A STUDY ON FLOOD HAZARD MITIGATION OF GUWAHATI CITY

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Abstract
The problem of urban flood of Guwahati, a city located in the northeast part of India, is one of the burning problems at present. The topography of the city is such that rainwater cannot drain out easily from the heart of the city. With rapid growth of residential area in the surrounding hills, sediment yield from the immediate upper catchment is increasing and deposition of the same in drains is adding another dimension to this problem. Therefore innovative planning and efficient design of the drainage network is necessary. An effort has been made to study finer details of the siltation process by investigating a small part of the drainage system. Theoretical analysis has revealed that for the existing cross section and bed slope, flow velocity in the drain should have exceeded the required scouring velocity to make the channel a self cleansing one. Thus, sedimentation occurs due to other factors. Possible factors responsible for sediment deposition have been analyzed and some remedial measures have been suggested. Scope of restricting sediment and water yield from the hilly watershed by implementing ecological management practices (EMP) has also been investigated and a concept of adopting optimal EMP has been suggested.

Key words: Urban flood, sediment control, Ecological Management Practices

1. Introduction

 Improper design of the sewer system leads to urban flooding in many countries. Proper design to prevent this flooding has emerged as a challenge for the engineering community. Various   studies were carried out all over the world for modeling and prevention of this phenomenon. Geerse and Lobberecht (2002) carried out a study to assess the performance of urban drainage during dry period and during storm event by developing performance index. Janusz Niemczynowicz(1999) discussed present and future trends in urban hydrology. Mannina *et al.* (2011) presented the results of a study in which the uncertainty levels associated with a detailed and simplified sewer sediment modelling approach have been compared. John A. Cross (2001) discussed the vulnerability of megacities towards hazards and showed that in many respects residents of small cities and rural communities are more vulnerable to disasters. Mark *et al.* (2004) presented a one dimensional model to simulate urban flooding. Thorndahl(2008) presented event based uncertainty assessment in urban drainage modeling. They applied the Generalized Likelihood Uncertainty Estimation (GLUE) methodology. Burton and Pitt (2001) reviewed catchment and receiving water modeling in relation to stormwater. They classified the catchment models primarily according to the complexity ranging from simple methods (based on export coefficients or event-mean concentrations multiplied by runoff volume) to complex models that are typically spatially distributed and processed based. Mc Alister *et al* (2003) reviewed urban storm water quality models, and stressed the importance of using suitably small temporal resolution and continuous simulation over one or more years. Beecham (2002) presented key features of four models for water sensitive urban design, but did not discuss their suitability. Schmitt *et al* (2004) presented a detailed dual drainage simulation model based upon hydraulic flow routing procedures for surface flow and pipe flow. Special consideration is given to the interaction between surface and sewer flow in order to compute accurately water levels above ground as a basis for further assessment of possible damage costs. Andrew Swan (2010) explores the relationship between increased urbanisation and subsequent capacity problems within drainage infrastructure. Stefan Achleitner (2006) developed a code in matlab for the

design of urban drain. Ana Delectic(2004) carried out an extensive laboratory study on artificial grass in order to examine the processes of sediment transport in runoff over grass. The study was focussed on grass utilisation in control of urban runoff, and therefore low to moderate loads of fine silt were used as inflows into the grass.

The focus of this paper is to present 1) a detailed experimental investigation on particle size characteristics in various parts of a selected drain to make further analysis for scouring velocity, 2) an approach for determining optimal ecological management practices for controlling sediment and water yield from an urbanized hilly watershed.

The drainage system of Guwahati city is not satisfactory as it cannot drain out floodwater during the monsoon period. Topography of the city is such that it is difficult to have required gradient in many part of the drainage system. The outlet of the drainage system is connected to river Bharalu which is again connected to river Brahmaputra. Another problem of the drainage system is that at the time of peak flow the water level of river Bharalu rises to such a level that the water of the drainage system forms a backwater profile and the flow velocity drops almost to zero. This contributes towards sedimentation and aggravates the flood problem in the city. A sluice gate was constructed at the confluence point of the river Bharalu and Brahmaputra to prevent the backflow flow from river Brahmaputra to Bharalu and then to the city drain. It was proposed to pump out the stagnant water during the flood time. However insufficient pumping system could not solve this problem in the city. As high sediment generation from the hills and their subsequent deposition in the drains located in the plain are the primary cause of urban flooding, a small part of city drain, which was renovated in 1994 to have a sufficiently large section to carry the monsoon flow, was selected to study various issues of sedimentation and flow stagnation. On the other hand, to restrict sediment yield from the hills at minimum possible cost, an optimization model has been developed to decide optimal EMP combination that can restrict the sediment and water yield within permissible limit.

1.1 Theory of sedimentation
The settling velocity of sediment particles is governed by the size and the specific gravity of the sediment and also the viscosity of the sewage. In this study settling velocity was computed by using the approximate equation as given below.

Stoke's law:

$$V_s = g/18(S_s - 1)\ d^2/\mu$$

Where,
V_s=Settling velocity in m/sec.
g=Acceleration due to gravity.
S_s=Specific gravity of the grit particle.
d=Size of the particle in metre.
μ=Kinematic viscosity m^2/sec

Stoke's law holds good for Reynold's number below 1.

1.2 Theory of erosion and scouring
The soil particles which are detached from the current location and moved with the flow of water are referred to as sediments. When the shear stress between the water and the sediments exceeds the frictional resistance, the sediments start to move in the direction of flow. When the shear stress is almost equal to the frictional resistance, the particles just start to move and this condition is called incipient motion condition. But the original bed of the channel under study is made of concrete and the bed level rises due to accumulation of sediments carried by the flowing water. So, the channel bed, having sediment deposited in it, behave like a mobile boundary channel .Water flowing over a channel bed has a gradient in the vertical direction. Due to this velocity gradient, water exerts a shear stress on the particles lying on the stream bed.This shear stress is known as boundary shear stress.

The channel carries a large amount of suspended matter which remains floating or suspended due to the flow of the sewage. Therefore while designing the channel the velocity of flow should be such that no solid gets deposited and that minimum velocity is called self cleansing velocity.
The formula for self cleansing velocity is given as,

$V = 8K/f(S_s-1)gd_s$

Where V=Velocity of flow

K=characteristics of solid usually which is taken as .04 to .06
f =Darcy's coefficient of friction which is usually taken as 0.03
Ss=Specific gravity of solid which is usually taken as 2.65
d_s=Effective grain size

2. Field and laboratory investigation

To study the problem of artificial flood a part of the whole drainage system was selected and silt samples were collected at regular intervals from the channel bed. A sampler was fabricated for sample collection. Collected samples were brought to the laboratory and a part of the whole sample was kept for determining the decomposable matter in it. The remaining part of the sample was dried for a week in sunlight. The sample was then ovendried for 24 hours at a temperature of 105^0C. The ovendried sample was then sieved in the sieve shaker of sieve sizes IS4.75mm,2.00mm,1.18mm,1.00mm,0.6mm,0.3mm 0.15mm and 0.075mm.The experimental data obtained from this analysis was plotted to obtain the uniformity coefficient, coefficient of curvature and effective grain size of each sample. The debris contained in the each sample were also separated during sieve analysis and weighed separately. The percentage of debris in each sample was then calculated.

2.1 Fabrication of sediment sampler

The samplers consist of a round hollow cylinder of diameter 4.5cm. One end of the cylinder having a cutting edge is inserted in to the bed for sample collection. The sampler can be opened and closed at the bottom by operating a valve from the top. The valve is basically a thin circular plate, hinged at one circumferential point of the cylinder and can be operated by a small rod connected to the plate at angle 120 degree with the plane of the plate.

2.2 Experimental findings: Samples were collected from following ten points along the drainage line starting from upstream to downstream and results are tabulated in Table-1

| Table-1: Field data of various points			
Observation locations	Uniformity coefficient	Coefficient of curl	Decomposable Organic matter (%)
Zoo Road Tiniali	3.62	0.75	2.24
R.G.Barua road	2.69	0.95	6.27
In front of AIDC petrol pump	2.28	0.85	6.29
In front of Uday Path	2.77	1.98	6.64
In front of AIDC bus stoppage	2.93	1.1	6.64
In front of Rupali Path	3.78	1.11	19.63
In front of Akashi Path	3.75	0.87	15.16
At the point where the Bharalu and the drain meet	4.15	1.15	6.33
In front of La Mare institute of IT	6.18	1.07	5.98
In front of office of the director of border area	7.6	0.86	11.3
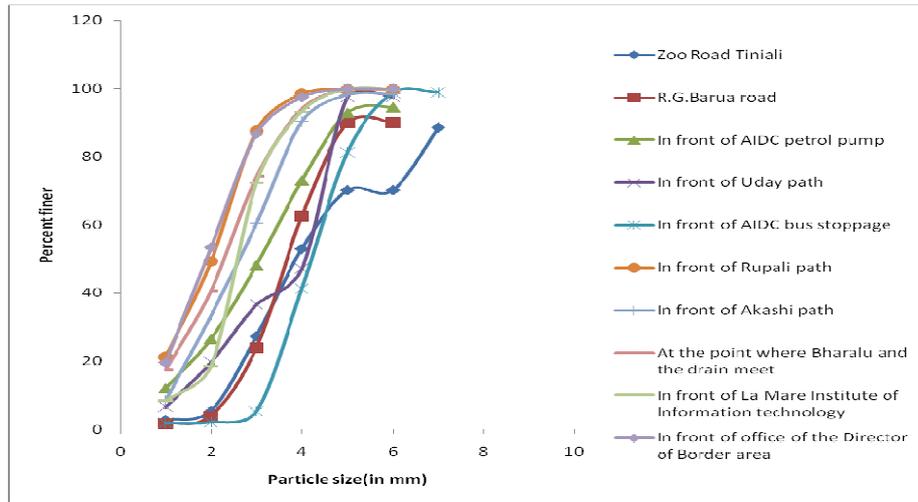
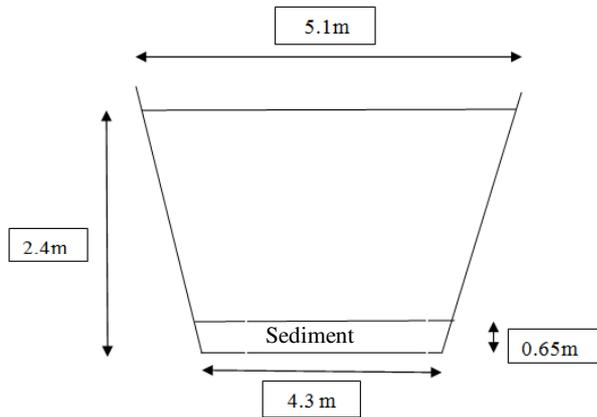Figure1.   Plot of particle size vs percent finer of silt particles
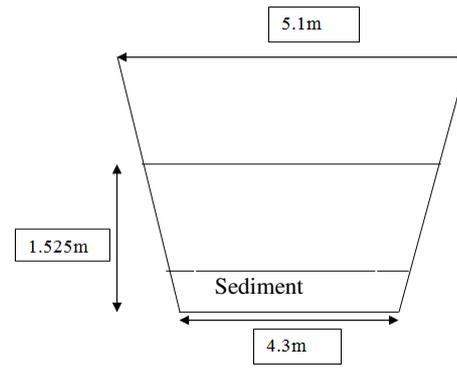

Figure 2 Channel nearly full

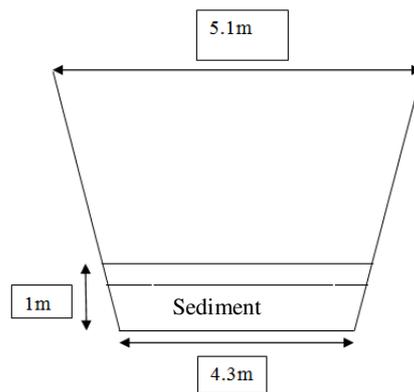Figure 3 Channel flowing half full

Figure 4 Channel during lean period

2.3 Calculation of uniform flow velocities and scouring velocity

Uniform flow velocity and scouring velocity for the sediment was calculated for the channel for three different stages: case 1-nearly full condition, case 2-half full condition, case-3 low flow condition. These velocities were compared to see the scope of the sediment deposited being removed automatically by the flowing water.

Case1: When the channel is in nearly full flow condition (Figure 2)

Cross section of the channel=1/2(5.1+4.3)(2.4-0.65)=8.225 sq.m
Perimeter of the channel=4.3+(2 x 3.22)=10.74m
So hydraulic mean depth R=8.225/10.74=0.76m
Here bed slope= 0.0024
Using Manning's formula, velocity =3.982m/sec
Scouring velocity = 0.193 m/sec

Case 2: When the water level is half of the full flow condition (Figure 3)

In this case depth of flow=1.75/2=0.875m
So cross sectional area=(4.7+4.3)(0.875)(0.5)=3.94 sq m
Perimeter of the section=4.3+ (0.8056) x 2 =5.91m
So hydraulic mean depth R=3.94/5.91=0.67m
So using Manning's formula velocity=3.64m/sec which is much greater than the scouring velocity

Case 3: Flow during lean period (figure 4)
Flow depth(1-0.65)=0.35m
So cross sectional area=(4.46+4.3)(1/2)(0.35)=1.533 sq.m
Perimeter of the channel=4.3+ (0.129) x 2=4.56m
So hydraulic mean depth R=1.533/4.56=0.336m
So velocity=2.299m/sec

From the above calculations it has been observed that scouring of the particles in the channel bed should have been taken place. Thus, the basic cause of sedimentation is not just the inadequate size but some other factors are responsible for siltation in the drain.

3. Possible causes of siltation

Due to rise in the water level in the river Bharalu during the rainy season, the water level in the channel also increases. But the water level in the channel remains low with respect to the river Bharalu due to which a back water profile is formed at river Bharalu.This results in decrease in the flow velocity towards the outlet of the channel. Thus scouring action decreases at that point and silt gets deposited slowly.

The analysis of sediment characteristic has shown that because of poor management of solid waste, the sediment getting mixed with garbage behave in a much different way so far its property towards scouring under water current is concerned.

Existence of narrow bottle neck in many places cause afflux at upstream which reduces the flow velocity and promote sediment deposition.

With the increase in the deposition of silt, starting from the confluence point of the drain, and the river Bharalu, the bed slope of the channel also reduces progressively and silt gets deposited quickly.

4. Remedial   measures:

After analyzing the entire problem we have found that effort should be diverted more towards controlling sediment yield from the upper catchment. For controlling sediment yield and water yield from the hilly urban area it is necessary to apply ecologically sustainable and economically viable management practices that can restrict sediment and water yield within a permissible limit. Such practices can be named as Ecological management Practices (EMPs).

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4.1 Ecological Management Practices: So far, there is no well established EMP recognized as suitable for urban residential developments. However, various traditional land management practices are available for controling the sediment yield and runoff volume for agricultural areas. Some of such practices are contour terracing, mulching, grass land development, creation of buffer zone with grass and tree, agro forestry, vegetated waterway and gully control measures. These practices, if suitably modified considering the necessity of an urban area, can also be used for land management of urban residential areas. Some of possible EMPs for urban residential areas are suggested below:

a) **Grass land**: Grass reduces the velocity of surface runoff, minimizes the impact of rain on soil and its root system helps in increasing infiltration. In urban area, grass land can also serve as open land that is needed according to the municipal rules.

b) **Forest land**: Tree canopy reduce the direct impact of rain on soil. Besides, forest land, covered with falling leaves, also reduces the surface runoff velocity and increases infiltration. Falling leaves and decaying braches act as mulches and thus tree cover can control sediment yield and runoff volume.

c) **Covering rain impacted areas with pebble, vegetation or wood chips:** Erosive power of rain drop depends on size of rain drop and its falling height. Size of rain drop that falls from inclined roof of a house become quite large and thus strikes the ground with very high erosive power. Thus, the portion of ground lying below the line of the roof edges is *prone to more erosion as the accumulated rain over the roof falls with a high velocity. Such drop line areas of water around the house can be covered with pebble or wood chips or erosion resisting vegetation can be allowed to grow, which protect the soil from the direct impact of rain drop and also allow more infiltration.*

d) *Detention drain and Retention pond:* To capture the excess surface runoff, detention drains can be constructed across the slope and retention ponds can be constructed in a suitable location. This can minimize downstream erosion and flooding.

e) *Vegetated waterways:* If the paths (or channels) of accumulated surface runoff are covered with vegetations, then the vegetation provide an obstruction to the flowing water. It reduces velocity and hence the erosive power of the flowing water. This reduces erosion of channel bed and bank and prevents gully formation. Root systems of a vegetated waterway not only increase bondage of soil and make it resistant to water erosion, but also promote infiltration. Depending on the status of degradation of the waterway, different types of vegetation can be suggested.

f) *Rainwater Harvesting System: :* Rainwater harvesting is a technique of collection and storage of rain water in surface (storage tanks) or sub surface aquifer before it is lost as surface runoff. Rainwater harvesting system helps in reducing the peak runoff and also recharges ground water. The collected rainwater through the rainwater harvesting system can also be used during the period of water shortage.

4.1.1 Concept of Optimal EMPs

EMPs differ in their implementation and maintenance cost form site to site and time to time. Scope of implementing an EMP in a particular site will have to be assessed by taking into consideration various site condition such as slope, soil characteristic, land ownership, land availability, present land cover and logistic of future maintenance. Besides, pollutant removal efficiencies of EMPs are also site-specific. Based on this, planning and design of EMPs should be done in such a way that they are efficient to capture and treat the pollutant loaded water and are ecologically and economically feasible.

4.2 Eliminating sediment and debris from drainage system.

Even after adopting EMPs, some amount of sediment and debris will reach the drains. Similarly the water yield may also increases beyond channel capacity if rainfall exceeds the design storm. For such situation following measures can be adopted.

a) **Debris control:** Flow of debris in to the channel can be controlled by placing a suitable screen at inlet of the channel. This will prevent the flow of debris and large sized objects into the channel which may obstruct the channel and can promote deposition of silt. The screen should be cleaned at regular intervals of time to increase its efficiency.

b) **Provision of R.C.C. cover slab on the top of the channel:** The obstruction caused by throwing large sized objects like cartoon, bamboo piece etc may be stopped by covering the whole channel with R.C.C. slab throughout its length.

c) **Silting basin at the inlet point:** At the confluence of the primary and secondary drain a silting basin can be provided.The velocity of flow at the basin will get reduced and deposition of silt will occur at the basin . As a result, water containing lesser amount of silt will enter the channel main channel.

d) **Silting basins throughout the length of the channel at regular intervals:** Suitable number of silting basins can be provided throughout the length of the channel to collect the silt carried by the flow.The basins should be cleaned after regular time intervals.

e) **By pumping of sewage during peak flow:** If backflow occur at the junction point of river Bharalu and the drain, pumping of sewage can be done by constructing a sluice gate. The pump should be such that it can pump out both water and silt very efficiently.

f) **Proper maintenance:** To prevent further deposition of silt the bed of the channel should be cleaned at regular interval of time because deposition of silt in the channel bed reduces the cross section as well as longitudinal section of the bed.

5. Conclusion

A study conducted on drainage problem of Guwahati, a city located in the northeastern part of India has revealed that sediment yield from the surrounding hilly area is a major factor that leads to flooding of the city area located in the plains. Drain designed on the basis of scouring velocity capable of removing sediment deposited in the bed, though apparently looks like efficient, cannot perform in real situation due to various other factors. While EMPs can be implemented in the hilly urban area for controlling sediment and water yield from the upper catchment, due emphasis will also have to be given towards controlling sediment and debris from entering into the drainage system by various traditional method. Pumping in suitable locations is also required from increasing efficiency of the drainage network.

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