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Climate Change induced flash floods damage estimation for residential buildings: a case of Bhopal

Rajat Soni
Department of Architecture and Planning
Maulana Azad National Institute of Technology
Bhopal, India
sonirajat@gmail.com

Abstract

Floods have been integral part for most of the riverside cities. Flash floods due to Climate Change have become a relatively new term in our urban system. Excessive rainfall in short periods has been addressed as one of the outcome of Climate Change in many parts of the world. Natural carrying capacity of urban drains becomes highly insufficient in event of excessive rainfall leading to Urban Flash Floods.

Urban areas are continuously growing larger creating huge quantum of solid and liquid waste. Urbanization also adds slums and encroachments in vulnerable low lying areas of the city. Expansions of urban areas are capturing longer lengths of these natural drains in urban areas. These already stressed natural drains carry much higher than their capacity in event of excessive rainfall creating urban flash floods. Urban flash floods move swiftly with enormous force carrying solids, debris and dirt within it. It might happen for shorter periods destroying everything that comes in its way.

Floods lead to various social, economical, physical and personal damages. These damages have been classified as tangible and non tangible damage for the purpose of damage estimation. This paper is an attempt to address tangible damage estimation for built infrastructure in urban areas with specific focus on residential buildings.

Index Terms—flood loss estimation, stage-damage functions, flood inundation, damages, hazard management, drainage, flood control, flood risk management, urban flooding, resilience, impact assessment, urban water management.

I. Introduction

Floods in flood plains are common while flash floods due to heavy rains are becoming a frequent event in many urban areas. Their distinct features paint a stark picture. Flash floods happen suddenly, easily and frequently, are very destructive, and difficult to protect against. It happens when the rainfall intensity increases by the carrying capacity or resistance level of the infrastructure. Flash floods are distinctly characterized by very swift rise and recession, associated with debris flows and landslides, occurring along channels and rivers with small drainage area. In view of Global warming induced Climate Change it is expected that the rainfall variability would intensify in future, resulting in more intense rainfall in short spans of time; this poses high risk of urban flash floods.

The patterns of urban flash floods are almost identical in its force to riverine flood. Small streams, canals, channels, and drainage ditches become fast flowing dangerous rivers. Where the terrain is flat, primary and secondary roads are inundated with torrents of floods, streets and parking lots becoming rivers of moving water. Flash floods rise rapidly within a few minutes or hours of heavy rainfall. As the water rises rapidly and moves swiftly, carrying cars, ripping trees from the ground, and even destroying roads, bridges and buildings.

Handling the challenges of flood risks in densely populated areas has been a constant historical factor in human settlements. Most cities are located in the valleys, flood plains and the coasts. Cities through their nature of having large impervious areas produce large run-offs which the drainage network cannot accommodate, and are potentially exposed to floods. It has been acknowledged that the damage potential of floods in the cities is extraordinarily high. Given the high population density in urban areas, even small scale flash floods may cause considerable damage. At the extreme end of the disaster spectrum, urban flash floods can result in disasters that set back development drastically. With climate change and global warming resulting in increased frequency of floods and their magnitude, continuing urbanization and disproportionate growth, the economic costs of flash floods will soar. Sustainable management of urban flood risks is becoming an increasingly challenging task for city/municipal authorities.

Disaster damages and impacts in urban areas can be long lasting. The direct damages of any disaster can be calculated within a set timeframe, but the long term impacts can be assessed only until all damages has been repaired, redone, set right or alternatives has been provided. Such study would generally require a considerable time measuring in years to complete or at-least the period before the likely next happening of the similar event.

Government incur huge amount in relief and restoration work after such disasters. Similarly the insurance companies also have to settle numerous damage claims. As a matter of fact we do not have properly recorded urban flash flood damage data for most of the regions. There is a serious need for a methodology and a base work to carry out damage estimation that may be applied to different urban areas. Although it would be fine and desirable for every study to come to results with the highest level of precision, this is often not possible due to budget or time restrictions. If only a small budget and/or little time are available for a study, quick, easy and approximate methods have to be chosen in order to finish the study under these restrictions.

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II. The area under investigation

The city of Bhopal had heavy rains in the month of January 2006 which led to urban flash floods in many areas of the city hence it was chosen to carry out this pilot study. Studying all inundated area would be beyond the scope of work as that would require much time, finances and efforts to complete; therefore a selected inundated site study has been carried out for 'Gautam Nagar' area of Bhopal, considering it as representative of the whole city.

This area was originally a low lying area with a large natural drain, in the region of BHEL campus, which was later given to housing board for development of a residential campus through 'Gautam Nagar society' in 1970's. The natural course of drain was straighten, realigned and channelized as per the needs of development during the development period. The low lying areas thereafter were filled with debris for further development. The catchment of this natural drain is 'Arera hill' which was unpopulated during the development period (1970-1975), however during the course of time lot of development took place in the catchment area which resulted in increased garbage and liquid discharge in the drain simultaneously due to development the rain water absorption reduced in the catchment. The flood of 2006 was the combined effect of reduced capacity due to non maintenance / non-cleaning of drain along with pressures of Urbanization and Climate Change (heavy rains) in the catchment.

III. Aims and Objective

The basic aim of the study is to carry-out a methodology for damage assessment of flash floods on urban build infrastructure with specific focus on residential buildings. The objective of this study is to give only a quick and approximate overview of the amount of damages, therefore a less precise, less costly and less time-consuming method might be sufficient and appropriate.

IV. Conceptual tool, research Methods

Damage data of such events needs to be collected, organized and analyzed, over the time period. Unfortunately we do not have a ready reference data for such studies in our country. This study is an attempt to establish a methodology to calculate damages arising out of urban flash floods.
One of the objectives is to establish a system of data analysis that can be used for further damage assessment studies of similar nature. This is possible through proper recording of data in a suitable format/ system so that it can be used further and save the time.

Flood affected developed countries like Japan and Britain had used their primary collected data to create stage-damage-curves which are further useful and timesaving for later damage assessments in similar locations/situations. These stage-damage-curves can be strengthen/ modified after every flood by post flood investigative surveys.

The study has been done in Bhopal. An exploratory survey was done initially throughout the city to identify the flood affected areas and type of damages during the flash floods of 2006 rains. Parallel meetings were also done with various stakeholders to identify the nature and vastness of damages.

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Out of the surveyed a suitable location was selected on merits and suitability for quick study, out of that the parameters of the study has been identified for detailed survey.
The goal of the study was to develop a methodology for quick assessment of damages on residential built infrastructure of the city due to flash floods. The methodology has been addressed to only primary tangible losses on the physical built (residential) infrastructure. Intangible damages were out of the scope of this study and methodology. However this study focuses only on the assessment of damages whereas a separate study would be required to study the quantum of precipitation due to climate change and possible flooding arising out of that for future preparedness, risk profile, mitigation, adaptations and warnings that makes the work comprehensive.

The structural damage to residential building is considered as:

$$Ds = Fa \times Rc \times Ci$$

Damages on plot other than building are considered as

$$Doa = Oa \times Rc \times Co$$

Where, Ds =Damage to structure;
Fa = Building floor area under inundation;
Rc = Replacement cost per unit for respective category;
Ci = Depth-damage function for respective category for inside damages;
Doa = Damage to open areas;
Oa = Outside open area on plot under inundation;
Co = Depth-damage function for respective category for outside damages;

To assess the structural damage to buildings, probable damage to its components, systems and other necessary costs were considered. The damages are classified as “Structure/building damages” and “outside Structure/building Damages”. The major damages that are considered for Structure damage are - damage to Foundations, Plinth, Floor, Walls, Plaster, Doors, Finishes, Water supply system, Drainage system, Electrical system etc. Similarly damages that are considered for ‘outside structure’ are – damages to Boundary wall, Pavements, and Landscape. The other associated costs like - General Cleanup costs, Service Cleanup cost, Debris removal cost and Demolition cost are also considered as ‘outside structure’ damages.

Total 50 buildings were reported to be affected by this flood however for 7 of them the data could not be collected as the owners left the place, sold it or died in the mean time. Therefore a total of 43 buildings out of 50 were studied under this project. Total five category of inundation were considered for this study starting from one foot to five feet and levels above five feet are considered as five feet.

Outcome of the survey is plotted below in five charts for different inundation depths. The thick bold line in the chart represents the average value for various categories. Since the inundation depth is considered above the plinth level of individual buildings the actual flood level above ground differs from plot to plot due to change in topography. Since this study is carried out after a long time after

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happening of event, parameters like flow rate of water and the time of inundation are not possible to be considered here.

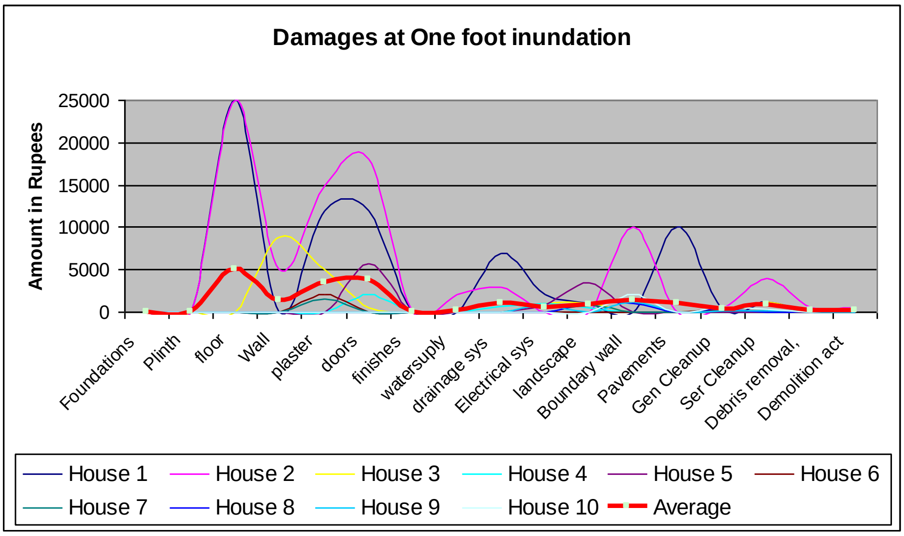

Chart 1: showing damages at one feet inundation above plinth level.

Damages at one foot inundation above plinth are minimal. Damages are observed on floor, doors and plaster. No major structural damages are observed.

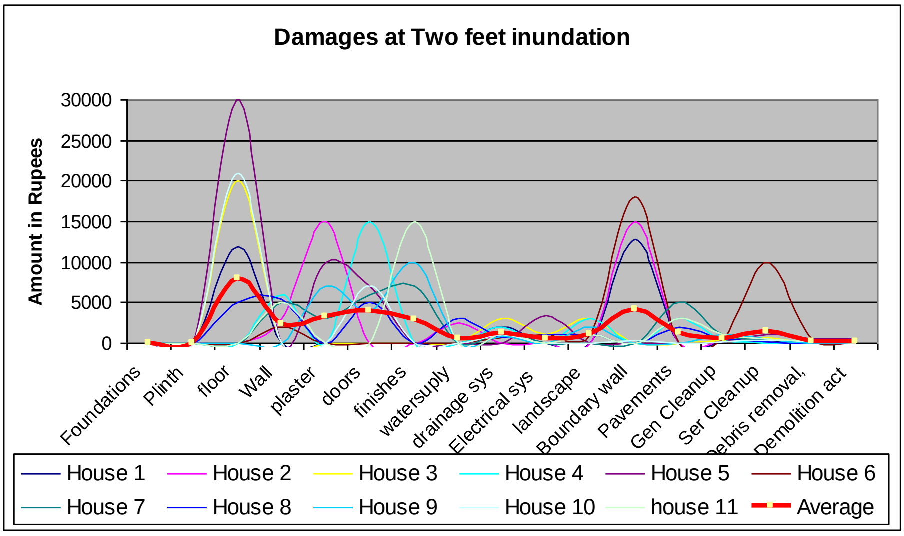

Chart 2: showing damages at two feet inundation above plinth level.

Damages at two feet inundation above plinth are more than one foot. Damages are observed on floors, plaster, doors and boundary wall. No major structural damages are observed.

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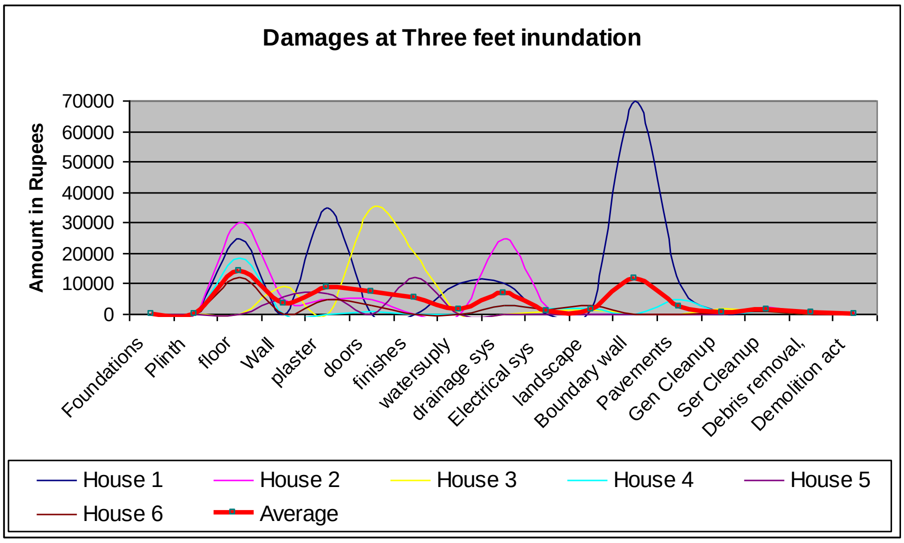

Chart 3: showing damages at three feet inundation above plinth level.

Damages at three feet inundation above plinth are more or less same as at two feet. Damages are observed on floors, plaster, doors, drainage system and boundary walls. No major structural damages are observed except breaking of boundary in some cases.

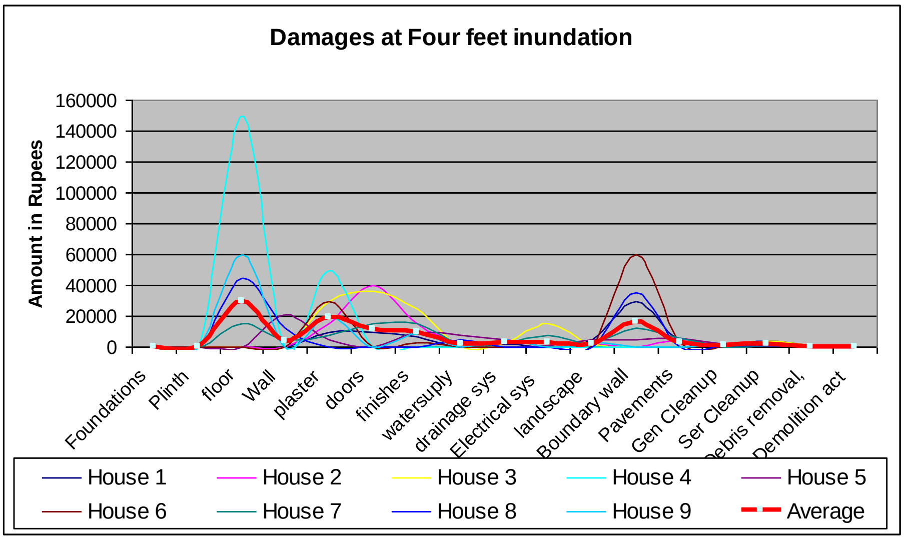

Chart 4: showing damages at four feet inundation above plinth level.

Damages at four feet inundation above plinth are more severe than at three feet. Damages are observed almost in all components of study, large damage is observed on floors, plaster and boundary wall. No major structural damages are observed except ripping of floor and breaking of boundary in some cases.

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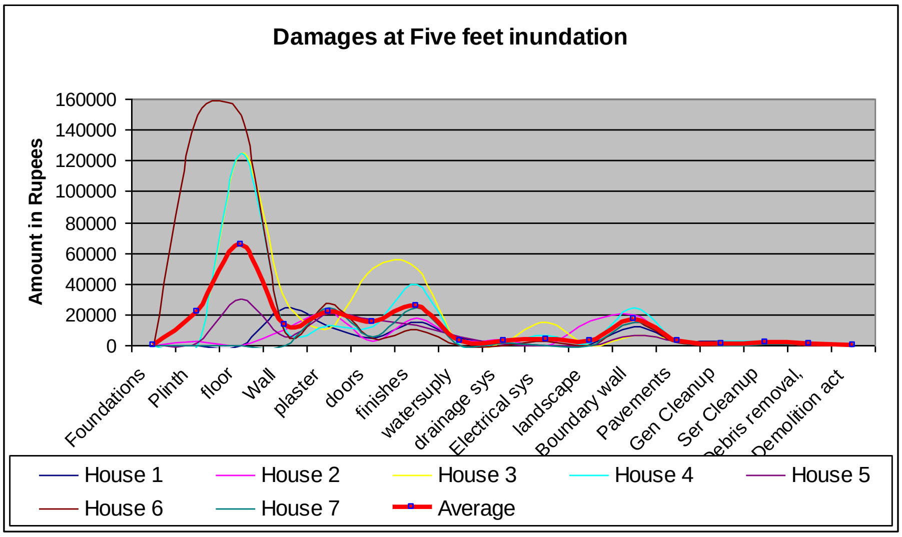

Chart 5: showing damages at five feet and above inundation over plinth level.

Damages at five feet inundation above plinth are more severe than at four feet. Damages are observed almost in all components of study, maximum damage is observed on floors, plaster, plinth, doors, finishes and boundary wall. Structural damages are observed in plinth, ripping of floor and breaking of those boundary walls that happened to be obstructing the direct flow of water.

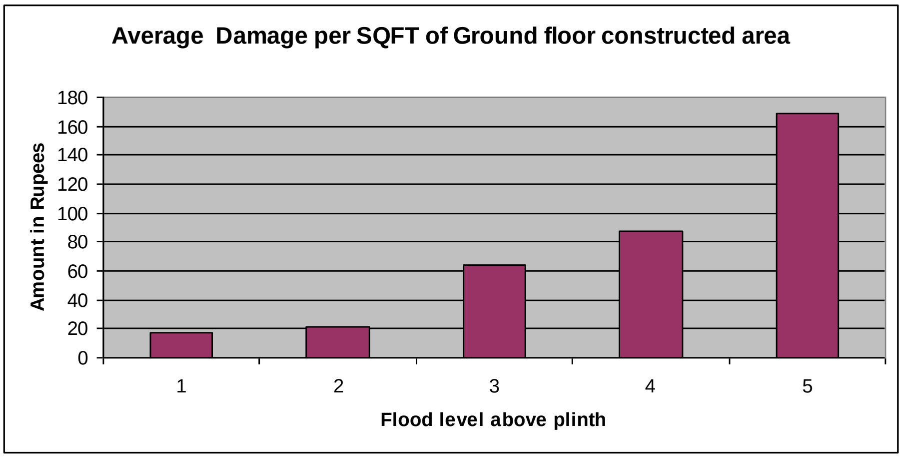

Chart 6: showing total damages in reference to inundation over plinth level.

On analyzing the average damages in monetary terms at different levels of inundation it is observed that there is rise in damage costs with the rise in inundation level. Up to two feet of inundation the losses were moderate; up to four feet the losses were comparatively high but beyond four feet there is sudden rise in the damages cost.

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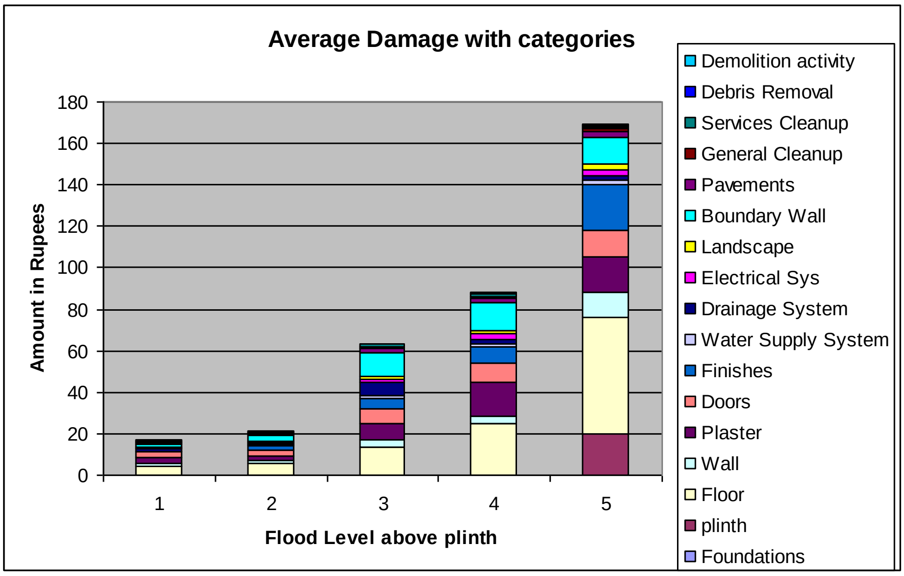

Chart 7: showing category wise damages with reference to inundation above plinth level.

The chart above clearly describes the contribution of various components in the average damage. There is proportionate rise in components damage with rise in inundation depth. On analysing it evident that building could easily manage the floods up to two feet of inundation however beyond which there is sudden rise in damages to most components.

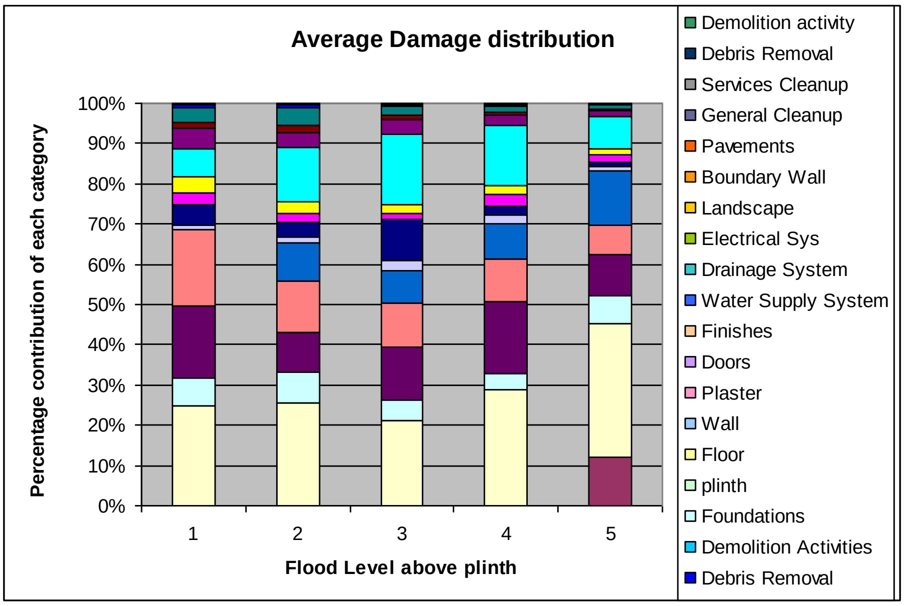

Chart 8: showing percentage damage of each category in total damage with reference to inundation above plinth level.

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This chart describes the percentage contribution of various components in the average damage at various inundation depths. It is observed that the percentage contribution of different components is not consistent but changing this is due to different vulnerability of components to inundation levels. However the vulnerability of these components largely depends upon the age of structure, materials used and the maintenance.

V. Conclusion:

Damages due to urban floods are associated with various factors like depth of inundation, Time of inundation, flow rate of water and the quantum of debris flowing along the flood water. Since the damages assessment surveys are done after floods, the actual values therefore are practically difficult to calculate except the inundation depth which leaves imprint after happening. Therefore most important parameter of the study came out to be inundation depth.

It has been observed that the damages to buildings remain very less or negligible until the flood level remains below solid plinth however the damages increases once it is above the plinth level. Therefore the flood levels above plinth have been considered here for calculation of damages, the actual flood level may differ due to different heights of plinth and undulations on land.

This area was developed by Housing Board (government entity) in 1970's, and as per the needs of those time it was developed as low rise low density with majority of the buildings having similar structure and design, therefore for the purpose of calculations the average replacement cost of buildings has been taken as Rs 600 per sq ft. The official cost in the government records at that time may also be considered for the purpose. To calculate damages to different types of residential buildings respective cost of replacement needs to be considered.

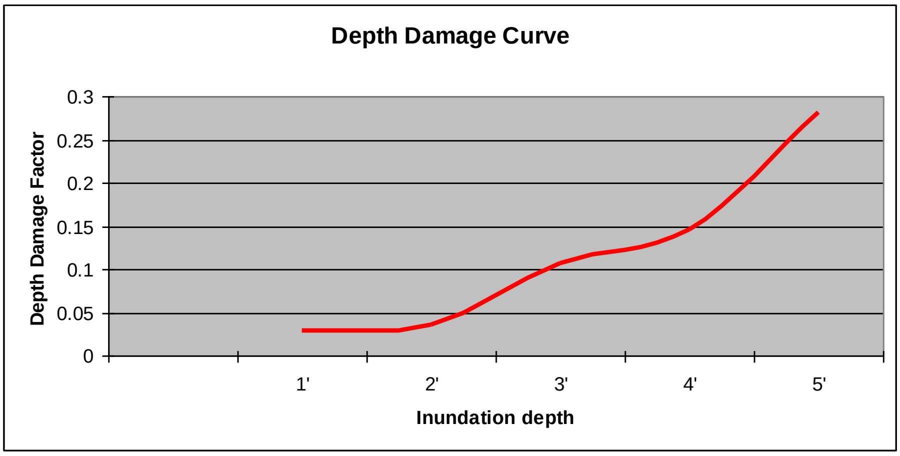

Chart 9: showing Depth Damage curve.

For various inundation depths the depth damage factor is calculated and plotted above as Depth Damage Curve. Using this curve damage factor at various depths can be identified and used in the given formula to arrive at probable damage cost. This curve is specifically useful for calculating

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Government compensation, insurance claims and total damage assessment due to floods. The curve shall be updated every time after floods to incorporate the changes.

To avoid similar flooding in future the various localities that are vulnerable to such flooding needs to be identified and their causes like - insufficient capacity of the natural drains; their banks; solid waste in drains; encroachments in and over drains; insufficient cleaning / maintenance etc. needs to be addressed at-least before every rainy season. Whenever there is possibility of heavy rains, warning in the local cable network, radio station and news papers shall be given to alert the people and authorities to minimise the damages.

Identification of problem and vulnerabilities is not a single step process. Policy and decision makers need to understand the extent of problem and its impact over the infrastructure in specific and society in large. Attempts should be made to identify the mitigation measures that can be implied in phases with regular development such that providing reduction of problem as well as adding value to the society.

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