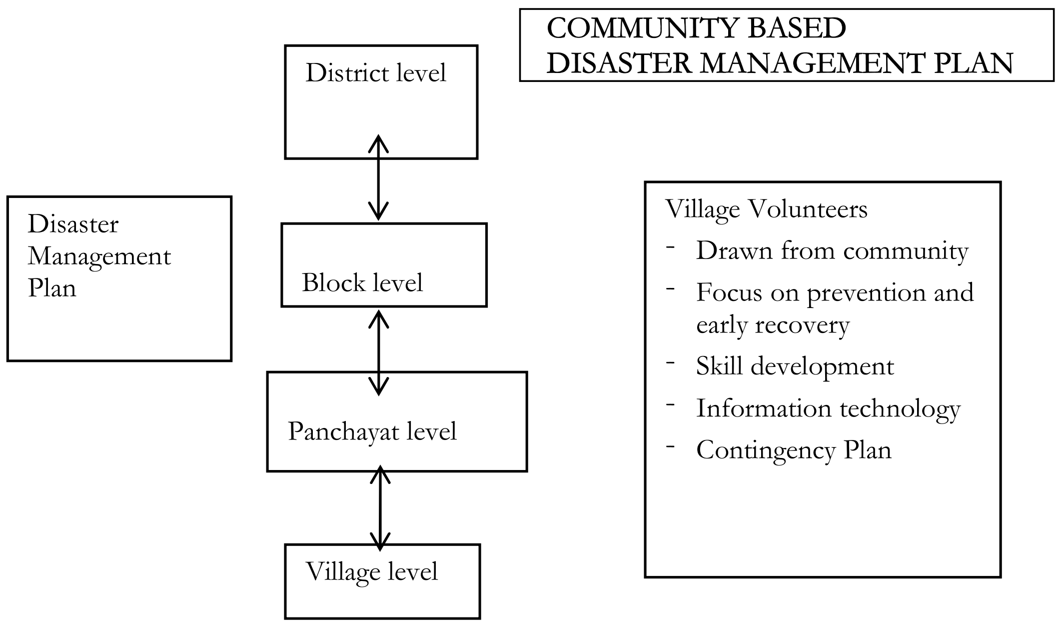
The first responders in any natural event is community at large, therefore the local people should be supported in all possible ways in capacity of analysis of vulnerabilities and response. The aim should be resilient community with sustainability. Odisha and Andaman Islands in India are few examples were community has taken step by believing in self-participation and empowerment. Keeping in mind the increasing risk of disasters especially due to climate changes, and their grave sudden impacts, a bottom up approach is quintessential to address the issues. This should start from village and should be up scaled by various inputs at varying levels. The NDMA act, address many of these but needs to be substantiated by local workers such as Village volunteers as advocated by Venkatesan K, (2015).

Data should be provided and collected at local level, regarding

i) Village origin and development. —Demography, households, hamlets, distance from headquarters etc.

ii) Past disasters— type of hazard, last occurred, preparedness, estimates of damage etc.
iii) Disaster time line with village social map
iv) Risk and Vulnerability mapping—areas which are under constant threat.
v) Resources available—police station, fire station, market etc.
vi) Mitigation plan- so as to reduce risks, toilets, hall, phone, water source, early warning system etc.

Prakash Tewari (2004) and Santosh Kumar (2012) had also emphasized in capacity building of community and creation of Community Based Disaster Response Reduction (CBDRR) by building skills, planning by vulnerable sections, competency building for initial steps of rescue and relief and above all participation in reconstructions.



E) Early warning systems for landslides triggered by rainfall:

This can be created based on:

1) Spatial Aspects- known triggering factors related with terrain failure susceptibility.
2) Temporal factors- include external events such as rainfall or earthquake.

Therefore, a warning system was developed based on relationship of intensity and duration of rainfall with destabilization of slope. Statistical, historical and empirical data were incorporated to create the relationship and hence the threshold above which likelihood is high. Parameters used were: a) Duration of rainfall, b) Intensity of rainfall, c) Duration and Intensity based rainfall event. These were combined to derive the slope failure probability.

During development of early warning system, a logistic regression was used based on daily, 3 and 30 days cumulative rainfall as predictors of slope destabilization.

"$z=-3.817+DR*0.077+3DCR*0.058+30DAR*0.009$

$f(z)= 1/1+e-z$; z: $-\infty$ to $+\infty$"

Probability:

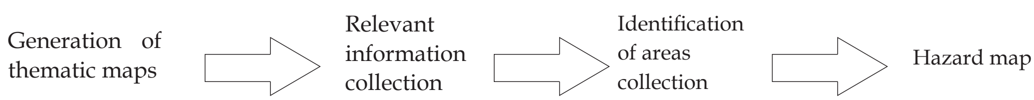
a) if $p < 0.75$ for any day = Low to Moderate susceptibility [ADVISORY]

b) if p = 0.75-0.85 = Moderate to high probability [WATCH]

if $p > 0.85$ = High to very high probability [WARN]

F) Landslide Hazard Zonation Mapping:

Its a map dividing the terrain prone to landslide into various zones as per degree of susceptibility. It comprises of spatial prediction, which depends on geological characteristics, and temporal prediction i.e. time of rainfall. However, as its difficult to comment on time of occurrence, it is stated as "Landslide Susceptibility Zonation" (LSZ). After demarcation of zones, they are ranked as per susceptibility. These maps are must for assessment of damage potential and risks. The knowledge of particular factors also help in planning out mitigation measures. Earlier, field workers developed it, but now aerial photographs and satellite imagery are used.



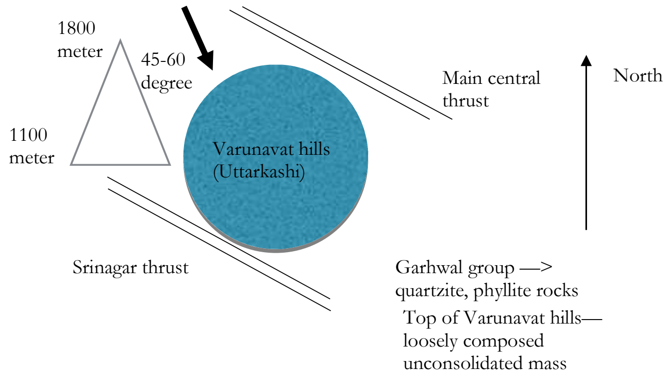
2.6 Landslide in Uttarkashi

"Treatment and Stabilization of Varunavat Parvat Landslide, Uttarkashi District, Uttarakhand" (S. Sarkar, 2010; Approach Document, GeoSciences Group, July 2015)

On 24 September 2003, a massive landslide occurred on Varunavat Parvat, which caused much devastation, by burying many premises located at toe of hill. Though there was no loss of human life, but it lead to a loss of property worth Rs 50 crores. This was due to timely awareness and preparation of district administration. The enormity was first noticed by GSI geologists in an advance of one month, and notified the same to administration for prompt evacuation and other actions. A subsequent task force report by GSI highlighted following facts:

a) Geology and tectonics:

Uttarkashi town (N and south) is vaulted by 2 faults: Srinagar and Main Central Thrust



b) *Causes of Landslides*

Heavy rainfall led to over saturation of loose mass and lubrication of underlying weathered quartzite. Hence, landslide was triggered, which in way uprooted pine trees and created dust cloud submerging habitations.

Another important factor leading to such accident was anthropogenic activities at toe of hill, increasing the vulnerability.

c) *Post-Disaster Management*

Priorities were set for safe execution of stabilization works:

I priority: Works for immediate and urgent safety of human lives

- Wide platform creation at "El1670" to safeguard habitations from debris.
- Protection from rolling boulders by way of dykes
- Structures at toe to check even small rocks.
- Grudging of Hanging mass/rocks
- GSI mapping at scale of 1:1000, testing of mass, slope stability assessment, studies for bio-restoration.

II priority: Work for stabilization

- Stabilization of crown
    1. Crown Treatment: Removal of overburden unconsolidated or overhanging mass, creation of platform, creation of design slopes and there stabilization, steel barricading at platform area, Cable anchors and rock bolting of top.
    2. Creation of Benches (a total of 25 were made), followed by management of channels of chute.
- Chute treatment: concrete steps, stabilization of margins of chute by soil reinforcement system, surface drainage system, use of geo-jute to retain the soil

- Toe treatment: Concrete retaining walls and cladding, geogrid walls and catch pits for falling debris, later geogrid walls were handed over to forest department for plantation.

III priority: Precautionary work for protection

- Geogrid wall and Bypass tunnels

d) Results: The work was completed in 2008, with no further incidents in last 5 years, despite many incidences of heavy rainfall. There are further plans for comprehensive monitoring and scaling of the methods in other areas.

2.7 Examples of other landslide mitigation strategies

A) Hong Kong (K. Y. Choi, 2013)

Hong Kong is famous worldwide for intense urban development, despite 93% of land being hilly of which 63% is steeper >15 degree and 30% >30 degrees. Most of the developments are on hillsides or slopes and due to heavy rainfall in the region poses high risks for landslides. This is further aggravated due to inadequate or lack of adoption to proper engineering studies in the region. Hence, the situation in Hong Kong is more or less similar to that in Uttarakhand.

Due to two grave accidents in 1972 (Po Shan landslide) and 1976 (Sau Mau Ping landslide), Government of Hong Kong launched "Landslip Preventive Measure Programme" (LPM), so as to strengthen ill structured slopes. This programme was further expanded in 2010, as "Landslip prevention and Mitigation Programme" to focus on remaining slopes and develop mitigation approaches for high-risk terrains through engineering works.

The Land Slip Preventive Measures Programme from 1977 to 1994

Slopes included initially were those slopes, which were near to or were affecting habitations. The terrains were designed and retrofitted in a four stage process:

Stage 1 : Identification of slopes with urgent repair if needed

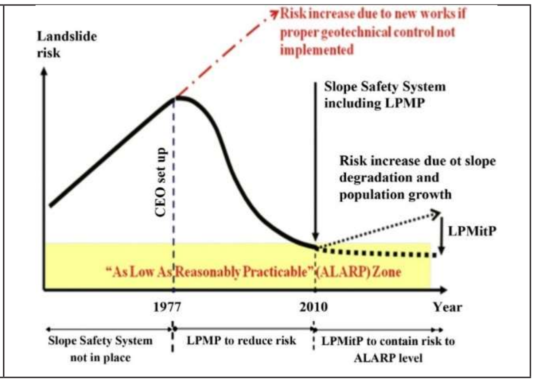
Stage 2 : Detailed study including aerial photograph, site and stability evaluation (safety screening)

Stage 3 : Designing slope to required statutory standards

Stage 4 : Construction as per design plan through tender, contract and site supervision.

Acceleration of the LPM Programme "1995-2010"

Following fatal landslide in 1994 at Kwun Lung Lau, a comprehensive investigation was conducted with help of international geotechnical expert, followed by initiation of Slope Safety Review to examine provisions related to landslides. As per report, this programme was accelerated, but this time risk based priority ranking was initially done based on instability score (age of slope, geometry, instability records, proximity of habitations etc.). During this period the rate of slope strengthening was five times of previous with an average of 250 slopes / year (Cheung and Shiu, 2000).



Landslip Prevention and Mitigation Programme"

Though following successful implementation of LPM programme bringing risks substantially low, Government left no room for complacency. In this scheme focus was on terrains where significant hazards were likely.

Slope upgrading works:

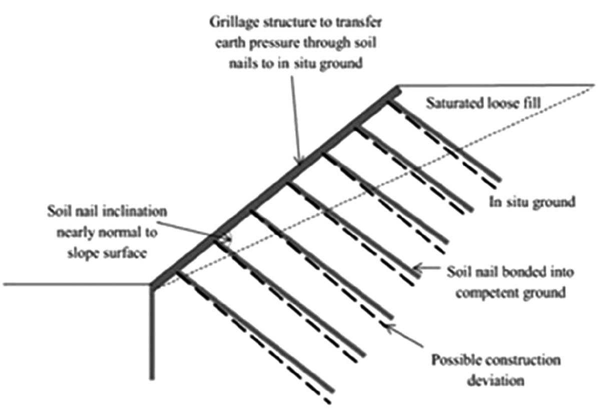
Slope Up gradation Works	
Removal	Reducing gradient by cutting the slope
Reinforcement	Use of soil nails (steel bars) for strengthening
Retention	Structures for support
Replacement	Use of concrete or soil to reform slopes

Newer improved methods were employed post 2010, which included:

i) Fill slopes:

The slopes laden with loose materials are susceptible when saturated, therefore they were compacted using coarse soil or cement.

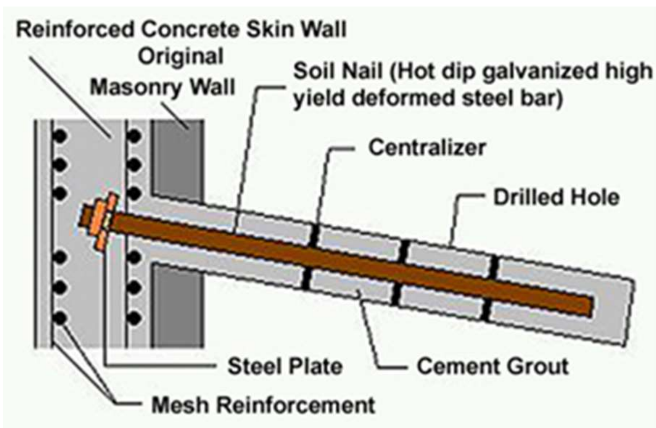
Fig. 1. Typical soil nail design in loose fill slopes in Hong Kong.



Due to environmental and feasibility concerns due to removal of trees and access issues, newer methods were used, which included a) use of rock cap; b) soil nails and grillage developed by Hong Kong group of engineers. In this technique, nails are installed through compact material and heads of the nails are connected using grillage technique.

ii) Soil cut slopes:

Earlier, trimming slope and converting it from steep to gentle, and later covering it with vegetation cover achieved stability. They were risky, as hydrological and geologic conditions were not looked into.



Typical Soil Nail Detail

Therefore, newer methods were utilized in which soil nailing was done by means of grouting and drilling.

iii) Retaining Walls

In place of old masonry walls, newer methods were used, which included soil nailing, and caissons construction behind the wall to ensure adequate drainage.

iv) Rock cut slopes

As the stability of slopes of rock depends on orientation of minor faults and hydrology (as hydrostatic pressure can alter the joints), detailed ideological information is needed. This is to be followed by mesh netting, adequate drainage provisions and rock bolting.

v) Hazard profiling of the region

This was achieved by use of aerial photography and satellite imagery and was later confirmed by site specific analysis. It is noteworthy that extensive stabilization is impractical, hence focus was on mitigation by adopting defensive measures such as concrete barrier construction at toe of hill side.

vi) Debris mobility modeling

This encompasses assessment of distance to which debris will travel and which will further depend upon its mass, momentum and friction rheology. A model was developed by GEO to assess the distance and influence zone.

vii) Flexible debris resisting barriers

These are formed of steel ring nets attached between steel posts, with added advantage of maintaining serenity of landscape. They act as shock absorbers, and are usually erected at toe of hills or where there are risks of rock fall.

viii) Managing Public expectation:

The variety of engineered methods used can only reduce the impact, but community needs to be aware of such situation and this could be achieved by way of public education.

ix) Landscaping to slopes:

It is a policy of government to give a natural touch to all the slopes, by use of vegetation s cover or use of masonry finish on hard rocks and toe planter. Research is also going in direction of use of natural vegetation to minimize visual aberrations.

B) Washington: ("Landslide Mitigation Action Plan, Final Report,2014, Washington")

Every year, landslide was a big problem for passengers between Seattle and Everett, as it used to interrupt rail services. Therefore, collaboration was made between "Washington State Department of Transportation", and other stakeholders to look into causative factors and design short and long term mitigation methods.

The documented impacts of such events were Direct Costs, which included cost for debris removal, loss of passengers and commutation and Indirect Costs, which were subsequent, increased congestion on roads, loss of revenue and rapid depreciation of properties.

Common factors identified were more or less same corresponding to landslides in other parts of world, namely, precipitation, steep slopes, faulty management practices, construction along slopes etc.

Working Group explored mitigation strategies based on feasibility, time, and effectiveness. They classified them as:

a) Interim near future, low cost strategies:
   - Education and outreach to engage community especially landowners for improved slope management.
   - Look into cheap options, such as drainage, fences etc.

- For incentivizing, monetary benefits to those who managed drainage facilities.
- Development of land inventory so as to enable local agencies in creation of LHZ and regulations.

b) Mid-term strategies:

- Experimentation and development of model to assess landslide potential and contingency plan.
- Construction of 6 projects in high prone areas to alleviate landslide problems.

c) Long-term solutions:

Continue community capacity building and awareness.

- A permit process for restoration and redesigning of projects in such locations, along with identification of crediting agency.
- Evaluating long-term solutions for shifting of debris and restoration.
- Exploring structural designs for stabilization and developing a plan for implementation.
- Constructions of easements by acquisition of adjoining land in high-risk areas.

Strategies employed

a) Stabilization: also known as improvement solidity of projects.

- Common structural measures: (low cost-with long term effectiveness)
    1. Transmuting unstable area to a lower gradient
    2. Construction of Rock buttress
    3. Reinforcing walls with high tensile mesh of steel.
- Non-structural measures:
    1. Decreasing human activities
    2. Storm water rerouting from abrupt slopes.
    3. Vegetation
    4. Adequate disposal of debris.

b) Protection and Avoidance:

This method was deployed for protection of routes; hence emphasis was on deviation and restraining of debris.

Measures taken:

- Walls, Berms, Basins especially made of timber and steel in certain places.
- Restructuring slope away from routes, tunnels and elevations to create unrestricted path for debris.

c) Maintenance and Monitoring:

This included observations and assessment of works done, proactively maintaining catchment areas, weather monitoring etc. These activities extensively helped in reducing the impact of disaster.

d) Both reactive and proactive mitigation strategies:

These both were employed as to balance the costs, better conditions of delivery as well as reducing need of emergency operations. The reactive approach is also very important because not all prone areas could be dealt with proactive strategies.

e) Strategies to reduce or prevent landslides:

- **Community education and outreach:**
  - Engaging all stakeholders to use slopes judiciously.
  - A public information system on innovative practices.
  - Pilot projects for demonstration.
- **Management of Vegetation:**
  - Vegetation based on recommendations of specialists.
- **Long term debris removal and disposal plan:**
  - Beach nourishment while ensuring ecological function.
- Creation of land hazard inventory, which can be utilized for impact assessment, and management system.

3. Results of comparative analysis:

Parameters	USA	Hong Kong	Uttarakhand (India)
Location	Washington	Kwun Lung Lau	Varunavat, Uttarkashi
Causative factors	Precipitation, Steep slopes, faulty management practices, construction along slopes	Heavy rainfall, irregular terrain, faulty construction practices	Vaulted by two faults, Heavy rainfall, anthropogenic activities
Guarantee	No guarantee that landslides will not occur.	No, hence focus on community awareness	Though no guarantee was given, but since last 5 years no incident has occurred.
Participatory approach from non-government agencies	Yes (public + private)	Public	Public
Land Hazard Zone mapping	Yes, by Working group of various stakeholders	Yes, by Geotechnical Engineering Wing	Yes, by GSI task force

Parameters		USA	Hong Kong	Uttarakhand (India)
Numerical Measures for planning and designing structures		Yes, 3-D seepage analysis + Deformation analysis	Yes, for feasibility studies	No documentation available on secondary data sources
Remote Sensing methods		Yes	Yes	Yes
Early Warning Systems		Yes	Yes, debris mobility warning system	Yes, by GSI
Engineering methods adopted	Modification of slope geometry	Transmutation slope to lower gradient, Rock buttress,	Fill slopes, Soil Cut slops using rock nails and grillage, grouting and drilling	Platform creation, Dykes, Removal of Hanging Rocks
	Drainage	Yes, rerouting storm water from abrupt slopes	Yes, caissons behind walls	Yes, surface drainage system
	Retaining structures	Yes, Walls, Berms, High tensile steel mesh wire	Yes, old masonry walls, soil nails, flexible debris retaining barriers	Yes, Geo-jute to retain the soil, concrete retaining walls, cladding, geogrid walls
	Debris flow mitigation measures	Yes, Restructured slopes to divert debris	Yes, rock bolting, tunnels	Catch pits, Surface drainage, dykes
Non-structural strategies	**Community outreach and education**	Yes, to ask them to use slopes judiciously, a public information system	Yes, as such engineering methods can only reduce the impact	Not as such, apart from explaining possibilities of such events
	Construction of pilot projects for demonstration	Yes	Yes, but not for demonstration	No
	Bio-technical methods and use of native vegetation	Yes	Yes	Yes, was handed over to Forest agencies for vegetation.

3.1 Varunavat, Uttarkashi

Progress and construction works taken at Varunavrat parvat, Uttarkashi:

a) Before disaster; b) Post –Disaster (view from left bank); c) Platform and steel Barricading at El 16770; d) Treated benches and slopes; e) Concrete Cladding; f) Drain on Benches; g) Installed cable anchors; h) Geogrid; i) geo-jute; j) vegetation and ecological management; k) Catchpit of geogrid wall

3.2 Hong Kong:

Figures illustrating:

a) 1994, fatal landslide at Kwun Lung Lau; b) Soil nails and grillage; c) Recompaction d) Application of rock-fill cap; e) Construction of nails in soil cut slope; f) Flexible barrier at toe; g) Plantar holes and toe planter

3.3 Washington

Figures illustrating:

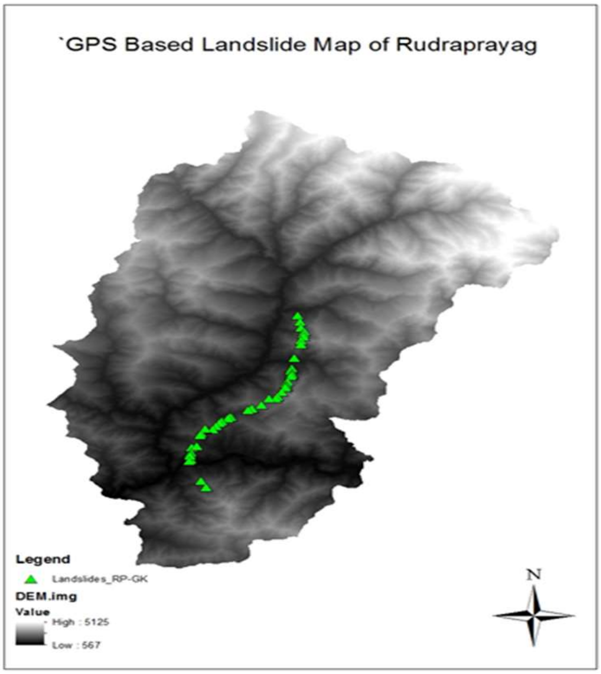
a) Train Car derailed by landslide b) Slope reinforcement project undertaken c) Reinforcement using high tensile steel wire mesh d) Debris containment wall

The table highlights that though location of landslide events differ but causative factors in all three cases were strikingly similar. This also reveals that proactive measures of Land hazard Zone Mapping, early warning Systems and remote sensing methods were utilized in all three. It is noteworthy that LHZ map of entire Uttarakhand is being prepared and government is planning to proactively take measures in locations with high risk (K.S. Sajwan, 2016).

All approved engineering methodologies were adopted in three locations, i.e. slope geometry modification, drainage channels, retaining structures, and debris flow mitigation strategies; though there was variation in measures adopted, such as Use of Geo-jute, catchpits, dykes were peculiar feature in Uttarkashi mitigation strategy. The measures utilized in other locations could also be tried after pilot tests in other landslide prone areas in Uttarakhand.

Most importantly, there was a uniformity in use of non-structural methods, be it community involvement, or ecological measures of vegetation. However, there was variation in scale of deployment. Uttarakhand can also employ demonstration on mitigation by undertaking certain pilot projects.

Further methods, which can be adopted



1) Employment of private agencies in restoration of such slopes, as done in Washington by way of permit process and credit agencies. Various models can be developed looking into interests of private players in such cases. Need of time is to develop partnerships between government-government, government-academia, government-private sector.
2) Use of Community led GPS tracking of landslide prone areas: GPS is one of the novel innovations in recent decade. With help of GPS, actual location of any landslide can be mapped, and further these can be used for implementation of mitigation projects.
3) Evaluation of long term solutions for debris removal, as it consumes much of time, energy and currency. This also envisages development of model for emergency response and early warning system so as to minimize the disastrous consequences.
4) Community awareness and outreach is quintessential as all such methods can only reduce the impact and cannot guarantee cent percent protection. An informed society needs to be aware of costs, risks and mitigation strategies. The aim is to reduce life risks, economical and environmental costs, and that is possible only by support of community.
5) Various pilot projects should be taken for demonstration of common public based on regulatory measures.
6) International practices may be used on pilot basis for landslide management in Uttarakhand (as mentioned in above table).

7) There is also need of a app or web based public information system, which will entail all information related to state, prone areas, marking sites of faulty constructions, probability of landslides and common steps which can be undertaken.

4. Figuring New Role and Responsibilities

Element	Present Condition	National Level	State level	Local	Private	Academic institutions
Research and Innovation: Understanding key concepts and precipitating factors	This is being done by GSI, ISRO, IMD, CGWB, etc. Still much more comprehensive study is needed to predict the probability	To coordinate research. Undertaking such projects for demonstration and devising strategy Using and publishing results Access to Public Information System.				Extensive Research
Hazard Maps and Analysis: LHZ and ranking various terrains	Such inventory and susceptible areas are highly essential. Despite various studies, no uniform standard for mapping	Framing Standards LHZ mapping based on such standards Research, analysis and assessment (including field survey) Use in planning, preparedness and mitigation				
Real Time Monitoring: Of areas with substantial risks	Is available but not universal	Development and Universalization of such capabilities Establishment of Emergency and EWSs.			Innovations in Early warning systems	
Assessment of Loss: Including human, economical and environmental scales.	Still documentation is lacking	National and state based strategy Compilation, maintenance of data and sharing of information +Archiving				
Training and Dissemination of Guidelines	Urgent need for incentives, guidelines and training for researchers and decision makers	Regulations, guidelines and their implementation				
Public awareness building	Is one of the lacking factor in local communities	By way of media, advertisements, and education programmes on planning, designing of land and urgent risk reduction strategies.				

Element	Present Condition	National Level	State level	Local	Private	Academic institutions
Mitigation strategies	Should be based on bottom-top approach	-Policies targeting mitigation -Financial incentives for support -Encourage both structural and non-structural strategies.		Adoption of such strategies		Advisers and consultants
Emergency Response	Need to be adequately prepared	Training and capacity building of response teams (NDMA act)			Expertise to better tackle emergencies	

5. Conclusion

Various newer techniques have been developed which can be utilized in various manner to minimize repercussions of landslides, especially in state of Uttarakhand. Now, mitigation is no more a science or art instead is collaboration of art & science.

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Vadapalli Boat accident in West Godavari, Andhra Pradesh, 2018- A case study

Kartikeya Misra, IAS

1. Vadapalli Boat accident: An introduction:

This document is an incident report regarding the boat mishap near Vadapalli (V), West Godavari carrying East Godavari passengers. On 15 May 2018, a boat named *"Lakshmi Venkateshwara"* was ferrying between limits of East and West Godavari Districts. It started from Ramalayam ghat (Devipatnam mandal, East Godavari District) at around 3.30 PM, moved to Singanapalli (West Godavari District), then to Devipatnam Police Station ferry point (Devipatnam mandal, East Godavari District) and the destination of the boat was Kondamodalu (V), Devipatnam (M), East Godavari District. At around 4.45 PM, the passenger boat was approaching Vadapalli (V), Polavaram (M), West Godavari District to drop few passengers. There were sudden high velocity winds because of which the boat toppled and drowned.

2. Receipt of First Information

The survivors along with the Launch owner who came to the banks informed local villagers in Vadapalli, Devipatnam and Manturu and to Village Revenue Assistant, Devipatnam then the information flowed to Polavaram SHO (WG), Devipatnam SHO (EG), Tahsildar Devipatnam who further informed to higher & lateral level officers without wasting time.

3. First Responders

VRAs, VROs, Constables were immediately mobilised to habitations from Devipatnam to Manturu by Tahsildar & SHO. As soon as the message was received, PO ITDA Rampachodavaram, Sub-Collector Rampachodavaram and ASP Rampachodavaram reached the spot and started search & rescue efforts. As it was dark ASKA emergency lights were established on the bank of Manturu village to facilitate staff on duty.

Soon the District Collector and Superintendent of Police of East Godavari also reached the spot, took stock of the situation and planned & carried out further course of action.

4. Force deployment for Search & Rescue

Two NDRF teams comprising of 70 men along with Commandant; Two SDRF teams comprising of 65 men; 2 Mist Vehicles, 2 Fire engines, 1 Bus, 3 Boats, 46 men along with necessary rescue equipment from Fire Department; 4 divers and 2 helicopters from Indian Navy and 6 ambulances with 5 medical teams were deployed to search, rescue and retrieve. The Municipal Commissioner & Sub-Collector, Rajamahendravaram established Control & Support room at Rajamahendravaram to support the force. The Joint Collector, East Godavari headed the Command & Communication centre at District Headquarters, Kakinada.

Photo 1 : Establishment of Emergency lights for throughout night operations and Deployment of Motor boats for Search operation

Further, immediately revenue staff was dispatched to the habitations of the passengers to prepare a list of missing family members and relatives. With this a list of 20 missing persons and a list of 17 survivors were prepared by the District Administration.

5. Co-ordination between District administration & State

The Command & Communication Centre (CCC) from Real Time Governance Department established communication with District Collector, PO ITDA Rampachodavaram and Sub-Collector, Rampachodavaram. Also State Disaster Management Authority (SDMA) officials were also in constant touch over Phone call and Text Messages giving us timely feed.

The CCC & SDMA provided details of NDRF, SDRF, Navy teams and played the role of link between State, District HQ and force on field.

6. Course of Operation

The District Collector and SP of East Godavari visited the site of accident in the night where they were briefed by Police and Fire Department teams regarding the situation at hand. Due to lack of visibility under water and murkiness due to recent rains, much success could not be achieved on the night of 15 May 2018. The next day with the first light, search & rescue operation was relaunched.

Photo 2 : District Collector and SP of East Godavari taking stock of the situation on the night of 15 May 2018 along with Sub-Collector, Rampachodavaram

Overnight mobilization of men and material was done like Boats, Cranes etc. OSD Chinturu joined the efforts. Force of employees headed by District Collectors of East & West Godavari analysed the situation and found that the Launch had gone down vertically getting struck in the sand below. The divers in their first few dives ascertained the location of the drowned Launched and tagged a marker which floated vertically on the drowned site.

Firstly, the Navy divers tethered the launch to three tourist boats and attempted to pull out the launch to the bank. This attempt failed as the ropes snapped unable to take the load. Finally, it was decided that tethering the launch to Crane and pulling towards bank will give success. This time the launch was successfully pulled out.

By afternoon of 16 May 2018, 14 (fourteen) bodies were recovered. 1 (one) more body was recovered in the evening of the same day. On the morning of 17 May 2018, 4 (four) more dead bodies were recovered. Total of 19 (Nineteen) dead bodies were retrieved from water. As on evening of 17 May 2018, search operations were on to trace the 20th body. Also, all Police Stations were on alert to immediately report any Missing Person Report. Later it was found that the 20th person by name Konuthula Yesubabu did not board the boat at all and was now found in his village. This was confirmed by Village Revenue Officer who visited the village personally. Therefore, only 19 people were missing, and all 19 bodies are recovered.

Photo 3 : Navy helicopters providing aerial support to Navy dive team, searching for any bodies floating and providing any valuable inputs to staff on ground.

To ensure that all the formalities relating to dead bodies were done soon and dead bodies handed over to the families of the deceased, Post Mortem camp was established on the banks of Vadapalli (V), West Godavari with 5 medical teams. As soon as the bodies were recovered from the river, the relatives were made to identify the body and after the identity was established, Post Mortem was conducted on the spot. The report was kept with the officials and bodies was handed over to the families of the deceased. Ambulance and boats were arranged to take dead bodies to the villages of the family.

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7. Team work

The team work of SDMA, RTG, District Administration, NDRF, SDRF, Indian Navy and smooth coordination of District Administration of East and West Godavari ensured that the Search, Rescue and Retrieve operation was completed quickly within 48 hours.

Government's support to the bereaved families

Honourable Chief Minister of Andhra Pradesh visited the incident site and interacted with the kith and kin of the deceased. He announced 10 Lakh rupees ex-gratia from the Government to the deceased for those who were not covered under *Chandranna Bim*a and 5 Lakh ex-gratia from the Government & 5 Lakh rupees from *Chandranna Bima* for those who were covered under *Chandranna Bima* scheme.

Table 1 : Details of the deceased who were covered under Chandranna Bima scheme

Sl. No.	Name of the deceased	Age	Gender	Aadhaar number	Address
1.	Konathula Chiranjeevi S/o Veeraswamy	34 Years	Male	388539220725	Talluru (V), Devipatnam (M), EG
2.	Konathula Siva Kumari W/o Chiranjeevi	32 Years	Female	688724654074	Talluru (V), Devipatnam (M), EG
3.	Neram Durgamma W/o Veeraswamy	54 Years	Female	735243448168	Katchuluru (V), Devipatnam (M), EG
4.	Illa Savithri W/o Krishna	40 Years	Female	681954422830	Katchuluru (V), Devipatnam (M), EG
5.	Kondla Rami Reddy S/o Chinnareddy	64 Years	Male	735054376072	Tadiwada (V), Devipatnam (M), EG
6.	Nadipudi Akkamma W/o Abbai Reddy	39 Years	Female	392464161685	Tadiwada (V), Devipatnam (M), EG
7.	Konuthula Bullamma W/o Ramulu	45 Years	Female	602031383953	K Gonduru (V), Devipatnam (M), EG
8.	Padam Nagajyothi W/o Suribabu	49 Years	Female	852330343832	K Gonduru (V), Devipatnam (M), EG
9.	Chiduguri Subba Lakshmi W/o Posibabu and D/o Linga Reddy	19 Years	Female	483681408937	K Gonduru (V), Devipatnam (M), EG
10.	Madi Buchamma W/o Narasanna Dora	50 Years	Female	453819305046	Peddabeerampalli (V), Rampachodavaram (M)
11.	Kunjam Ramayamma W/o Kunjam Venkanna Dora	32 Years	Female	744376998983	Peddabeerampalli (V), Devipatnam (M), EG

Table 2 : Details of the deceased who were not covered under Chandranna Bima scheme

Sl. No.	Name of the deceased	Age	Gender	Aadhaar number	Address
1.	Konuthula Ramudu S/o Chiranjeevi	1 Year	Male	NA	Talluru (V), Devipatnam (M), EG
2.	Konuthula Laxman S/o Chiranjeevi	1 Year	Male	NA	Talluru (V), Devipatnam (M), EG
3.	Tokala Subbarao S/o Ravibabu	5 Years	Male	420663408807	K Gonduru (V), Devipatnam (M), EG
4.	Konuthula Manoj	4 Years	Male	NA	K Gonduru (V), Devipatnam (M), EG

Sl. No.	Name of the deceased	Age	Gender	Aadhaar number	Address
5.	Kamisetti Chantabai S/o Venkata Ramayya	79 Years	Male	526633197798	K Gonduru (V), Devipatnam (M), EG
6.	Murla Mangatayaru W/o Bhusanam	70 Years	Female	869118007172	K Gonduru (V), Devipatnam (M), EG
7.	Tokala Anitha W/o Ravibabu	30 Years	Female	492425656708	K Gonduru (V), Devipatnam (M), EG
8.	Yeddida Seetharamulu S/o Pentayya	55 Years	Male	594227931951	Kondamodalu (V), Devipatnam (M), EG

Apart from this, Tribal Welfare Department of Government of Andhra Pradesh sanctioned Rs.1 Lakh/- per deceased to the family members of the deceased.

The District Collector went on boat to the habitations where he distributed ex-gratia to bereaved families on 20 May 2018. PO ITDA and Sub-Collector, Rampachodavaram also visited habitations in person and distributed Tribal Welfare ex-gratia. Family members profiling was done to provide TRICOR loan and providing education to children of bereaved family in Best Available Schools.

8. Reasons for mishap

Additional SP said, "The apparent strong/gusty wind is the reason behind the boat toppling."

Apparently due to the heavy wind and storm, they have locked the boat doors, which in turn became a curse for the passengers. While a few jumped out and reached the bank safely, the remaining got stuck inside the boat.

"Everyone from our villages knows how to swim. It is because the shutters were downed that they were trapped and didn't get a chance to escape,"

9. Actions taken after the incident

1. A considerable number of private boats operate in Godavari, could not withstand the gusty winds. So the boats without licences and life jackets would not be allowed to move in River Godavari.
2. Operation of boats in the Godavari from Devipatnam to Papikondalu has been stopped for the time-being.
3. All temporary licences issued to boats and launches have been cancelled.

10. Recommendations

1. to follow the boat safety norms strictly to avoid these type of mishaps
2. there would be stringent rules for granting of permissions and licences
3. a separate authority would be constituted to give permissions to boats and licences to boat drivers.

Case Study on Kanniyakumari Floods, 2018

Pratik Tayal, IAS

1. Overview

Due to heavy and incessant rainfall from 14^{th} – 16^{th} August, 2018, the district of Kanniyakumari was affected by heavy floods. The magnitude of the disaster was such that within a span of 48 hours, 361 families had to be evacuated, 230 hectares of cropped area was inundated, a dozen road and bridge damages were reported, and 6 trains were cancelled. However, despite such figures, the loss of lives were minimzed. This happened due to the successful management of the floods by the district administration.

This document seeks to present a case study highlighting the actions taken, the learnings learnt and the recommendations proposed in the wake of these floods. It first, presents a brief profile of the district and its vulnerability to different types of disaster, with a view to put the disaster in context. The second part studies the nature of the current disaster and its causes. The third part seeks to portray the sequence of events of the disaster in order to redevelop a case study. The fourth part attempts to analyze the action taken by the district administration during the disaster. The subsequent part seeks to present the learnings from this event and recommends certain modifications that can be made in the process.

2. Profile of the district:

2.1. Geographical location:

It is the southernmost part of Tamil Nadu with an area of 1672 square kilometres. This tiny district lies between $77^0$15 and $77^0$36 of the eastern longitude and $8^0$03 and $8^0$35 of the northern Latitude. Kerala forms its North West, while it is bound by Tirunelveli District on the North and the east. The district is surrounded by three seas, the Bay of Bengal at the East the Arabian sea at the West and the Indian Ocean at the South.

2.2. Physiography:

Coastal length of Kanniyakumari district along Arabian Sea is 59 km and along Bay of Bengal is 11 km. The Topography of the land varies from different altitudes ranges 50 MSL to above 1000 MSL.

2.3. *Vulnerability*

Kanniyakumari holds a unique distinction of being the only district to have a coastline in both the Arabian Sea and the Bay of Bengal. Along with a long coastline of 72 kms, it is also a district with wide swathes of Western Ghats. This geography coupled with the climatic conditions that shower it with both South West and Northeast Monsoons make it vulnerable to a variety of disasters. The history of this district has been an evidence of the same. The district was devastated by floods in the year 1992 and 2010. It was engulfed by tsunami in the year 2004 and was badly affected by the cyclone in the year 2017.

2.4. *Climate*

The district witnesses rainfall both during the South west and North East monsoons. The South west monsoon period starts from the month of June and ends in September, while the North East monsoon period starts from October and ends in the middle of December.

2.5. *River System in Kanyakumari*

The major river in the district is Thamirabarani locally known as Kuzhithuraiar. This river has two major tributaries, Kodayar and Paralayar, with the Pechiparai Dam and Perunchani Dam, respectively, built across them. There are many tributaries for the Kodayar River of which Chittar I and Chittar II, with their dams, are the major ones.

The two rivers from Perunchani and Pechiparai meet at the Puthen Dam. It forms the major head work of the entire system from which the river flows forward. As the river flows, it distributes itself into major distributaries. But the main river channel flows with the Lakshwadeep Sea near Thengapattanam, about 56 kilometres (35 mi) west of Kanyakumari town.

3. Description of the Incident

3.1. *Scale of the disaster*

The disaster caused significant damages to the infrastructure of the district. This can be seen from the following parameters:

Damages:

Taluk	Human Loss	Missing Fishermen	Live Stock Loss	Hut Damage		Tree Fallen	Boat/ Vallam Damage	Poles
				Partly	Fully			
Agasteeswaram	-	-	-	8	3	5	-	10
Thovalai	-	-	-	37	4	13	-	15
Kalkulam	-	-	-	22	5	4	-	31

Taluk	Human Loss	Missing Fishermen	Live Stock Loss	Hut Damage		Tree Fallen	Boat/ Vallam Damage	Poles
				Partly	Fully			
Vilavancode	2	0	-	30	10	2	Boat-4, Vallam-6	114
Total	**2**	**0**	**-**	**97**	**22**	**24**	**-**	**170**

Damage to Bridges/Culverts

Name of the Department	MI Tank/ Pond	Bridge Damaged	Culvert Damaged	Amount required for (Rs. in lakhs)	
				Temporary Restoration	Permanent Restoration
Rural Development	2	4	4	4.50	812.00
Town Panchayat	4	-	2	28.35	42.00
Total	**6**	**4**	**6**	**32.85**	**854.00**

Road Damages

Sl. No.	Category	Number	Kms	Amount required for (Rs. in lakhs)	
				Temporary Restoraion	Permanent Restoration
1	Rural Development Road	47	38.63	12.7	121.5
2	Town Panchayat Road	97	89.63	206	3060.30
3	Municipal Road	5	2.64	11.0	-
4	State Highways Road	10	6	12.0	-
5	District Highways Road	12	9.510	19.02	-
6	Other District Road	60	48.246	96.49	-
7	National Highways Road	2	46	100	750
	Total	**233**	**240.656**	**457.21**	**3931.8**

Families Evacuated

Sl. No.	Taluk		Area	No of families evacuated	Remarks
1.	Agasteeswaram	1.	Ozhuginasery	12	In Shelter
2.	Thovalai	1.	Keeripparai Labour colony	23	In relative House
		2.	Puthu Nagar	3	In relative House
		3.	Kokkalvilagam	15	In shelter
		4.	Nangandi	14	In Shelter
		5.	Puthenchanalkarai	3	In Shelter

Sl. No.	Taluk		Area	No of families evacuated	Remarks
3.	Kalkulam	1.	Ayacode Village malavilai	27	In relative House
		2.	Aruvikarai Village	2	In relative House
		3.	Kumarankudy Village	4	In relative House
		4.	Thiruvattar Village, near RI quarters	5	In relative House
		5.	Thiruvattar Village, Niranchothivilai	6	In relative House
		6.	Pechiparai.	18	In shelter
4.	Vilavancode	1.	Kuzhithurai Town Village, Chenkamoolai	2	In relative House
		2.	Arudesam Village Pallikal	37	In Shelter
				35	In relative house
		3.	Kunnathur Village, Ottavilai	15	In relative house
		4.	Pacode A Village Malaiyaranthottam	4	In relative house
		5.	Thickurichi, Pacode B Village	2	In relative house
		6.	Kuzhithurai Vavupali	2	In relative house
		7	Munchirai Village, Parthivapuram	16	In Shelter
		8	Mancadu, Munchirai Village	7	In Shelter
		9	Anjalikadavu, Vilathurai Village	10	In relative house
		11	Vilampathottam, Kuzhithurai Town	20	In relative house
		12	Palavilai, Vilavancode	16	In relative house
		13	Kadayalumoodu.	9	In Shelter
		14	Kalingarajapuram	54	In shelter
Total families evacuated				**391**	

PWD Damages

Sl. No	Name of Infrastructure	Major Breaches			Minor Breaches			Total Breaches		
		No. of Breaches	Estimate Amount in Lakhs		No. of Breaches	Estimate Amount in Lakhs		No. of Breaches	Estimate Amount in Lakhs	
			T	P		T	P		T	P
1	Tank	1	20.00	30.00	17	28.10	158.00	18	48.10	188.00
2	Channel/ Canal	7	83.50	120.00	18	23.90	122.00	25	107.40	242.00
3	River	0	0.00	0.00	2	6.00	35.00	2	6.00	35.00
4	slide/ Slipped in channel	2	50.00	0.00	5	4.50	38.00	7	54.50	38.00
5	Others	2	22.00	0.00	1	4.00	0.00	3	26.00	0.00
	Total	**12**	**175.50**	**150.00**	**43**	**66.50**	**353.00**	**55**	**242.00**	**503.00**

T: Temporary; P: Permanent

Crop Area Affected

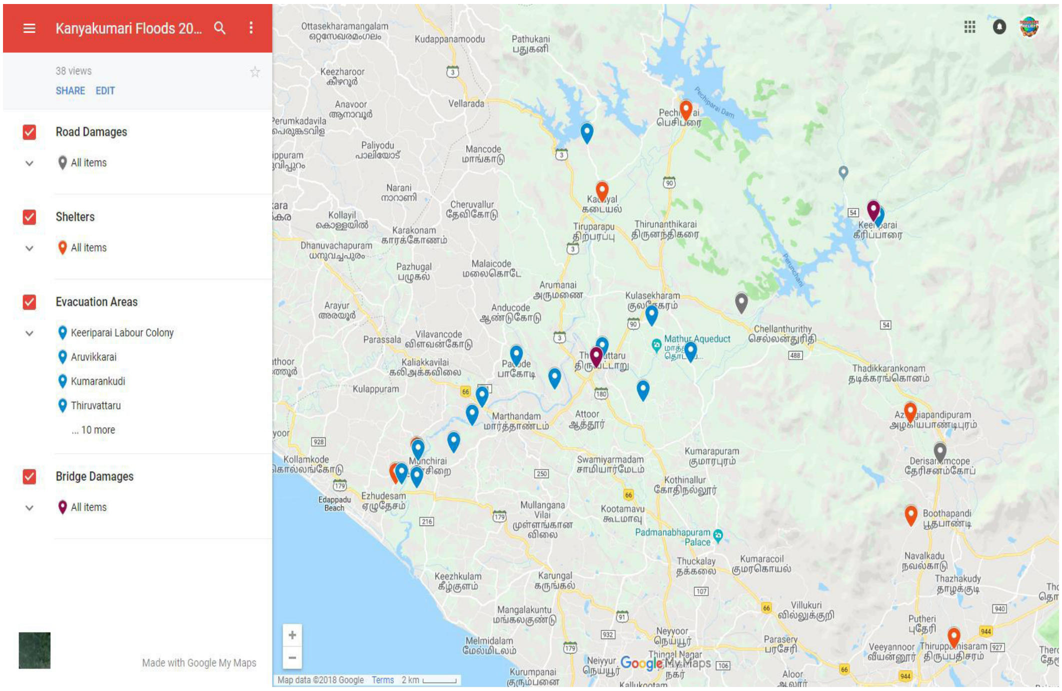
Crop: Paddy (18.08.2018)

Sl. No	Block	Revenue Village	Total Paddy Area Covered in Ha.	Area under Submergence in Ha.	Crop Stage	More than 33% Damage	Remarks
1	Thovalai	Derisanamcope	123.51	1	Maturity	0	Assessment can be done after drainage of water from the field.
		Thazhakudi	420	10	Tillering, Flowering	0	
Block Total				**11**		**0**	
2	Agastheeswaram	Suchindram	195	25	Harvest Stage	0	
		Therekalputhoor	105	0.2	Maturity		
		Kulasekarapuram	115	0.8	Maturity	0	
Block Total				**26**			
3	Thuckalay	Thiruvithancode	5.02	1.5	Flowering	0	
Block Total				**1.5**		**0**	
4.	Munchirai	Methukummal	0.6	0.14	Flowering	0	
		Adaikkakuzhi	1.0	0.3	Flowering	0	
		Kulappuram	0.38	0.2	Flowering	0	
		Arudesam	0.3	0.3	Flowering	0	
		Vilathurai	3.1	1	Flowering	0	
Block Total				**1.94**		**0**	
5	Melpuram	Pacode	3.5	2.84	Flowering	0	
Block Total				2.84		0	
Grand Total				**43.28**		**0**	

Shelter homes

Sl. No.	Name	Male	Female	Children	Total	Family
1.	ARC school, Keeriparai	25	15	7	47	23
2.	Pallikal Government Middle School	14	50	10	74	37
3.	Mancadu Government Primary School	6	8	1	15	7
4.	Parthivapuram Government Middle School	18	23	6	47	16
5.	Gnalam, Lutharan Primary School	7	26	11	44	15
6.	Government Middle School, Esanthimangalam	16	16	10	42	14
7.	Government High School, Thirupathisaram	3	5	2	10	3
8.	KNSK Govt. High School, Ozhuginasry.	13	19	9	41	12
9.	DVD HSS, Kottar, Nagercoil.	0	4	27	31	0
10.	Theroor Town Panchayat Community Hall.	3	22	9	34	18
11.	Govt. HSS, Kadayalumoodu	8	12	3	23	9
12.	Govt. ST Residential HSS, Pechiparai.	18	22	10	50	18
13.	Tsunami Shelter - Govt. AD Welfare HSS, Kalingarajapuram.	60	66	39	165	54
14.	Govt. Middle school, Uthachikottai.	22	31	02	55	30
	Total	**213**	**319**	**146**	**678**	**256**

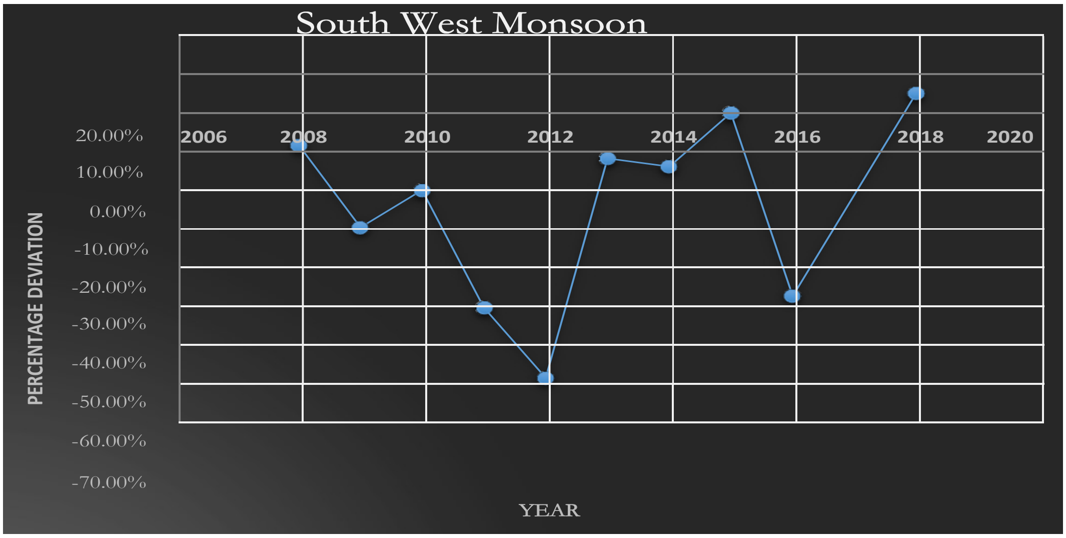
Map showing areas affected area



2.2. *Causes*

The primary cause of the disaster was heavy to very heavy rainfall on the days of 14-16.8.2018. The rainfall was not of the nature of a cloudburst, but involved incessant rains. These rains were unpredicted giving negligible time for disaster preparedness. A long-term analysis of the rainfall pattern in Kanniyakumari district depicts the extraordinary nature of this rainfall.

Sl. No.	Year	South West Monsoon		% Deviation (+ or – or =) from Normal
		Normal	Actual	
1	2008	559.1	556.56	-0.45%
2	2009	559.1	438.29	-21.61%
3	2010	559.1	492.10	-11.98%
4	2011	559.1	322.42	-42.33%
5	2012	559.1	221.05	-60.46%
6	2013	559.1	537.751	-3.82%
7	2014	559.1	525.87	-5.94%
8	2015	559.1	603.62	7.96%
9	2016	559.1	339.23	-39.33%
10	2018	559.1	631.52	12.95%



As the figure depicts, in a 10-year period, 2018 saw the highest ever rainfall that was received in the South West Monsoon. It is to be further noted that while in the month of July, Kanyakumari received 150mm rainfall, in only two days, Kanniyakumari received 170 mm rainfall. Further, in the 24-hours till 8 am on Wednesday, Kanyakumari district recorded an average rainfall of 94.45 mm. Thus, the primary cause of the floods was the unprecedented rainfall in the catchment areas of Perunchani and Pechiparai. The South West Monsoon was further aggravated by the presence of a very high Northeast Monsoon in the year 2017, as a result of which the dam level was already high. The rainfall in the last year is depicted in the following table.

North East Monsoon		
Normal	**Actual**	**% of Deviation**
526.0	709.29	High (+34.85)

As the figure depicts, in a 10-year period, 2018 saw the highest ever rainfall that was received in the South West Monsoon.

2.3. Sequence of Events

14.8.2018

Sl. No	Time	Event
1	07.30 pm	• Evacuation efforts began at Vallayatuvayal • Keeriparai Labour colony bridge collapsed
2	09.00 pm	• Visit to the dam site
3	10.00 pm	• Alert sounded to all zonal officers • Continuous monitoring of dam and rainfall level by district collector and district officials through the night of 14 and 15.8.18.

15.8.2018

Sl. No	Time	Event
1	05.30 am	• Continuous documentation and updation of damages caused – taluk wise report sought. • Keeriparai Labour colony bridge collapsed.
2	06.00 am	• The 1992 and 2010 vulnerable areas details were and asked to act upon.
3	06.20 am	• Flood arrangements in upcoming shelters ensured • Continuous sharing of IMD reports of weather forecasts and warning.
4	07.00 am	• Flood warning in pechiparai also sounded
5	07.45 am	• Pallikal village rescue operations began – inflatable boats arranged
6	08.00 am	• Perunchani to Kuttiyani Road damaged • Kodayar Left canal channel bund damaged.
7	08.15 am	• Therisanamcope to Arumanaloor road damaged
8	08.30 am	• Thiruvattar bridge over Paraliyar river submerged
9	08.45 am	• Kunnathur village Ottavilai low lying area 15 families evacuated • Ayacodevillagedmalavilai low lying area 27 families evacuated • In Aruvikkarai village area 2 families evacuated • In Kumarankudy village area 4 families evacuated • In Thiruvattar near RI Quarters area 5 families evacuated
10	08.50 am	• In Kuzhithurai Town Chenkamoolai area 7 families evacuated
11	09.30 am	• 5 Boats and 6 Vallams damaged in Thengapattinam Fishing • Harbour and 2 Fishermen reported missing while return after tying their boats in the safe place.
12	09.35 am	• Thiruvattar village Niranchothivilai area area 6 families evacuated
13	09.45 am	• In Pallikal Govt Middle School shelter open.
14	10.15 am	• In Puthunagar area 3 families evacuated. In Pallikal area 72 families evacuated. Pacode village area 6 families evacuated.
15	10.30 am	• In Kuzhithuraivavupali area 2 families evacuated and the things in the shop were safely kept in a mandapam.
16	10.35 am	• In Partheevapuram area 13 families evacuated
17	10.40 am	• In Aathivilai village the land sliding at railway track near Eraniel and Guruvayur express stop.
18	11.05 am	• In Mangadu GPS and Partheevapuram GMS shelters open.
19	11.25 am	• In Mangadu village area 10 families evacuated.

Sl. No	Time	Event
20	11.30 am	• 55 houses partly damaged and six houses fully damaged, 21 EB poles damaged and 24 trees fall.
21	12.30 pm	• In Gnalamluthern PS 1 shelter opened totally 200 families evacuated and 174 persons took asylum in shelters.
22	02.30 pm	• 227 persons took asylum in shelters 218 families evacuated.
23	03.00 pm	• In GMS Esanthimangalam and GHSS Kadayal new shelters opened 283 persons took asylum in shelters.
24	03.30 pm	• In Vilathurai village and Aalancholai24 families evacuated.
25	04.00 pm	• In Derisanamcope 40 Hectares of paddy submerged in Arumanalloor 2.85, In Thiruppathisaram 5, In Thalakudy 20, In Suchindram 15 Hectares of paddy submerged.
26	05.00 pm	• Shelters opened in GHSS Kadayaal and GHS Thiruppathisaram.
27	06.00 pm	• ARC Keeripparai shelter closed.
28	06.15 pm	• Horticulture crop banana 148 Hectares and Rupper 4.5 Hectare inundated.
29	06.45 pm	• Putheri Neenda Kulam bund damage.
30	08.00 pm	• New shelter opened in Ozhuginasery KNSK GHS, DVD HSS kottar, Theroor Town Panchayat Community Hall.
31	1.30 m	• 359 persons took asylum in shelters.
32	08.45 pm	• Valayathuvayal Puthunagar road damaged, Kadukkarai Eraviputhoor road damaged.
33	09.00 pm	• Thellanthi Kesavaneri road damaged, Kattuputhoor Perunthalaikadavoo road damaged.
34	09.45 pm	• Kadukkarai Nedupanchaarkulam outlet channel damaged.
35	09.55 pm	• Kattuputhoor Annuvettikulam inlet channel damaged.
36	10.00 pm	• Petchipaarai zeropoint area evacuated started and Government • ST Residential HSS Petchipparai shelter opened.
37	10.30 pm	• Totally 391 families evacuated and 678 persons took asylum in 14 shelters.
38	10.45 pm	• Chirakulam pond bund breached.
39	11.00 pm	• Kuttiyani to Perunchani alternative road damaged, Surulacode to Arumanalloor road damaged.

3. Disaster Management

3.1 Efficient dam management:

In this disaster, Effective Dam management lied at the heart of its successful management. The management of two dams was done simultaneously in such a manner that first, neither of the dams suffered a breach and second, both of the dams did not supply water more than the holding capacity of the downstream channel.

Theoretically, dam management involves the decision of when and how much water to release. This decision is the single most important factor in determining the level of flooding in downstream vulnerable areas. But, this decision is a difficult one to take as it is based on a number of factors including:

1. Maximum capacity of the dam
2. Maximum holding capacity of the downstream river
3. Estimated amount of inflow in the near future
4. Estimated amount of rainfall in the downstream areas, as that has to be adjusted in the calculations

At all times, it needs to be ensured that the level of water is such that the dam safety is not compromised and such that, it does not lead to flooding (or immediate flooding of the downstream villages) in the downstream habitations.

a. Perunchani Dam

The dam management was deftly dealt by the district administration. On receipt of information on the evening of 14.8.2018, the District Collector visited the Perunchani dam and assessed the situation.

The level of the dam had reached 76.4 feet on 8 pm, when the maximum capacity is 77 feet. At this time, the decision was taken to increase the outflow of the water more than the inflow. It was done in anticipation of more rainfall and to avert any possible situation of dam overflow. At the same time, it was done in cognizance of the fact that the river downstream has a carrying capacity of 30,000 cusecs.

In the given figure, it can be seen that up until 9.30 pm, the outflow was less than the inflow. The highlighted portion shows the critical points of decision making. At 11 pm, despite the decrease in inflow, the outflow was maintained at 15590 cusecs.

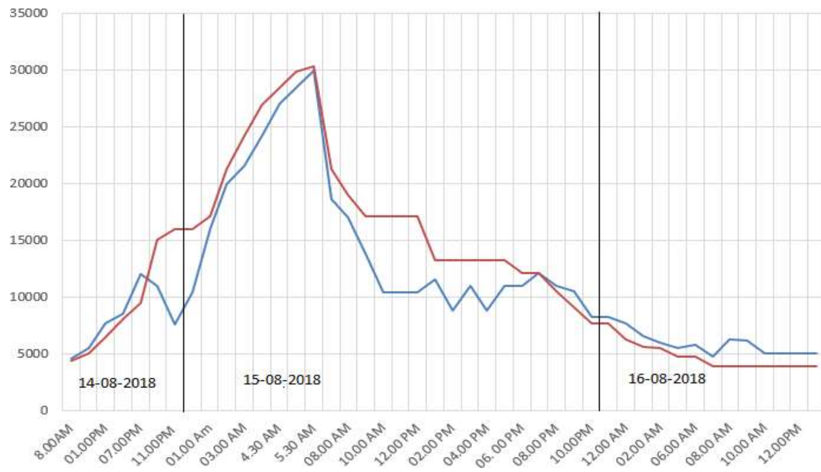
Perunchani - 14.08.2018				
Sl. No.	**Total Feet**	**In flow**	**Out flow**	**Time**
1	76.20	4600	4400	08.00 A.M.
2	76.25	5500	5000	11.00 A.M.
3	76.35	7707	6500	01.00 P.M.
4	76.35	8500	8060	03.00 P.M.
5	76.40	12000	9500	07.00 P.M.
6	76.15	11000	15000	09.30 P.M.
7	75.80	7619	15950	11.00 P.M.
8	75.55	10396	15950	12.00 A.M.

Crucial phase – Night of 14th and 15th

Perunchani - 15.08.2018				
1	75.50	15950	17156	1.00 A.M.
2	75.65	19933	21300	2.00 A.M.
3	75.60	21581	24140	3.00 A.M.
4	75.55	24140	26980	4.00 A.M.
5	75.55	26980	28400	4.30 A.M.
6	75.55	28400	29820	5.00 A.M.
7	75.55	29920	30360	5.30 A.M.
8	75.26	18646	21300	7.00 A.M.
9	74.90	17000	19000	8.00 A.M.
10	74.75	13778	17112	9.00 A.M.
11	74.5	10445	17112	10.00 A.M.

As was anticipated, the rainfall kept pouring the entire night, with the inflow reaching to 24000 cusecs at 4 am and then to 29000 cusecs at 5 am. This night was the most crucial time in hindsight. But for the timely decision of increase of outflow as compared to the inflow, the dam level could not have been maintained. At 11pm, when the inflow decreased, the continued sustenance of high outflow allowed a dam level to reach 75.55 feet, giving a breathing space to the district.

At 5.30 am, the outflow of the dam had reached 30000 cusecs. This meant the carrying capacity of the downstream river had been reached by just the outflow of one dam. This water was to be in addition to the rainfall that is poured directly in the downstream areas. This meant a situation of flooding in these areas.

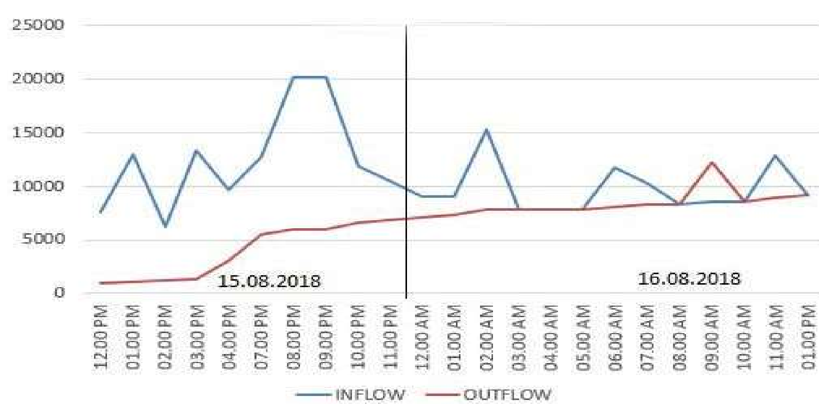


The inflow at 7 am, however reduced to 18000 cusecs. This was a factor of good luck, as had the rainfall continued to pour, the dam management would have become difficult. As the inflow receded, the outflow was also moderated, while at all times keeping it higher. It was this decision, based on the anticipation of higher rainfall, that the dam level could reach 74.5 feet by 10 am. As the inflow in Perunchaniremaind almost constant through the day of 15.8.18 and the outflow was kept higher, the dam level could be brought down to 73.15 feet. The following chart depicts the deft management of the dam based on its outflow and inflow.

The importance of the ingenious management of the dam does not only lie in the fact that it was saved from a breach. But more importantly, a breathing space of 4 feet in Perunchani meant that Pechiparai, another dam which lent its water into the same downstream river channel, could be managed freely.

b. Pechiparai Dam

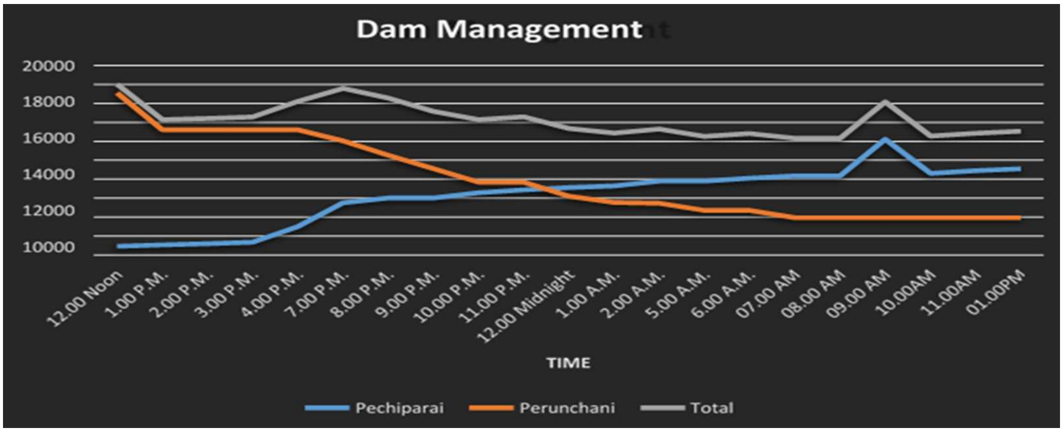
The Pechiparai dam, as stated above, lends water to the same downstream channel as Perunchani. The rainfall in the catchment area of this dam, fortunately, increased at around noon of 15.8.18. If the Pechiparai catchment had seen the same rainfall as Perunchani on the night of 14th, then the situation could have been much worse.



In this dam, the inflow steadily increased to 7000 cusecs at 12 noon on 15.8.2018. However, the outflow was consciously kept at 900 cusecs. Even when the inflow increased to 13000 cusecs, the decision was made to hold the water and to let the dam level increase. The dam level was allowed to reach till 37.40 feet till 12th midnight of 15th and 16th night, when the maximum capacity was 39 feet. It was only at 8 am on 16.8.2018 that the outflow was made to increase the inflow to moderate the level in Pechiparai dam.

c. Combined Dam Management

As mentioned above, the management of both the dams allowed that neither of the dams at any instance reached the breach barrier. Simultaneously neither of the dams, together, released more water than 30000 cusecs, as shown in the chart below.



3.2 *Evacuation and Rescue operations:*

The evacuation and rescue operations conducted by all the district officials were swift, timely and effective. This ensured the minimization of losses to both lives and livelihood.

a. Early identification and evacuation from vulnerable areas

Most of the vulnerable areas were evacuated before the inundation reached the danger mark. This was possible due to early identification of the vulnerable areas, done based on a correct assessment of the situation and on reliance over historical data. On the night of 14.8.2018, the areas in the catchment of the Perunchani Dam including Vallayivattall and Keeriparai Labour colony were identified and evacuated.

b. Early warning system

In anticipation of the increase in outflow, on the night of 14th, all zonal officers and first responders of the respective vulnerable areas in the downstream channel were alerted. As all the zonal officers were present in the district, there was no time delay in reaching the spot. This is of special importance because had there been a delay in reaching, it would have become impossible to reach because of subsequent road damages. On the morning of 15.8.2018, as the water release in Perunchani reached its maximum, evacuation and rescue operations in all the vulnerable areas were started in full swing.

c. Coordination of all line departments

The response was quick with the necessary resources being procured at the earliest. For instance, within 2 hours, 4 inflatable boats were arranged through the fire services department for rescue operations in the areas of Pallikal and Mankadu.

In addition, there was proper resource and role division amongst the district officials. Officers were divided into teams that visited different parts of the district. Teams under the leadership of Sub collector and AC trainee were present in Vilvancode and Kalkulam Taluk. A team comprising of DRO and DC trainee overlooked the operations in Thovalai and Agasteeswaram.

d. Quick mobilization

The floods also saw the identification of 16 new vulnerable areas that were not anticipated. In response to these, quick mobilization of teams and resources were made by the administration.

3.3 Data Management

As can be seen from Figures above, the frequency of data generation regarding the dam level increased successively. This was, at the same time, being recorded in a table to allow an informed decision by the Collector. It is noteworthy on the part of the officials to continuously record, update and compile this crucial data at the time of disaster. Other notable features include:

- Presence of crucial historical data on the basis of which decisions could be made.
- Hourly reports from DEOC for situation assessment
- Continuous flow of information on one single WhatsApp group

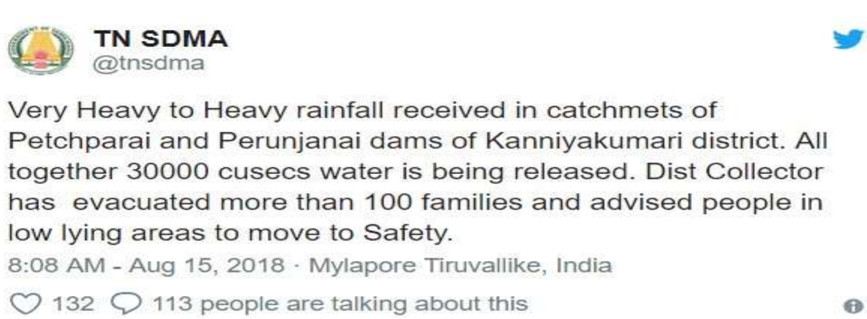
3.4 Media and Public Perception Management

Media and public perception management is one of the most important aspects of disaster management. A disaster is not merely a physical impact on lives and livelihoods, but has a significant psychological impact. Given this, it becomes essential for the district administration to allay the fear of the people and to avert a situation of pandemonium. The proactiveness of the administration provides an assurance to people of safety, allows an opportunity for people to contact in case of emergency and provides a platform for people to approach in case they want to help.

Understanding the need of this, the district administration of Kanniyakumari took timely and adequate steps to provide information to the public through several routes:

a. Use of social media

Bits of information on Twitter were regularly posted by officials. An example of a proactive early warning system on the morning of 15th August itself by the TNSDMA has been illustrated below:



Other platforms of social media such as Whatsapp and Facebook were effectively used to spread information about the floods. Messages on Whatsapp such as this were circulated on a periodical basis.

b. Media Management

A press release was given on the morning of 15.10.2018. This was followed by adequate bites of information at regular intervals. The PRO and the APRO updated the government's relief and rescue measures to the public from time to time. Bites to media also continued after the disaster had passed. Consequently, the presence of officers on the field was also highlighted by both print and news media. The Monitoring officer Thiru T. K Ramachandran was also present on 16th august, 2018 and addressed the media personnel answering all questions.

c. Public Announcement Systems

Vehicles mounted with public address systems were driven across the district for flood warning. The helpline number 1077 was also widely publicized. This was also accompanied by an active Kanyakumari website.

d. Rumor Management

In the case of disasters, rumor mongering is at the highest. The district administration ensured that this was taken care of. It released and circulated information on a timely basis. It also kept a tab on the different negative news items that floated on different platforms.

3.5 Relief Operations

a. Shelter Homes

The relief operations were carried out effectively and smoothly. The evacuated and rescued victims were sheltered in shelter homes. The provision for electricity, food, bedding, sanitation, among others was provided for in the shelter homes. It is noteworthy that at 6 am itself on 14.8.2018, the shelter homes of all vulnerable areas were asked to be ready in anticipation of the coming persons. This ensured the absence of last minute hassle or disgruntlement of the victims.

The shelter homes were personally visited by the officers to ensure the safety and comfort of victims. Adequate assurance was given by the district collector and the monitoring officer in this process.

b. Medical Relief Camps

For health check-ups and other medical emergencies, medical relief camps were organized at important locations and shelter homes.

4. Recommendations:

4.1. Major Objectives:

Recommendations are given in order to strengthen or improve upon the following aspects of disaster management:

1. **Resource Management –** There is a need for improved centralized management of resources during disasters. This means that there should be an inventory of the resources present, the location at which they are kept, and the officer who is responsible for their storage. The resources, here, include the (1) the equipments needed for rescue such as boats, ladders, motor pumps, saw machines, etc., (2) the relief material needed in the shelter homes.

Resource Management serves two primary benefits:

(i) The Resources can be procured in times of need from the nearest location.

(ii) A continuous enumeration of the resources would allow estimation of future needs and permit easier procurement in times of need

2. **Strengthening Information Flow–** The information flow mechanisms need to be strengthened. The present disaster was of a short duration, but in case of lengthy spells of rain such as the one faced by Kerala, the information management can be an issue given the systems.

   The primary aim of disaster management is to avoid chaos and the most important tool to ensure control is information. Therefore, information flow channels should be strengthened further.

3. **Clearer Delineation of the function of District Emergency Operations Centre –** There should be a clearer guideline on the functions expected out of the DEOC. The DEOC is considered to be the nerve centre of the district during disasters. It is submitted that a greater clarity on the role of DEOC is required.

4. **Improving Management of Shelter Homes–** there is a need for improvement in the management of shelter homes. While no difficulty was faced in their management, the recommendations seek to strengthen the systems in wake of the learnings from Kerala Floods.

4.2 Recommendations:

4.2.1. 'System of Representative Nominees in the DEOC':

Reference is cited to North East Monsoon Preparedness Circular Rc. No. N.C.I (4)/ 3838/ 2018, Annexure IV, point number 3, which stipulates the presence of one officer from departments of Fire and rescue, PWD, Police, etc. to be positioned in the DEOC at all times during disaster.

It is proposed that this system be further concretized. It is recommended that there be a representative nominee of each of the following important departments in the DEOC in the following format:

A. Head:

1. DRO
2. Complaints Cell / Tahsildar DM
3. PRO / Social media
4. Logistics
5. Data Generation

B. Line Department

1. Police
2. Fire
3. Fisheries
4. Health
5. TNEB
6. PWD
7. Rural Development
8. Town Panchayat
9. Municipalities
10. PA(G)

11. TNSTC
12. Forest
13. Highways

C. Separate Rooms

1. Meeting Room
2. Waiting room plus resting place
3. Record room
4. Support staff
5. Printing + Pantry

They are proposed to be the links for effective coordination of the entire district administration in the district. The following roles are proposed to be fulfilled by them:

1. Role of Resource Management:

Function #1 – Pre-Disaster Inventory Management

Each of the RN (representative nominee) is supposed to have an inventory of the resources available with the department, along with the place and the officer with which the said resource is present.

Function #2 - During Disaster - Updation of Inventories

The RN should continuously update the utilization of the said resources during the disaster. For instance, if the Fire and Rescue department has 10 boats and 4 have been used in Pallikal, then the RN should note it down. This would allow a continuous assessment of the resources.

The second benefit of this will be that the RN shall be the nodal officer to provide the number of equipments that are needed in the district in case external help is needed. In the case of Kerala Floods, the absence of the needs of the districts was a major problem.

Function #3 – During Disaster: Efficient Resource Allocation

They would be responsible for the allocation of the resources asked by zonal officers to the DEOC. Since the RN will be in knowledge of the inventories, he shall allocate the best resource from the nearest location to meet the demand.

At times, the zonal officers on field contact the DEOC for procurement of a particular resource. The DEOC in that case looks for resources from where it can be contacted. The presence of RNs from different departments would ensure that the DEOC does not waste critical time in arranging resources.

It will also allow better coordination between departments. For instance, if a resource of ladder is required, it may either be arranged from the fire department or by the electrical department. While the zonal team may only think of fire department, the DEOC can utilize all resources.

2. Role of Information Generation:

Function #1 – Information generation from their departmental sources

The RN will be responsible for gathering of information about the important events from its own sources. At present the situation report is gathered only from Tehsildars. The over reliance on Revenue Department should be reduced. For instance, the EB pole damage report reported by Taluks was 38, while that reported by Electricity Department was 127.

Therefore, it is submitted that presence of RN will allow better information generation.

3. Role of Communication, Command and Coordination:

Function #1 – Communication

It so happens that the line departments cannot be contacted during disasters because of communication problems. The RN will be in a better position to contact the respective department official, through other departmental channels. For instance, if the AE is not communicable, the RN may easily get the number of his driver from some source.

Function #2 –Command

It will ensure that the commands of the DEOC are better met by department officials, as the departmental senior is responsible for the command of the order.

5. Role of Link with the Zonal teams

Interdepartmental zonal teams have been constituted for effective and localized response to disasters and are allotted vulnerable areas to monitor. It comprises of members from different line departments, which are present for better coordination and to best make use of the principle of subsidiarity. For the same reason, they are good innovations in the field of disaster management.

However, certain problems exist in their operations on field:

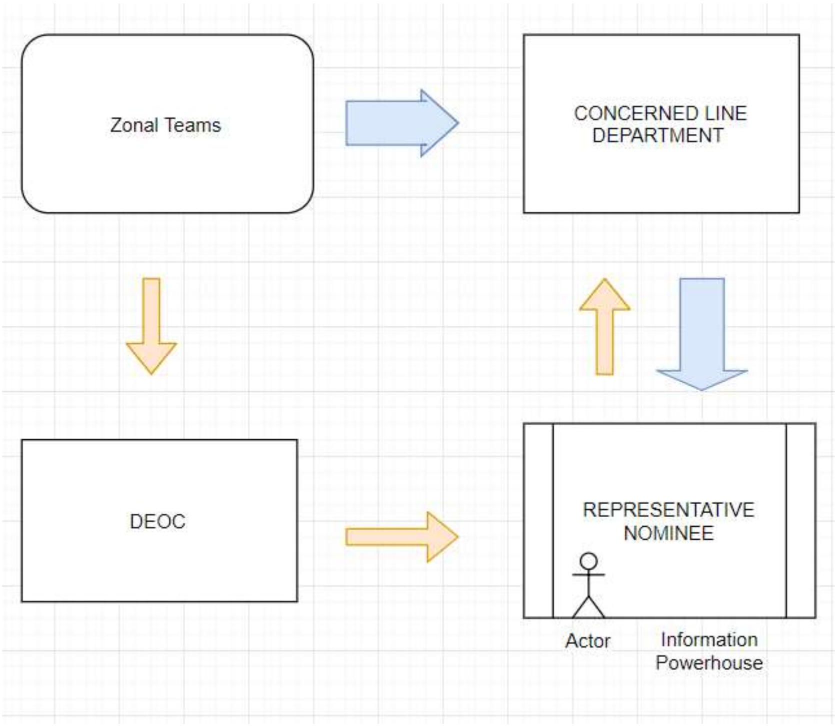
1. There is an absence of a connect with the DEOC, which forces them to work in silos. There becomes an individualized response mechanism for different areas, with no oversight from anyone.
2. When the zonal teams procure resources, like boats and ladders, at their own level, the resource management for the entire district becomes difficult.

There is a need to maintain an adequate balance between centralized management and the principle of subsidiarity. Therefore, a stronger link needs to be established between the two institutions that can be done by the RNs.

The proposed change includes a link line between the zonal team and the DEOC, with the representative nominees being the nodes. In practice, the zonal teams have two courses of actions: One to approach a department himself, or second, through the DEOC. In the former case, it is proposed that the concerned department should be mandated to inform the RN of any such help extended to the zonal team (shown in blue arrow).

In this way, the representative nominees, on one end, will receive information from their own field departments about the resources being used and continuously update the inventories. On the other end, they will command the field level functionaries for the supply of said commodities which the zonal teams want. Essentially, they act as (1) the information cells of the departments and (ii) coordination links to all the functionaries.

The proposed setup would thus be:

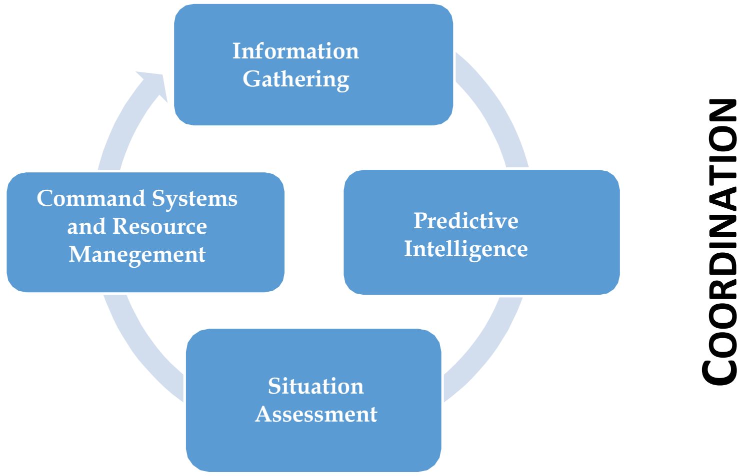


4.2.2 *Disaster Emergency Operations Centre:*

Having alluded to the District Disaster Management Plan (DDMP) and after witnessing its actual functioning, it is believed that clearer and more precise objectives for DEOC need to be laid down. Certain recommendations are given to improve the capacity of this institution.

4.2.2.1 Functions

The following document seeks to outline detailed functions of the DEOC and on that basis, recommends introduction of certain systems, personnel and resources:



4.2.2.1.1 Information gathering, as opposed to data collection:

The DEOC is responsible for collection and collation of actionable information about the disaster. As of now, the DEOC primarily aims at collecting data points so as to fill certain formats. These data points may be from single sources and may not reflect the complete picture. Consequently, it is proposed that first, an ideological change in its role of information gathering is required to be undertaken. The following amends are proposed:

A. Ensuring Comprehensive Information

- Inclusion of other departments for information generation instead of over reliance on the revenue department. It is proposed that the representative nominee of each line department should be responsible for the relay of information of events from his own sources.
- Installation of Cameras in critical locations and their imaging on TV screens in DEOC so as to receive real time information. Example, one camera can be placed at the dam site to do remote real time analysis of the water level.
- Monitoring of Local new channels for information gathering, perception management and curbing rumors. Consequently, it is proposed that TV screens be placed in the DEOC.

B. Ensuring Reliability of Information

- The information should be reliable. It is proposed that every time any information is received, the source of the information, along with its time be written. For the same, a new system of data enumeration and a new format of data entry has been proposed in the section on Personnel Management.

4.2.2.2 Predictive Intelligence

It is required that certain predictions also be made about the near future. This should be done on the basis of inputs from the following tentative sources:

- Weather forecast received from IMD, CWC and IIRS- ISRO
- Private sites such as Tamil Nadu Weathermen
- Flood Simulation (See Structural measures)
- Historical Data, which should be digitally recorded.
- Camera inputs
- News Channels

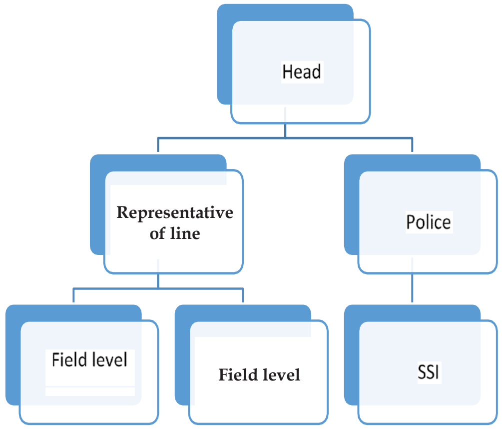
A separate component of predictive intelligence should be included in the situation assessment reports. This should study all or some of these parameters and continuously update them. Thereafter, efforts for preparedness for the same should be made on its basis.

4.2.2.3 Wholistic Situation Assessment

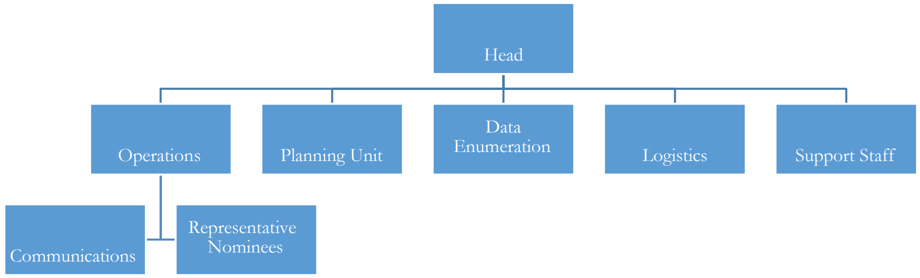
On the basis of the above information, a wholistic situation assessment should be made by the DEOC. Collection of information should be followed by collation and evaluation. The head of the cell should be able to understand and present a situation assessment report. Therefore, it requires the presence of an officer with good analytical skills, prior experience and adequate training.

4.2.2.4 Command Systems

There should be an Operations Unit comprising of the Head Commander and the representative nominees of the department as its aides, as shown in the diagram.



4.2.2.5 Personnel Management and Division of Labour



- **Operations –** Responsible for coordinating the tactical response of all jurisdictional field operations in support of the emergency response. This will comprise of the communications unit and the presence of representative nominees of important departments.
- **Planning Unit –** responsible for collection, collation and analysis of data to generate predictive analysis. As discussed above, its sources will be Satellite images, TV news channels and installed cameras.
- **Data enumeration –** One person should be there to intercept the calls and write down the data. This requires the presence of a phone with two receiver sets. The same information should be heard by the Head as well as the Data enumerator. The rationale behind this is that presently the head of EOC is embroiled in giving data to the operator which leads to a significant amount of time being wasted.
- **It is also proposed** that the information should be noted in a format, which includes the time and the source of information. (Proposed format in Annexure 3). It should then be included in the preparation of Data in the already specified formats being followed.
- **Logistics Support -** for operation of google maps, CCTV cameras, maintenance of communications systems and other equipment.
- **Support Staff**

4.2.2.6 Resources

- **Digital satellite maps software -** To show the forests, roads, water bodies, etc. The maps present as of now are grossly insufficient. Even after receiving information, application of mind is not possible, as one doesn't know about the area and its neighboring locations.
- **Presence of Big Digital Screens -** Their purpose would include:
  1. Projection of Maps
  2. Projection of real time data
  3. Projection Flood Simulation
- **Big TV sets linked to CCTV cameras i**n important vulnerable locations (See Structural Measures).
- **Presence of a phone handset, which has two receivers** – The particular handset will be used in a manner where one receiver will be held by the Head and the second by the Data enumerator. This will reduce the burden of the Head to sit beside the computer assistant to feed data into computer.
- **Communications network** – Presence of a Satellite phone and other advanced communication devices like VHF, Radio sets, etc.
- **Flood simulation software –**Such software is being worked upon by Mr. Johny Verghese, IAS 2013, and are also present with companies like IBM. These should be procured and used during times of floods.

➤ **Infrastructure upgradation**, as discussed below.

4.2.2.7 Room Interiors

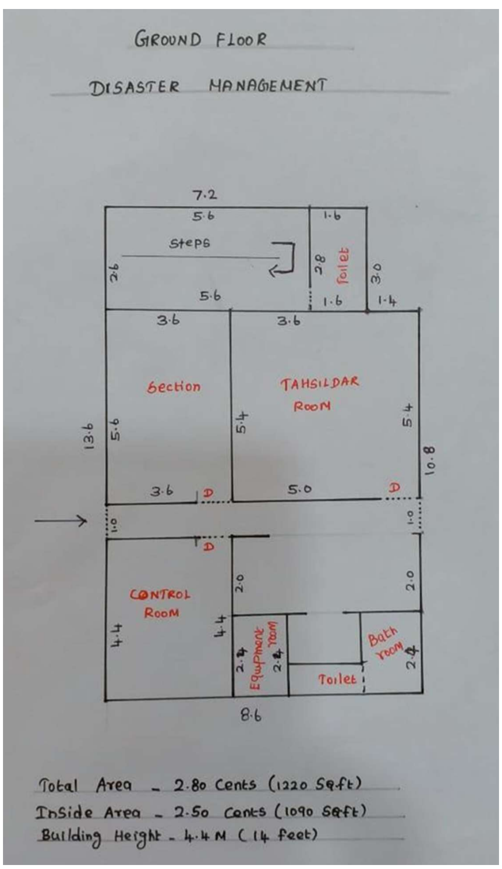
The following should be present in a DEOC:

1. Chamber for district Collector (with attached toilet)
2. Small meeting room (with video-conferencing facilities)
3. Communication Room (with TV, Radio, Wireless, Telephone and other communication equipments)
4. Workstations for line departments (with 2 or 3 local phone facilities)
5. Visitor's Room / Waiting Room
6. Store Room
7. Pantry
8. Rest Room / Retire Room (with toilet) for 2 people
9. General toilets

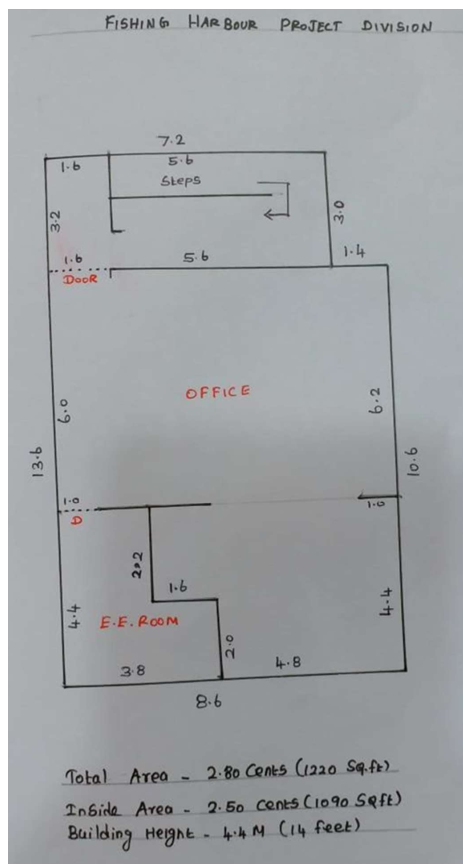
As the facilities in the present building are limited, the following refurbishment is suggested. The first floor is thought to be the main DEOC:

Present Facility

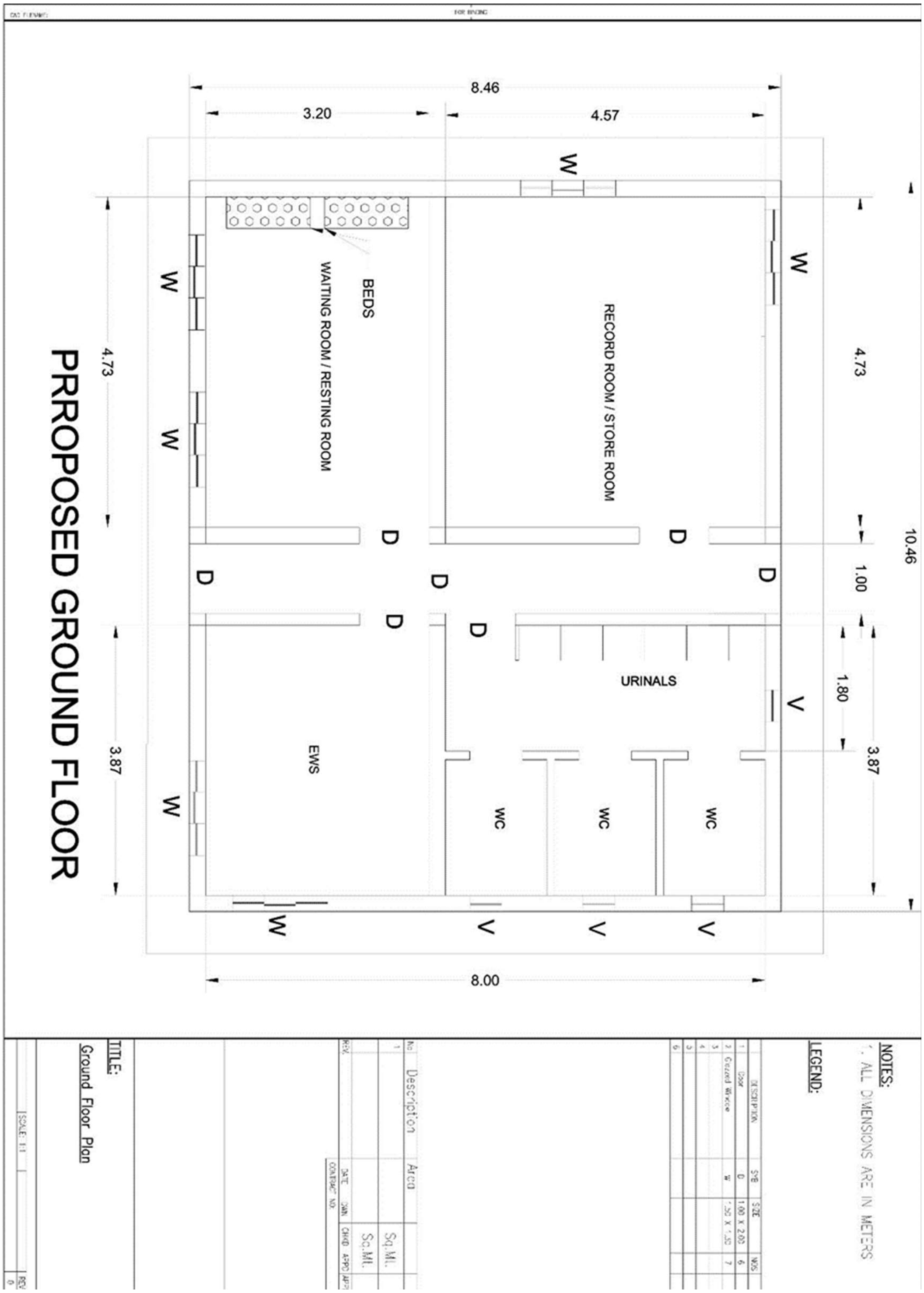
Ground Floor



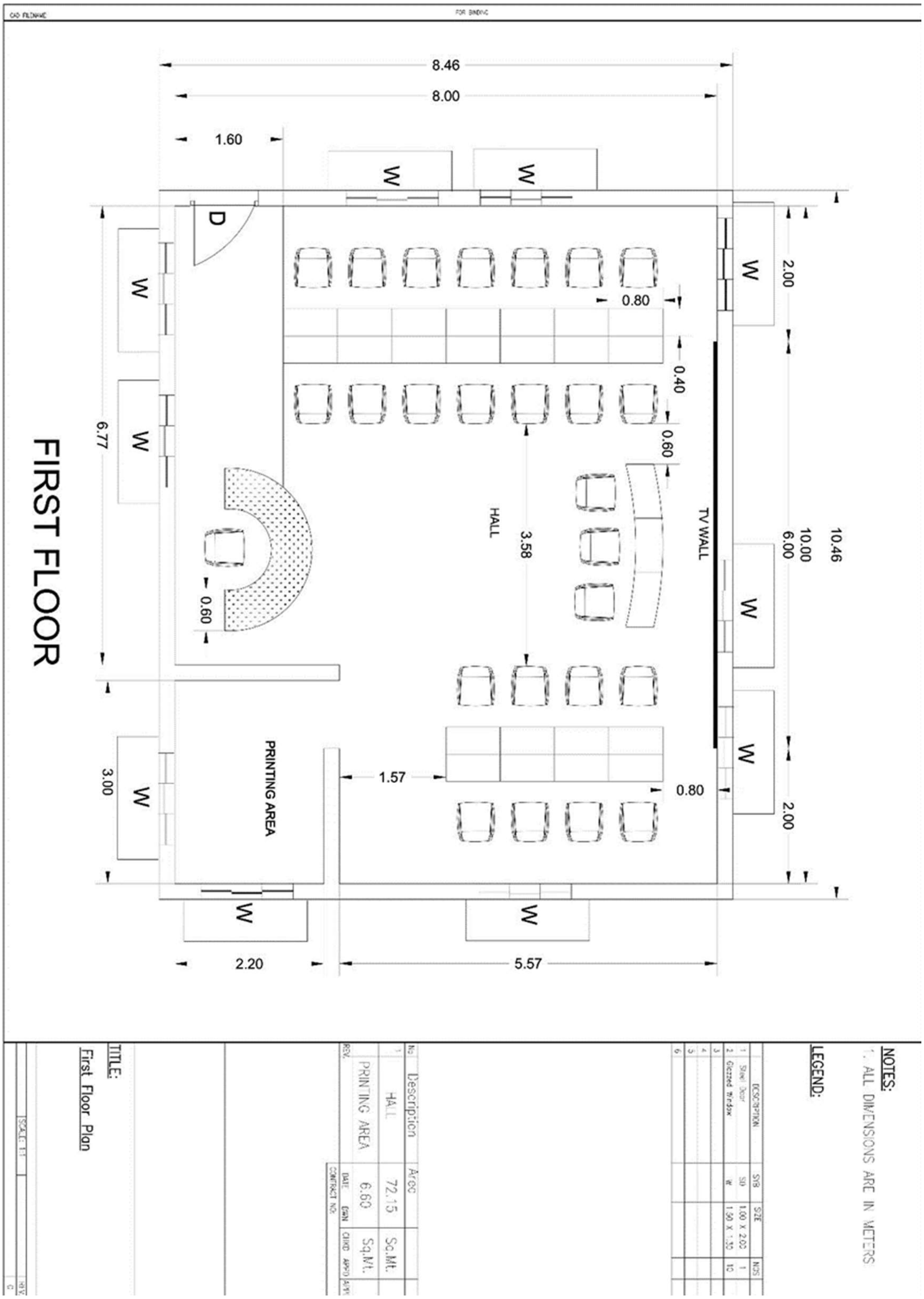
First Floor



Proposed Facility



First Floor – Main DEOC



4.2.2.8 Conclusion:

In conclusion, it is submitted that the DEOC must be the nerve center for the disaster management. There should be an institutional mechanism that is in itself capable of handling disasters. At present, the system is solely dependent on the Collector's skills to take decisions which varies on his experience, foresight and composure. While the overall control should be with the Collector, there is a need to provide proper institutional support with a head who also can act as proxy when the collector is unable to, due to any reason.

Given the ground realities and constraints, fulfillment of such functions does seem difficult at once. However, best effort should be made for them so that if not in entirety, some element of strategic thinking and leadership is inculcated in the organization.

4.2.3. Shelter Homes:

4.2.3.1 Identification and Mapping of shelter homes:

The shelter homes should be reviewed again on the basis of following parameters:

1. Presence of adequate facilities.[1]
2. Distance from the areas of evacuation and distance from markets[2]
3. Good accessible roads for delivery of materials
4. Presence of a clear compound area[3]
5. Safety from the type of disaster – consequently, multiple shelter homes for the same location can be seen. For example, cyclones require dome shaped shelter homes and the present ones would not be effective. Therefore, Disaster specific shelter home list can be prepared. The unlikely disasters like Tsunami can have fewer shelter homes, but nevertheless they should be present.

[1] **Including:**

1. Space for bedding
2. Adequate furniture
3. Sanitation facilities
4. Presence of open space
5. Strength of the structure
6. Electricity arrangements

[2] It is essential as the livestock and other things need to be tended to by the people once in a day. Such a possibility should not be obliterated. Simultaneously, it is important for them to be near the place of supply.

[3] A compound area is necessary for in case there is a requirement for sorting of relief items that is received.

4.2.3.2. Appointment of nodal officers and supporting staff

- Appointment of one caretaker and nodal officer for one shelter home – He or She should be the one contact point for all the information on the shelter home, including the number of victims and their needs.
- Appointment of one person who would arrange the food from local sources, and simultaneously acquaint the nodal officer for data updation.

4.2.3.3 Generation of formats

- Rough estimation of the requirements of men and women in shelter homes - Once a person comes in, what he/she needs to be provided is a constant. Therefore, the requirements become essentially a function of the number of people in the home. This format/tentative list of requirements should be ready. (Annexure 1 for list of items that may be required).
- There should be a format for receipt of goods, and disbursement of materials to relief victims. (Annexure 2).
- There should be an enumeration of the maximum capacity of the shelter home.

4.2.3.4 Provision of Necessary Resources:

- Presence of 1 computer in every shelter home.
- Presence of packed food items, bedsheets and other things in every shelter home at all times. The nodal officer should be tasked with its safety.
- Generators should be kept ready, or the person responsible for their arrangement should be pre-determined.
- Satellite phones – while they may not be given to the nodal officers right now, few phones can be procured and kept ready so that they may be supplied in times of need.

4.2.4 Review of Vulnerable Areas

Disaster should be used as an opportunity to review and revise all the previous lists of vulnerable areas from the ones actually affected.

- Addition of new vulnerable areas
- Review of the existing vulnerable areas and checking the extent of damage
- Consequent Modification, Alteration or Deletion of areas that are vulnerable on paper, but not on ground.

4.2.5 Structural Measures:

Camera Towers - Construction of 50-feet high towers with four high resolution cameras that can cover a 360-degree view of the important vulnerable areas of the district. The importance of height is to give a vast coverage area and to allow its exclusive use for disasters. The height may have certain disadvantages in terms of maintenance and interference by birds, but these can be managed with suitable measures. In the alternative, normal CCTV cameras can also be installed in vulnerable locations to keep a continued watch.

Drones- Presence of few drones in the district to monitor situation – Drones have a number of applications in real time situation assessment, and even, at times, in delivery of essential commodities in inaccessible locations. Therefore, a drone can be acquired for these purposes.

Roads- Upgradation of Roads is a necessity for improved accessibility. Construction of Thewar blocks where there is high water flow.

Mangroves- Undertaking Mangrove plantation projects to reduce the impact of floods and Tsunami.

4.2.6 Zonal Teams:

The problems in the functioning of the inter departmental zonal teams have been discussed in the heading of 'Link with zonal teams'. In brief, the primary problem discussed is how the zonal teams work in silos. For the same, it has been proposed that there is a need to integrate their functioning with the DEOC so that an information flow to and from these groups is maintained.

In addition to the above proposal, the following recommendations are made:

1. Periodical platforms for interaction of the members - It has also been observed that there is a constant reshuffle in the zonal team members due to frequent transfers. This affects the coordination of the zonal teams as the members do not know each other.
2. The zonal teams need to be periodically trained in disaster drills or Table-Top-Exercises. An important aim of these exercises should be developing seamless information relays.
3. Ensuring they have functional BSNL connections and smart phones.

Conclusion and Summary of Recommendations

Sl. No.	Problem	Recommendations
1	Need for generation of predictive intelligence even during the disaster	Inclusion of such a column in the Situation Assessment Report Format. Presence of necessary systems such as Big screens, satellite images, CCTV cameras
2	Overburdening of the Tehsildar with the work of Data Entry	Presence of a phone handset with 2 receivers Presence of a person dedicated for Data enumeration who receives information on the second handset
3	Zonal teams work in silos and the information flow to the DEOC is absent or lacking. (DEOC should be the information)	Introduction of the system of representative nominees, who receive information from either the zonal team or the line departments (system proposed above)
4	Lacking resource management, of example ladders and boats, that may be needed in rescue, evacuation, shelter homes, etc.	Representative nominees would be nodal officers responsible for the maintenance of inventories and their continuous updation.
5	Communication problems in contacting field level line departments by zonal teams	DEOC to be informed which shall then make Representative nominees contact through their own channels. Provision of one BSNL connection to every zonal team member Strengthening communications network
6	Shelter Homes identification needs to be reviewed	Parameters provided
7	Shelter homes	Appointment of a nodal officer for responsible of shelter homes in the parameters provided in the document
8	Coordination of zonal teams	Periodic platforms for interactions of officers Table Top Exercises and continuous drills
9	Accessibility is low	Upgradation of roads Putting CCTV cameras in important areas, for instance in Perunchani dam to monitor dam level.
10	Information Gathering as opposed to mere Data points enumeration	Inclusion of more sources (list provided) Change in format of data collection to increase reliability Representative nominees
11	Infrastructure of DEOC	Suggestions given
12	Lack of division of labour	Suggestions given
13	Structural measures	Suggestions given
14	Miscellaneous	Suggestions given

Annexure- 1: Format for Shelter Homes

S. No.	Type of Material	Material	Quantity requirement per persons	Total number of persons	Total requirements	Requirements met	Requirements left
1	Food Items	Biscuits (packets)					
2		Bread (packets)					
3		Rusk (packets)					
4		Snacks (packets)					
5		Water Bottles (units)					
6		Milk Powder (packets)					
7		Lactogen/ Baby Food (packets)					
8		Tea/Coffee Powder (packets)					
9		Cooking Oil (units)					
10		Rice/Aval (kg)					
11		Dal/Paruppu (kg)					
12		Wheat (kg)					
13		Sugar (kg)					
14		Salt (kg)					
15		Groundnut/ Kadalai (kg)					
16		Rawa					
17		Maida					
18		Masala (units)					
19		Pickles (units)					
20		Juices (units)					
21		Vegetables					
22	Clothes	Towel (units)					
23		Sari (units)					
24		T Shirts (units)					
25		Lungi/ Veshti (units)					
26		Nighty					
27		Underwear (units)					
28		Kids wear					
29		Sweaters (units)					

S. No.	Type of Material	Material	Quantity requirement per persons	Total number of persons	Total requirements	Requirements met	Requirements left
30	Medicines	Oxygen Cylinders					
31		Chlorine Tablets					
32		Paracetamol tab					
33		Paracetmol syrup (units)					
34		Metrogyl syrup (units)					
35		Whitield Ointment					
36		Cough Syrup (units)					
37		Amox syrup					
38		Amox Cap-250mg					
39		Lopramide Tab					
40		Ciprofloxacin Tab-250mg					
41		Dibirizide.M					
42		Amlodipine 5mg					
43		Tab Atenolol 50mg					
44		Tab Cipro + Tini					
45		Syrup Oflox + Tini					
46		Tab Ranitidine					
47		Doxy Cap					
48		Electral liquid					
49		ORS(pkts)					
50		Miscellaneous					
51	Household Goods	Bath Soap (units)					
52		Washing Soap (units)					
53		Sanitary Napkins (units)					
54		Diapers (units)					
55		Mosquito Coil (units)					
56		Mosquito Nets (units)					
57		Match Box (units)					
58		Candles (units)					
59		Tooth Brush (units)					

S. No.	Type of Material	Material	Quantity requirement per persons	Total number of persons	Total requirements	Requirements met	Requirements left
60	Household Goods	Tooth Paste (units)					
61		Bedsheet (units)					
62		Pillows (units)					
63		Napkins (units)					
64		Umbrellas (units)					
65		Slippers (pairs)					
66		Buckets (units)					
67		Mugs (units)					
68		Cooking Utensils (units)					
69	Miscellaneous	Tarpaulin (units)					
70		Cattle feed					
71		Sleep mats					

Annexure- 2

Format for Camps Receiving and Sending Relief Materials

Sl. No.	Name	Address and Phone Number	Item	Quantity Received			Value
				Boxes	In each box	Total	
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							

Annexure- 3

First Point Information Collection by Data Enumerator

Sl. No.	Name	Address and Phone Number	Item	Quantity Received			Value
				Boxes	In each box	Total	
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							

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Urban Flood Simulation
- A case study of Hyderabad city

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Abstract

Urban flooding is a universal phenomenon and possesses a great challenge to the urban planners of the world over. Over the past decades, there have been an increasing number of extreme rainfall and flood events occurring globally due to climate change, which paralyze cities and result in serious social and economic consequences. Conventional 1D modeling approaches are able to simulate quite accurately the drainage network. However, in cases of major rainfall events, these types of models are unable to simulate inundation depth in built-up areas and to visualize flood extent. Coupling of the 1D and 2D hydrodynamic model is necessary to consider flow interactions between underground pipes and the ground's surface. This paper presents the efforts in assessing three different modeling approaches for the simulation of urban flooding for a small urban catchment in Hyderabad city in Telangana. Hyderabad city has witnessed flooding in the year 2001, 2003, 2008, 2016, 2017 due to heavy rainfall and many low lying areas were inundated. HEC-RAS, a hydraulic model was used to simulate the behavior of flow of water in open channels and PCSWMM, a hydrologic and hydraulic model was used to evaluate runoff from a rainfall event and behavior of flow of water through pipes. Further, a terrain based model called HAND was used to identify the vulnerable low lying areas in the city. The results of the study demonstrate that the three models gave efficient results and complement each other in different meteorological conditions.

Keywords: *Urban Floods, Hyderabad, HEC-RAS, PCSWMM, HAND*

1. Introduction

Urban flooding is one of the most severe disasters as it directly affects mostly mankind in urban areas. Urban floods are caused by many factors but one of the major factors is the precipitation in a short duration of time means high rainfall intensity. Urban floods are also caused by encroaching floodplains, poor storm water draining capacity of natural drains like nalas or storm water sewer and dumping unwanted waste in nalas resulting blockage. Urban population forecast states that 5 billion people will be residing in cities and towns by 2030 and the urban population of Africa and Asia continents will be twice in a single generation[1]. The United Nations (UN) reported that the world's population living in urban areas has overtaken the rural population, and it is projected that the world's urban population will grow both in absolute terms, and as a fraction of a growing global population[2]. As more people move to the cities they inevitably turn green areas into impervious areas, increasing urban runoff, and as more people live in densely populated urban areas, often situated on flood plains and low-lying coastal areas, their exposure to flood hazards is increased. The possibility for climate change also leads to more extreme rainfall which is variable across temporal and spatial scales. As for future projections, a Special Report of the Intergovernmental Panel on Climate Change reports that "it is likely that the frequency of heavy precipitation will increase in the 21st century over many areas on the globe", although recent analyses have highlighted fairly large uncertainties and model biases[3]. The notable examples of urban flooding in India which caused huge loss in terms of money and human life are Chennai in 2015, Srinagar in 2014, Mumbai in 2005 and Kolkata in 2013 and Hyderabad in 2016[4].

Many researchers have reviewed the applicability of various rainfall-runoff models for urban areas [5,6,7]. Two well known and most used models are SWMM[8] and MOUSE. Urban drainage models earlier used were conventional 1D model based on mass, energy and momentum conservation and were able to simulate the drainage system correctly unless there is no overflow from the drainage network but if it overflows it becomes difficult to reproduce actual flood extents[9]. However, in cases of major rainfall events, these types of models were unable to simulate inundation depth in built-up areas and to visualize flood extent[10]. Hydrodynamic models are solid tools in urban storm water management. Numerical simulations of urban floods are important when scientifically planning and designing urban drainage systems and providing efficient urban flood disaster control and management strategies. Although many models have been developed for river and coastal flooding, urban flooding models have not yet been adequately developed; this partly attributes to the complex flow processes in urban areas when inundation occurs [11,12&13]. To accurately simulate detailed urban flood propagation and inundation of the ground's surface, coupling of the 1D and 2D hydrodynamic model is necessary to consider flow interactions between underground pipes and the ground's surface, and the 1D model and 2D model in the coupled model are used to simulate flows in the pipe/ river drainage system and surface inundation, respectively.

For the representation of the surface flooding depth and simulating flooding in urban areas, new models like PCSWMM (Storm Water Management Model) and MIKE URBAN have been introduced by coupling 1D with 2D flood inundation models [14]. Some hydraulic models like HEC-RAS (Hydrologic Engineering Centre River Analysis System) are capable to solve 2D Equation and can be used for urban flooding in the case where flooding is due to overflowing of the streams in urban areas. Another terrain based model called Height Above Nearest Drain model (HAND) was used to find the possible low lying areas or floodplains along the local drainage line. This model normalizes topography according to the local relative heights found along the drainage network which is used. The results will assist the local urban municipal corporation for identification of low lying areas, probable inundated areas in spatial format at the time of flooding, and decision making for resource allocation during disaster. This paper presents and assesses three different modeling approaches for the simulation of urban flooding for a small urban catchment in Hyderabad city in Telangana.

2. Study Area

Major floods in Hyderabad were witnessed during 2001, 2002, 2006, 2008, 2016, 2014, and 2016 mainly due to the major urbanization of Hyderabad which started after 1990. This had an impact on the average annual rainfall of the city. From 1971 to 1990 the average rainfall of Hyderabad city was 796 mm per year further it has increased to 840 mm per year during 1991-2013[15]. The soil type found in Hyderabad city is mainly red sandy with areas of black cotton soil and falls in the seismic zone -2 which is least exposed to earthquake. The drainage system in Hyderabad city is old and comprises of natural drains called Nalas that ultimately discharges in to Musi River. Severe floods in August 2016 had created havoc in the city and puts pressure on Greater Hyderabad Municipal Corporation (GHMC), a local governing body for mitigation. The GHMC area is covered with 16 catchment zones. The study area has an average elevation of 474.5 meters above mean sea level and lies between the latitudes 17.492^0 N and 17.502^0 N and longitudes 78.453^0 E and 78.463^0 E. The study area falls in zone 12 which is located to the north side of Musi River covering the local areas like Sainagar, Srinivas nagar, Gandhinagar, Kakatiya nagar, Vani nagar, Prasuna nagar, Ambedkar nagar. Figure-1 shows the study area.

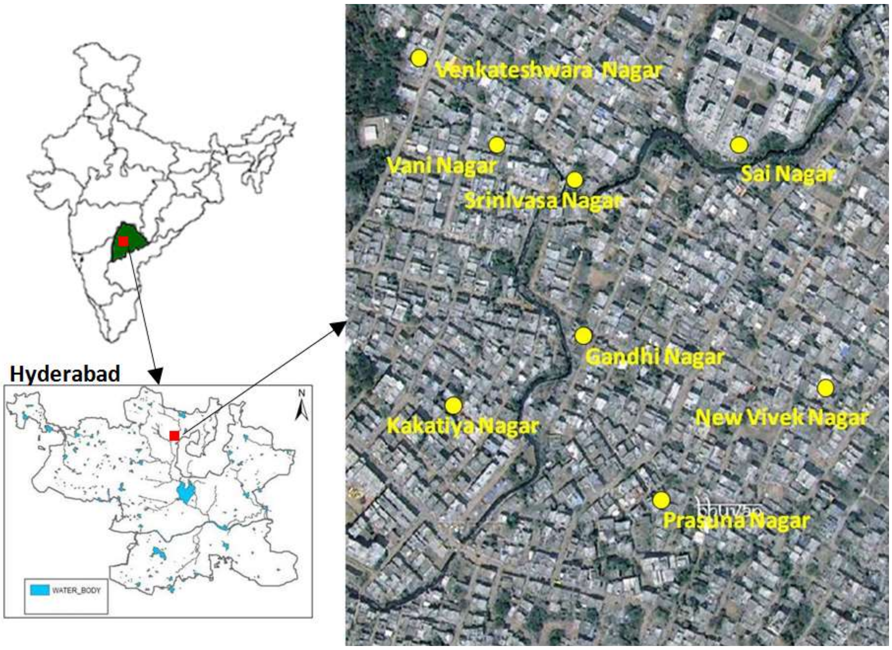

Figure-1: Study Area

3. Data used

The type of data varied for different models. Common data used for all three models is Digital Elevation Model (DEM) from CARTODEM 10-meter resolution which is a product of CARTOSAT-1 satellite designed and maintained by Indian Space Research Organization (ISRO). Further, for PCSWMM model hourly rainfall was collected from Indian Meteorological Department (IMD) located at Begumpet, Hyderabad. The discharge data flowing in nalas/streams was used for hydraulic modeling by HEC-RAS.

4. Methodology

PCSWMM is hydrologic model in which routing portion transfers the runoff to the collection system in urban areas, HEC-RAS is hydraulic model and HAND model is a tool to find low lying areas along the drainage. So all the three models have different approaches.

4.1 HEC-RAS Model

HEC-RAS 5.0.1 version was used to simulate flood inundation due to overflowing of Nalas. HEC-RAS has capabilities to solve 2D Full momentum equation (Saint Venant equation) or 2D Diffusion wave equation. For the present study, full momentum equations were used as it includes all parameters for simulations. The brief outline of the methodology is shown in figure 2.

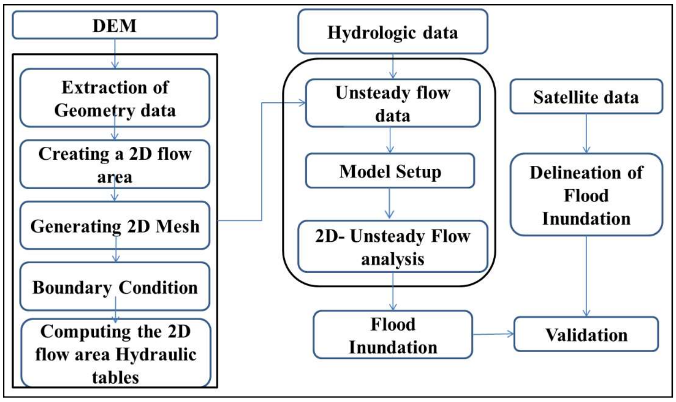

Figure-2 : Methodology for HEC-RAS

A Triangular Irregular Network (TIN) is created from input CARTODEM 10-meter resolution as shown in figure 3. Further, the 2D polygon area contributing maximum flood extent within the study area are defined as shown in figure 4 and boundary conditions are assigned as shown in figure 5. The upper boundary condition is the flow hydrograph and the downstream boundary condition is kept as normal depth. The inflow hydrograph provided at Qutubullapur is shown in figure 6 and normal depth 0.000345 was assigned at Ganesh nagar according to topographic conditions of study area.

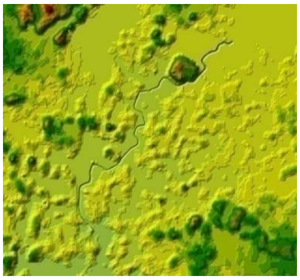

Figure-3 : Terrain in TIN

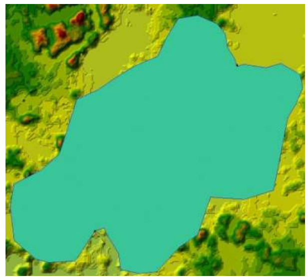

Figure-4 : Defined polygon

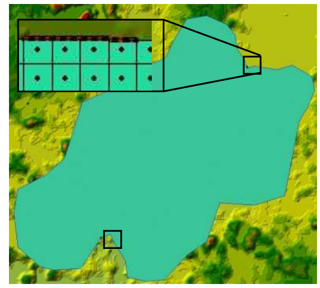

Figure-5 : Boundary condition

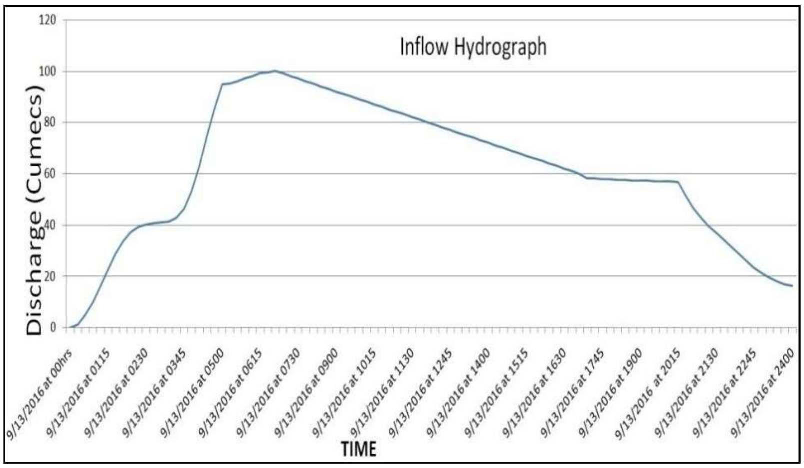

Figure-6 : Inflow hydrograph boundary condition at Qutubullapur

4.1.1 HEC-RAS simulations:

HEC-RAS 2D 5.0.1 beta version was used to solve diffusion wave and full momentum equation. Diffusion wave considers parameters such as gravity, friction and pressure whereas full momentum equation considers parameters like gravity, friction, pressure, acceleration, turbulent eddy viscosity and Corollis effect. For the present study, full momentum equation was used to simulate the flood event and all parameters were considered. The full momentum equations for two directional specific flows p and q are shown in Equation 1 & 2.

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\frac{(p^2)}{(h)}+\frac{\partial}{\partial y}\frac{(pq)}{(h)}=-n^2pg\frac{\sqrt{(p^2+q^2}}{h^2}-gh\frac{\partial s}{\partial x}+pf+\frac{\partial}{\rho\partial x}(h\tau_{xx})+\frac{\partial}{\rho\partial y}(h\tau_{xy}) \quad ...1$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial x}\frac{(q^2)}{(h)}+\frac{\partial}{\partial y}\frac{(pq)}{(h)}=-n^2qg\frac{\sqrt{(p^2+q^2}}{h^2}-gh\frac{\partial s}{\partial y}+qf+\frac{\partial}{\rho\partial y}(h\tau_{yy})+\frac{\partial}{\rho\partial x}(h\tau_{xy}) \quad ...2$$

where, p and q are the specific flow in the x and y directions (m^2/sec), n is the manning's resistance, s is the surface elevation in (meters), h is the water depth (meters), g is gravitational acceleration (m/sec^2), ρ is the density of water (kg/m^3), $\tau_{xx,}$ $\tau_{yy,}$ τ_{xy} are the components of effective shear stress and f is the Corollis (/sec).

4.2 PCSWMM

PCSWMM was primarily developed for urban areas and can be used for the design, analysis and planning of drainage systems, and for the simulation of runoff quality [16,17,18&19]. It is a spatial decision support system for EPA SWMM5 (Storm Water Management Model) utilized for storm water management, wastewater and watershed modeling. The model can be used to perform both single event and long-term (continuous) simulation of runoff quantity and quality, primarily for urban areas. Its runoff component operates on a collection of sub catchment areas that receive precipitation and generate runoff and pollutant loads.

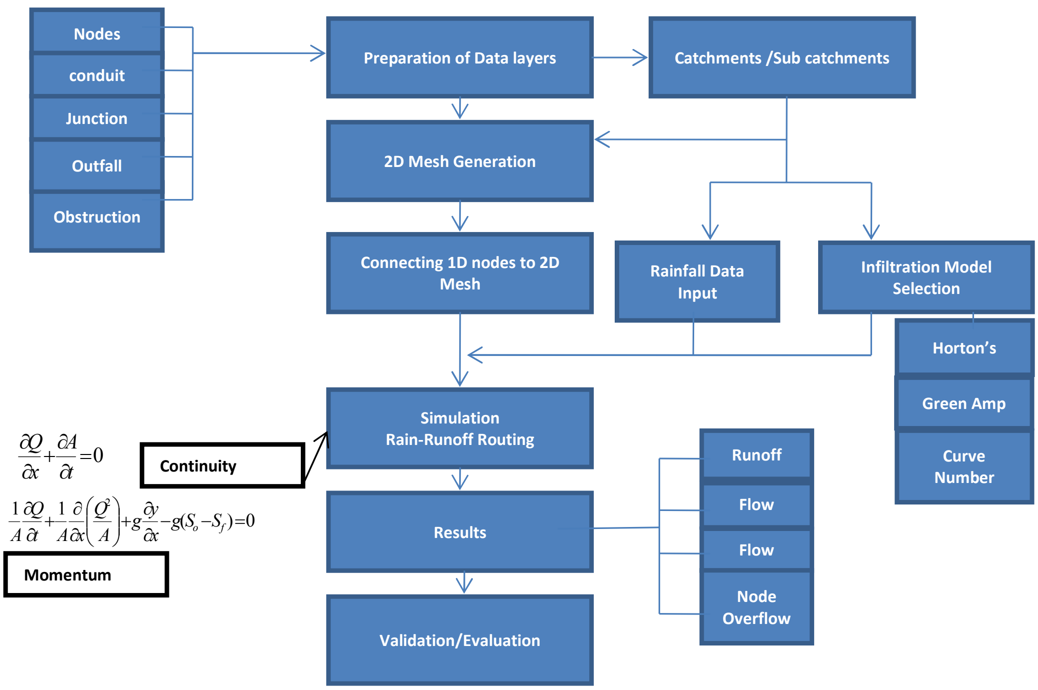

Figure-7. Methodology for PCSWMM

To simulate the rainfall-runoff process in urban areas, the study area is firstly divided into 12 sub catchment areas, these represent land areas that collect rainwater and allow infiltration and drainage to a specific node. These sub catchments are then divided into impervious and pervious areas to enable the separate calculation of runoff, and the Horton infiltration method is used to simulate the infiltration process in pervious area. Rainwater collected by the sub catchments finally drains to the drainage network, and the 1D model is used to calculate the flow routing in the drainage network. The routing portion transports this runoff through a system of pipes, channels, storage or treatment devices, pumps and regulators. The quantity and quality of runoff generated within each sub catchment and the flow rate, flow depth, and water quality in each pipe and channel during a simulation period were tracked.

The Dynamic Wave (DW) model was used for the hydraulic calculations and infiltration was calculated using the Curve Number (CN) method. The main parameters for a sub catchment in SWMM software are: (i) area (ha); (ii) width (m); (iii) slope (%); (iv) percent impervious; (v) Manning's n for pervious and impervious areas; (vi) depression storage (mm) in pervious and impervious areas. Parameters (i), (iii) and (iv) were determined using the appropriate tools in ArcGIS 10.3.1. The width of the sub catchments (parameter ii) was determined as the area divided by the average maximum length of the sub catchment. Finally, for parameters (v) and (vi), typical values from the literature were used.

4.3 HAND Model

The application of the HAND model provides the possibility of capturing and examining heterogeneities in local environments in a quantitative and widely comparable manner [20]. The HAND model normalizes the topography in respect to the drainage network through two sets of procedures on a DEM. First, it runs a sequence of computations to create a hydrological coherent DEM, define flow paths and delineate the drainage channels as shown in figure 8. The correct definition of the stream network is the key to the HAND procedure because the elevations of the drainage channel system are used to calculate the normalized terrain heights. Depressions in the DEM data can interfere with the determination of flow directions[20].

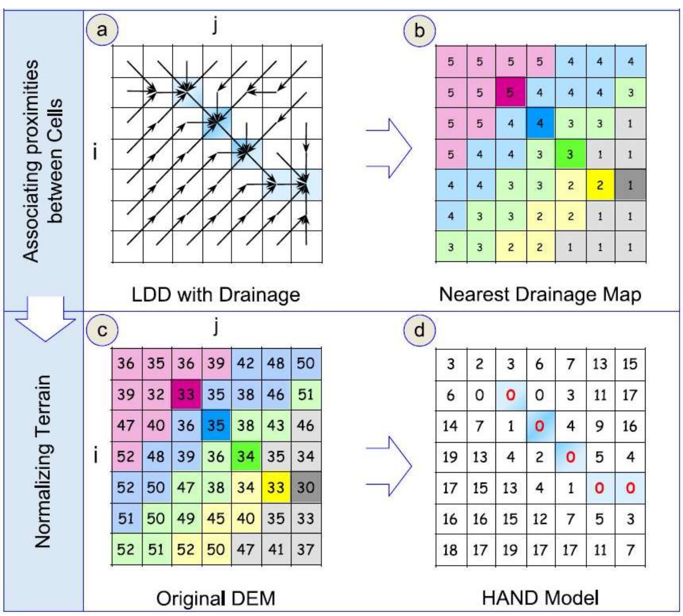

Figure-8 : Methodology for Hand Model

4.3.1 Defining HAND classes

A HAND terrain class is defined as the range of vertical distances to the nearest drainage reference level that bears roughly uniform hydrological relevance[20].

The HAND classes were defined in order to know the water logged area within a catchment. From ground truth sources, local news and past flood experiences in the catchment the values of HAND 1meter and 2 meter are best estimated classes for water logged area within the catchment. HAND 1meter and 2meter classes are designated as high vulnerable and low vulnerable respectively.

5. Result and Discussion

5.1 HEC-RAS

The outputs of HEC-RAS model are the inundation extent with depth, water surface elevation and velocity with respect to time. Simulated raster results are stored in two decimal floating point numbers in *tiff* file format. The simulation was carried out for 13 September 2016 from 00.00 hrs to 2400 hrs, since highest rainfall was recorded on that day. The flood simulated area for 0.05 roughness coefficient is 11.3268 hectares. Figure-9 shows the flood depth layer generated for the inflow hydrograph and draped over the satellite image. The localities Vani Nagar, Gandhi Nagar, Kakatiya Nagar, Srinivas Nagar, Venkateshwara Nagar are highly vulnerable to floods. In the study area, the depth of the nala/stream is about 4m which is the highest and in the flooding localities the depth of water is in between 0.5 m to 3.9m. The locality Sai Nagar is not inundated since it is at a higher elevation.

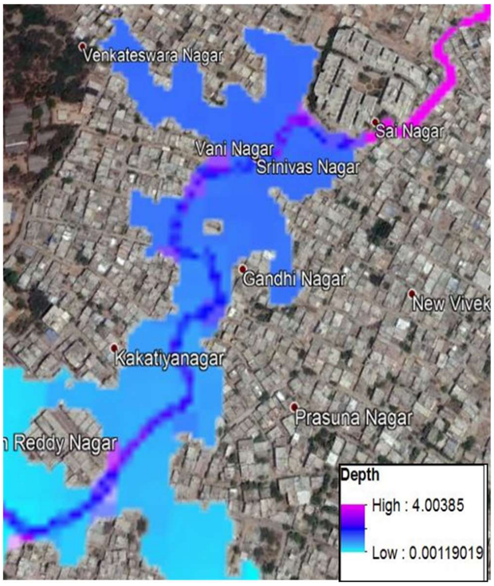

Figure-9 : Flood depth from HECRAS model

5.2 PCSWMM

The capabilities of both hydrological and hydraulic modeling have been investigated. At each node, the water overflow, hours flooded, maximum hours of flooding, total flood volume, maximum rate and hours surcharged were calculated with respect to time. Node is an element where runoff water enters or comes out when node is overflowed. Links are the connectivity between two nodes which can be storm water pipes or open channel like stream, nalas or river. Figure 10 shows the flood depth layer draped over satellite image and Figure 11 shows the urban flood map. For the present study, links are in the form of nalas. For the catchment 12 of Hyderabad it can be concluded that if 144 mm of rainfall occurs uniformly over the catchment within 10-12 hrs, the catchment will experience flooding and the localities Srinivas Nagar, Gandhi Nagar, Kakatiya Nagar, Vani Nagar and Prasuna Nagar get inundated.

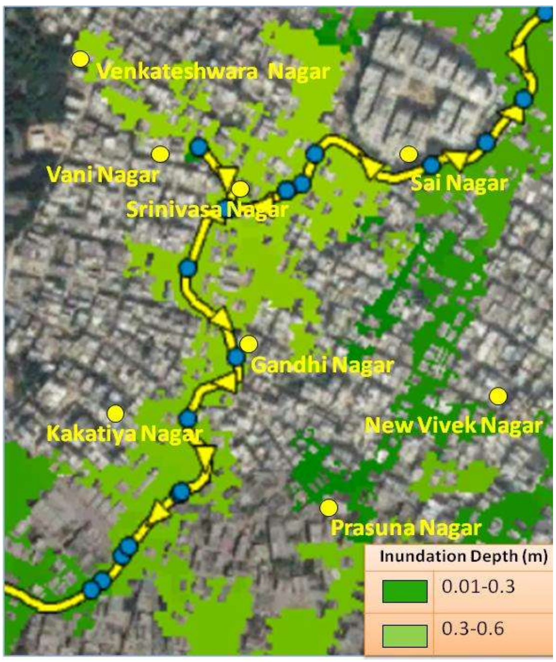

Figure-10 : Flood depth from PCSWMM Model

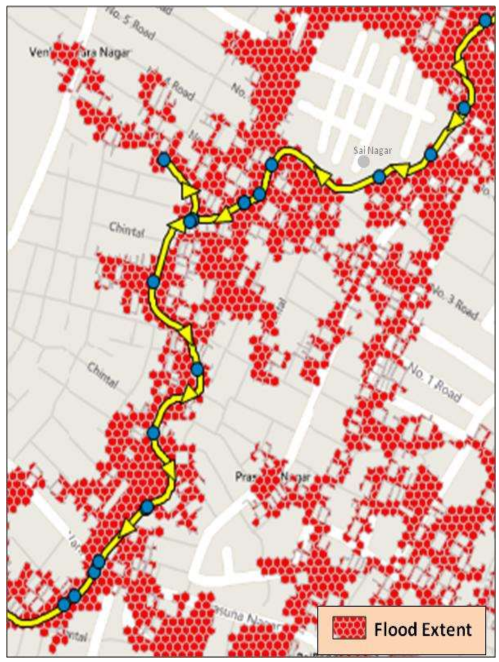

Figure-11 : Urban Flood Map

5.2.1 Conduits Surcharge

Surcharge is overloading of the sewer beyond its design capacity due to inflow of water. A surcharging sewer often results in sewer overflow at manholes. Table 1 shows conduit surcharge summary results for the study area and it is inferred that the conduits are full in hours.

Table 1. Summary of the conduit surcharge

	Hours full			Hours	Hours
Conduits	**Both ends**	**upstream**	**Downstream**	**Above full Normal flow**	**Capacity Limited**
C-53	0.01	0.01	0.63	0.01	0.01
C-54	1.21	1.21	5.99	0.01	0.01
C-55	5.8	5.8	9.88	0.01	0.01
C-55_1	10.31	10.31	14.96	0.01	0.01

5.2.2 *Sub catchment Runoff*

Runoff is a parameter which depends upon precipation, infiltration, evaporation loss and subcatchment area. Runoff from any subcatchment is assumed to flow directly to the outlet. Table 2 shows the summary of subcatchment runoff in the form of depth, discharge, volume for the corresponding subcatchments.

Table 2. Summary of the sub catchment runoff

Sub-catchment	Total Infiltration (mm)	Total Runoff (mm)	Total Runoff $x10^6$ Litre	Peak Runoff CMS	Runoff Coefficient
S1	6.46	124.61	3372.76	80.31	0.41
S10	13.13	272.2	210.31	4.17	0.906
S11	13.13	265.55	491.95	10.01	0.874
S12	39.39	165.08	859.19	18.04	0.543
S2	6.46	282.42	168.73	3.3	0.929
S3	13.13	273.75	239.66	4.77	0.901
S4	6.46	286.24	173.47	3.35	0.942
S5	13.13	259.4	380.71	7.85	0.854
S6	13.13	285.88	28.75	0.55	0.941
S7	22.59	258.92	170.29	3.5	0.852
S8	6.46	275.78	344.93	6.89	0.908
S9	13.13	280.29	77.12	1.5	0.922

5.2.3 *Runoff Quantity Continuity:*

The total runoff quantity is the result of precipitation-infiltration- storage from all the sub catchments. Table 3 shows the runoff quantity continuity.

Table 3. Runoff quantity continuity

Runoff Quantity Continuity	Volume Ha-m	Depth (mm)
Total Precipitation	1237.246	303.85
Evaporation Loss	0	0
Infiltration Loss	48.053	11.801
Surface Runoff	651.783	160.069
Final Storage	537.745	132.063

5.2.4 *Flow Routing Continuity*

For the present study, flow routing has been carried out using dynamic wave routing which solves the Saint Venant flow equations that consist of the continuity and momentum equations for conduits and a volume continuity equation at nodes. Channel storage, backwater, entrance or exit losses, flow reversal and pressurized flow can be represented using this form of routing equation. Table 4 shows the results of flow routing continuity for study area.

Table 4. Flow Routing Continuity

Flow Routing Continuity	Volume (Hectare-meter)	Volume x 10^6 Litre
Dry weather Inflow	0	0
Wet weather Inflow	651.442	6514.22
Initial Stored Volume	0.012	0.019
Final Stored Volume	214.693	2146.93

5.3 HAND Model

We have generated various classes in the model showcasing vulnerable areas in the study area as shown in Figure- 12. The localities within study area like Gandhi Nagar, Kakatiya Nagar, Srinivas Nagar, Venkateshwara Nagar are found to be highly vulnerable whereas New Vivek Nagar is less vulnerable. During September 2016, when heavy rainfall was reported in Hyderabad resulting in urban flooding, HAND model was used to simulate the vulnerable localities. Low lying regions were extracted and flood vulnerability maps were generated based on the increase of water level by one metre. From the ground survey, it is observed that Sriinvas Nagar, Gandhi Nagar, and Vani Nagar get flooded every year with low intensity rainfall. The model is calibrated and a threshold is fixed. Subsequently, various zones are defined and the low vulnerable regions are delineated. These maps were provided to the State line departments for decision making in the emergency management. The Hyderabad city police have used them for traffic regulation operations.

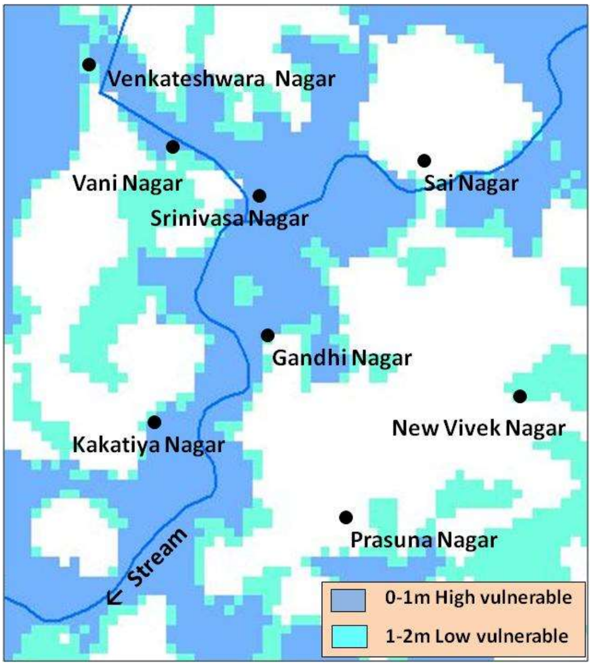

Figure-12 : Flood vulnerable areas from HAND Model

6. Conclusion

This paper presents three models SWMM, HEC-RAS and HAND for the simulation of a small urban catchment in Zone 12 in Hyderabad city. Though the three models are different in nature and theory, the model results have their own operational applicability and utility. All the three models gave appreciable and encouraging results. It is found that when the flooding is due to overtopping of river/nalas or any open channels in the urban areas, it is suggested to use HEC-RAS Model. For the catchment zone 12 of Hyderabad, it is concluded that if 144 mm of rainfall occurs uniformly over the catchment within 10-12 hrs, the catchment will experience flooding. SWMM model is suitable in cities where systematic sewerage network, closed conduits and storm water drainage network exists. HAND model which has the potential to systematically classify the ground terrain has a greater applicability in the field of surface hydrology, land-use and hazard risk assessment. GIS maps can be generated providing information on delineation of flood plains, zone areas and risk zones for protection from flooding and management of different types of land use. These measurements, coupled with forecasts of rainfall based on weather radar and global ensemble predictions, can provide a digital overview of the risks associated with the potential urban flood disaster. In addition, there is a growing need for storm water management strategies to reduce urban flood risk. Further research work is to be focused on the implementation of an alert system based on the simulation results. A sensitivity analysis is also to be carried out for all the models. The results showed a spatial variation of flood depth for a given rainfall intensity which helps for hazard and risk assessment and identification of low-lying areas which can aid in emergency management like real time traffic management, decision making, resources allocation, rescue operations.

7. Limitations

For urban flood management and modeling, high resolution DEM of centimetre accuracy will produce more accurate results. However, due to non-availability of high resolution DEM, the study is carried out with CARTOSAT satellite derived DEM of 10 meters resolution with vertical accuracy of 1-2 meters.

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